sciendo

Folia Forestalia Polonica, Series A – Forestry, 2021, Vol. 63 (4), 300–307

ORIGINAL ARTICLE

DOI: 10.2478/ffp-2021-0030

The damage caused by wind in middle-aged Scots pine stands on permanent thinning experimental plots

Tadeusz Zachara ✉, *Wojciech Gil*

Forest Research Institute, Department of Silviculture and Genetics of Forest Trees, Sękocin Stary, Braci Leśnej 3, 05-090 Raszyn, Poland, phone: +48 603693559, e-mail: T.Zachara@ibles.waw.pl

Abstract

In July 2002, the very strong hurricane appeared in northern Poland, which caused destruction of forest cover of area more than 10,000 ha. The permanent thinning research plot in a 53-year-old pine stand located in Myszyniec forest district (150 km north of Warsaw) was lying on the edge of damaged area. The following treatments were tested on this plot: 1) control plot (without thinning); 2) schematic cut in 20-year-old stand, selective thinning to 40 years, then thinning from below; 3) schematic cut in 20-year-old stand, then selective thinning; 4) selective thinning in young stand (20–40 years), then thinning from below and 5) selective thinning all the time.

A significant part of this plot was completely destroyed and in the other part of the plot, some trees survived. A small part of the plot resisted the wind attack. An analysis of the amount of destroyed trees (measured by basal area) showed no differences between particular silvicultural treatments. The level of damage differed between particular parts of the plot.

Another plot located in Ostrów Mazowiecka forest district (100 km NE of Warsaw) with the same thinning treatments was touched by heavy wind in July 2011 when the stand was 62 years old. Unlike the hurricane of 2002, this storm did not destroy the experimental plot which was located outside the zone of heaviest calamity. Therefore, damage on this plot had point and group character. Although on particular measurement units, share of broken or fallen trees did not exceed 10% of total basal area, it can be observed that the lowest level of damage was noticed on plots with selective thinning in young age and thinning from below in older stand.

Key words

Pinus sylvestris, silviculture, windbreak

Introduction

Wind belongs to the most important disturbing factors having an influence on the forest growth (Mitchell 2013). Its importance may increase in the future according to predicted trends in climate (Peltola et al. 2010). Full protection against this factor is impossible, especially in case of extreme winds (Wood 1995). So, there are three different strategies of forest management in the context of wind threat (Gardiner and Quine 2000):

1) acceptation of loss caused by wind;
2) taking loss into account by insurance and/
3) investment in silviculture measures to minimise the potential loss.

Received 24 June 2021 / Accepted 14 October 2021

The first and second strategies are the most popular in countries frequently touched by storms (Savill 1983) and the last one is preferred in regions of moderate risk of wind catastrophe (Zajączkowski 1991). Between silvicultural operations, thinning seems to be of key importance to shape trees and tree communities resistant to atmospheric factors. Although each thinning brings a short period of instability (Quine 1995; Jalkanen and Mattila 2000; Valinger and Fridman 2011), but in the long run, it may increase tree resistance if properly performed (Huss 1983, 1993; Zajączkowski 1991; Suvanto et al. 2016). The problem of thinning is especially important in the case of coniferous species, which are generally more susceptible to wind damage than broadleaves (Konôpka et al. 1987; Zajączkowski 1991; Peltola et al. 2000; Valinger and Fridman 2011). Contradictory recommendations on thinning regime are made due to following different silvicultural strategies connected to stand stability, focused on individual or group resistance (Slodičak 1995). The first strategy leads to strong growth and tapered trees by wide initial spacing (Donis et al. 2020) and rarely repeated heavy thinnings (Abetz 1976; Huss 1983, 1993). The second one is oriented on preventing the penetration of wind into interior of the forest. Therefore, moderate and frequent thinnings are preferred, without breakage of the forest canopy, respecting the natural groups of strong trees (Fleder 1990; Zajączkowski 1990). It is also possible to mix both these strategies by performing heavy thinning interventions in the young stand and light ones in the maturing stand (Slodičak 1995). The forming of stand edge in both cases has a great importance (Dupont and Brunet 2008). However, independent of silvicultural measures, their influence on forest stability decreases with increasing wind speed. Trees are prepared to resist only the particular strength and direction of wind like they ‘remember’ from their history (Quine 1995; Wood 1995; Talkkari et al. 2000), forming their crowns and stems according to wind exposure (Tomczak et al. 2014).

