Evaluating the Edge Effect on the Initial Survival and Growth of Scots Pine and Norway Spruce After Planting in Different Size Gaps in Shelterwood

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Abstract

The optimum size of gaps made in a forest stand in group shelterwood or selection cuttings is an important issue for foresters working with continuous cover forestry methods. In Latvia, shelterwood and selection 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.

To assess the influence of gap size on the growth and survival of seedlings, rectangular gaps (size 100 to 1600 m^2) were created in two 100-year-old Scots pine (pine) dominated stands in *Hylocomiosa* forest type. Pine and Norway spruce (spruce) were planted in the gaps and arranged in a square pattern, so that the distance from the gap edge would be known for each tree planted.

For performance analysis of the planted trees, the survival and height increment over a period of three years was used. Significance of the test site, initial tree height, gap size and the distance from the closest gap edge on survival and growth of seedlings was tested using univariate analysis of variance.

Survival rate of the pine 3 years after planting notably differed between test sites (66% and 24%), but did not differ regarding the gap size and the distance from the closest gap edge. Survival rate of the spruce 3 years after planting was at least 86% regardless of gap size, and at least 80% regardless of the position within the gap.

Gap size had a significant ($p < 0.05$) influence on the growth in height for both species, but the distance to the closest gap edge only had a significant ($p < 0.05$) influence on the growth of spruce.

Based on these results, it can be concluded that the gap size must be larger than 10×10 m to ensure sufficient growth during the first years after planting pine and spruce.

Key words: gap, edge effect, survival, growth, *Pinus sylvestris, Picea abies.*

Introduction

Over the last few decades, imitation of natural disturbances in forest management has become increasingly more common in Europe. It has begun to replace the previously dominant clear-cut form of management with continuous cover forestry. One of the reasons for such change is that people prefer to use areas, where shelterwood cutting is implemented rather than clear-cutting for recreational purposes (Lindhagen 1996, Holgen et al. 2000, Edwards et al. 2010, Edwards et al. 2012). Shelterwood forests are considered to be more visually attractive (Karjalainen 2006, Donis 2008, Gundersen and Frivold 2008, Kearney et al. 2010) and consequently, from the community point of view, it is better to harvest forests using continuous cover forestry methods. Therefore, shelterwood cutting can be a compromise solution for forest management to reduce economic, ecological and social contradictions.

Researchers, who have explored the effects of forest edges on canopy gap environments, have focused on issues related to species diversity or regeneration dynamics in the context of gaps as a natural disturbance (e.g. Sipe and Bazzaz 1994, Gray and Spies 1996, Drobyshev 1999, Pham et al. 2004). While results from these gap studies have helped forest managers design silvicultural practices that mimic natural disturbances, they provide little insight for predicting the effect of edges on the growth of trees within artificially created gaps created in group shelterwood cutting.

In this study, the edge is defined as the boundary line between the opening created by cutting a group of trees and the matrix of intact (residual) forest. Whereas, the edge effects are defined as the ecological phenomena associated with environmental gradients that develop across the gap boundary and extent into the adjacent communities (*sensu* Chen et al. 1992).

One of the unknown effects of gap size is the loss that results from a decrease in growth productivity associated with the edge effect from small stand gaps. To solve this problem, many studies based on artificially created openings have focused on a suitable (usually the minimum) opening size in order to achieve the objectives of forest management, i.e. successful natural regeneration and growth of the desired tree species within openings (Gray and Spies 1996, Malcolm et al. 2001, Coates et al. 2002, Page and Cameron 2006, Donis 2008, Rouvinen and Kouki 2011, Axelsson et al. 2014). In more intensively managed forests, studies are concentrated on quantifying the influence of opening size and the position within the opening on the survival and growth of the planted seedling (Palik et al. 1997, Coates 2000, Gagnon et al. 2003, York et al. 2003, York et al. 2004, Donis 2008, Erefur 2010, Kern et al. 2012). However, the question on the optimal opening size for different tree species, including the Scots pine (henceforth pine) and the Norway spruce (henceforth spruce), largely remains unanswered. Ideally, a forest manager could choose the appropriate gap size based on the knowledge of optimal growing conditions for each tree species and thereby influence the future forest composition (Messier et al. 1999).

Shelterwood and selective cutting in Latvia have been studied extensively in the middle of the last century (e.g. Kundziņš 1949, Zviedris 1949, Суна 1957, Igaunis 1961). So far, however, there is a lack of studies in relation to how gap size and the distance from the gap edge impacts the artificial regeneration. In Latvia, shelterwood and selection 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. It should be noted that clear-cutting in Latvia is forbidden in 9.9% of pine stands. According to Latvian legislation, these stands can be managed only with selective cutting. However, the question is whether it is possible to maintain pine as the dominant species of future stands after selective cutting has taken place, particularly in fertile forest types, while also taking into account that pine is a light demanding tree species.

