SILVA FENNICA

Silva Fennica 46(5) research articles

www.metla.fi/silvafennica · ISSN 0037-5330
The Finnish Society of Forest Science · The Finnish Forest Research Institute

Seedling Establishment on Small Cutting Areas with or without Site Preparation in a Drained Spruce Mire – a Case Study in Northern Finland

Hannu Hökkä, Jaakko Repola, Mikko Moilanen and Markku Saarinen

Hökkä, H., Repola, J., Moilanen, M. & Saarinen, M. 2012. Seedling establishment on small cutting areas with or without site preparation in a drained spruce mire – a case study in northern Finland. Silva Fennica 46(5): 695–705.

A large proportion of drained spruce mire stands is currently approaching regeneration maturity in Finland. We studied the effect of cutting – small canopy openings (78, 177, and 314 m^2) and small clear-cuts (0.25–0.37 ha) – with or without site preparation (scalping) on the establishment of natural Norway spruce seedlings in one experimental drained spruce mire stand in northern Finland. The cuttings were made in winter 2004–2005 and site preparation with scalping in early June 2005. The experimental design was composed of four blocks with altogether four clear-cuts and 33 canopy openings. The seedling establishment was surveyed annually (2006, 2008–2010) from five circular sample plots (one 10 m^2 and four 5 m^2 plots in size) located within the canopy openings and from 18 circular 5 m^2 sample plots systematically located in the scalped and untreated halves of the clear-cuts. Site preparation was found unnecessary, because it resulted in a clearly lower number of seedlings in the openings. A slight negative effect was also found in the clear-cuts. In the two years following the cuttings, the number of seedlings increased quickly in the canopy openings, but more gradually in the clear-cut areas. In 2010, on average 15 500 new seedlings were observed in the canopy openings and 6700 in the clear-cut areas, of which 5050 and 1200, respectively, were >0.1 m tall spruces. The proportion of birch increased in the last two years, being ca. 22% in the openings and 45% in the clear-cuts in 2010. The spatial distribution of seedlings was more uneven in the clear-cuts than in the openings, with 41% and 20% of survey plots empty, respectively.

Keywords canopy gaps, clear-cut, drained peatlands, natural regeneration, *Picea abies*, seedling establishment, site preparation
Addresses *Hökkä* and *Repola*, Finnish Forest Research Institute, Rovaniemi Unit, P.O. Box 16, FI-96301 Rovaniemi, Finland; *Moilanen*, Finnish Forest Research Institute, Oulu Unit, Oulu, Finland; *Saarinen*, Finnish Forest Research Institute, Parkano Unit, Parkano, Finland
E-mail hannu.hokka@metla.fi
Received 12 September 2012 **Revised** 21 November 2012 **Accepted** 22 November 2012
Available at http://www.metla.fi/silvafennica/full/sf46/sf465695.pdf

1 Introduction

A total of 1.5 mill. hectares of spruce mires have been drained for forestry purposes in Finland (Hökkä et al. 2002). The tree stands in these sites are characterized by pure stands of Norway spruce (*Picea abies* (L.) Karst.) or various mixtures of Norway spruce and hardwood species, mainly pubescent birch (*Betula pubescens* Erhr.) (Heikurainen 1971, Hörnberg 1995, Norokorpi et al. 1997).

A large proportion (42%) of drained spruce mire stands is currently approaching regeneration maturity (Hökkä et al. 2002). Traditionally, spruce mires have been regenerated with clear-cutting and planting with Norway spruce, which has been shown to be a rather reliable method of regeneration (Moilanen et al. 1995). Currently it is the main method used and includes efficient soil preparation and planting with vigorous seedlings to ensure a sufficient regeneration result. Manual control of ground vegetation and fast-growing non-valuable deciduous pioneer tree species is generally required at the early ages. Costly early age investments and the potential leaching of nitrogen, phosphorus and suspended solids through the drainage networks into the receiving water bodies following clear-cutting and soil preparation (Nieminen 2004) are the problems of artificial regeneration in fertile drained peatland sites.

Alternatively, natural regeneration with strip cutting (Lukkala 1946), shelter-tree cutting (Hånell 1993, Holgén and Hånell 2000), or small-scale clear-cutting (Moilanen et al. 1995, 2011) have been applied in spruce mires. Recently Hökkä et al. (2011) showed that the cutting of small canopy openings will result in a good regeneration of spruce mire stands. Moilanen et al. (1995) and Moilanen et al. (2011) observed that Norway spruce naturally regenerates also in clear-cuts without any additional soil preparation or regeneration measures. Spruce seed crop easily covers a clear-cut area extending several hundred meters, but the problems with spruce in larger clear-cuts are frost (e.g. Hånell 1993, Moilanen et al. 1995, 2011) and competition with ground vegetation (e.g., Hannerz and Hånell 1993, Moilanen et al. 1995), due to which clear-cut alone has not been recommended as a method of natural regeneration. Nevertheless, these previous results suggest that the potential for natural regeneration in drained spruce mires is high and may offer a reasonable alternative for the artificial regeneration methods. For practical forestry, shelter-tree cutting, release of natural advance growth, and regeneration under birch nurse trees are the methods recommended for the natural regeneration of spruce mires (Hyvän metsänhoidon… 2007), but most commonly artificial regeneration is applied.

