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Seedling Survival and Establishment in Small Canopy Openings in Drained Spruce Mires in Northern Finland

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A large proportion of drained spruce mire stands is currently approaching regeneration maturity in Finland. Traditional regeneration methods with effective site preparation and planting generally result in satisfactory seedling stands also in spruce mires. However, natural regeneration methods may be more appropriate in protecting watercourses and minimizing regeneration costs. We studied the survival of advance growth and establishment of new seedlings in small canopy openings that were cut at three different diameters in two experimental drained spruce mire stands in Northern Finland (Tervola and Oulu) in 2004. The number of seedlings was repeatedly surveyed from five small circular plots (one 10 m^2 and four 5m^2 plots in size) located within the opening. Advance growth which survived the cutting and new seedlings were separated in the surveys. The density of advance growth was on average 9000 ha^{-1} after cutting, and it decreased by 30% during the five-year monitoring period (2006–2010) due to natural mortality. The number of new seedlings increased rapidly within the three years after cutting the openings. In 2010, 11 000–26 000 new seedlings ha^{-1} in Tervola and 12 000–16 000 ha^{-1} in Oulu on average were observed. The size of the opening had no clear effect on the regeneration result. The proportion of birch of the new seedlings increased with time and opening size in Tervola. The results show that Norway spruce regenerates naturally in small canopy openings cut in mature drained spruce mire stands.

Keywords canopy gaps, drained peatlands, natural regeneration, *Picea abies*, seedling establishment
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1 Introduction

Spruce mires are common peatland site types which have been drained for forestry purposes altogether 1.5 mill. hectares 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). Due to their naturally good timber productivity, virtually all spruce mires have been forested at the time of drainage (Heikurainen 1971, Gustavsen and Päivänen 1986), and when drained, they have displayed high wood production potential (Hånell 1988, Gustavsen et al. 1998, Zalitis and Indriksons 2004).

Because of the enhanced stand development following the drainage operation, a large proportion (42%) of drained spruce mire stands is currently approaching regeneration maturity (Hökkä et al. 2002). Forest regeneration in spruce mires aims at spruce-dominant stands for spruce stems in the mature stand are significantly more valuable than those of pubescent birch. Traditionally, spruce mires have been regenerated by clear-cutting and planting with Norway spruce, which has been shown to be a rather reliable method of regeneration (Moilanen et al. 1995).

After clear-cutting in highly productive soils, it is necessary to apply an efficient site preparation method and vigorous seedling material to ensure a sufficient regeneration result. The beneficial effect of site preparation lasts for only a couple of years due to emerging vegetation (Hannerz and Hånell 1993, Moilanen et al. 1995). Control of ground vegetation and fast-growing non-valuable deciduous pioneer tree species generally demands manual cleaning of the seedling stand at an early stage. These all mean costly investments at the beginning of the rotation, which, in turn, affect the economy of the whole management schedule. In northern locations, where stand productivity is strongly constrained by the climatic conditions but regeneration costs are not any lower than in the south, the economy may become a critical factor even in highly productive sites. One additional problem is the potential for leaching of nutrient compounds (mainly those of nitrogen and phosphorus) and suspended solids through the drainage networks into the receiving water bodies following clear-cutting and site preparation in fertile drained peatland sites (Nieminen 2004). These facts necessitate forest management methods that are cost effective, have minimal impact on the water environment but also result in acceptable regeneration of spruce mire stands.

Natural regeneration with different practical variations has been studied on spruce mires for decades (e.g. Multamäki 1939, Lukkala 1938, 1946, Hånell 1993, Holgén and Hånell 2000). Natural regeneration is supported by several studies which show that the conditions for seed germination are specifically favorable in moist Sphagnum moss (Place 1955, Sarasto and Seppälä 1964, Mannerkoski 1971, Johnston 1977, Wood and Jeglum 1984, Groot and Adams 1994). The shelter tree method has been proven to produce good regeneration results on spruce mires (Hånell 1993, Holgén and Hånell 2000), but not so good results in mineral soil sites (Leinonen et al. 1989, Nilsson et al. 2002). The shelter tree method involves the retention of 150–200 shelter trees per hectare after regeneration cutting. However, the shelter tree method is not a common tool in practical forestry to regenerate mature stands. The capital cost of the standing shelter trees as well as their harvesting cost after establishment of a new tree generation may be significant. Further, the retained stems are susceptible to wind-throw after shelter tree cutting (Hånell and Ottosson-Löfvenius 1994).