The objective of the study is to evaluate the impact of the edge effect on the initial survival and growth of pine and spruce planted in different gap sizes. Our hypothesis is that in larger gaps at a greater distance from the gap edges, the growth in height for pine and spruce is greater and survival rate increases.

Materials and Methods

The study was carried out on two experimental sites situated in Kalsnava and Mezole, which are located in the eastern part of Latvia (Figure 1) on the hummock relief (elevation of Kalsnava is ~125 m a.s.l., Mezole is ~165 m a.s.l.) on moraine soils with slopes of ~15%. The coldest month is January (mean temperature is ~ –7°C) and the warmest month is July (mean temperature is ~16.5°C), and the length of the vegetation period is ~125–145 days. Annual precipitation is 700–800 mm (Anon, 2011).

Research sites are located in mature (about 100 years old) pine stands with spruce in understorey on mesic average fertility *Hylocomiosa* forest type according to the classification by Bušs (1976). Mezole site has a smaller proportion of pine within stand in comparison to Kalsnava site (60% vs. 80%), and there are also differences in the average diameter (35.2 cm vs. 31.3 cm), the mean height (29.5 m vs. 25.8 m) and the stand basal area (31.6 m^2 ha^{-1} vs. 29.2 m^2 ha^{-1}), respectively. The dominant ground vegetation species prior to harvesting differed only marginally – in both sites *Vaccinium myrtillus* (L.) and *Calamagrostis arundinacea* ((L.) Roth) were present, but in Kalsnava the third dominant species was *Pteridium aquilinium* ((L.) Kuhn), while in Mezole it was *Melampyrum pratense* (L.). *Hylocomium splendens* (Hedw.) and *Pleurozium schreberi* ((Brid.) Mitt) dominated at the moss layer in both sites.

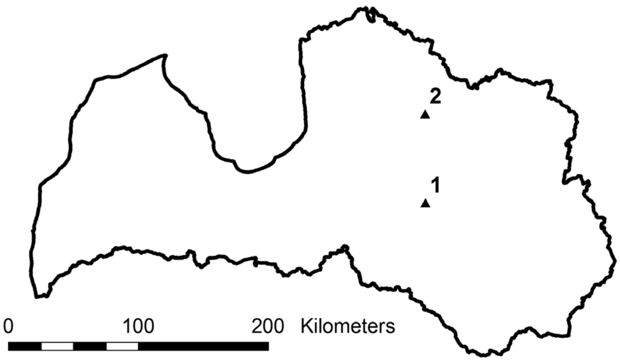

Figure 1. Location of research sites in Latvia (1 – Kalsnava; 2 – Mezole)

This research sites were established in 2005, initially creating a network of squares 40×40 m throughout the compartment. Circular sampling plots with a radius of 12.62 m (500 m^2) were established in the middle of each square. During the winter of 2006–2007 rectangular openings (gaps) of different sizes – 10×10 m, 20×20 m, 20×40 m (with the longest side arranged in the N–S (henceforth NS) or E–W (henceforth EW) direction) and 40×40 m – were marked and cut. The distance between the gaps was at least 20 m (with the exception of 10×10 m gaps, where the smallest distance between the gaps was 10 m). The possible influence from overly close neighbouring gaps (less than average tree height) was not considered because of a problem that sites were shaded by the understorey of spruces in surrounding uncut parts of the stand.

During the spring of 2008, the harvested gaps at Kalsnava site were divided and marked into 10×10 m squares, parts of which were planted with three-year-old bare-rooted spruce seedlings (h_{mean} = 27.1 ± 6.0 cm) without soil preparation (Figure 2). In the spring of 2011 additional parts of the squares were planted with containerised one year old pine seedlings (h_{mean} = 17.5 ± 0.2 cm) on patches (0.4×0.4 m), which had previously been scarified by hand tools.

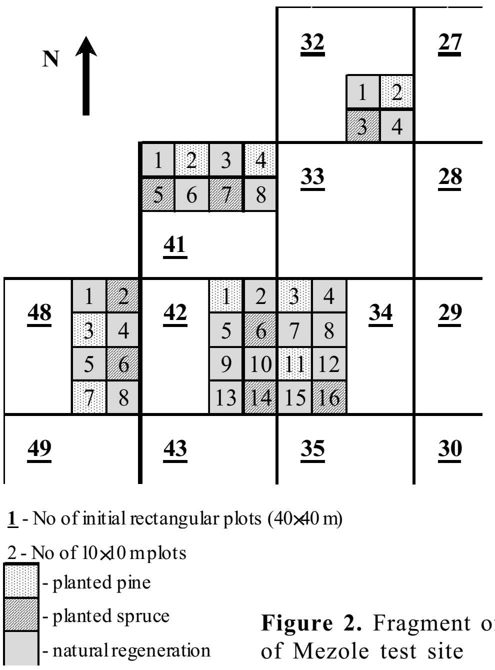

Figure 2. Fragment of the scheme of Mezole test site

Spruce seedlings were spaced 2×2 m apart (25 plants per marked 10×10 m square), but pine seedlings were spaced 1.75×1.75 m apart (30 plants per marked 10×10 m square), thus the distance from the gap edge was known for each seedling.