Site preparation has been found to be necessary in many drained Scots pine peatland sites because of the thick layer of raw humus (poorly decomposed residues of feather moss species) which develops on the top of the peat layer within some decades after drainage (Saarinen & Hotanen 2000). The raw humus is not a proper substance for seed germination because it disables the capillary water connection between soil surface and the peat layer. The raw humus should be removed in site preparation to expose the moist top peat layer. Moilanen et al. (2011) observed that in a northern Finland spruce mire regeneration area, site preparation (machine rutting or scalping) increased the number of natural spruce seedlings three to four-fold compared to unprepared treatments within four years from cutting. After 15 years, the highest spruce density was, however, found on unprepared plots (Moilanen et al. 2011).

Currently there is still a lack of knowledge on the results and applicability of alternative natural regeneration methods of spruce mire stands. The aims of this study were to i) compare the natural regeneration of Norway spruce in small canopy openings and small clear-cuts and ii) study the effects of scalping on regeneration. The study was done by monitoring the number of established seedlings for five growing seasons after cutting in an experimental drained spruce mire stand in northern Finland.

2 Materials and Methods

2.1 Study Site, Experimental Design and Treatments

The study site was located in Tervola, northern Finland (N = 7341008, E = 440177) and was classified as a eutrophic, shallow-peated spruce

Table 1. Stand characteristics at the time of establishment (2004) by blocks (1–4) in the field experiment used in the study. BA = stand basal area, D_{Med} = median diameter at 1.3 m height, H_{dom} = stand dominant height, V = stand volume.

Block	Stand characteristics				
	Stems, ha^{-1}	BA, m^2ha^{-1}	D_{Med}, cm	H_{dom}, m	V, m^3ha^{-1}
1	1478	27	20	17	181
2	1901	29	20	18	198
3	1776	33	21	18	227
4	1322	25	22	18	170
Mean	1619	29	21	18	194

Table 2. The number of canopy openings and clear-cut plots with or without site preparation by blocks in the field experiment used in the study.

Block	Canopy openings		Clear-cut	
	No site preparation [b)]	Site preparation	No site preparation [b)]	Site preparation
1	3 [a)]	6 [a)]	1 [a)]	1 [a)]
2	12	0	1	0
3	3 [a)]	3 [a)]	1 [a)]	1 [a)]
4	6	0	1	0
Total	24	9	4	2

a) Canopy openings and clear-cut plots which were used in composing the data for analysing the effect of site preparation on the number of seedlings (model 1)
b) Canopy openings and clear-cut plots which were used in composing the data for analysing the effect of cutting treatment on the number of seedlings (model 2)

swamp (Vasander and Laine 2008) with peat thickness varying from 10–50 cm. The average annual temperature sum (with 5 °C threshold) during 2000–2010 was 1076 dd °C (Venäläinen et al. 1995) and the altitude 105 m above sea level. The site was initially drained in the 1960s, and the present tree stand was composed of mature Norway spruce with a variable admixture of pubescent birch. Stand dominant height varied from 17 to 18 m, and stand volume from 170 to 227 m^3 ha^{-1} (Table 1).

The experiment was established in autumn 2004. The experimental design was composed of altogether 4 randomized blocks, each including the three different opening sizes (10, 15, and 20 m in diameter) replicated 2–4 times (Fig. 1, see Hökkä et al. 2011). The opening size was not point of interest of this study. A clear-cut plot was included in every block to enable the comparison of the regeneration results in the openings and clear-cut areas. The sizes of the clear-cuts were 0.25, 0.27, 0.33, and 0.37 ha.

Site preparation treatment was implemented in early June 2005 in six openings in block 1 and three openings in block 3 (Table 2). In both blocks also one half of the clear-cut area was prepared. The applied site preparation was scalping, i.e., 5–10 cm of the uppermost layer of the peat soil was removed using the bucket of the excavator. This resulted in approximately 25–40% of the soil surface treated.

The cuttings were done in winter 2005. Haulage trails were also cut while carefully avoiding unnecessary removal of stems. After harvesting, the forwarding machine was used to remove most of the cutting residuals and tree tops from the area of the opening.