As a shade-tolerant species, Norway spruce is capable of regenerating under a mature tree stand. According to Leemans (1991), the most important factor influencing the establishment of seedlings of different species in old-growth forest is the amount of light available at ground level. In small openings, the light intensity may be high enough to permit germination and establishment of spruce seedlings, but pioneer species need clearly larger openings to become established (Leemans 1991, Qinghong and Hytteborn 1991, Groot et al. 2009). Since pubescent birch effectively regenerates naturally in moist soils from sprouts and seeds after cutting, it is likely that spruce seedlings suffer from competition with birch. From the management point of view, it would be beneficial if the regeneration of birch could be limited and that of spruce enhanced. As a method of regeneration for white spruce (*Picea* *glauca* (Moench) Voss), circular canopy openings have been studied by Carlson and Groot (1997) in Ontario in terms of microclimatic conditions. They found that temperature extremes in canopy openings were smaller than in clear-cut areas. To control the amount of light, different sized openings are necessary to compare and pinpoint the critical size that may encourage sufficient regeneration of spruce, but likewise constrain the establishment of deciduous species.

The aim of this study was to evaluate the regeneration success of Norway spruce in small canopy openings of different size cut in mature drained spruce mire stands. This was done by investigating the survival of advance growth seedlings that were established before the cutting and establishment of new small seedlings after the cutting. We hypothesized that the openings will regenerate naturally after cutting, the regeneration density will increase over time, and that the regeneration density and species composition are influenced by the size of the opening. The data were based on two field experiments in Northern Finland which had been monitored for five growing seasons after cutting.

2 Materials and Methods

2.1 Study Sites, Treatments, and Experimental Design

Two field experiments were established in 2004–2005 in Northern Finland, one in Lintupirtti, Tervola and another one in Sanginjoki, Oulu (Fig. 1). According to Vasander and Laine (2008), Tervola site was classified as a eutrophic, shallow-peated spruce swamp, which was drained in the 1960s. The Oulu site was a blueberry type spruce swamp, which had been originally drained in the 1930s. Peat thickness varied from 10–50 cm in Tervola and from 35–60 cm in Oulu. In both sites, the stand was composed predominantly of mature Norway spruce with a variable admixture of