The aim of this work was to check the influence of thinning methods applied in a permanent experimental plot on the level of damage caused by strong wind accidents that appeared in the years 2002 and 2011.

Material and methods

The research plot was located in Ostrów Mazowiecka Forest District (21°50′E, 52°45′N), where in 1968, a 19-year-old Scots pine (*Pinus sylvestris* L.) stand was established with direct sowing. A similar experiment was conducted in 1970 in Myszyniec Forest District (21°38′E, 53°20′N) in a 21-year-old Scots pine stand established by planting. Forest habitat in both cases is defined as fresh coniferous forest on haplic arenosol soil, site class I (Myszyniec) and I.5 (Ostrów Mazowiecka). On both plots, thinning treatments were applied with 5–6 year intervals. The treatments are as follows:

1. K – control plot (without thinning);
2. LD – schematic cut in 20-year-old stand, selective thinning to 40 years, then thinning from below;
3. LS – schematic cut in 20-year-old stand, then selective thinning;
4. SD – selective thinning in young stand (20–40 years), then thinning from below and
5. SS – selective thinning all the time.

In the case of selective thinning treatments, future crop trees had been chosen in the number of 500 pcs per hectare and cuts were concentrated on their strongest competitors. Intensity of thinning, measured with basal area units, varied between 20% and 30%. In the case of schematic cuts, each fifth row was removed at the beginning of the experiment. In the case of thinning from below, only the trees belonging to third and lower Kraft’s class were removed.

Experimental design was the random block system with five replications. The surface of each research unit was equal to 0.1 ha. On the plot Myszyniec, the random block design was not completed since 1990 after four units were excluded from the experiment because of big gaps caused by the fungal pathogens *Heterobasidion annosum* (Fr.) Bref. and *Armillaria mellea* (Vahl) P. Kumm. However, all the plots were measured. Each 5 years, the diameters of all trees had been measured and the height of 25 trees per unit was used to calculate the mean height. The last measurement was done in July 2001 and thinning was prescribed. Trees chosen for removal in the plot had been cut already in the winter of 2001/2002. Cuttings on the rest of the plot were left to the next season.

On 4 July 2002, strong windbreak occurred in some forest district in the northeast of Poland. The reason was the cold front that occurred between two air masses causing storms accompanied by a sudden violent squall wind from the SW direction (Mikułowski 2002; Gil and Mikułowski 2003; Lorenc 2012). The wind speed exceeded 40 m s^{-1}. The forest district Myszyniec belonged to this area and the storm touched the thinning experimental plot too. In fact, this plot was located on the border between the zone of totally destroyed stand and the zone where it was only partially damaged. It caused visible differences in the amount of damage between blocks of experiment. That is why, this factor was also taken into account during the analyses of results. Trees that survived the storm had been noticed in autumn 2002, including the units that were left out of the experiment. Basal area, mean dbh and height were calculated for the stand remaining and removed, based on the data collected the year before. It was the last measurement on this plot which disappeared after the storm.

On the plot Ostrów Mazowiecka, full measurement was done in 2008. Thinning was not prescribed at that time, and so, only sanitary cuts were performed. On 20 July 2011, a local strong convection storm occurred in the part of forest district. The strength of this wind is unknown because of the distance to the closest meteorological station. The experimental plot belonged to the area subjected to damage. The inventory of this plot was performed in spring 2014. Based on previous measurements and inventory of damage, calculations of basal area, mean height and dbh of broken and uprooted trees were done. This plot exists to this time.

To analyse the differences between the amounts of damage, in particular thinning treatments, it was necessary to use non-parametric test (Kruskal–Wallis) because the distribution of this feature differed from the normal one. Additionally, to compare the differences between basal area of damaged trees on two parts of Myszyniec plot (thinned last year before the storm and 5 years earlier), the Mann–Whitney U test was applied. Analyses have been done using STATISTICA work package (Statistica 2007).