The smallest (10×10 m) gaps were planted with only one species. In the larger gaps, only a part of the marked 10×10 m squares were planted. For example, in areas with a gap size of 20×20 m, for every four marked squares one was planted with pine and one with spruce (Figure 2; Table 1).

Table 1. Number of different size gaps in the study areas

Gap size	Gap area, m^2	Number of gaps		Replicates per gap
		Kalsnava	Mezole	
10×10	100	6	6	1
20×20	400	2	3	1
20×40 EW	800	2	3	2
20×40 NS	800	2	2	2
40×40	1600	3	3	3..4

At Mezole site, planting with three year old bare-rooted spruce seedlings (h_{mean}=35.1 ± 6.0 cm) and one year old pine containerised seedlings (h_{mean} = 8.5 ± 0.2 cm) was carried out in the spring of 2009 in a similar manner. In this site, pine seedlings were spaced in the same way as spruce seedlings, i.e. 2×2 m. In total, 1252 pines (Kalsnava – 627; Mezole – 625) and 1175 spruces (Kalsnava – 500; Mezole – 625) were planted. Weeding was done each July on an annual basis. In Kalsnava site, pine seedlings were treated with repellent (Cervacol extra) and this was performed every autumn.

Immediately after planting the initial seedling height was measured. Seedling height was also measured in autumn during the third year. Each autumn, the status of the trees (alive, damaged, or dead) was recorded. If damaged, the type of damage (browsing, disease, etc.) was also identified.

After gap harvesting, a visual assessment of vegetation composition was carried out at Kalsnava site during July of the second year. Only those squares with artificial regeneration were observed. Average height of the vegetation as well as the proportion of the square area occupied by the vegetation was estimated.

Data analysis

For data analysis, the distance to the nearest gap edge was divided into distance groups: 1 m (including 0.5; 0.75; 1.0; 1.5 m), 3 m (including 2.25; 2.5; 3.0; 3.25 m) etc. Due to the small quantity of pine seedlings (a maximum of three observations) available for tree height increment calculations in the distance groups of 5 m in 10×10 m gap and 9 m in 20×20 m, 20×40 EW and 20×40 NS gaps, these distance groups were merged with the nearest groups, 3 m and 7 m, respectively. Similarly, the distance groups of 13 m, 15 m, 17 m and 19 m were merged with the 11-m distance group at 40×40 m gap. This combined group is hereafter referred to as ≥11 m. Due to a greater proportion of survived and undamaged trees, spruce quantity for tree height increment analysis in this distance group was sufficient, however to make the results comparable, the distance groups were merged in the same way as for pine.

Due to considerable differences between pine and spruce planting material, the statistical analysis was done separately. The proportion of survived trees and total tree height increment (henceforth ΔH) during 3 growing seasons after planting was calculated. Assumptions for normality (Shapiro-Wilk test) and equality of the variances (Levene's test) were tested for ΔH data. For spruce data assumptions were not met and data were logarithmically transformed. Survival data were transformed by arcsine for both species. Confidence intervals for the proportion of surviving trees were calculated. Differences between proportions were evaluated using *t*-test. Analysis of ΔH was done using analysis of variance (GLM Univariate) in SPSS14. Factors influencing ΔH were tested: the site (only spruce), initial tree height, gap size and the distance to the nearest gap edge. At Mezole site, ΔH of pines was not analysed due to the small proportion (23.7%) of survived pines. For the survival analysis, all planted trees were used, yet for ΔH analysis only the undamaged trees were used.

After performing the univariate analysis of variance, the initial tree height (for spruce ΔH as well) was found to significantly ($p < 0.05$) differ between the sites for both tree species. Therefore, further analyses were made for each study site separately. At further analysis factors influencing ΔH gap size and the distance to the nearest gap edge were tested, but for spruce the initial height was used as the covariate. To identify significant differences between ΔH, Games-Howell test for pine and Fisher's least significant difference test for spruce were used. Differences were considered statistically different with $\alpha < 0.05$.

Results

Seedling survival

Pine. At the end of the first growing season after the planting, a total of 96.3% of the planted pines in Kalsnava site survived, with a higher percentage of 98.9% in Mezole site. At the end of the second growing season after planting, the survival percentage differed considerably between sites, with 90.0% in Kalsnava site and 56.2% at Mezole site. At the end of the third growing season after planting, only 23.7% of the planted pines had survived at Mezole site, but in Kalsnava site 66.4% were still alive. The highest survival for pines in Kalsnava was found in the 20×20 m gaps (78.7%) and in the 20×40 NS gaps (76.1%), but the lowest in the 10×10 m gaps (51.1%), and in the 40×40 m gaps (64.1%) (Figure 3). The opposite was observed in Mezole; more trees survived in the 40×40 m gaps (36.4%) and in the 10×10 m gaps (22.7%) but less in the 20×40 NS gaps (12.0%) and in the 20×20 m gaps (9.3%). In both sites, differences were significant between mentioned gaps.