2.2 Method of Seedling Survey

In order to study the germination of new seedlings after cutting and site preparation, a design of small-sized seedling survey sample plots

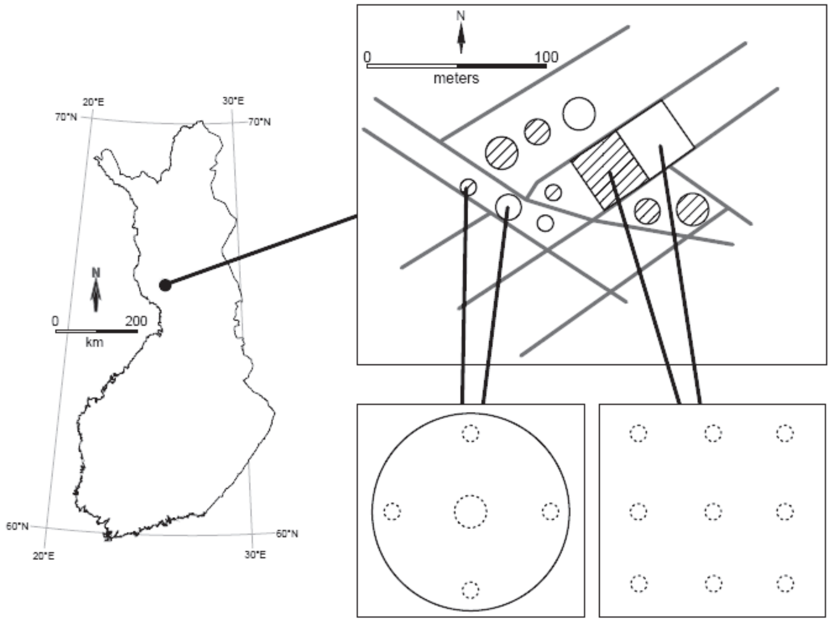

Fig. 1. Location of the study site and experimental design in Block 1 and an example of setup of seedling survey plots (dotted circles) in an opening and a clear-cut. Site preparation is indicated by hatching.

was established. A sample plot of 10 m^2 in size (radius = 1.79 m) was located in the middle of each opening. Circular 5 m^2 (radius = 1.26 m) plots were established in each cardinal direction (n, e, s, w) at a 1.5 m distance from the edge of the opening (Fig. 1). The center points of these seedling survey plots were marked with a plastic pipe. In the clear-cuts a systematic grid of altogether 18 seedling survey plots (5 m^2) was established in a way that an equal number (9) of plots was located on the untreated and scalped halves of the clear-cut area.

The seedling survey was made first time in 2006, after one growing season had elapsed since cutting and site preparation, and was repeated in 2008, 2009, and 2010. The survey was made in the spring before the growth of the ground vegetation. In the field the seedling survey sample plots were further divided into four equal-sized sectors according to the cardinal points. The number of seedlings was inventoried by the sectors by classifying the seedlings into two height groups (< 0.1 m or > 0.1 m). Seedlings shorter than 0.1 m were assumed to be germinated after cutting ('new') and were counted by tree species. When necessary, the time of the seedling's establishment was defined by counting the number of leader shoots to determine whether it was germinated before or after cutting. Seedlings larger than 0.1 m in height in 2006 were excluded from this study. In later surveys, when part of the seedlings with initial height <0.1 m exceeded this height, all seedlings were classified into two height categories (<0.1 or >0.1 m). Because of the occurrence of other deciduous species than pubescent birch was marginal, they are all combined with birch in the analysis.

The number of new seedlings in an opening or a clear-cut on a hectare-basis was calculated as an average of the number of seedlings in each survey plot weighed by the area of the survey plot.

2.3 Analysis Methods

The analyses were based on graphical and statistical comparison of mean seedling numbers (ha^{-1}) between site preparation treatments (scalping vs.

no site preparation) and between cutting treatments (canopy openings vs. clear-cuts). In the analysis both the number of new seedlings and number of spruce seedlings were used as the response variables.

In the first analysis the effect of site preparation on the number of new seedlings or new spruce seedlings was tested using only the openings and clear-cuts from block 1 and 3 where soil preparation was made (see Table 2). The total numbers of unprepared and site prepared openings were 9 and 6. The comparison was made separately for openings and clear-cuts. Size-differences among the openings were not accounted for in the analyses, i.e., openings were pooled by blocks thus giving altogether two observations for both site preparation treatments (Table 2). In the clear-cuts the number of observations in both treatments was also two (i.e., two site-prepared and two unprepared halves). The following repeated mixed ANOVA model was applied to carry out the four comparisons between site preparation treatments over the four measurements occasions:

$$N_k = PREP + YEAR + u_k + e_{k(t)} \quad (1)$$

where

N_k = total number of new seedlings (ha^{-1}) or number of new spruce seedlings (ha^{-1}) in block k in the opening or in the clear-cut; logarithmic transformation was applied for N_k except for the total number of seedlings in clear-cuts.

$PREP$ = effect of site preparation treatment (scalping, none)

$YEAR$ = effect of survey year

u_k = random effect of block k

$e_{k(t)}$ = random error

In the second analysis the untreated canopy openings (altogether 24) and clear-cuts with no site preparation (altogether two complete clear-cuts and two halves) were included from all of the four blocks (Table 2). In the analysis different-size openings were pooled by blocks, thus resulting in altogether four observations from the opening cuttings. The number of clear-cuts was also four (one from each block).