Results

Case study – Myszyniec

A part of the plot was totally damaged and in the rest of the area, distribution of broken or uprooted trees was very irregular. Taking into account particular thinning treatments, it differed from 25.5% of the basal area in control treatment (K) to 71.2% in LD treatment (Tab. 1). The area excluded from the experiment was destroyed in amount of 50%. The mean diameter of damaged trees was close to the mean diameter of total stand, and in control plots, it was even higher than average.

Table 1. Amount of damage in different thinning treatments (Myszyniec, July 2002)

Treatment	N	G		H	D	
	pcs ha^{-1}	m^2 ha^{-1}	%	m	cm	%
O[1]	470	14.189	50.1	19.4	19.7	102.0
K	384	9.099	25.5	19.9	20.0	105.9
LD	800	22.487	71.2	19.4	18.1	95.6
LS	518	12.428	46.4	18.7	17.5	95.3
SD	643	17.033	53.0	20.0	19.7	100.7
SS	575	16.247	55.3	18.6	17.4	96.3

[1] Plots out of the experiment; other treatments described in the section 'Materials and Methods'.

N – number of damaged trees, G – basal area of damaged trees, G % – basal area of damaged trees in relation to total basal area before windstorm, H – mean height of damaged trees, D – mean diameter of damaged trees, D % – mean diameter of damaged trees in relation to mean diameter of total stand.

The Kruskal–Wallis test did not allow to reject the zero hypothesis about equality of mean ranges of damaged trees in different thinning treatments. *p*-Value was equal to 0.6210 in the case of number of trees and 0.5378 in the case of basal area. The big dispersion of results is shown in Figure 1.

Comparison of damage between the blocks of the experiment showed visible differences between them (Tab. 2). The first block was almost completely destroyed. Relatively big losses were noticed in the second and fourth blocks. In the third block, damage was moderate. On the fifth block, the stand resisted almost untouched.

The Kruskal–Wallis test allowed to reject the hypothesis about compatibility of distribution of number of damaged trees in particular blocks with *p*-value equal to 0.0036 and their basal area with *p*-value equal to 0.0055. Significant differences appeared in both cases between blocks 1 and 3 as well as between blocks 1 and 5 (Fig. 2).

Additional analysis was done for comparison between the minor part of the plot thinned just few months before the storm and the major part where thinning was

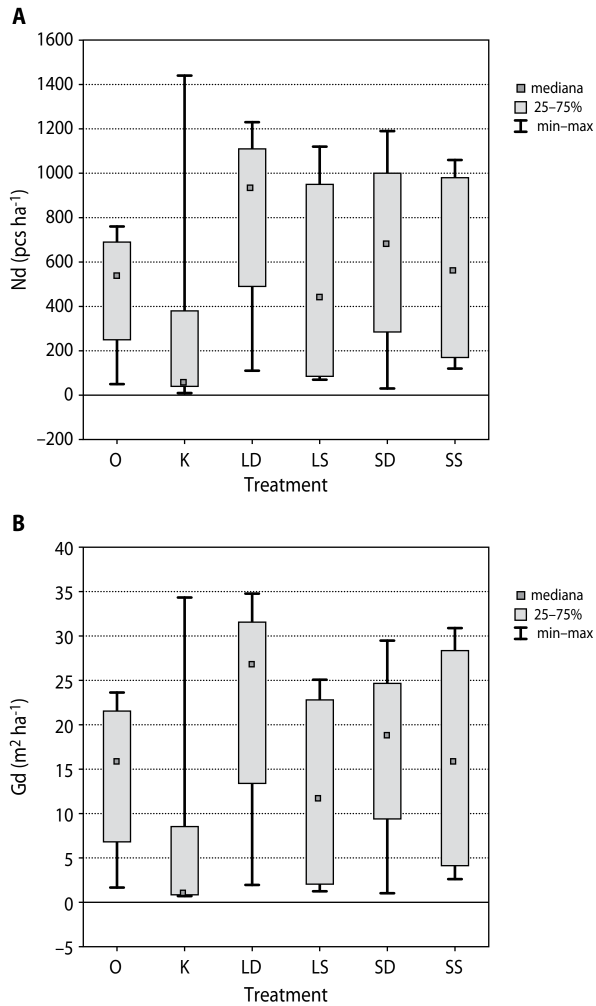

Figure 1. Number of damaged trees (A – Nd) and their basal area (B – Gd) in different thinning treatments (Myszyniec)