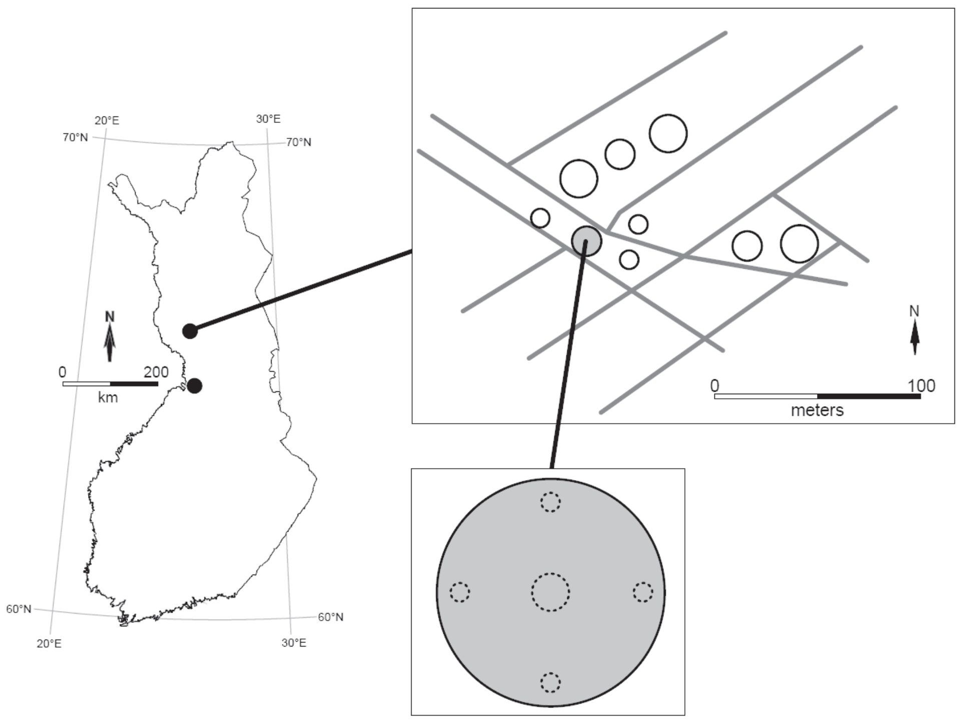

Fig. 1. Location of the study sites, experimental design in Tervola Block1, and an example setup of seedling survey sample plots in a canopy opening.

Table 1. Stand characteristics at the time of establishment (2004) in Tervola and Oulu study sites by blocks (B1–4). BA = stand basal area, D_{Med} = median diameter at 1.3 m height, H_{dom} = stand dominant height, V = stand volume.

Site/block (B)	Stand characteristics				
	Stems, ha^{-1}	BA, $m^2 ha^{-1}$	D_{Med}, cm	H_{dom}, m	V, $m^3 ha^{-1}$
Tervola/B1	1478	27	20	17	181
Tervola/B2	1901	29	20	18	198
Tervola/B3	1776	33	21	18	227
Tervola/B4	1322	25	22	18	170
Tervola, mean	1619	29	21	18	194
Oulu/B1	672	35	27	22	340
Oulu/B2	672	31	29	23	288
Oulu/B3	1017	24	23	19	193
Oulu, mean	787	30	26	21	274

pubescent birch. The stand dominant height in Tervola varied from 17–18 m, and in Oulu 19–23 m and stand volumes calculated by block averages varied from 170 to 227 $m^3 ha^{-1}$ in Tervola and from 193 to 340 $m^3 ha^{-1}$ in Oulu (Table 1).

The experimental design included three different-sized canopy openings. The diameter (D) of the largest opening was determined to be approximately the same as the stand dominant height (H_{dom}). Based on earlier findings, an opening larger than this will increase the regeneration of deciduous trees substantially (Leemans 1991, Qinghong and Hytteborn 1991). The diameter of the smallest opening was half of the dominant height and the diameter of the middle-sized opening was ¾ of the dominant height. Thus, the openings were 10, 15, and 20 m in diameter (D) in Tervola (Fig. 1) and 15, 20, and 25 m in diameter in Oulu. The corresponding D/H_{dom} ratios were 0.57, 0.84 and 1.11 in Tervola and 0.73, 0.92, and 1.20 in Oulu, respectively.

The openings were located in the selected study stands in a way which ensured that a buffer zone (mostly 10–20 m) of uncut forest separated them from each other and from neighboring stands (Fig. 1). Possible larger natural gaps were avoided. The size of the stand constrained the number of the openings that could be established.

The experimental design followed randomized blocks. Blocking was used because the openings were cut in 3–4 stands isolated from each other. In Tervola, there were 4 blocks altogether, each including the three different opening sizes replicated 2–4 times (Fig. 1). In two of the blocks, some of the openings were treated with site preparation in the spring 2005. These openings were excluded from this analysis. In Oulu, 3 blocks, each including three different-sized openings replicated twice, were set up.

Before cutting the openings, the trees within the area of each opening and a 5-meter buffer zone outside each opening, were mapped and measured in the summer 2004 by species and breast height (1.3 m) diameter of every tree and height of selected sample trees. Trees that were to be removed were marked. Based on tree measurements, stand characteristics were calculated for each opening on a hectare basis (Table 1).

In both sites, cuttings were done in the winter 2005. Haulage trails were also cut by carefully avoiding unnecessary removal of stems. Because the soil was frozen, it incurred no damage during harvest. After harvesting, most of the cutting residues and tree tops were removed from within each opening with a forwarder.

In order to study the occurrence and development of advance growth as well as germination of new seedlings, a design of small-sized circular seedling survey sample plots was established. A sample plot of 10 m^2 in size (radius = 1.79 m) was located in the middle of each opening. In northern, eastern, southern, and western directions,

Table 2. The seedling surveys in the study areas. New seedlings = seedlings established after cutting.

