Stem Volume Increment after Group Shelterwood Cutting in Scots Pine Stands in *Myrtillosa* Forest Type

LEONĪDS ZDORS[1*], GUNTARS ŠŅEPSTS[2] AND JĀNIS DONIS[1,2]

[1] *Meža nozares kompetences centrs Ltd., Dzērbenes str., 27, Rīga, LV-1006, Latvia; leonids.zdors@silava.lv; +371 67976707*

[2] *Latvian State Forest Research Institute "Silava", Rīgas str., 111, Salaspils, LV-2169, Latvia*

Zdors, L., Šņepsts, G. and Donis, J. 2017. Stem Volume Increment after Group Shelterwood Cutting in Scots Pine Stands in *Myrtillosa* Forest Type. *Baltic Forestry* 23(2): 463-470.

Abstract

There are only a few studies on the reaction of stands after a group shelterwood cutting.

The research tasks were to find out whether an additional increment is formed in the retained part of the stand after group shelterwood cutting; after how many years following cutting the gaps does the additional increment of the retained part of the stand begin to form; if there are differences in additional increments for trees located at a variety of distances from the gap edge; if the storm of 2005 has affected the additional increment of trees.

The study was done in five Scots pine (pine) stands, each roughly 110 years old and located within *Myrtillosa* forest type. In each stand, 2-3 gaps were selected. Around each gap four plots were measured in the uncut part of the stand. In each plot pines were sampled with an increment borer. At least 40 trees in 5 control stands were sampled with an increment borer as well. An additional increment method elaborated by I. Liepa was used in order to determine the response of trees to the gaps. In the uncut parts of the stand additional increment was found to be positive in the first years after group shelterwood cutting for trees closer than 7 m from the gap edge. Six years after cutting the cumulative additional increment in the parts of the stand closer than 7 m from the gap were 2 to 5 times greater compared to the parts of the stand at a distance greater than 7 m, and the differences were significant (at the 95 % confidence level) in 4 of 5 stands. There was a trend that in the year 2005 after the storm, additional increment and tree ring width decreases. However, this trend was not significant ($p > 0.05$), and independent to the distance from the edge of gap.

Key words: *Pinus sylvestris*; group shelterwood; additional increment; distance to the gap edge.

Introduction

Different researches done by many authors indicate a different pace in the reaction of trees to stand thinning. It has been concluded that during the first three years after thinning Scots pine – *Pinus sylvestris* (L.) (further pine) stands show negative growth, and afterwards they show a positive growth (Liepa and Driķe 1979). Similar tendencies are observed after shelterwood cutting in pine stands (Юркевич and Голод 1969). Another study shows that thinning in older stands has no effect or has a negative effect on additional radial stem increment, but this effect is positive in younger stands (Donis 2013). Романовский and Кочановский found that moderate thinning can significantly increase the current increment of growing volume (1972). The stem growth after stand thinning increases only after several years (Niemistö et al. 1993, Varmola et al. 2004). However, there are also studies indicating that the annual ring growth of pines can start within the next year after cutting (Звиедрис and Калнынь 1968). Growth culmination fluctuates from 7-11 years (Jakobsson 2005) up to 15–20 years (Niemistö et al. 1993). J. Donis (2013) found that thinning had a short-term effect.

It should be pointed out that the majority of studies on stand reaction to thinning have been done in middle-aged and pre-mature stands. Only a few studies have been done in mature conifer stands and mostly they have been done with the aim to find out the additional increment of retained trees after the first stage of uniform shelterwood cutting (Latham and Tappeiner 2002, Holgen et al. 2003) or as a result of seed tree cutting (Niemistö et al. 1993, Jakobsson 2005). However there are no extended studies on the effect of group shelterwood cutting on additional increment in retained trees. It is usually assumed that the ability of trees to react to changes decreases as its age increases (Лиепа 1980, Столяров and Кузнецова 1972), yet other studies show that the tree's age does not affect its ability to react after stand thinning (Jonsson 1995), and pines after 200 years (Jakobsson 2005) and spruces after 140 years are able to react to improvement of growth conditions (Naslund 1942, cited from Holgen et al. 2003).

In Latvia, shelterwood cuttings are usually practised in forests, where clear-cutting is forbidden or there are a high proportion of mature stands, as well as in private holdings. In Latvia between 2006-2014 shelterwood and selective cuttings were done in ~1450 ha per year of pine stands or ~12.2% from the total final cutting areas (Anon. 2015). Knowledge about how retained shelter trees grow after gap creations in mature stand will be useful for shelterwood management guidelines and help to provide reliable predictions on the economic return from the additional increment of retained trees.

The research tasks were to find out whether an additional increment is formed in the retained part of the stand after group shelterwood cutting; after how many years following cutting the gaps does the additional increment of the retained part of the stand begin to form; if there are differences in the additional increment for trees located at a variety of distances from the gap edge; whether the storm of 2005 has affected the additional increment of trees.

Materials and Methods

The study was carried out in five sites which are located in the Piejūras (AKM19; AKM77; KNP; 604) and Kursas (ABA) lowlands (elevation 15–45 m a.s.l.) in the western and central part of Latvia (Figure 1). The coldest month is January (mean temperature is ~ -4 °C) and the warmest month is July (mean temperature is ~17 °C), with a vegetation period lasting ~135–155 days. Annual precipitation is 700–800 mm (Anon, 2011).

