The Effect of Site Preparation on Seed Tree Regeneration of Drained Scots Pine Stands in Finland

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Abstract

We studied the success of natural regeneration for eight years after seed tree cutting on four drained peatland Scots pine stands in central and northern Finland (Parkano, Sievi, Vaala, Simo) when retaining ca. 50 Scots pine stems ha^{-1} followed by site preparation. The total number and the number of crop seedlings and their mean height were investigated by species and methods of site preparation (control, scalping, mounding). The results showed that the total seedling numbers were very high (9,600 – 51,000 ha^{-1}) in all sites and treatments. The share of downy birch seedlings was 64 –76 %. The total number of crop seedlings varied from 1,550 to 2,000 ha^{-1} (2,000 maximum density accepted), with number of Scots pine seedlings varying from 600 in Parkano to 1,950 ha^{-1} in Sievi. Site preparation increased the number of pine crop seedlings on two of the four sites: at Parkano by 900 – 1,100 seedlings ha^{-1} and at Vaala by 600 – 800 seedlings ha^{-1}. On average, the number of pine crop seedlings was slightly higher and that for all birch seedlings clearly higher when site preparation was applied. About 22 – 81% of crop seedlings were grown in a prepared surface in scalped plots and 75-91% on mounded plots. The mean height of the crop seedlings was not significantly affected by the site preparation treatment. With respect to the minimum requirements set for the regeneration result required by forest legislation, seed tree cutting appeared to provide sufficient regeneration in eight years in terms of the total seedling density and the number of crop seedlings when downy birches were included. The beneficial effect of soil preparation was seen in the increased share of Scots pine crop seedlings.

Keywords: drained peatlands, mounding, natural regeneration, *Pinus sylvestris,* scalping, seedling density, regeneration result

Introduction

A total of 4.7 million ha of peatlands have been drained for forestry in Finland (Hökkä et al. 2002). Saarinen (2013) estimated that the area of peatland forests that have reached maturity was almost 400,000 ha and it is expected to reach 700,000 ha within ten years. According to the recent national forest inventory in Finland (NFI11 2009-2013), the mean stand volumes in the mature pine peatland stands are 178 and 126 m^3 ha^{-1} in southern and northern Finland, respectively (Ihalainen 2014). Scots pine (*Pinus sylvestris* L.) is the most dominant tree species in pine bogs, but an abundant admixture of downy birch (*Betula pubescens* Ehrh.) is also typical, especially in originally sparsely forested composite peatland sites (see Laine et al. 2012, Päivänen and Hånell 2012). Composite site types (or combination site types) are typically a combination of fully forest-covered mires with hummock level vegetation and treeless mires with wet lawn or hollow level vegetation.

For regeneration of Scots pine stands on recently drained peatlands seed tree cutting has been recommended (Lukkala 1938, Heikurainen 1954). Because of the high moisture of the substrate, possibilities for natural regeneration of Scots pine in *Sphagnum* moss communities without site preparation are good (Place 1955, Heinselman 1957, Johnston 1977, Wood and Jeglum 1984, Groot and Adams 1994, Saarinen 2002). However, in older drainage areas the ground vegetation is mainly composed of forest moss species, which are considered more difficult to regenerate naturally (Kaunisto 1984, Kaunisto and Päivänen 1985, Saarinen 1997, Saarinen and

Hotanen 2000, Saarinen 2013). Development of so-called raw humus on top of the peat in some peatland sites forms a further obstacle for natural regeneration (Saarinen and Hotanen 2000, Kaunisto 1984, Kaunisto and Päivänen 1985). Raw humus has a low density containing a lot of air space and thus breaks the capillary rise of water in the soil column up to the surface of the moss layer.

Site preparation by removing the live surface vegetation and possible raw humus layer (typically 3-5 cm) uncovers the original moist peat surface and could increase the possibilities for natural regeneration in older drainage areas. The vegetation layer can be removed by scalping (a form of patch scarification made by an excavator). Shallow scarification made by rotavation can be used if the raw humus layer is shallow (Kaunisto and Päivänen 1985, Saarinen 1993, Helenius and Saarinen 2013). However, mounding has been recommended and is most commonly used practice in forestry. Site preparation has generally been observed to increase the number of natural Scots pine seedlings in studies made on poor site types in a transformed phase, i.e., when the ground vegetation is already composed mostly of upland species (Kaunisto 1984, Moilanen and Issakainen 1984, Saarinen 1993, 2002). Site preparation may lead to high amounts of non-wanted downy birch seedlings germinating on the prepared surfaces (Kaunisto and Päivänen 1985, Saarinen 2013, Hökkä et al. 2016). Thus, investment in site preparation can increase the cost of tending of the sapling stands.

Natural regeneration is a less expensive method than planting and if an acceptable crop tree stand can be established without site preparation it would be even more economic. Lower regeneration costs would be of significant importance in the management of drained peatlands. For several reasons, forestry on drained peatland sites is not as profitable as that on mineral soil sites. Harvesting removals are generally lower but harvesting costs are higher compared to those in mineral soil stands. Furthermore, ditch network maintenance, and in some cases also fertilization is needed to warrant the good growth of trees. Consequently, natural regeneration would in many cases be a very attractive regeneration method in drained peatlands to minimize the regeneration costs. However, it is likely that natural regeneration would take a longer time than planting to achieve a seedling stand of good restocking. Thus, studies covering only a couple of years may fail to report the final regeneration result.