The following repeated mixed ANOVA model was used to compare the seedling densities between the cutting treatments over the four measurement occasions:

$$N_k = CUT + YEAR + u_k + e_{k(t)} \quad (2)$$

where

N_k = total number of new seedlings (ha^{-1}) or number of new spruce seedlings (ha^{-1}) in block k

CUT = effect of cutting treatment (opening, clear-cut)

$YEAR$ = effect of survey year

u_k = random effect of block k

$e_{k(t)}$ = random error

Constant correlation structure was assumed for the successive measurements in all analyses. The models were estimated with the Mixed procedure implemented in the SAS software (SAS Institute Inc. 2002–2008).

Overall spatial distribution of seedlings was studied in non-scalped openings and clear-cuts by calculating the number of empty survey plots (no seedlings) in 2010. The proportion of seedling survey plots where no spruce seedlings, or no >0.1 m tall spruces were found was investigated for every survey year.

3 Results

3.1 Effect of Site Preparation on Seedling Establishment

Seedling establishment was significantly faster and more effective in those canopy openings where scalping was not implemented (for all seedlings $p < 0.0001$, for spruce seedlings $p < 0.0001$) (Fig. 2a). After three to four years, the number of seedlings in the untreated openings was ca. threefold compared to the scalped openings, where seedling number also increased annually but with a lag (Fig. 2a). In 2010, the number of >0.1 m tall spruces was on average 4460 (1450–12300) in the untreated openings and 1370 (334–3678) in the treated openings.

In the clear-cut areas, site preparation did not cause such clear differences as in the openings (Fig. 2b). Both the number of all seedlings and the number

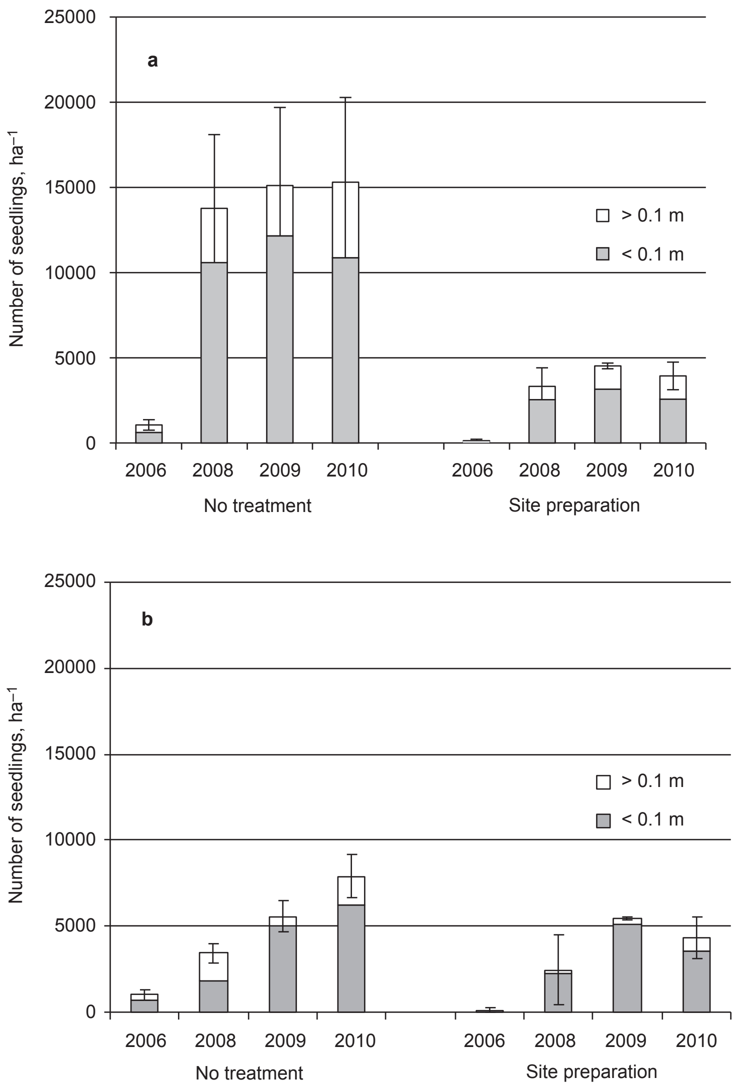

Fig. 2. (a, b). The effect of site preparation on the total number of new seedlings (<0.1 m and >0.1 m in height) in the canopy openings (a) and clear-cuts (b). Bars in columns indicate standard error among blocks.

of spruces were slightly higher in the untreated areas, but the differences were non-significant ($p=0.0847$, $p=0.1724$). In 2010, the number of >0.1 m tall spruces was low both in the untreated (1670 ha^{-1}) and treated clear-cuts (780 ha^{-1}).