Research sites were located in mature pine dominated stands (comprising at least 70% pine) with an average tree age of 104–125 years at breast height (Table 1). All stands were with an understorey of spruce on mesic average fertility *Myrtillosa* forest type (classification by Bušs (1976, 1997) on well drained mineral soils. The dominant ground vegetation species were *Vaccinium myrtillus* (L.), *Vaccinium vitis-idaea* (L.), *Calamagrostis arundinacea* ((L.) Roth) and *Pteridium aquilinium* ((L.) Kuhn).

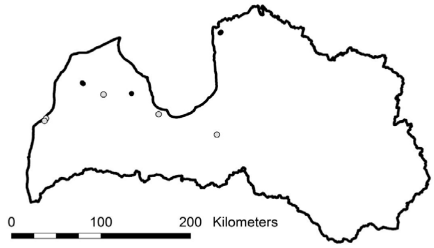


Figure 1. Geographical location of the research stands in Latvia (grey circles – group shelterwood; black circles – control stands

From 2001 until 2003, group shelterwood cutting has been implemented in these stands by cutting relatively evenly located, round gaps with the diameter of 20–30 m, and cutting all trees within those gaps. The remaining parts of the stand between cut gaps were not thinned, except the object (ABA) where the second storey of spruce was cut. In each stand 2 or 3 gaps were measured. At the beginning, each selected gap had its centre determined, and from the centre to the four cardinal directions (N, E, S, W) of 18 m distance circular sample plots with a radius (Figure 2) of 12.62 m (500 m²) were established.

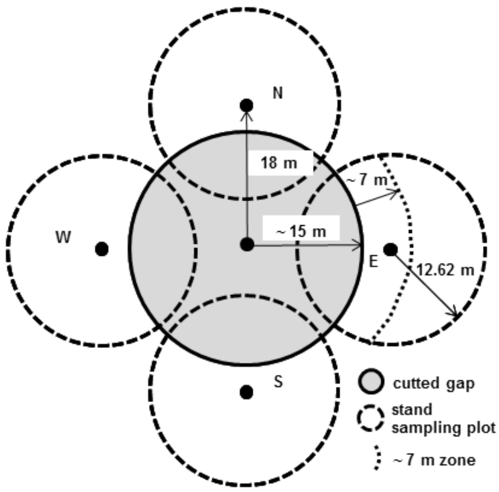


Figure 2. Sampling plot layout in stand

Table 1. Research stand parameters

Site	Composition	A, years	D, cm	H, m	W-F, %	Year of cutting	Year of sampling	Number of sampled trees
ABA	10P	125	36.7	25.2	n/d	2001	2008	67
604	7P3S+B; II storey S	107	37.2	28.3	n/d	2002	2011	32
KNP	10P+S; II storey S	114	37.7	29.2	10.8	2002	2011*	71
AKM19	9P1S+B; II storey S	104	46.8	30.6	4.5	2003	2008	42
AKM77	10P+S; II storey S	108	40.4	25.9	1.5	2003	2008	57

Notation: A – average age at 1.3 m height; D – average diameter; H – average height; W-F – wind-felled trees, % from total basal area; P – Scots pine; S – Norway spruce; B – Silver birch; * – stand first measuring year 2006; n/d – no data

In these sample plots, the tree diameter at breast height, azimuth, and distance to the plot's centre were measured for all the trees with a diameter above 6.0 cm at breast height. Trees with a diameter from 2.1 cm to 6.0 cm at breast height were measured within a radius of 5.64 m (100 m^2). The height of the trees was measured for subsample of each forest element separately, and for at least 9 trees from each forest element in each object. In three sites (KNP, AKM19; AKM77) within the sampling plots wind-fallen trees with a diameter above 6.0 cm at breast height were measured. In order to determine the age of the stand and for additional increment calculations, samples of radial increment at breast-height to the pine trees (from six trees in the sample plot or if there was a lower number – all pines) were collected with an increment borer.

In the laboratory, increment cores from trees were mounted on a wood strip and sanded with grit sandpaper (graininess 120-200) until the rings were clearly visible. The width of annual rings was obtained by using LINTAB IV. For the initial data processing, TSAP Win Scientific 0.55 software was used. In order to calculate the additional increment, the methodology developed by I. Liepa (1996) was used. When analysing the additional increment of the stand, the average tree method was used (Liepa 1996). In order to calculate additional increment, initially 5 control stands (age at breast height 85-107 years) from the materials of LSFRI "Silava" archive were selected. Within each control stand radial increment samples from 40–74 trees were obtained. The retrospection period used for calculations was 10 years. In the control sample plots trees were selected whose radial increment showed a statistically significant correlation $r_{10;0.05} = 0.6319$ (critical value of Pearson correlation coefficient at n=10 and α=0.05) with valuation stand average radial increment in retrospection period. Control stands with the largest number of selected trees, as well as with the highest calculated determination coefficient (for power regression equation between affected and control stands) was used for further calculations. The determination coefficients of power regression used in further calculations were from 0.64 to 0.96 (Table 2) within the retrospection period. In order to evaluate the effect, annual (Tp_{red}) and cumulative (Kp_{red}) additional tree volume increment per unit of stand basal area m^3 m^{-2} was used (Liepa 1996). Tp_{red} was calculated as the cumulative increment difference between consecutive years. Kp_{red} was obtained by recalculating the additional cumulative increment per 1 m^2 of the stand basal area. Cumulative additional stem volume increment calculation was done by using the equation (Liepa 1996):