Table 2. Amount of damage in different blocks of experiment (Myszyniec, July 2002)

Block	N	G		H	D	
	pcs ha-1	m² ha-1	%	m	cm	%
1	1104	27.916	96.4	19.4	18.1	99.9
2	730	17.849	58.9	18.1	17.7	98.9
3	194	5.751	20.6	19.5	20.7	106.1
4	680	21.631	62.5	20.8	19.5	97.2
5	80	1.861	5.7	19.2	17.6	95.6

N – number of damaged trees, G – basal area of damaged trees, G % – basal area of damaged trees in relation to total basal area before windstorm, H – mean height of damaged trees, D – mean diameter of damaged trees, D % – mean diameter of damaged trees in relation to mean diameter of total stand.

delayed, so at the moment of the catastrophe, it was untouched from 6 years (Tab. 3). Differences between

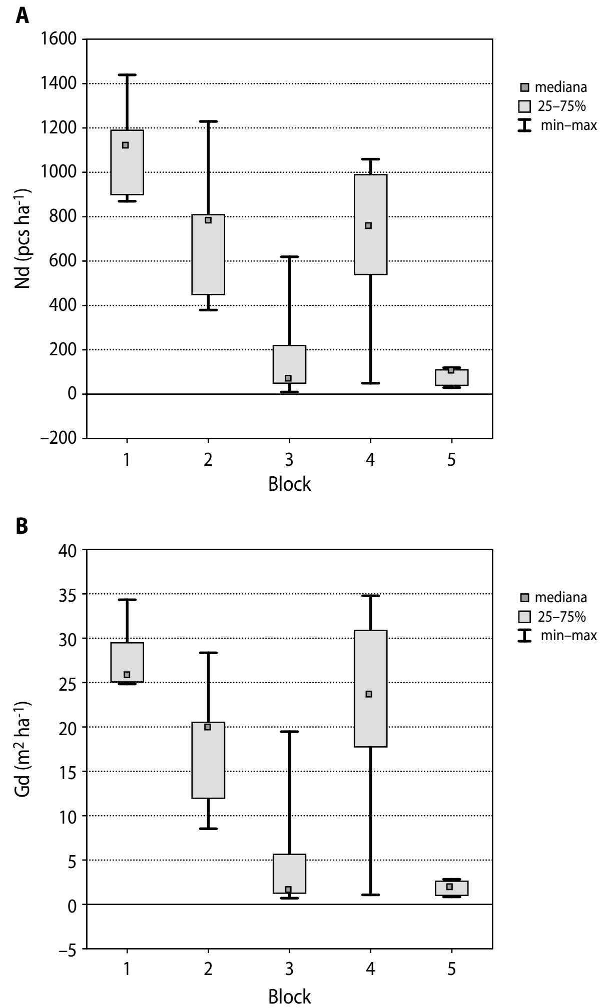

Figure 2. Number of damaged trees (A – Nd) and their basal area (B – Gd) in different blocks of the experiment (Myszyniec)

Table 3. Amount of damage dependent on time of last thinning (Myszyniec, July 2002)

Thinning 2001/2002	N	G		H	D	
	pcs ha-1	m² ha-1	%	m	cm	%
Yes	1043	26,040	91.4	18.8	17.9	99.6
No	329	9.807	30.7	19.7	19.1	99.6

N – number of damaged trees, G – basal area of damaged trees, G % – basal area of damaged trees in relation to total basal area before windstorm, H – mean height of damaged trees, D – mean diameter of damaged trees, D % – mean diameter of damaged trees in relation to mean diameter of total stand.

Table 4. Amount of damage in different thinning treatments (Ostrów Mazowiecka, July 2011)

Treatment	N	G		H	D	
	pcs ha^{-1}	m^2 ha^{-1}	%	m	cm	%
K	58	1.113	3.1	19.9	15.3	76.1
LD	60	1.862	5.7	22.0	19.7	89.5
LS	40	1.400	4.8	21.8	21.9	96.2
SD	30	0.737	2.3	20.0	17.5	85.1
SS	60	1.349	4.7	20.9	19.7	89.1

N – number of damaged trees, G – basal area of damaged trees, G % – basal area of damaged trees in relation to total basal area before windstorm, H – mean height of damaged trees, D – mean diameter of damaged trees, D % – mean diameter of damaged trees in relation to mean diameter of total stand.