Site preparation did not have a significant effect on birch proportion in either cutting treatment (Fig. 3), although the average number of birch seedlings in 2010 was clearly lower (780 ha^{-1}) in the openings compared to that in the clear-cut areas (1787 ha^{-1}).

3.2 Seedling Establishment in the Untreated Canopy Openings and Clear-Cut Areas

In general, the seedling density was significantly higher in the canopy openings than in the clear-

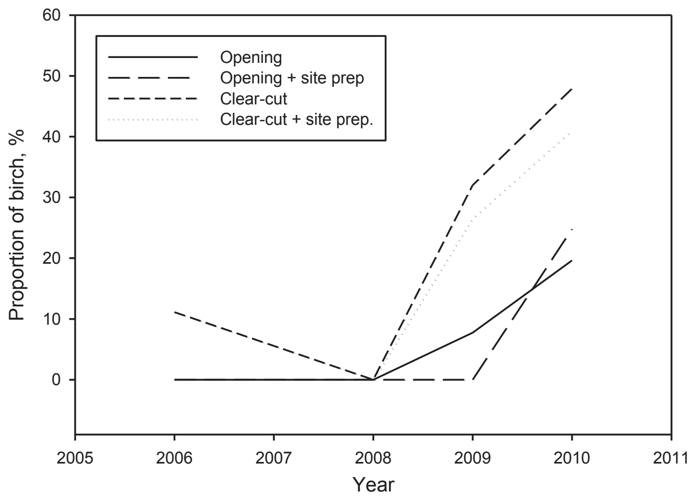

Fig. 3. Development of the proportion of pubescent birch (other deciduous species included) of total number of seedlings in the openings and clear-cuts and the effect of site preparation.

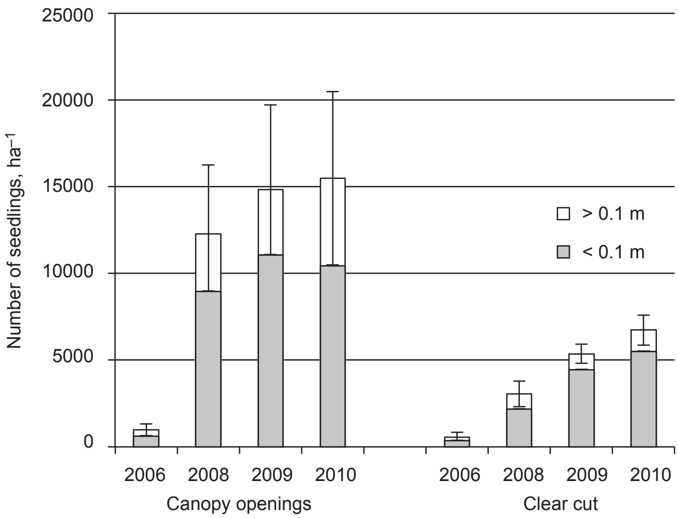

Fig. 4. The average number of new seedlings (<0.1 m and >0.1 m in height) in the canopy openings and clear-cut areas. Bars in columns indicate standard error among blocks.

cut areas (for all seedlings $p=0.0006$ and for spruce seedlings $p=0.0001$) in every survey year (Fig. 4). The time effect was also significant, but there was no significant interaction. In the first year after cutting (2006), the number of seedlings was <1000 ha^{-1} with both cutting treatments, but within three years, seedling establishment increased on average three-fold in the canopy openings compared to that of the clear-cut areas. In 2010, on average 15500 seedlings ha^{-1} were found in the canopy openings and 6700 seedlings ha^{-1} in the clear-cut areas. Most of the increase in seedling density in clear-cut areas was in the number of small seedlings (height <0.1 m),

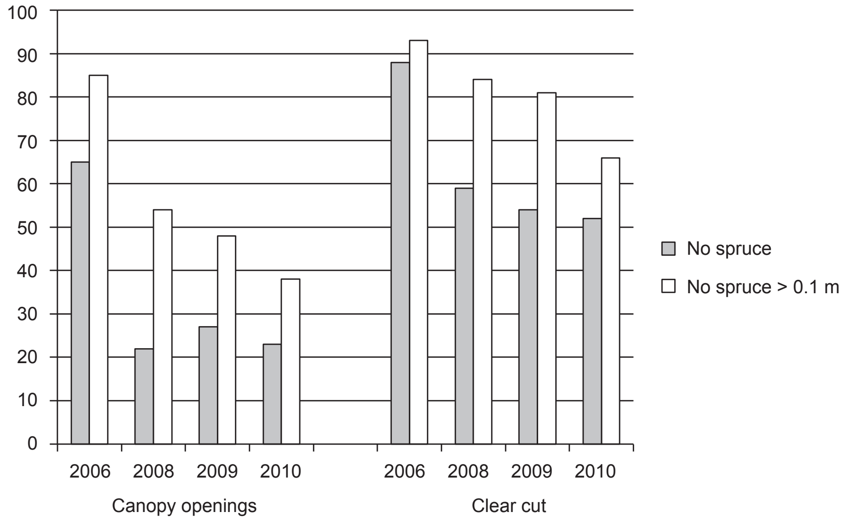

Fig. 5. Development of the proportion of seedling survey plots without any spruce seedlings or without spruce seedlings taller than 0.1 m in the canopy openings and clear-cuts.