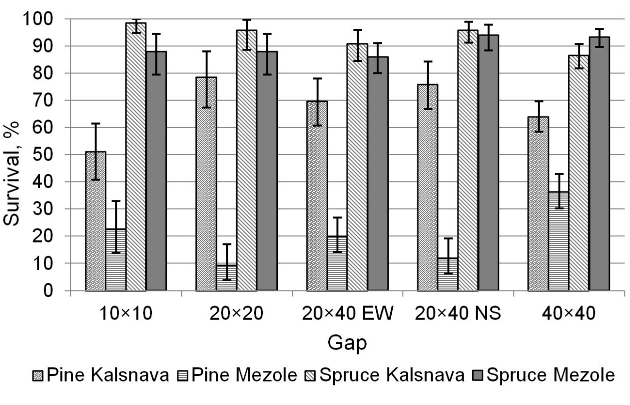

Figure 3. Planted pine and spruce survival (±95% confidence interval) during 3 years after the planting in the gaps of different size in the test sites of Kalsnava and Mezole

In Kalsnava site, the highest (average 77.0%) survival within one gap size was in the distance of 3 m from the gap edge (Figure 4). In distances closer and greater than 3 m from the gap edge, survival was lower (except for the 20×20 m gaps). In gaps larger than 10×10 m, the lowest survival was at the greatest distance from the gap edge.

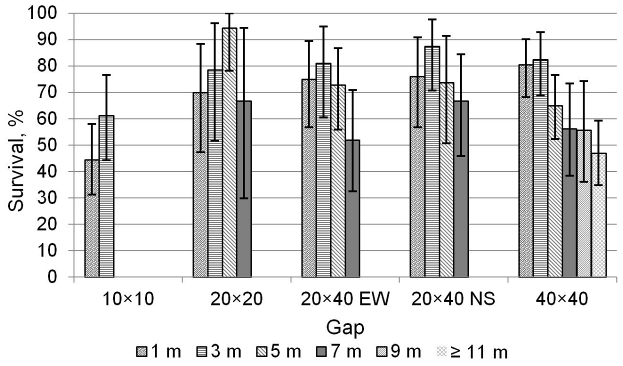

Figure 4. Planted pine survival (±95% confidence interval) at the end of the third growing season after planting at different distances from the gap edges in gaps of different size in test site Kalsnava

In Mezole site, the highest average survival (24.6%) was found at the distance of 1 m from the gap edge (Figure 5). However, in the 10×40 NS gaps of this distance no survived pines were found, and the highest survival was found directly at the greatest distance from the gap edge at 7 m (25.0%). Meanwhile, in the 40×40 m gaps, the highest survival was found at 9 m from the gap edge (55.6%). On average, the lowest survival (17.9%) was found at 5 m from the gap edge.

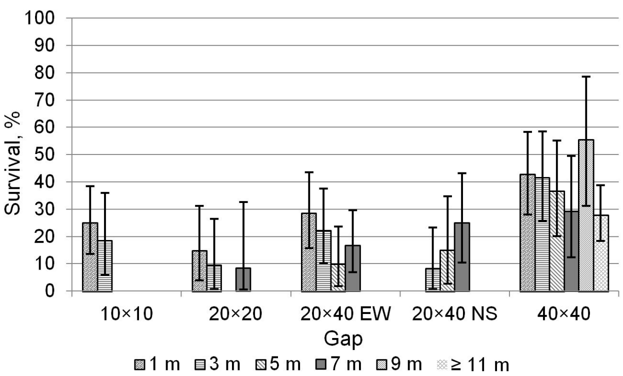

Figure 5. Planted pine survival (±95% confidence interval) at the end of the third growing season after planting at different distances from the gap edges in gaps of different size in test site Mezole

In Kalsnava site there was a tendency that at a distance of 1 m and 3 m from the gap edge a higher survival rate was found in the larger gaps. By contrast, at a distance of 5 m and 7 m from the gap edge this trend was not observed, and the highest survival rate was in the 20×20 m gaps.

In Mezole site, regardless of the distance from the gap edge, the highest survival was in the 40×40 m gaps. At a 5 m and 7 m distance from the gap edge in the larger gaps, a higher survival for pines was observed.