$$Z_M^{kp} = 12732.4\psi\,(GH^{\alpha}D^{\beta\,lgH+\varphi-2} - G_tH_t^{\alpha}D_t^{\beta\,lgH+\varphi-2}), \qquad (1)$$

where: Z_M^{kp} – cumulative additional stem volume increment m^3 ha^{-1}; $\psi, \alpha, \beta, \varphi$ – empirical coefficients depending on tree species (for pine: ψ =0.00016541; α = 0.56582; β = 0.25924; φ = 1.59689); t – evaluation period of environmental influence ($1 \leq t \leq 20$), years;

G, G_t – basal area of stand and predicted values at the end of t period, m^2 ha^{-1}:

$$G_t = \frac{D_t^2\, G}{D^2}, \qquad (2)$$

D, D_t – stand average diameter at breast height with bark and predicted value at the end of t period, cm:

$$D_t = D - 0{,}1Z_D^{kp}, \qquad (3)$$

Z_D^{kp} – cumulative additional increment of the stand average diameter, cm;

$$Z_D^{kp} = 2u\,(\Sigma_{t'+1}^{t}\, i_j - \Sigma_{t'+1}^{t}\, i_j'), \qquad (4)$$

u – empirical coefficient of the thickness of the bark depending on tree species (for pine – 1.103);

t' – the interval of retrospection, years;

i_j – average width of evaluated stand annual ring data at period $t + t'$, mm;

i_j' – adjusted width of annual ring of evaluated stand, mm:

$$i_j' = \eta\, i_{k;j}^{\rho}, \qquad (5)$$

i_k – width of appropriate control annual rings, mm;

ρ, η – calculated equitation coefficients from each pair of evaluated and control stand according to the width of annual rings at period t'.

H, H_t – stand average height and predicted value at the end of period t:

$$H_t = H - Z_H^{kp}, \qquad (6)$$

Z_H^{kp} – cumulative additional increment of stand average height, m:

$$Z_H^{kp} = \frac{HZ_D^{kp}(ad+b)}{u(cD+100)}, \qquad (7)$$

a, b, c – empirical coefficients depending on tree species (for pine: a = 0.00016541; b = 0.56582; c = 0.25924).

The total Tp_{red} and Kp_{red} of trees in sample plots established in the uncut parts of the stand was calcu-

Table 2. Relation between control and evaluated stands growth in retrospection period

Valuation stand	Control stand	Number of selected adequate control trees	R^2
604	S1	10	0.64
ABA	U2	16	0.96
AKM17	S1	24	0.92
AKM77	U2	17	0.76
KNP	U2	20	0.92

lated. In order to compare whether the additional increment in uncut parts of the stand is similar regardless of the tree's distance from the gap edge, the trees were divided into two groups – trees located closer than 7 m from the gap edge, and trees located further than 7 m from the gap edge. The distance from the gap edge that divides the borders of the two groups was selected as per the impact zones determined in other studies of 5 m (Donis 2007) and 8 m (Zdors and Donis 2012), as well as the possible impact zones 0.3-0.6 from the average tree height within the stand (Ермохин and Судник 2001). Additional increment was calculated for each group separately. In order to calculate the upper and bottom 95% confidence limit of Kp_{red}, 2 standard errors were added and subtracted from the average annual ring width value of the affected stand and a recalculation of Kp_{red} was done. Hereinafter in the text, the Tp_{red} and Kp_{red} of the uncut part of the stand and the Tp_{red} and Kp_{red} of the trees located closer than 7 m and further than 7 m from the gap edge are mentioned. However, by taking into account the fact that sample plots in the stands were not arranged in a transect manner or in another way that would allow us to fully describe the stand, the calculations do not represent the full Tp_{red} and Kp_{red} of the particular stands, rather they describe the Tp_{red} and Kp_{red} of the sample group.

Taking into account the fact that the analysed stands were cut, as well as the fact that the radial increment samples were obtained in different periods of time (Table 1), the analyses were done by evaluating the total development of Tp_{red} and Kp_{red}. The effect of the storm of 2005 was evaluated by using Tp_{red} and the width of the annual rings. When evaluating the effect based on the width of annual rings, the widths of annual rings from 2004 and 2005 were compared using univariate analysis of variance.

Results

It was found that Tp_{red} and Kp_{red} was positive during the first years after cutting in all five stands where group shelterwood cutting was performed (Figure 3; 4). The increment develops differently for each stand; nevertheless, it was found that the largest Tp_{red} was observed 4–6 years after cutting in four out of five stands. However, the evaluation period for two stands (AKM19; AKM77) was only six years so the mentioned correlation must be considered with caution because the largest Tp_{red} for the stand (604) with the longest evaluation period (10 years) was found within the last year of evaluation. Six years after cutting, the Kp_{red} of stands ranged from 0.063 to 0.321 m^3 m^{-2} (Figure 3). The lowest Kp_{red} was observed in the stand AKM19.