whereas the number of larger (height >0.1 m) seedlings remained virtually the same (ca. 1000 ha^{-1}) in the 2008, 2009, and 2010 inventories. In the canopy openings, also the number of >0.1 m seedlings increased slightly every year. In 2010, the number of >0.1 m tall spruces varied from 500 to 11890 in the openings and from 400 to 2000 seedlings ha^{-1} in the clear-cuts. The proportion of birch increased in the last two years in both cutting treatments, but clearly more in the clear-cut areas (44%) than in the canopy openings (22%) (Fig. 3). The number of birch seedlings in 2010 exceeded 3000 ha^{-1} both in the canopy openings (3010 ha^{-1}) and the clear-cut areas (3790 ha^{-1}). This increase was almost entirely of small (height <0.1 m) birch seedlings in both treatments.

3.3 Spatial Evenness of the New Seedlings

On average, 41% of the seedling survey plots were without any seedlings in clear-cut areas and 20% in the canopy openings in 2010 in the non-scalped treatments (data not shown). The establishment of spruce seedlings was very uneven in both cutting treatments in 2006, but became more even in the later inventories (Fig. 5). In the canopy openings ca. 20% of the survey plots were lacking spruce seedlings while in the clear-cut areas the share was about 50%. In both areas the larger spruces (height >0.1 m) were situated less evenly than the small ones (height <0.1 m).

4 Discussion

The results of this case study demonstrated that in a drained peatland spruce mire, site preparation did not improve the regeneration result in the small canopy openings or in the small clear-cuts. Especially in the canopy openings, site preparation even appeared to hamper the regeneration process. In the first survey in 2006, the density of <0.1 m seedlings was low in both untreated and treated openings, but the mean was six times higher in the untreated openings (Fig. 2a). Seedling number increased also in the scalped openings in 2008–2010, but remained at a level below 5000 ha^{-1}. Site preparation was carried out in June, after the dispersal of the year 2005 seed crop in early spring. Since site preparation was carried out on a considerable surface area, it possibly eliminated a major amount of potential stock of regeneration in 2005. The poorer performance of the scalped openings in

2008–2010 is probably explained by an invasion of highly competitive herbaceous vegetation on the exposed peat surface.

The results also showed that a considerably higher density of Norway spruce seedlings established naturally in small canopy openings than in small clear-cut areas within 5 years. The most likely reason for the result is the remarkable difference in opening sizes: even though the clear-cut areas were small, they were 8–12 times larger than the largest canopy openings. As a result of fertile soil and a sudden increase in light availability, herbaceous species quickly dominated the surface cover in all clear-cuts and left very few locations for spruce seedlings to establish. Hånell (1993) stated that the increased abundance of ground vegetation in clear-cut areas of spruce mires hampered the development of spruce seedlings. Based on visual inspection, the quantity and height of ground vegetation on the clear-cuts were considerably larger than on the openings. In this study, however, detailed measurements on ground vegetation changes were not made in the seedling inventories.

After five years, the total seedling density (all heights and all species combined) on the non-scalped plots was sufficient for a new tree generation on both cutting alternatives (>6000 ha^{-1}). However, the average number of larger spruce seedlings (height >0.1 m) in 2010 was 1650 ha^{-1} in the clear-cuts, whereas in the canopy openings the number of larger seedlings was 4500 ha^{-1} (Hökkä et al. 2011). This suggests that most of the germinated seedlings died before exceeding 0.1 m height in the clear-cuts, probably due to the competition from the ground vegetation.

There was a significant problem with the spatial evenness of the seedlings in the clear-cuts: in 41% of the survey plots no seedlings were found after five growing seasons, and in over half of the plots no spruce seedlings were found (cf. Valkonen et al. 2011). This is typical for establishment of advance growth and reflects the scarcity of suitable places where the seedlings could establish, as does the fact that the seedlings were concentrated in the same survey plots. It also suggests that in the canopy openings, light intensity is more limited and can prohibit the invasion of herbaceous species, subsequently offering better and spatially more even establishment conditions for the spruce seedlings. Also in the openings, almost 40% of the survey plots were without larger (height >0.1 m) seedlings still after 5 growing season, indicating that the regeneration was not yet complete. It is possible that the comparison of seedling density favours the canopy openings, because in the clear-cuts the seedling survey plots were on average several meters further away from the forest edge than those in the openings (Hanssen 2003).