Spruce. In the first year after planting, in both sites 94.7% of spruce had survived on average, but in the second year this had reduced to 92.2%. Three years after planting, in both sites a similar proportion of spruces had survived: 91.6% in Kalsnava, and 90.4% in Mezole. The highest survival in Kalsnava site was found in the 10×10 m gaps, *i.e.* 98.7% (Figure 3), but the lowest in the 40×40 m gaps, *i.e.* 86.7%, and the difference was found to be significant. The highest survival at Mezole site was found in the 20×40 NS gaps at 94.0%, and the lowest was found in the 20×40 EW gaps at 86.0%, however the difference was not significant.

No pronounced tendencies of survival dependant on the distance from the gap edge or gap size were found. Moreover, in Kalsnava site survival for spruce was from 81.3% to 100%, but in Mezole site it ranged from 80.0% to 100%.

Damages to seedlings

During three years, the majority of the survived pines at both sites were damaged (75% in Kalsnava and 56% in Mezole) with most of the damaged pines (71% and 39%) at both sites being identified as snow-bent. It should be noted that 17% of the damaged pines in Mezole were browsed, but in Kalsnava this percentage was only 1.

In both sites, over the three years an equal proportion (9.7%) of the survived spruces were damaged. In Kalsnava 84% of the damages were due to browsing, while in Mezole this type of damage constituted only 7%, but the rest of the damaged spruces were identified with other types of damages also (diseases, pests).

Height increment

Pine. The initial tree height and the distance from the gap edge had no significant impact on pine ΔH. However, ΔH was significantly affected by the gap size.

In almost all gap sizes ΔH was the lowest at a distance of 1 m from the gap edge (Figure 6), but differences with pines which were located at a greater distance from the gap edge were not significant.

In the 10×10 m gaps, ΔH was lower compared with larger gaps, and differences at a distance of 1 m were significant compared with the 20×40 EW and 40×40 m gaps. Also, at 3 m distance from the gap edge, ΔH was lower in 10×10 m gaps and the differences were not significant. A significant result was only found with 20×20 m gaps.

In the 40×40 m gaps, at a greater distance from the gap edge, ΔH was higher and peaked (49 ± 8 cm) at a distance of 9 m from the gap edge. However, differences were not significant. While at the greatest distance of ≥11 m from the gap edge (graduation class also includes up to 19 m from the gap edge) ΔH was lower (47 ± 6 cm).

At a distance of 7 m from the gap edge at the larger gaps ΔH was higher but differences were insignificant.

Spruce. The initial tree height and the distance from the gap edge were found to have a significant impact on spruce ΔH. Gap size significantly affected ΔH only in Mezole, while in Kalsnava this effect was insignificant.

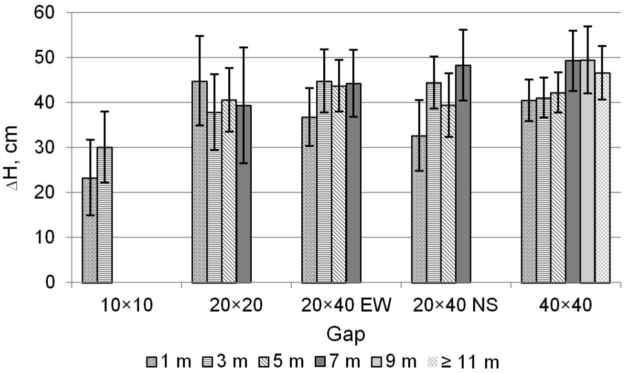

Figure 6. Planted pine height increment during 3 growing seasons (ΔH) (±95% confidence interval) at different distances from the gap edges in the gaps of different size in test site Kalsnava

There was a tendency that at the same gap size at a greater distance from the gap edge ΔH was higher (Figure 7), however, differences between the classes were mainly not significant. Also, the differences between the research sites should be taken into account (Figure 8). For example, at a

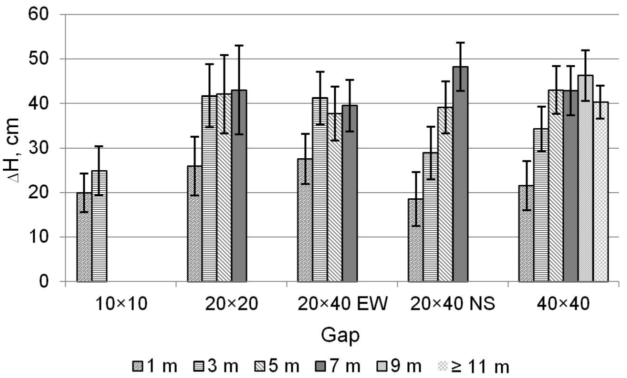

Figure 7. Planted spruce height increment during 3 growing seasons (ΔH) (±95% confidence interval) at different distances from the gap edges in the gaps of different size in test site Kalsnava