Table 5. Amount of damage in different blocks of the experiment (Ostrów Mazowiecka, July 2011)

Block	N	G		H	D	
	pcs ha^{-1}	m^2 ha^{-1}	%	m	cm	%
1	68	1.719	5.5	19.5	16.2	83.5
2	32	0.778	2.4	21.1	18.5	83.9
3	28	1.003	3.0	23.2	21.8	85.9
4	42	1.048	3.4	21.0	18.9	86.7
5	80	1.914	6.1	20.0	18.8	89.2

N – number of damaged trees, G – basal area of damaged trees, G % – basal area of damaged trees in relation to total basal area before windstorm, H – mean height of damaged trees, D – mean diameter of damaged trees, D % – mean diameter of damaged trees in relation to mean diameter of total stand.

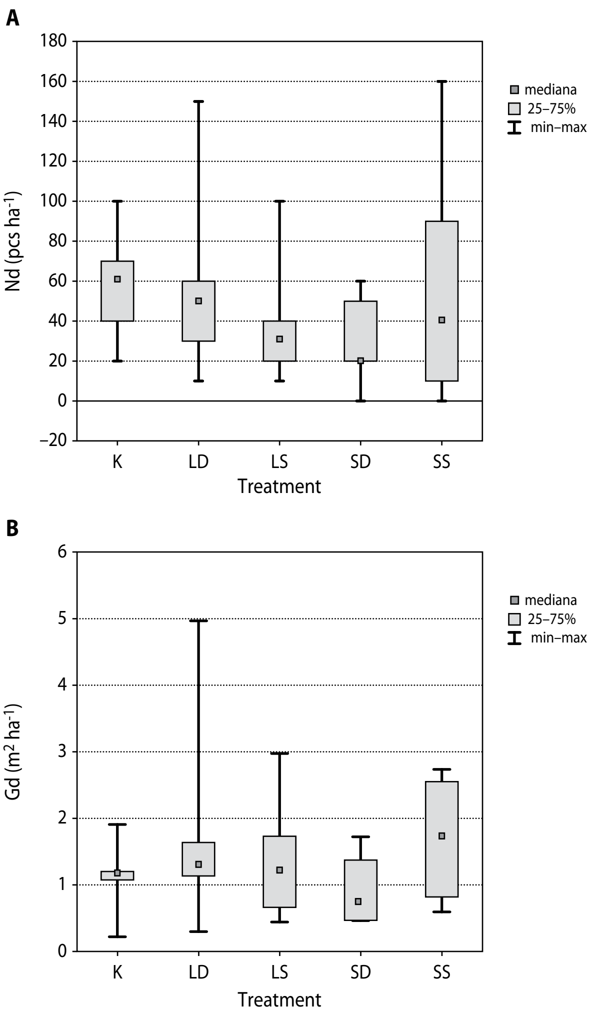

Figure 3. Number of damaged trees (A – Nd) and their basal area (B – Gd) in different thinning treatments (Ostrów Mazowiecka)