Crop trees, i.e., seedlings that could be left to grow at least until the first commercial thinning, were not separately considered in the seedling surveys. It is thus likely that some of the larger seedlings (height >0.1m) cannot fulfill the requirements of crop trees due to quality reasons or spatial location, and the target density after five years from regeneration cutting, especially in the clear-cut areas, remains clearly less than 1600 stems ha^{-1}, which is expected in the silvicultural recommendations (Hyvän metsänhoidon suositukset… 2006).

In this study, the proportion of pubescent birch of all new seedlings in the canopy openings was none during the first three years, but increased after that – significantly less than in the clear-cuts, however. This is in accordance with the known differences in the light requirements of the two species (Leemans 1991). Pubescent birch needs more light than Norway spruce to establish itself. According to Valkonen et al. (2011) the density of deciduous species increased towards the patch center in patch clear-cuttings of Norway spruce in mineral soil sites. Moilanen et al. (1995) showed that after 8 growing seasons, most of the natural seedlings in a spruce mire clear-cut (20 000 to 70 000 per hectare) were birch. In peatlands, site preparation generally increases the germination of birch, but there was no such trend in these data.

Some reservations are needed when interpreting the results. In general, the experimental design was not well suited for testing the effects of site preparation on seedling density because the low number of replicates (only two) caused the statistical test to be ineffective. Thus more emphasis should be put on the results of graphical analysis (Fig. 2) than in the estimated statistical significance. A draw-back of the study is also the lack of pre-treatment survey to confirm the density of small seedlings in a mature forest. Despite the careful assessment of the time of seedling establishment it is possible that some of those seedlings counted as 'new' in 2006 survey had in fact established before cutting and not during the 2005 growing season. Another weakness is the size of the clear-cuts: in practice, clear-cuts are larger than 0.5 ha in size, and none of the clear-cuts in the study achieved this area. The results thus cannot be generalized to commonly used larger clear-cut areas.

The means to enhance the performance of small spruce seedlings in clear-cut areas are most likely related to the control of ground vegetation. As an alternative to a complete clear-cut, partial cutting which retains part of the canopy could create the necessary shade to limit the expansion of ground vegetation. Since seed production may not be the most important factor, the retained trees could be low-value sub-canopy stems which can be grown as nurse trees for the seedlings. Such harvesting resembles cutting with a diameter limit or with regeneration protection, which have been used in Ontario as a method to support the natural regeneration of peatland Black spruce (*Picea mariana* (Mill.) B.S.P.) stands (Groot 1996). There the new tree generation is based on both the abundant number of advance growth and the establishment of new seedlings after harvest (Groot 1996). A prerequisite for this procedure is that sub-canopy trees can be found in the mature forest, which, in turn, requires a rather uneven size structure of the mature stand.

In southern Finland and Sweden, early summer frost commonly damages spruce shoots in clear-cut areas (e.g., Hånell 1993, Moilanen et al. 1995). In this study, frost damages were observed neither in seedlings growing in the openings nor in those growing in the small clear-cuts. Small scale canopy openings lower the risk of frost damage because they decrease the extreme temperatures compared to larger clear-cuts, which is especially important in early summer (Carlson and Groot 1997). The location of the regeneration area also plays a great role in frost damage (Moilanen et al. 1995). Another reason may be that severe early summer frosts have not occurred after the set-up of the studied experiment.

It should be borne in mind that the results of this study are based on only one experiment and thus have the nature of a case study. Consequently, the results cannot be generalized very widely until more supporting evidence can be found.

5 Conclusions

The results of this case study showed that site preparation with scalping appeared to hamper the seedling establishment and was thus found unnecessary in natural regeneration of drained spruce mire stands using small canopy openings or small clear-cuts. Natural establishment of Norway spruce seedlings was sufficient and clearly better in small canopy openings than in small clear-cuts. In the clear-cuts it was not possible to obtain a sufficient regeneration density in five years because the rate of spruce seedlings establishment remained low and the seedlings were unevenly distributed over the clear-cut area.

Acknowledgements

We wish to thank the landowner Metsähallitus for their good co-operation. Mr. Lauri Karvonen and Mr. Matti Siipola from Metsähallitus are acknowledged for their contribution to the planning of the experimental design. Mr. Eero Siivola from the Finnish Forest Research Institute was responsible for the careful implementation of the experimental design and Mrs. Riitta Maunuvaara calculated the stand characteristics. Comments from Dr. Seija Sirkiä and two anonymous reviewers greatly improved the manuscript. The English language was revised by Mr. Aki Moilanen.

References

Carlson, D.W. & Groot, A. 1997. Microclimate of clear-cut, forest interior, and small openings in trembling aspen forest. Agricultural and Forest Meteorology 87: 313–329.

Groot, A. 1996. Regeneration and surface condition trends following forest harvesting on peatlands. NODA Tech. Rep. TR-26. 12 p. + append.