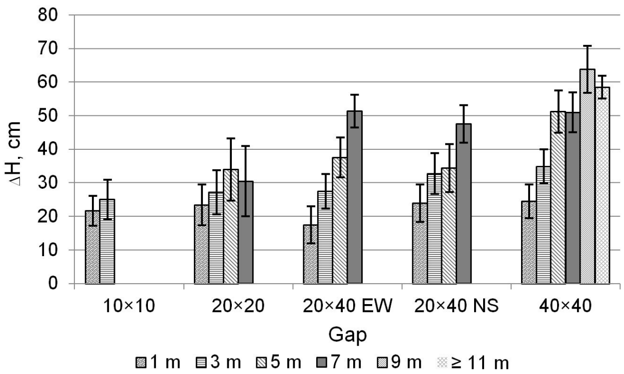

Figure 8. Planted spruce height increment during 3 growing seasons (ΔH) (±95% confidence interval) at different distances from the gap edges in the gaps of different size in test site Mezole

distance of 1 m from the gap edge there was no significant difference for all gap sizes, and ΔH was the smallest. However, at a distance of 3 m, there was a significant difference at Kalsnava in the 20×20 m, 20×40 EW and 40×40 m gaps, but only in the 40×40 m gaps in Mezole. Whereas spruces at a distance of 3 m from the gap edge had the second smallest ΔH in almost all cases except for the 20×40 gaps in Kalsnava.

As in the case of pine, ΔH was higher for spruce seedlings in the 40×40 m gaps at a greater distance from the gap edge, peaking (46 ± 3 cm) at a distance of 9 m from the gap edge. At the distance of 9 m, spruces had a significantly higher ΔH compared with spruces at a distance of 3 m and 1 m to the gap edge. At a distance of ≥11 m from the gap edge, ΔH became lower (by 5–6 cm).

In the case of pine, ΔH had the lowest values in the 10×10 m gaps compared with the larger gaps, while in the case of spruce the situation was different, whereby the lowest values of ΔH were found in the 10×10 m gaps only at a distance of 3 m from the gap edge.

Vegetation

In Kalsnava site by the second growing season after gap harvesting in the 40×40 gaps at marked squares along gap edges *Rubus idaeus* (L.) covered about 13% of the area of squares with an average height of 0.9 m. At squares in the middle of the 40×40 m gaps this was 19% and 1.0 m (Table 2). *Calamagrostis arundinacea* in marked squares along the gap edge covered 17% with an average height of 1.6 m, but in the middle squares this increased to 30% with the same average height.

Table 2. Ground cover and height of main species in forest understory in the second year after different size gap cutting in Kalsnava

Gap		*Rubus idaeus*		*Calamagrostis arundinacea*		*Pteridium aquilinium*	
		Ground cover, %	H, m	Ground cover, %	H, m	Ground cover, %	H, m
10×10		2	0.7			1	0.5
20×20		33	0.9				
20×40 EW		21	1.0	1	1.3	3	0.6
20×40 NS		8	0.9			9	0.9
40×40	border	13	0.9	17	1.6	3	0.6
	centre	19	1.0	30	1.6	6	0.7

Discussion

Between the survival of the planted trees and their height increment there are considerable differences both between the sites and the species. When assessing the survival of pine, no clear trends were found between sites in overall survival of seedlings, in survival in the different size gaps and distances from gap edges. The only common tendency is that at a distance of 1 m and 3 m from the gap edge, the highest survival was in the 40×40 m gaps, which could be explained by a better light regime compared with the smaller gaps. The difference between the sites could be explained by the substantially different initial tree heights and by research site characteristics, such as a better light regime in Kalsnava. The better light regime can be explained by a different mixture of shelterwood species (pine proportion in stand at 80% vs. 60%), and a different shelterwood height, ~26 m vs. ~30 m. Stands with a higher proportion of pine have a better light regime (Sonohat et al. 2004, Zdors and Donis 2011). Also, shorter trees give less shade. Better light regime also contributes to the growth of the competing vegetation, which might explain why in Kalsnava there were less survived pines in the larger gaps at a distance above 3 m from the gap edges.

Differences between the research sites in pine survival could be explained by different planting times (2009 and 2011) as well as by the different planting time after creation of the gaps, i.e. the third growing season after felling in Mezole compared with the fifth growing season after felling in Kalsnava. The longer the time after cutting, the greater the competing vegetation cover after shelterwood cuttings (Marozas and Sasnauskiene 2012), similarly as after clearcutting (Nilsson and Örlander 1999). It could also explain why in Kalsnava there was a lower survival for pines in the larger gaps at a distance above 3 m from the gap edges.