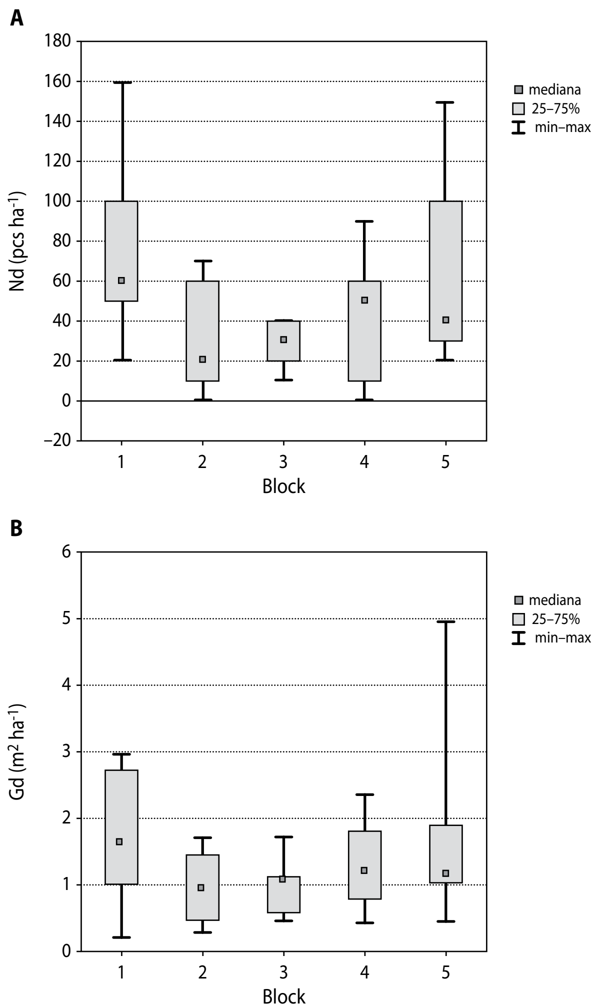

Figure 4. Number of damaged trees (A – Nd) and their basal area (B – Gd) in different blocks of the experiment (Ostrów Mazowiecka)

the amounts of damage in both parts of the plot are visible and they have been confirmed with Mann–Whitney U test. Zero hypothesis was rejected with *p*-value equal to 0.0005 in the case of number of trees and 0.0032 in the case of basal area.

Case study – Ostrów Mazowiecka

Contrary to the Myszyniec plot, the damage in Ostrów Mazowiecka did not have a surface character. Only single trees or small groups of trees were broken or uprooted. The greatest number and basal area of damage were noticed in LD treatment (schematically cut in the youth) and the lowest in SD treatment, that is, in the stand thinned selectively in the youth and from below in the medium stage (Tab. 4). Mean diameter of damaged trees was generally lower than the mean diameter of total stand before the windthrow, especially in the control unit.

Similar to Myszyniec, the differences between treatments were insignificant. The Kruskal–Wallis test did not allow to reject the hypothesis about compatibility of distribution of both features. In the case of number of trees, p-value was equal to 0.7013 and in the case of basal area, it was equal to 0.7844. The lowest dispersion of results characterised the stand in SD treatment (Fig. 3).

Analyses of damage in different parts of the plot showed its biggest amount in the first and the last blocks of the experiment. However, in all blocks, it was relatively small and did not exceed 10% (Tab. 5). The Kruskal–Wallis test did not allow to reject the zero hypothesis. p-value was equal to 0.3373 in the case of number of trees and 0.8510 in the case of basal area (Fig. 4).

Discussion

Wind damage appeared in both cases of experimental plots where history of silvicultural interventions was well documented. It gave the opportunity to check different theories connected to damage prevention by different thinning methods. Results obtained by this are, however, not sufficient to formulate trusted silvicultural conclusions. Generally, they confirmed the opinion that in case of extreme wind, the possibility to prevent damage is limited (Quine 1995; Talkkari et al. 2000). Such a situation appeared on the plot Myszyniec, where some parts were subjected to total destruction, independent of the thinning treatment. Similar summer storm, with 'bow echo' effect, touched 15 years later, in August 2017 in the forests of northwestern Poland (Dmyterko and Bruchwald 2020) and caused large-scale destruction of forest stands. Another summer storm that struck in June 2016 destroyed parts of forests in eastern Poland (Bruchwald and Dmyterko 2019).

The difference in damage between thinned and non-thinned parts of the plot might be caused by the temporal instability caused in the short period after intervention (Quine 1995; Jalkanen and Mattila 2000; Valinger and Fridman 2011). However, the material is too poor for drawing hard conclusions on this basis. An equal probable reason might be a local variability of wind gusts blowing from untypical direction, especially in the area close to stand edge (Quine 1995; Wood 1995). Results obtained on this plot did not confirm the rule that trees suffering from the wind are thinner than average (Abetz 1976; Huss 1983, 1993; Skatter and Kucera 2000). It was probably caused by the extremal strength of the wind, when such regularity may disappear (Valinger et al. 1993).