Year	2005	2006	2007	2008	2009	2010
Advance growth						
Tervola	x	x	x	x	x	x
Oulu	x			x	x	x
New seedlings						
Tervola		x		x	x	x
Oulu				x	x	x

circular 5 m^2 (radius = 1.26 m) survey plots were established at 1.5 m distance from the edge of the opening (Fig. 1). Center points of all these sample plots were marked with a plastic pipe.

2.2 Measurement of Advance Growth

The post-cutting survival of advance growth was surveyed in the circular sample plots in May 2005 in Tervola and in September 2005 in Oulu. The survival survey was repeated annually in Tervola, but less regularly in Oulu (Table 2). In Tervola, this survey was done only in two of the four blocks (altogether 12 openings) and in Oulu in all three blocks (altogether 18 openings). For all seedlings taller than 0.1 m, the location (angle and distance from the center of plot), tree species, total height, annual height growth in the past 5 years, possible visually perceptible damages, description of microtopography of the seedling growing location, and proportion of logging residues covering the sample plot area were recorded in 2005. For trees taller than 1.3 m and shorter than 2.5 m, diameter at breast height (dbh, mm) was also recorded. For birch seedlings, height growth was not recorded. In later surveys, mortality was recorded individually with the help of the detailed tree maps.

2.3 Measurement of New Seedlings Established after the Cutting

Seedlings assumed to have germinated after the cutting (= 'new') were surveyed by tree species from the small circular plots in 2006 in Tervola only and in 2008, 2009, and 2010 in both experiments (Table 2). This measurement permitted monitoring of the development of the number of seedlings in successive surveys, but neither characteristics nor survival was measured for individual small seedlings. In the surveys, the small new seedlings were classified into two height groups (< 0.1 m or > 0.1 m). Since the occurrence of other deciduous species besides pubescent birch was marginal, all are combined with birch in the analysis.

2.4 Analysis Methods

Analyses were made for both experiments independently because different site conditions did not permit analysis of combined data. Most of the analyses were based on graphical comparisons of the number of seedlings in an opening in different years. The number of seedlings in an opening on a hectare basis was calculated as an average of the number of seedlings in each small seedling survey plot weighed by the area of the plot. The proportion of birch of all new seedlings was also calculated and studied over time. The proportion of birch was analyzed according to opening size by studying the proportion of those seedling survey plots where birch was not present in different surveys.

Statistical analysis was carried out to test the effect of time and opening size on the density of advance growth, the total number of new seedlings, and the number of new birch seedlings. Based on the experimental design and the successive measurements, the following two-way mixed ANOVA model was used in the statistical analysis:

$$N_{kij} = \mathbf{bx}_{kij} + u_k + v_{ki} + e_{kij}(t) \quad (1)$$

where

N_{kij} = number of seedlings (advance growth, new seedlings, new birches, ha^{-1}) for the opening j in the replicate i of block k

$\mathbf{x}_{kij}$ = vector of independent variables for the opening j in the replicate i of block k

$\mathbf{b}$ = vector of fixed parameters

u_k = random effect for the kth block

v_{ki} = random effect for the ith replicate in block k

$e_{kij}(t)$ = random error for the opening j in the replicate i of block k, function of time

In the analysis, the dependent variable (N_{kij}) was transformed into logarithmic scale in order to obtain normally distributed residuals. The vector $\mathbf{x}_{kij}$ included alternative explanatory variables such as opening size, time since cutting, and interaction between opening size and time. In the analysis of the advance growth density, basal area in the opening before cutting was also tested as a covariate. Random error $e_{kij}(t)$ was assumed to have the autoregressive correlation structure between successive measurements. The models were estimated with the Mixed procedure implemented in the SAS software (SAS 9.2 Online Documentation).

3 Results

3.1 Development of the Density of Advance Growth

After cutting (in spring 2005), the largest number of advance growth (≥0.1 m height) was found in the largest openings (Fig. 2). The number of seedlings showed high variation among the canopy openings: in Oulu, the minimum and maximum numbers of seedlings were 668 and 19729 ha^{-1} while in Tervola, the range was even higher from 1672 to 37787 ha^{-1} (Table 3). Mean height of the seedlings was 0.46 m in Oulu and 0.51 m in Tervola and the admixture of birch in both sites was mainly <10% (data not shown).