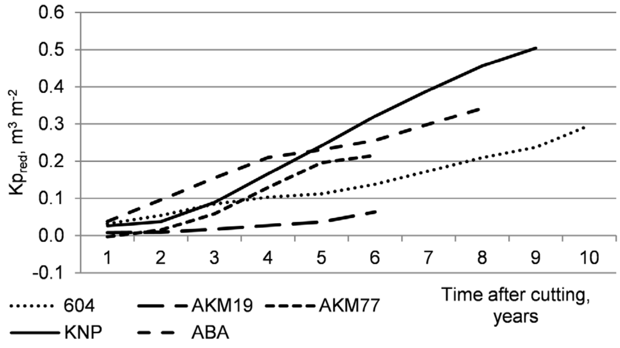


Figure 3. Cumulative additional volume increment (Kp_{red}) of research stands (AKM19; AKM77; KNP; ABA; 604) in uncut parts

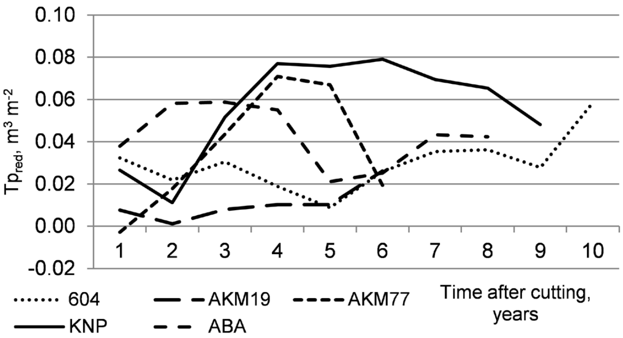
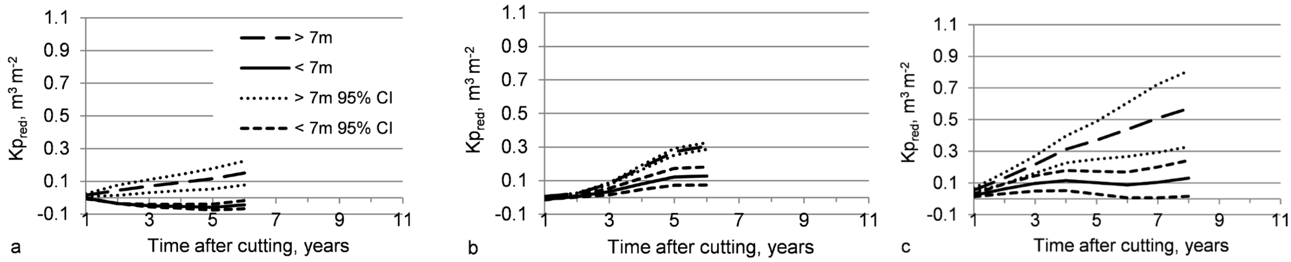


Figure 4. Annual additional volume increment (Tp_{red}) of research stands (AKM19; AKM77; KNP; ABA; 604) in uncut parts

Kp_{red} for trees located closer than 7 m from the gap edge was positive already during the first years after cutting (Figure 5), and after six years it was two to five times higher than for trees located further than 7 m from the gap edge with Tp_{red} reaching 0.146 $m^3 m^{-2}$ per year (KNP). Tp_{red} fluctuates around zero but did not exceed 0.046 $m^3 m^{-2}$ per year, and was practically insignificant at a distance further than 7 m from the gap edge (Figure 6). In the ABA stand where a second stage was done six years after the first stage by thinning the uncut parts of the stand, a small positive Tp_{red} was monitored during the following years, yet it was unsubstantial.

In the stand KNP, the Kp_{red} for trees closer than 7 m from the gap edge and further than 7 m from the gap edge with 95% confidence does not differ during the first two years after cutting. In the other three stands at the end of the first year of evaluation, the Kp_{red} is significantly higher for trees located closer than 7 m from the gap edge in comparison with Kp_{red} for trees located further than 7 m from the gap edge. In one of the stands (604) the difference between Kp_{red} for trees located closer than 7 m from the gap edge and further than 7 m from the gap edge, was not statistically significant (with 95% confidence).



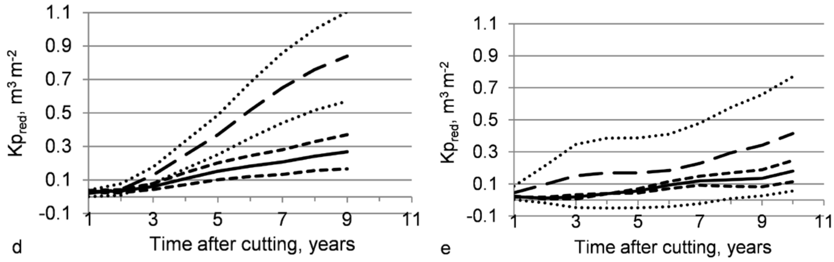
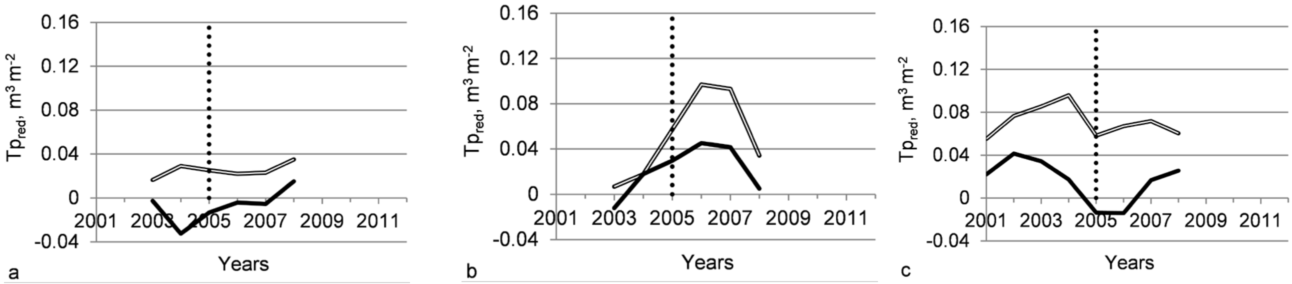