Quite a different situation appeared in Ostrów Mazowiecka, where the obtained results showed relatively low level of damage caused by wind of unknown speed (see Materials and Methods). According to the wind classification by Lorenc (2012) and based on the damage level, it may achieve a speed between 25 and 28 m s^{-1}. The differences between treatments were not significant; however, it could be observed that the lowest amount of damage was in treatment SD, where the stand was thinned selectively in the first stage and from below in the second stage. It is compatible to the opinion of the authors who suggested heavy interventions in young stands and weak or moderate interventions in medium-aged stands, without breakage of forest canopy (Zajączkowski 1990; Slodičak 1995). In comparison to Myszyniec plot, broken trees had usually smaller diameter than average. It can be stated that wind eliminated some kind of 'risk trees' (Abetz 1976), allowing the rest to resist. Therefore, we cannot deny the hypothesis about positive influence of thinning in Scots pine stands from the point of view of mechanical stability. It should be only emphasised that it is true until the wind does not exceed a definite threshold. However, even in the case of extremal wind, silvicultural measures can minimise losses in places lying on the border of calamity zones (Kohnle and Gauckler 2003).

Conclusions

- In the case of extreme wind, there are no significant differences between the levels of damage caused by different treatments of the experiment.
- Damage caused by summer storms is difficult to predict and to prevent by silvicultural measures.
- During the first vegetation season, after thinning, the medium-aged pine stand is especially vulnerable to wind damage.
- Regularly performed thinning can decrease the amount of damage in the case of moderate strength of wind or on peripheries of extremal windbreaks.

Acknowledgements

The authors are grateful to the staff of forest districts Myszyniec and Ostrów Mazowiecka for collaboration during the experiment and to colleagues from the Department of Silviculture and Forest Genetics of Forest Research Institute for the help in field measurements.

References

Abetz, P. 1976. Beitrage zum Baumwachstum. Der h/d-Wert – mehr als ein Schlankheitsgrad. *Der Forst- und Holzwirtschaft*, 19, 389–393.

Bruchwald, A., Dmyterko, E. 2019. Application of the wind damage risk model for the assessment of the probability of the location of damage to forests of the Regional Directorate of the State Forests in Białystok (in Polish with English summary). *Sylwan*, 163 (8), 629−636. DOI: 10.26202/sylwan.2019014

Dmyterko, E., Bruchwald, A. 2020. Assessment of the damage to Polish forests caused by a hurricane in August 2017 (in Polish with English summary). *Sylwan*, 164 (5), 355–364. DOI: 10.26202/sylwan.2019073

Donis, J. et al. 2020. A financial assessment of windstorm risks for Scots pine stands in hemiboreal forests. *Forests*, 2020, 11 (5), 566. DOI: 10.3390/f11050566

Dupont, S., Brunet, Y. 2008. Impact of forest edge shape on tree stability: a large-eddy simulation study. Forestry, 3, 299–315. DOI: 10.1093/forestry/cpn006

Fleder, W. 1990. Zur Z-Baum-Disskussion. *AFZ*, 32, 828–830.

Gardiner, B.A., Quine, C.P. 2000. Management of forests to reduce the risk of abiotic damage – a review with particular reference to the effects of strong winds. *Forest Ecology and Management*, 135, 261–277. DOI: 10.1016/S0378-1127(00)00285-1

Gil, W. Mikułowski, M. 2003. Wind-induced damage to Polish forests and the methods of mitigating its effect. In: Proceedings of International Conference "Wind Effects on Trees" (eds. B. Ruck, C. Kottmeier, C. Mattheck, C. Quine, G. Wilhelm), 16–18 September, University of Karlsruhe, Germany, 349–356.

Huss, J. 1983. Durchforstungen in Kiefernjungbeständen. *Forstwissenschaftliches Centralblatt*, 102, 1–17.

Huss, J. 1993. Waldbau von neuen Herausforderungen bei Waldverjüngung und Jungbestandspflege. *Forstwissenschaftliches Centralblatt*, 112, 278–286.

Jalkanen, A., Mattila, U. 2000. Logistic regression for wind and snow damage in northern Finland based on the National Forest Inventory data. *Forest Ecology and Management*, 135, 315–330. DOI: 10.1016/S0378-1127(00)00289-9

Kohnle, U., Gauckler, S. 2003. Vulnerability of forests to storm damage in a forest district of south-western Germany situated in the periphery of the 1999 storm (Lothar). In: Proceedings of International Conference "Wind Effects on Trees" (eds. B. Ruck, C. Kottmeier, C. Mattheck, C. Quine, G. Wilhelm), 16–18 September, University of Karlsruhe, Germany, 151–155.