One of the explanations of the low survival of pines observed can be the high proportion of snow-bent seedlings. Snow-bending of pines can be explained by the fact that the pine in an insufficient light regime has a tendency of a high H:D ratio, thus it bends more easily (Лабанаускас 1969). Dehlin et al. (2004) found that pine seedlings responded to shade by increasing seedling height, leading to a typical shade avoidance reaction (Aphalo et al. 1999) known to be pronounced in shade-intolerant species and corresponding to stem elongation at the expense of diameter growth. However, spruce as the mid-late successional species did not show any changes in growth when exposed to shade (Dehlin et al. 2004). Gaudio et al. (2011b) found that pine sapling height growth decreased when light decreased, but pine sapling diameter decreased more strongly than pine sapling height, leading to more slender pine saplings. By contrast, differences in the proportion of damaged pine due to browsing between the sites may be explained by the fact that each autumn pines in Kalsnava were treated with repellent, whereas in Mezole repellents were not used. It should be noted that pines in Kalsnava were planted repeatedly, and 56% of pines from the previous planting had damages from browsing (first planting was not treated with repellents). Spruce was less affected by browsing, which is also well known from other researches (Edenius et al. 2002, Miligan and Koricheva 2013), therefore foresters in Latvia often choose to plant spruce instead of pine (Mangalis 2004, Baumanis et al. 2014).

Differences between the research sites show no noticeable impact on spruce survival, mainly because of spruce shade tolerance. Although there are differences between the research sites in terms of how spruces survived in different size gaps, the overall survival was not less than 86.0% regardless of the gap size, and not less than 81.3% regardless of the distance from the gap edge. Our results are quite similar with the study carried out in Norway, where in 25×25 m gaps 6 years after planting more than 90% of planted spruce had survived (Granhus et al. 2003). A different result was obtained in the UK, where 4 years after planting in gaps with a diameter of 20 m only about 50% of the planted Sitka spruce survived (Page and Cameron 2006). However, our research confirms other studies results, that in light-limiting environments survivorship rates are higher for shade-tolerant species than for less shade-tolerant species (Chen 1997, Kobe and Coates 1997, Coates 2000, York at al. 2004, Mason et al. 2004). In our research, overall spruce survival was greater than pine survival.

There is a trend that in most cases at a greater distance from the gap edge ΔH was higher. In the case of pine, differences among the distances are not significant, yet for spruce some differences are significant. Both pine and spruce seedlings in the 40×40 m gaps had higher ΔH at a greater distance from the gap edge and peak at 9 m, but then at a distance of ≥11 m, ΔH slightly decreases. This indicates that up to a 9 m distance from the gap edge (because of a better light regime and a decrease of gap edge tree root competition) seedling growing conditions are improving, but at a greater distance the growth of seedlings was influenced by other background factors, such as the competing ground vegetation. In our case, this was mainly *Calamagrostis arundinacea* and *Rubus idaeus*. Also in other study, where ground vegetation was not controlled, a similar trend was observed, *i.e.* in greater gaps at a greater distance from the gap edge, the tree growth was also affected by the ground vegetation competition, which reduces the positive effect of improvement in the light regime (Kern et al. 2012). In contrast, Gaudio et al. (2011a) found that increasing competing plant species density had a highly significant negative impact on pine seedling diameter, but had almost no effect on pine seedling height growth. The ground vegetation competition smothering effect on seedling growth can explain why our results differ from results by de Chantal et al. (2003), who found that seedling size (aboveground dry biomass, height, and projected leaf area) of pine and spruce increased with increasing radiation, but shade-intolerant pine responded more strongly than shade-tolerant spruce. Although weeding was carried out once a year during our study, usually in July, apparently, it was not sufficient to mitigate the negative impact of ground vegetation (especially in the largest, 40×40 m, gaps). Ammer et al. (2011) concluded that despite the large body of literature on forest vegetation management, there are still inconsistent findings on the effect of overstorey density and gap size.

As previously mentioned, in the 40×40 m gaps at a distance greater than 9 m from the gap edges, ΔH of the seedlings did not change, thus it can be assumed that the edge effect is up to 9 m. However, given that the distance group ≥11 m also contained seedlings up to 19 m from the gap edge, it would not be correct to state any certain distance from which the edge effect is detectable. However, a comparison can be made with other similar studies. In the research of natural regeneration in different configuration gaps in pine stands of *Vacciniosa* forest type, Donis (2007) found that at a distance of less than 5 m from the gap edge pines were significantly shorter. In each distance group the trees were higher, though the difference was not significant (Donis 2007). Similar results were obtained by Jakobson (2005) in Sweden, who found that in young pine stands the volume production in the 5-m zone closest to the edge was 10 % of that beyond 5 m. A study from Finland shows that competition resulted in retarded height development, which extended up to about half of the dominant height of the edge stand (Siipilehto 2006). It should be noted that the research, which compared the growth of the pines planted in an uncut forest (500 trees per ha) and in a clear-cut, proved that four years after the planting the dry mass of the pines leading shoots in uncut forest was only 3% of that in a clear-cut (Erefur et al. 2011). But for the height growth the corresponding value was almost 30%. These findings indicate that height growth can be not a good measure for the overall growth of seedlings, especially not under shelterwood cutting (Erefur et al. 2011). However, crown, shoot and needle characteristics could reflect the acclimation to light conditions and indicate the performance of advance regeneration after release (Metslaid et al. 2007).