Figure 5. Tree cumulative additional increment (Kp_{red}) at different distances from edge of stand gap in research stands (a - AKM19; b - AKM77; c - ABA; d - KNP, e - 604). Notation: < 7 m - cumulative additional increment and 95% confidence interval (< 7 m 95% CI) of trees further than 7 m from gap edge; > 7 m - cumulative additional increment and 95% confidence interval (> 7 m 95% CI) of trees closer than 7 m from gap edge



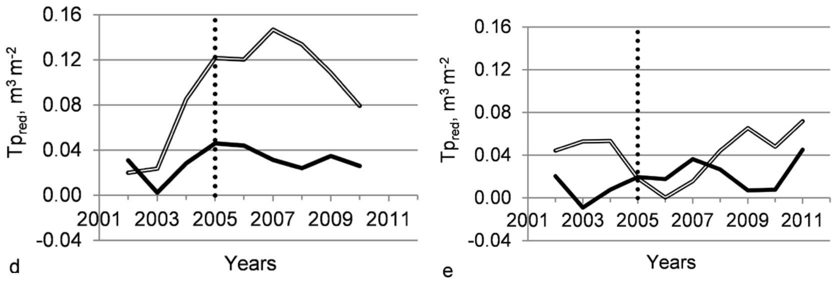
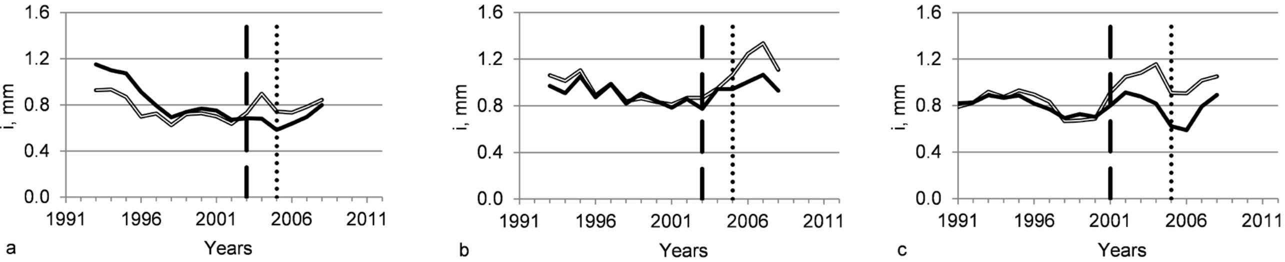


Figure 6. Tree annual additional increment (Tp_{red}) at different distances from edge of stand gap in research stands (a - AKM19; b - AKM77; c - ABA; d - KNP, e - 604). Notation: annual additional increment of trees farther than 7 m (full line) and closer than 7 m (empty line) from gap edge; dotted line - storm in year 2005

Storm felled trees were observed from 1.5 to 10.8% of the total basal area (Table 1). However, in the year 2005, Tp_{red} for trees located closer than 7 m from the gap edge decreased in two stands (604; ABA) where storm felled trees were not measured. In the rest of the stands, Tp_{red} decrease has not been registered - in the following years Tp_{red} was either similar to previous years, or Tp_{red} continued to increase (Figure 6). For trees located further than 7 m from the gap edge, Tp_{red} decrease was registered in only one of the stands (ABA). The average annual ring width for trees located closer than 7 m from the gap edge reduced in three stands (604; ABA; AKM19) in the following growing period after storm at 17 – 21% in comparison with the average annual ring width of the previous year (Figure 7). At a distance further than 7 m from the gap edge in the same stands the average annual ring width was reduced in the same three stands at 4 – 24%. The greatest reduction was in stand ABA, however, in no cases were these differences significant ($p > 0.05$).