During the five-year monitoring period, seedling mortality decreased the density of advance growth in the whole data by 31% on average (Fig. 2). In Tervola, where seedling survival was surveyed annually, the highest mortality was detected within 1–2 years after cutting the openings. According to the ANOVA model, only the time since cutting

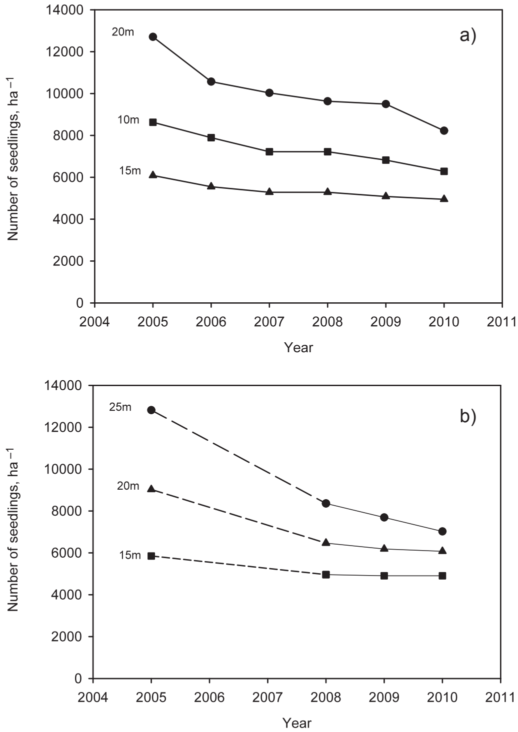

Fig. 2. The average density of advance growth (ha^{-1}) by opening size in Tervola (a) and Oulu (b) in different survey years. Opening diameters are shown in figures.

Table 3. The average number and range of surviving advance growth after cutting in Tervola and Oulu by opening size in 2005 and proportion of living seedlings (%) in 2010.

Site	Opening size	2005		2010	
		N, ha^{-1}	Range, ha^{-1}	%	Range, %
Tervola	10 m	8628	2675–11704	72	53–89
	15 m	6086	1672–10700	77	70–91
	20 m	12707	5016–37787	69	59–80
	Mean	9140		73	
Oulu	15 m	5852	668–14713	78	28–100
	20 m	9028	1672–15382	69	42–100
	25 m	12818	3678–19729	59	20–82
	Mean	8966		69	

significantly explained the density of advance growth in Tervola. One large opening existed in which the density was initially three-fold compared to others, which caused high variation in the results. In Oulu, time was a significant explanatory variable, but also the interaction between opening size and time since cutting was close to significant ($p = 0.0534$), i.e., mortality appeared to be highest in the largest openings (Fig. 2). Neither in Tervola nor in Oulu did the pre-harvest stocking (basal area, $m^2 ha^{-1}$) influence the density of advance growth in 2006. In 2010, 73% and 69% of the seedlings on average were alive in Tervola and Oulu, respectively (Fig. 2). Variation of seedling survival was high: in Tervola from 53% to 91% and in Oulu from 20% to 100% (Table 3).

3.2 Development of the Number of New Seedlings

The average number of new seedlings was clearly higher in Tervola than in Oulu (Fig. 3). Based on the ANOVA model, the total number of new