Hånell, B. 1993. Regeneration of Picea abies forests on highly productive peatlands – clearcutting or selective cutting? Scandinavian Journal of Forest Research 8: 518–527.

Hannerz, M. & Hånell, B. 1993. Changes in the vascular plant vegetation after different cutting regimes on a productive peatland site in Central Sweden. Scandinavian Journal of Forest Research 8: 193–203.

Hanssen, K.H. 2003. Natural regeneration of Picea abies on small clear-cuts in SE Norway. Forest Ecology and Management 180: 199–213.

Heikurainen, L. 1971. Virgin peatland forests in Finland. Acta Agral. Fenn. 12: 11–26.

Hökkä, H., Kaunisto, S., Korhonen, K. T., Päivänen, J., Reinikainen, A. & Tomppo, E. 2002. Suomen suometsät 1951–1994. [Peatland forests in Finland in 1951–1994]. Metsätieteen aikakauskirja 2B/2002. (In Finnish).

— , Repola, J., Moilanen, M. & Saarinen, M. 2011. Seedling survival and establishment in small canopy openings in drained spruce mires in northern Finland. Silva Fennica 45(4): 633–645.

Holgen, P. & Hånell, B. 2000. Performance of planted and naturally regenerated seedlings in Picea abies -dominated shelterwood stands and clearcuts in Sweden. Forest Ecology and Management 127 (2000): 129–138.

Hörnberg, G. 1995. Boreal old-growth Picea abies swamp forests in Sweden – disturbance history, structure and regeneration patterns. Swedish University of Agricultural Science, Department of Forest Vegetation Ecology. Umeå, Sweden. Diss. For. Veg. Ecol. 7. p. 1–25.

Hyvän metsänhoidon suositukset. 2006. Metsätalouden kehittämiskeskus Tapio. Metsäkustannus oy. 100 p. (In Finnish).

Hyvän metsänhoidon suositukset turvemaille. 2007. Metsätalouden kehittämiskeskus Tapio. Metsäkustannus oy. 50 p. (In Finnish).

Leemans, R. 1991. Canopy gaps and establishment patterns of spruce (Picea abies (L.) Karst.) in two old-growth coniferous forests in central Sweden. Vegetatio 93: 157–165.

Lukkala, O.J. 1946. Korpimetsien luontainen uudistaminen. Referat: Die naturliche Verjungung der Bruchwälder. Communicationes Instituti Forestalis Fenniae 34(3). 150 p.

Moilanen, M., Ferm, A. & Issakainen, J. 1995. Kuusen ja koivuntaimien alkukehitys korven uudistamisaloilla. Folia Forestalia – Metsätieteen aikakauskirja 2: 115–130. (In Finnish).

— , Issakainen, J. & Vesala, H. 2011. Metsän uudistaminen mustikkaturvekankaalla – luontaisesti vai viljellen? Metlan työraportteja 192. Available at: http://www.metla.fi/julkaisut/workingpapers/2011/mwp192.htm. 1–27. (In Finnish).

Nieminen, M. 2004. Export of dissolved organic carbon, nitrogen and phosphorus following clear-cutting of three Norway spruce forests growing on drained peatlands in southern Finland. Silva Fennica 38(2): 123–132.

Norokorpi, Y., Lähde, E., Laiho, O., & Saksa, T. 1997. Stand structure, dynamics, and diversity of virgin forests on northern peatlands. In: Trettin, C.C., Jurgensen, M.F., Grigal, D.F., Gale, M.R. & Jeglum, J.K. (eds.). Northern forested wetlands. Ecology and management. CRC Press, Lewis Publishers. p. 73–88.

Saarinen, M. & Hotanen, J.-P. 2000. Raakahumuksen ja kasvillisuuden yhteisvaihtelu Pohjois-Hämeen vanhoilla ojitusalueilla. Summary: Covariation between raw humus layer and vegetation on peatlands drained for forestry in western Finland. Suo 51(4): 227–242.

SAS Institute Inc. 2003–2008. SAS OnlineDoc version 9.1 (computer program). SAS Institute Inc., Cary, N.C.

Valkonen, S., Koskinen, K., Mäkinen, J. & Vanha-Majamaa, I. 2011. Natural regeneration in patch clear-cutting in Picea abies stands in southern Finland. Scandinavian Journal of Forest Research 26: 530–542.

Vasander, H. & Laine, J. 2008. Site type classification on drained peatlands. In: R. Korhonen, L. Korpela, & S. Sarkkola (eds.). Finland – Fenland. Research and Sustainable utilisation of mires and peat. Finnish Peatland Society. Maahenki Ltd. p. 146–151. ISBN 978-952-5652-47-5.

Venäläinen, A., Tuomenvirta, H., Pirinen, P. & Drebs, A. 2005. A basic Finnish climate data se 1961–2000 – description and illustrations. Finnish Meteorological Institute, Reports 2005:5. 27 p. ISBN 951-697-615-8.

Total of 23 references