Discussion and Conclusions

Звиедрис and Калнынь (1968) also found that the annual ring widening process for pine starts in the next year after cutting. Other observations of different conifers, however, indicate that even though immediate root growth reaction has been monitored (Urban et al. 1994, Kneeshaw et al. 2002, Vincent et al. 2009), the stem volume usually does not increase during the



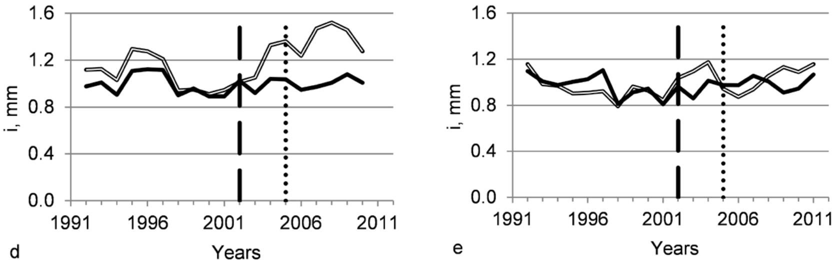


Figure 7. Tree annual increment (i) at different distances from gap edge in research stands (a – AKM19; b – AKM77; c – ABA; d – KNP, e – 604). Notation: annual additional increment of trees farther than 7 m (full line) and closer than 7 m (empty line) from gap edge; dotted line – storm in year 2005; dashed line – cutting year

first years after cutting (Youngblood 1991, Kneeshaw et al. 2002, Niemistö et al. 1993, Holgen et al. 2003, Varmola et al. 2004, Thorpe et al. 2007). This period usually lasts two to four years (Jakobsson 2005). Moreover, old-growth conifers have been found to delay their growth response for 5 to 25 years (Latham and Tappeiner 2002). Following cutting in pine stands in *Myrtillosa* forest type where the age of the stands does not exceed 50 years, negative stand reaction has also been observed, where the additional volume increment is negative during the first three years after cutting (Liepa and Driķe 1979).

In our research, Tp_{red} peaked mainly 4–6 years after cutting. Other studies have found that that the culmination of the increment reaction for spruce is observed 5–7 years after cutting (Holgen et al. 2003). Jakobsson (2005) found that the culmination on pine occurs 7–11 years after cutting, but Niemistö et al. (1993) found this happened later at 15–20 years after cutting.

The total stand Kp_{red} six years after gap cutting differed between stands by about 5 times. The stand which had the lowest Kp_{red} (AKM19) differed from the other stands with a larger average diameter (46.8 cm) and height of trees (30.6 m), and it was also the youngest stand. It is possible that it corresponds with a more fertile *Hylocomiosa* forest type. The gap size was also the smallest at around 25 m. The largest Kp_{red} was observed in the stand KNP whose stand parameters were similar to other stands. Unfortunately, the stand parameters representing the basal area and density of stands covered by this research were not available, as they could explain the differences in additional increment. If the competition among trees had been small prior to thinning, then thinning might have had a small effect because the tree growth did not depend on competition (Plauborg 2004). Research done by J. Donis (2007) found that in the case of uniform shelterwood cutting, the increment is significantly dependant on the basal area of the first storey of the retained stand. Research in Sweden has found that the annual basal area increment of seed trees retained in clearcuttings is 20% larger than prior to cutting (Rosvall et al. 2007, cited from Simonsen 2013).

Six years after gap cutting the additional cumulative tree volume increment for trees located further than 7 m from the gap edge fluctuates around zero and in four of five stands was significantly smaller than for trees closer to the gap edge. Similar results were obtained in studies on the edge effect of pine stand thinning in *Myrtillosa* forest type, with the effect close to the edge of the technological corridor being positive, however this gradually decreased towards the middle of strips (Liepa and Driķe 1979). Mäkinen et al. (2006) found that after thinning in middle-aged pine and spruce stands the edge effect progressively diminished when moving deeper into the strip and ended at a distance of about 3-4 m from the corridor edge. Consequently it can be that the distance we chose as our distance from the gap edge to divide the selected group borders (up to 7 m and further than 7 m) was somewhat imprecise. However, we had much greater gaps in the stand compared with the strip roads which are usually only 3-4 m wide.

Our results show that when evaluating the stand increment after group shelterwood cutting, it must be taken into account that the additional volume increment will only be observed around gaps, and the longer the distance between the gaps, the larger the area where the additional volume increment will not be observed. Additionally, if thicker trees are retained (such as thinning trees around gaps), then their response reaction will be relatively small (Лиепа 1980).

The reason there was no significant difference in growth response between trees closer and further than

7 m from the gap edge in one of the stands (604) could be due to an indistinctive difference in the growth of cored sample trees at a distance closer than 7 m from the gap edge, and a smaller number (14) of sampled trees also.

Storm felled trees during period of first 5-6 years after gap creation were 1.5-10.8% of basal area. It shows that gap creation in pine forests on well drained mineral soils in short term could have generally no effect on mortality of surrounding trees. Similarly Gray et al. (2012) found that gap creation in mature and old-growth Douglas-fir dominated forests in USA generally had no effect on mortality of surrounding trees.