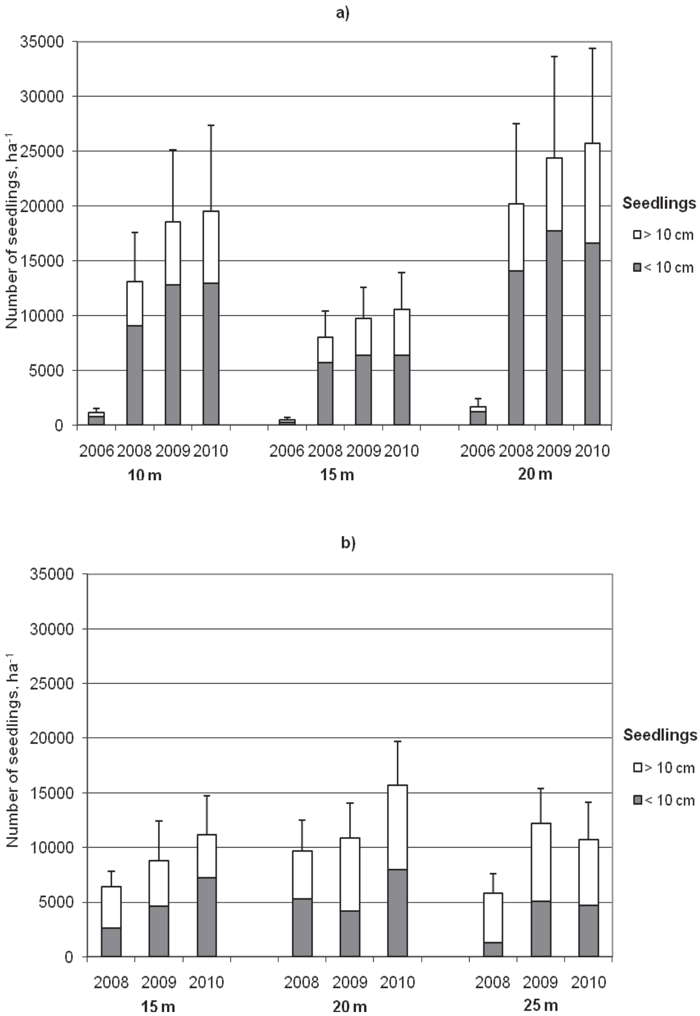

Fig. 3. The average number of new seedlings (established after cutting) in the different-sized canopy openings in Tervola (a) and Oulu (b). Error bars indicate standard errors of the total seedling number among the openings.

Table 4. Average number of new seedlings and range (among openings) in Tervola and Oulu by opening size and survey year.

Site	Opening size	Year	N, ha^{-1} Mean	Min.	Max.
Oulu	15 m	2008	6465	2675	11704
	15 m	2009	8806	1338	21402
	15 m	2010	11147	3678	25080
Oulu	20 m	2008	9698	1003	18058
	20 m	2009	10868	1672	20398
	20 m	2010	15717	2341	27755
Oulu	25 m	2008	5852	1672	11035
	25 m	2009	12206	334	21402
	25 m	2010	10701	1672	22739
Tervola	10 m	2006	1170	0	3010
	10 m	2008	13167	0	35446
	10 m	2009	18559	334	54507
	10 m	2010	19521	669	64539
Tervola	15 m	2006	543	0	1672
	15 m	2008	8067	669	18058
	15 m	2009	9739	669	21736
	15 m	2010	10575	669	28758
Tervola	20 m	2006	1714	0	6019
	20 m	2008	20189	2006	65208
	20 m	2009	24369	2341	83266
	20 m	2010	25749	4347	70224

seedlings was significantly influenced by time in Tervola. In Oulu, the effect of time was nearly significant ($p=0.0625$). No statistically significant differences arose in the number of new seedlings with respect to opening size in either site. This was due to the large standard errors associated with the means (see Fig. 3). The opening 20 m in diameter led to the best average result in both sites. No significant interaction occurred between time and size.

In Tervola, the number of new seedlings was low (<1200 ha^{-1}) one year after cutting (year 2006), but in three years the number of seedlings increased up to 10 000–25 000 ha^{-1}, on average (Fig. 3). Considerable variation materialized among the openings, e.g., in 2008 in Tervola two openings still entirely lacked new seedlings (Table 4). In Tervola, the number of new seedlings which were taller than 0.1 m steadily increased during the last three years while the number of <0.1 m seedlings increased between 2006 and 2008 (Fig. 3). The information from the first post-cutting year was not available from Oulu. In Oulu, the number of seedlings <0.1 m height increased between 2008 and 2010. Five years after cutting in 2010, new seedlings had become established in every opening in both sites (Table 4).