In the 10×10 m gaps at a certain distance from the gap edge, pines had a lower ΔH when compared with the larger gaps. In addition, the proportion of survived pines in these gaps in Kalsnava site was the lowest among all sizes of gaps, but in Mezole it was one of the lowest. With spruce seedling survival, such trends were not observed, still ΔH was the lowest (at a distance of 3 m from the gap edge) in the 10×10 m gaps when compared with the larger gaps. Consequently, when a group shelterwood cutting is done with the aim to grow pine, it is advisable to create gaps larger than 10×10 m. For pine stands, Zviedris (1949) recommends to initially cut 30×30 m gaps while Sūna (1973) recommends to cut gaps with a diameter similar to the tree height (approximately 25 m). In Sweden, the studies suggest to create 20–40×30–60 m gaps (Erefur et al. 2011). In the UK, in order to achieve satisfactory growth for pine it is suggested that the gap size should be not less than 0.2 ha, or the diameter should be similar to the height of two trees in a surrounding stand (Malcolm et al. 2001). In the northern part of North American temperate forests, it was found that the opening size should not necessarily be very large (0.1–0.2 ha) in order for plants to achieve growth rates similar to those of plants in the open conditions of clear-cut (Coates 2000).

When we compare ΔH of spruce between the gaps of 20×40 m where the longest edge is oriented in N–S or E–W directions, there are no similar tendencies at a given distance from the gap edge. While at one distance from the gap edge the ΔH of spruce was greater in the N–S oriented gaps, at another distance ΔH was higher in the E–W oriented gaps. For example, in Kalsnava site at a distance of 1 m and 3 m from the gap edge, ΔH was higher in the E–W oriented gaps, but at a distance of 5 m and 7 m it was higher in the N–S oriented gaps. On the other hand, a contrary trend was observed in Mezole site. Therefore, we can conclude that the differences in the growth 3 years after the spruce planting in the 20×40 m gaps were not observable, where the longest edge was oriented in the N–S or the E–W direction. ΔH of pine in Kalsnava site showed similar trends to spruce between these differently oriented gaps.

The reason that no significant differences were found between the different size gaps and distances from the gap edge could be the short observation period after planting. Observations over an extended period could reveal significant tendencies or allow time for new ones to appear. Bradshaw (1992) concluded that the magnitude of the edge effect has a temporal scale and it can be expected that the size of the edge effect will increase with the size of the saplings. Tree sapling light requirements increased with sapling dimension due to the increase of non-photosynthetic tissues involved in maintenance and building relative to photosynthetic tissues (Delagrange et al. 2004, Claveau et al. 2005, Balandier et al. 2007, Gaudio et al. 2011b). Canopy tree mortality after disturbances or harvest can also be an important issue as falling trees alter light conditions and soil moisture regimes. Köster et al. (2009) found that five years after wind made gaps in spruce forest, only 25% of the spruce trees survived in areas surrounding the windthrow. Nevertheless Gray et al. (2012) found that there was no difference between mortality rates of trees within 8 m of gaps and trees in closed-canopy controls, although mortality causes did differ for understory trees. Scots pine is a more resistant tree species to uprooting and stem breakage than spruce (Peltola et al. 2000), therefore, it can be expected to have a lower mortality rate around gaps. On the other hand, small gaps can even be closed by lateral crown extension of mature edge trees (Runkle and Yetter 1987, Valverde and Silvertown 1997, Webster and Lorimer 2005, Kern et al. 2013). However, the growth of boreal forest species crowns is less likely to close canopy gaps (Lieffers et al. 1999). In our case changes in growing patterns in the future could also be linked with seedlings growing above competing vegetation.

Conclusions

Pine survival 3 years after planting notably differed between test sites (66% and 24%), but did not differ regarding the gap size and the distance from the closest gap edge. Spruce survival 3 years after planting was at least 86% regarding the gap size and at least 80% regarding the location within the gap. Therefore, spruce can be used as an alternative (in medium fertile forest types) if pine planting results are unsuccessful.

Gap size had a significant ($p < 0.05$) influence on the ΔH for both species, but the distance to the closest gap edge only had a significant ($p < 0.05$) influence on the ΔH for spruce. In the 10×10 m gaps at a given distance from the gap edge the ΔH of pine was lower compared to larger gaps. In addition, survival of seedlings in these gaps was one of the lowest. Based on the results it can be concluded that the gap size should be larger than 10×10 m to ensure acceptable growth during the first years after planting pine. In most cases, the ΔH tended to be higher at a greater distance from the gap edge. However, in the 40×40 m gaps at a distance of more than 9 m from the gap edge, the ΔH did not continue to increase.

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