The additional increment decrease in 2005 and in some of the years following could be explained by the impact of the storm in 2005, which swayed the trees and disrupted the roots, thereby leaving an impact on tree growth. The greatest reduction was in the stand ABA where the decrease can be explained by the influence of thinning (cutting all second storey spruces). Thinning is known to reduce the wind firmness of stands (Lohmander and Helles 1987, Donis 2006, Albrecht et al. 2012, Zubizarreta-Gerendiain et al. 2012). Furthermore, leaving the second storey spruces in the stands appears to have reduced the loading on the main canopy trees as this has been found by a wind impact simulation on two storey stand done by Gardiner et al. (2005). Even though there was a tendency of a decrease in additional increment and width of annual rings in some stands in the year 2005 and in some of the years following, no significant effect of the storm in January 2005 was observed, regardless of the distance of the trees to the gap edge. Taking into account the possibility that the storm of 2005 had affected the growth of the control stands as well, and to some extent that the additional increment calculations only show the differences in the intensity of the effect of the storm, it was assumed that the storm effect could be found out more precisely by using the average width of annual rings. Nevertheless, it was not confirmed. Additionally, taking into account the indistinctive impact per stand, it is possible that the decrease of annual ring width and additional volume increment has been caused by other factors as well. It is possible that 2005 in general was a less favourable year for tree growth, and that the storm just enhanced this tendency. Albrecht et al. (2015) concluded that there have still been no studies carried out to compare the growth reduction and the growth increase as a reaction of the remaining trees to the release caused by storm damage. Furthermore, future studies should investigate whether there is a positive or negative net effect on growth (Albrecht et al. 2015).

Conclusions

1. In mature pine dominated forests growing on mesic average fertility *Myrtillosa* forest type gap formation during group shelterwood cutting initiates positive additional tree volume increment of pines in the uncut part of the stand close to the gaps.

2. Positive additional stem volume increment in the uncut part of the stand located closer than 7 m from the gap edge was already positive just two years after group shelterwood cutting.

3. Six years after gap cutting the additional cumulative tree volume increment for trees located closer than 7 m from the gap edge was two to five times larger than for trees located further than 7 m from the gap edge. In three out of five stands, the difference in the additional cumulative increment of the volume was significant (with 95% confidence) within the first year after gap creation in group shelterwood cutting. In another stand, the additional cumulative tree volume increment significantly differs starting from the third year after cutting.

4. Even though we observed a tendency for the width of annual rings and additional increment to decrease after the storm of 2005, no significant effect regardless of the distance of trees to the gap edge was observed.

Acknowledgements

Manuscript has been prepared under “Meža nozares kompetences centrs” Ltd. project No. L-KC-11-0004 (April 8, 2011). We are grateful to Samantha Jane Howlett for revising the English language.

References

Albrecht, A., Hanewinkel, M., Bauhus, J. and Kohnle, U. 2012. How does silviculture affect storm damage in forests of south-western Germany? Results from empirical modelling based on long-term observations. *European Journal of Forest Research* 131: 229 247.

Albrecht, A.T., Fortin, M., Kohnle, U. and Ningre, F. 2015. Coupling a tree growth model with storm damage modeling – Conceptual approach and results of scenario simulations. *Environmental Modelling and Software* 69: 63-76.

Anon. 2015. Meža statistikas CD 2015. gads [Forest statistics CD 2015]. Valsts meža dienests. State Forest service, Riga (in Latvian).

Bušs, K. 1976. *Latvijas PSR mežu klasifikācijas pamati [Basis of forest classification of the Latvian SSR]*. LRZTIPI, Riga, 24 pp. (in Latvian).

Bušs, K. 1997. Forest ecosystem classification in Latvia. *Proceedings of the Latvian Academy of Sciences. Section B* 51: 204-218.

Donis, J. 2006. Ekstrēmu vēju ātrumu ietekmes uz kokaudzes noturību novērtējums, lēmuma pieņemšanas atbalsta sistēmas izstrāde [Evaluating the resistance of forest stands against the winds of extreme speed to work out a support system for decision-making]. *Project report.* LSFRI "Silava", Salaspils (unpubl.), 64 pp. (in Latvian).

Donis, J. 2007. Nekailciršu meža apsaimniekošanas modeļu izstrāde [Developing a model of no clear-fells in forest management]. *Project report.* LSFRI "Silava", Salaspils (unpubl.), 105 pp. (in Latvian).

Donis, J. 2013. Mežaudžu augšanas gaitas un pieauguma noteikšana, izmantojot pārmērītos meža statistiskās inventarizācijas datus [Estimating the forest growth and yield using the re-inventoried data of forest statistical inventory. report]. *Project intermediate report.* LSFRI "Silava" LVMI "Silava", Salaspils (unpubl.). 73 pp. (in Latvian).

Gardiner, B., Marshall, B., Achim, A., Belcher, R. and Wood, C. 2005. The stability of different silvicultural systems: a wind-tunnel investigation. *Forestry* 77: 471-484.

Gray, A.N., Spies, T.A., Pabst, R.J. 2012. Canopy gaps affect long-term patterns of tree growth and mortality in mature and old-growth forests in the Pacific Northwest. *Forest Ecology and Management*, 281: 111 120.

Holgen, P., Soderberg, U. and Hanell, B. 2003. Diameter increment in *Picea abies* shelterwood stands in northen Sweden. *Scandinavian Journal of Forest research* 18: 163 167.

Jakobsson, R. 2005. Growth of retained Scots pines and their influence on the new stand. Doctoral thesis. Swedish University of Agricultural Sciences, Umeå, *Acta Universitatis Agriculturae Sueciae* 34: 33 pp.

Jonsson, B. 1995. Thinning response functions for single trees of *Pinus sylvestris* L. and *Picea abies* (L.) Karst. *Scandinavian Journal of Forest research* 10: 353 369.

Kneeshaw, D.D., Williams, H., Nikinmaa, E. and Messier, C. 2002. Patterns of above-and below-ground response of understory conifer release 6 years after partial cutting. *Canadian Journal of Forest Research* 32: 255 265.