3.3 Number and Proportion of Birch of New Seedlings

Results from the ANOVA showed that time since cutting ($p<0.0001$) and opening size ($p=0.0018$) significantly influenced the number of new birch seedlings in the openings. The relative proportion of birch respective to the total number of new seedlings increased when three years had passed since cutting in Tervola; the larger the opening, the faster this trend (Fig. 4). The same change in birch occupancy was evident when the proportion of seedling survey plots without any birch seedlings was studied by opening size and time. In the largest 20-m diameter openings, the

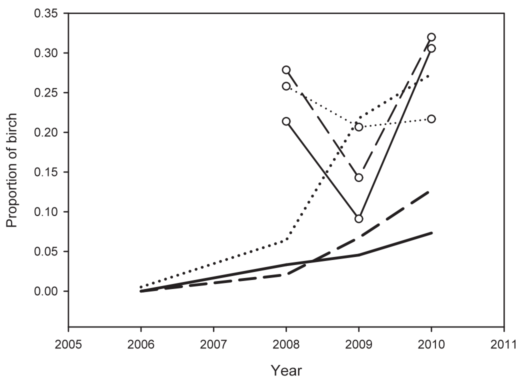

Fig. 4. The development of the average proportion of birch relative to the total number of new seedlings by opening size (20 m – dotted line, 15 m – dashed line, 10 m – solid line in Tervola (no symbols) and 25 m – dotted line, 20 m – dashed line, 15 m – solid line in Oulu (circles)) in different survey years.

Table 5. Proportion of seedling survey plots (%) where birch seedlings were not present according to survey year and opening size.

Area & opening size	Year			
	2006	2008	2009	2010
Tervola 10 m	100	88	73	68
Tervola 15 m	100	93	83	75
Tervola 20 m	98	83	48	43
Oulu 15 m	-	77	87	53
Oulu 20 m	-	73	67	43
Oulu 25 m	-	70	70	57

share decreased from 88% in 2006 to 43% in 2010, while the process was clearly slower in the smaller openings (Table 5). In Oulu, the decrease was not clearly related to opening size.

In Oulu, the proportion of birch was higher than in Tervola in 2008–2010 and showed great annual variation (Fig. 4). In 2010, 16% and 28% of the new seedlings on average was pubescent birch in Tervola and Oulu, respectively.

4 Discussion

The results of this study demonstrated that a high number of new Norway spruce seedlings established naturally within 5 years in canopy openings cut in mature Norway spruce stands growing on drained mires. Also, the density of advance growth which survived after cutting was primarily high enough to form a fully stocked seedling stand. Existence of natural undergrowth is generally considered a prerequisite for natural regeneration in spruce stands (Hyvän metsänhoidon… 2006, 2007). No similar studies to draw comparison exist, but in many previous studies the potential of natural spruce regeneration in drained peatlands has been attested to either via strip-cutting or clear-cutting (e.g., Multamäki 1939, Lukkala 1946, Moilanen et al. 2011), or shelter-tree cutting as shown by Hånell (1993) and Holgen and Hånell (2000). On the contrary, natural regeneration of spruce with shelter-tree cutting on mineral soil sites has resulted in unsatisfactory results in Finland (e.g., Leinonen et al. 1989), and the method is generally not recommended for spruce regeneration on mineral soils (Hyvän metsänhoidon… 2006).

One reason for the different natural regeneration results between peatlands and mineral soils is the suitability of peat substrate for germination of conifer seedlings as has been observed in many previous studies (e.g., Place 1955, Sarasto and Seppälä 1964, Mannerkoski 1971, Johnston 1971, Wood and Jeglum 1984, Groot and Adams 1994). In this study, the germination conditions were not studied in detail, but in general, the role of *Sphagnum* cannot be emphasized because coverage of *Sphagnum* species was very low especially in Tervola. Another explanation is that soil moisture conditions are probably more favorable for seed germination in peatland rather than mineral soil sites. Specifically in the Tervola site, the ditches were in poor condition and the soil surface was moist for most of the summer. In the years 2005 and 2007, Norway spruce also produced a good seed crop in Northern Finland (Siemensatoennusteiden… 2004, Kuusen… 2006), which provided a good start for the regeneration attempt. An increasing trend was observed in both the total number of new seedlings and the number of established (height > 0.1 m) new seedlings implying that the number of seedlings in openings will increase further in the coming years.