Konôpka, J., Petráš, R., Toma, R. 1987. Slenderness coefficient of main tree species and its importance for static stability of stand (in Czech). *Lesnictvi*, 33, 887–904.

Lorenc, H. 2012. The structure of maximum windspeeds in Poland (in Polish). In: Klęski żywiołowe a bezpieczeństwo wewnętrzne kraju (ed. H. Lorenc). Wyd. IMGW PIB, 33–59.

Mikułowski, M. 2002. Problems of forest management in region of wind catastrophe of July 2002 in North-East Poland (in Polish). *Prace IBL, Seria A*, 3, 129–133.

Mitchell, S.J. 2013. Wind as a natural disturbance agent in forests: a synthesis. *Forestry,* 86, 147–157. DOI: 10.1093/forestry/cps058

Peltola, H., Kellomäki, S., Hassinen, A., Granander, M. 2000**.** Mechanical stability of Scots pine, Norway spruce and birch: an analysis of tree-pulling experiments in Finland. *Forest Ecology and Management*, 135, 143–153. DOI: 10.1016/S0378-1127(00)00306-6

Peltola, H. et al. 2010. Impacts of climate change on timber production and regional risks of wind-induced damage to forests in Finland. *Forest Ecology and Management*, 260, 833–845. DOI: 10.1016/j.foreco.2010.06.001

Quine, C.P. 1995. Assessing the risk of wind damage to forests. In: Wind and trees (eds. M.P. Coutts, I. Grace). Cambridge University Press, UK, 397–403.

Savill, P.S. 1983. Silviculture in windy climates. *Forestry Abstracts,* 44*,* 473–488.

Skatter, S., Kucera, B. 2000. Tree breakage from torsional wind loading due to crown asymetry. *Forest Ecology and Management*, 135, 97–103. DOI: 10.1016/S0378-1127(00)00301-7

Slodičak, M. 1995. Thinning regime in stands of Norway spruce subjected to snow and wind damage. In: Wind and trees (eds. M.P. Coutts, I. Grace). Cambridge University Press, UK, 133–164.

STATISTICA. 2007. Data analysis software system, version 8.0, StatSoft, Inc. www.statsoft.com

Suvanto, S., Henttonen, H.M., Nöjd, P., Mäkinen, H. 2016. Forest susceptibility to storm damage is affected by similar factors regardless of storm type: Comparison of thunder storms and autumn extra-tropical cyclones in Finland. *Forest Ecology and Management*, 381, 17–28. DOI: 10.1016/j.foreco.2016.09.005

Talkkari, A., Peltola, H., Kellomäki, S., Strindman, H. 2000. Integration of component models from the tree, stand and regional levels to assess the risk of wind damage at forest margins. *Forest Ecology and Management*, 135*,* 303–313. DOI: 10.1016/S0378-1127(00)00288-7

Tomczak, A., Jelonek, T., Pazdrowski, W. 2014. Characteristics of selected morphological traits of trees in mature Scots pine stands exposed to wind (in Polish with English summary). *Sylwan*, 158 (3), 183−191.

Valinger, E., Lundquist, L., Bondesson, L. 1993. Assessing the risk of snow and wind damage from tree physical characteristics. *Forestry*, 66 (3), 249–260. DOI: 10.1093/forestry/66.3.249

Valinger, E., Fridman, J. 2011. Factors affecting the probability of windthrow at stand level as a result of Gudrun winter storm in southern Sweden. *Forest Ecology and Management*, 262, 398–403. DOI: 10.1016/j.foreco.2011.04.004

Wood, C.J. 1995. Understanding wind forces on trees. In: Wind and trees (eds. M.P. Coutts, I. Grace). Cambridge University Press, UK, 133–164.

Zajączkowski, J. 1990. Stabilisieriende Gruppendurchforstung in Kiefernbeständen. *Forstarchiv*, 61, 39–40.

Zajączkowski, J. 1991. Resistance of forest to harmful effect of snow and wind (in Polish). Publisher: Świat, Warszawa, Poland.