Latham, P. and Tappeiner, J. 2002. Response of old-growth conifers to reduction in stand density in western Oregon forests. *Tree Physiology* 22: 137 146.

Liepa, I. 1996. Pieauguma mācība [Increment science]. LLU, Jelgava, 123 pp. (in Latvian).

Liepa, I. and Driķe, A. 1979. Tehnoloģisko koridoru efekta taksācija. [Inventarization of the strip-road effect]. *Jaunākais mežsaimniecībā* 21: 8-15 (in Latvian).

Lohmander, P. and Helles, F. 1987. Windthrow probability as a function of stand characteristics and shelter. *Scandinavian Journal of Forest Research* 2: 227 238.

Mäkinen, H., Isomäki, A. and Hongisto,T. 2006. Effect of half-systematic and systematic thinning on the increment of Scots pine and Norway spruce in Finland. *Forestry* 79: 103 121.

Niemistö, P., Lappalainen, E. and Isomäki, A. 1993. Mäntysiemenpuuston kasvu ja taimikon kehitys pitkitetyn luontaisen uudistamisvaiheen aikana [Growth of Scots pine seed bearers and the development of seedlings during a protracted regeneration period]. *Folia Forestalia* 826: 26pp. (In Suomi with summary in English).

Plauborg, K. U. 2004. Analysis of radial growth responses to changes in stand density for four tree species. *Forest Ecology and Management* 188: 65 75.

Simonsen, R. 2013. Optimal regeneration method – planting vs. natural regeneration of Scots pine in northern Sweden. *Silva Fennica* 47, article id 928, 23 pp.

Thorpe, H.C., Thomas, S.C. and Caspersen, J.P. 2007. Residual-tree growth responses to partial stand harvest in the black spruce (*Picea mariana*) boreal forest. *Canadian Journal of Forest Research* 37: 1563-1571.

Urban, S.T., Lieffers, V.J. and Macdanold, S.E. 1994. Release in radial growth in the trunk and structural roots of white spruce as measured by dendrochronology. *Canadian Journal of Forest research* 24 (8): 1550-1556.

Varmola, M., Salminen, H. and Timonen, M. 2004. Thinning response and growth trends of seeded Scots pine stands at the arctic timberline. *Silva Fennica* 38: 71 83.

Vincent, M., Krause, C. and Zhang, S.Y. 2009. Radial growth response of black spruce roots and stems to commercial thinning in the boreal forest. *Forestry* 82: 557-571.

Youngblood, A.P. 1991. Radial growth after a shelterwood seed cut in a mature stand of white spruce in Interior Alaska. *Canadian Journal of Forest Research* 21: 410-413.

Zdors, L. and Donis, J. 2012. Malas ietekmes novērtējums uz stādītas egles augšanu dažāda lieluma audzes atvērumos [Evaluating edge effect on the growth of spruce planted in different size gaps]. *Mežzinātne*, 26: 20 40 (in Latvian with English abstract).

Zubizarreta-Gerendiain, A., Pellikka, P., Garcia-Gonzalo, J., Ikonen, V.P. and Peltola, H. 2012. Factors affecting wind and snow damage of individual trees in a small management unit in Finland: assessment based on inventoried damage and mechanistic modelling. *Silva Fennica* 46: 181-196.

Ермохин, М.В. и Судник, А.В. 2001. Реакция радиального прироста ели на образования окон в еловых насаждениях. [The reaction of radial growth of spruce in the formation of the gaps in spruce stands] В: Ипатьев, В. А. (отв. ред.), Проблемы лесоведения и лесоводство. Сборник научных трудов Института леса национальной академии наук Беларуси, 53, ИММС НАНБ, Гомель: 426-429 (in Russian).

Звиедрис, А.И. и Калнынь, А.Я. 1968. Лесоводственные основы постепенных рубок [Silvicultural bases of shelterwood cuttings]. В: Сарма, П. Э. (отв. ред.), Повышение продуктивности леса. Зинатне, Рига: 151-174 (in Russian).

Лиепа, И.Я. 1980. Динамика древесных запасов: Прогнозирование и екология. [Dynamics of wood resources: Forecasting and Ecology]. Зинатне, Рига, 170 сс. (in Russian).

Романовский, В. П. и Кочановский, С.В. 1972. Влияние промежуточного ползования на величину текущего прироста сосновых древостоев [The impact of the intermediate thinning on the value of the current increment growth in pine stands]. В: Текущий прирост древостоев и его применение в лесном хозяйстве. Доклады совещания 27-29 сентября 1972 г., Рига: 218-227 (in Russian).

Столяров, Д.П. и Кужнецова, В.Г. 1972. Динамика текущего прироста в разновозрастых ельниках после виборочных рубок [The dynamics of the current increment growth in multi-aged spruce stands after selection cutting]. В*:* Текущий прирост древостоев и его применение в лесном хозяйстве. Доклады совещания 27-29 сентября 1972 г. Рига: 115-123 (in Russian).

Юркевич, И.Д. и Голод, Д.С. 1969. Совершенствование рубок ухода в связи с типами и естественным возобновлением леса [Improving thinnings in relation with forest types and forest natural regeneration]. Наука и техника, Минск, 120 сс. (in Russian).

Received 30 June2015
Accepted 24 February 2017