Similarly to Moilanen et al. (2011), the high density of advance growth that survived in the cutting (ca. 9000, on average) suggests the presence of a rather dense natural undergrowth of spruce under the canopy of a mature stand. In some openings in the Oulu site, the advance growth density was below 1000 stems ha^{-1}, which is too little to ensure sufficient regeneration, but on average, the density was high enough to achieve a sustainable regeneration result. This suggests that seedlings become established under the canopy without large openings. In such a situation, a regenerated forest could result from the careful removal of the mature stand (cf. Groot 1996, MacDonell & Groot 1997). However, the regeneration success depends on the capacity of spruce advance growth to respond positively to overstory removal and the subsequent changes in environmental conditions, e.g., the flush of ground vegetation (Moilanen et al. 1995).

It should be pointed out that advance growth was not protected during the harvesting operation. The highest number of seedlings survived in the largest openings, which may be due to the fact that in small openings, the machines caused proportionally more damage to advance growth than in larger openings. Most logging residues were removed from all the harvested openings by the machines in order to avoid unnecessary variation in the regeneration results. Differences in the density of surviving advance growth among openings were not related to pre-treatment stocking levels. The number of surviving seedlings decreased about 30% over the monitoring period due to natural mortality, which was likely related to mechanical damages caused by the cutting. Also, the abrupt change in the light conditions may have increased mortality because it was highest in the largest openings.

In spruce mire clear-cuts, Moilanen et al. (1995) showed that the number of new natural seedlings after 8 growing seasons varied from 20 000 to 70 000 per hectare, but mostly comprised of birch. In the study by Moilanen et al. (2011), 37% of all natural seedlings (3500 ha^{-1}) in a clear-cut spruce mire site were pubescent birch after four years of cutting. In this study, the proportion of birch exceeded 25% within five years only in the largest openings, while in the smallest 10-m diameter opening the proportion of birch remained below 10% in Tervola site. These findings are in accordance with the hypothesis and results from earlier studies that effective regeneration of broadleaved pioneer species demand large canopy openings (Leemans 1991, Qinghong and Hytteborn 1991, Groot et al. 2009). A significant increase took place when the size if the canopy opening reached 20 m in diameter in Tervola. Due to the lack of first year measurements, results could not be obtained from the Oulu site.

Judged by the total number of new seedlings after five growing seasons, no clear trend was observed with respect to the size of the opening, i.e., even the smallest 10-m diameter (78.5 m^2 in size) opening resulted in good regeneration. This suggests that the critical change in light conditions to promote Norway spruce seedling germination appears to be rather small, caused by the removal of only a couple of trees. This result is in accord with Leemans (1991) who concluded that small canopy gaps created by the death of one to a few trees are closed by trees from the seedling bank, i.e., spruce seedlings germinate and establish in such gaps (also Qinghong and Hytteborn 1991).

In this study, a good regeneration result was obtained at no cost, which offers a significant financial benefit compared to artificial regeneration. From the point of view of careful management, cutting small openings has the advantage of distributing changes in forest cover over a longer regeneration cycle, although eventually, the intermediate areas need to be regenerated, too, in commercial management. When considering regeneration of spruce peatlands with small canopy openings, natural gap dynamics typical to old spruce mire stands can serve as a model (Hörnberg 1995). This kind of regeneration could bring heterogeneous stand structures to managed peatland spruce stands. Avoiding clear-cuts and favoring complex stand structures are likely more acceptable practices in areas where forest management is under public scrutiny.

It should be pointed out that the results here cover only a short time period and they only demonstrate the potential for seedling establishment. How much this type of regeneration influences the whole management schedule, and whether the further development of these seedlings is acceptable in terms of commercial timber production (and quality requirements) is necessary to investigate in detail. It is, however, clear that the early development of seedlings in canopy gaps will be considerably slower compared to that of seedlings in clear-cut areas as long as the shading and competition from the large canopy trees exist (Erefur et al. 2011).

5 Conclusions

The results showed that dense natural spruce advance growth exists in drained mature spruce mire stands, and if small canopy openings are cut in such stands Norway spruce effectively regenerates naturally in these openings. This is probably the most important prerequisite for practical application of natural regeneration. Despite the good regeneration result, the method needs further evaluation in terms of practical applications (i.e., second cutting cycle), seedling growth, and economics before it can be considered an alternative regeneration method for drained spruce mires.

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Total of 39 references