Forest regeneration success is understood as the establishment of a new generation of trees of the preferred species, which are adequately spaced, sufficient in density, and are of good health. In Finland, the criterion for a minimum regeneration result in terms of density and time since a harvest is defined in the forest legislation (Forest Act 2014). The target densities by species and sites are defined in forest management practices (Äijälä et al. 2014, Vanhatalo et al. 2015). The aim of this study was to determine whether natural regeneration of drained Scots pine peatland forests using seed-tree cutting can result in a successful regeneration result in eight years. We hypothesized that site preparation (scalping, mounding) would increase the number of Scots pine seedlings and result in higher stand stocking compared to no site preparation. We also hypothesized that site preparation would increase the regeneration of downy birch, which could fill up the seedling stand.

Materials and Methods

Study sites

Four field experiments were set up in mature Scots pine stands in central and northern Finland in 2006 to study the effect of site preparation on the success of natural regeneration in drained peatlands after seed tree cutting (Figure 1). The stands at the Parkano and Sievi sites were almost pure Scots pine forests with less than 2% of the stand volume consisting of downy birch. First ditching in Parkano was done in 1950s at 50 m ditch spacing and in Sievi with very wide spacing (200-300 m) already in the 1920s. The regular ditching in Sievi with a 40 - 50 m ditch spacing was done in 1965. At the same time the area in Sievi was fertilized with PK-fertilizer. The Vaala site had a mature Scots pine dominated stand with downy birch undergrowth. The site had been drained in the 1930s with wide ditch spacing (60-70 m) and in 1985 the ditch network was repaired using a ditch spacing of 30 – 36 m. The Simo site had a mature Scots pine dominated stand with downy birch forming a significant admixture along with some scattered spruces. The Simo

Figure 1. Location of the experiments

site had been drained for forestry in the 1930s and the ditch network had been maintained for the first time in the 1950s and for the second time in 1987 with ditch spacing varying from 30 m to 60 m.

The site type at Sievi and Vaala was a *Vaccinum vitis-idaea* drained peatland forest type and at Simo it was a *Vaccinium myrtillus* drained peatland forest type according to Laine et al. (2012). In Parkano, the site did not represent an average *Vaccinium vitis-idaea* type but was close to the more unfertile *Dwarf shrub* site type. The peat thickness was over 100 cm at Parkano, and exceeded 90 cm at the other sites. At all sites peat was composed of well-humified *Carex*-peat or *Carex-Sphagnum*-peat. The average (1984 – 2013, 30-year period) temperature sum (+5 °C as the threshold) in Parkano was 1,195 dd, while in Sievi it was 1,119 dd, Vaala 1,079 dd and at Simo 1,022 dd. The 30-year average June-August precipitation at the sites was 195 – 215 mm. The first summer following the site preparation (2006) was exceptionally dry and warm. The second summer was average and the third (2008) summer was cold and wet (Figure 2). The study period was warmer and wetter than the average 30-year period. At all sites, six growing seasons of eight ones were warmer and wetter than the average 30-year period.

mounds. At Parkano the uplifted soil in the mounds was flipped over to form a peat mound on unprepared ground next to the excavated pit without making any additional ditches. At Parkano the site preparation was done in May 2006 and at Sievi in November 2005. At Vaala the mounding was done in November 2005, and scalping was done in early May 2006. At Simo the scalping was done in the early summer in 2006. At Simo one additional ditch was dug in the area between the old ditches at the time of scalping and the ditch spacing was reduced to 30 m.

Experimental design and field measurements

At Parkano, 12 sample plots (1,500 m^2 in size), at Sievi six sample plots (4,407 – 8,300 m^2 in size), at Vaala 15 sample plots (1,980 – 2,160 m^2) and at Simo six sample plots (1,200 – 1,800 m^2) were established. For those plots, treatments (control, scalping, and mounding) were randomly subjected thus resulting in four replicates at Parkano, five replicates at Vaala, three replicates in Simo, and two replicates in Sievi.

In autumn 2013, eight growing seasons after site preparation 20 circular sub-sample plots of 5 m^2 (1.26 m in radius) were established on each sample plot in a systematic design. If necessary, the location of the sub-sample plots was moved so that their area was completely within the sample plot area. Sub-sample plots were marked with plastic tubes. All tree seedlings over 3 cm in height were inventoried according to their tree species. The location of each seedling was assessed (prepared soil, unprepared soil).

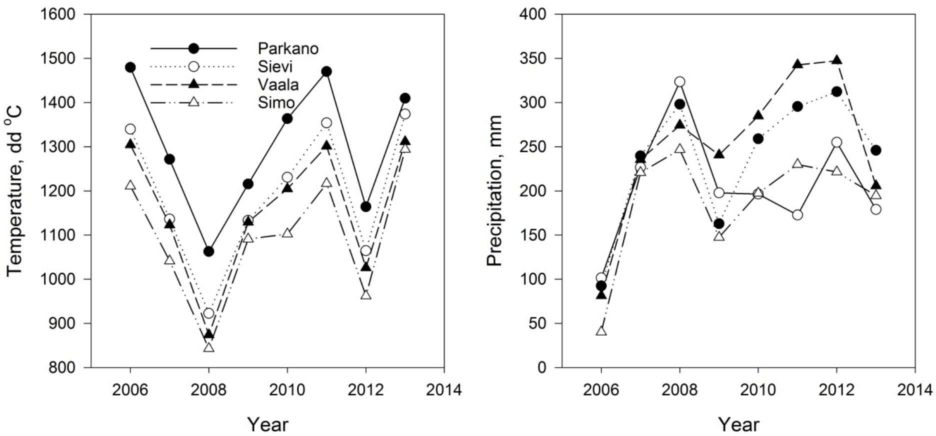

Figure 2. Annual temperature sum (A, dd threshold value 5°C) and precipitation (B) in June–August in 2006–2012 at the Parkano, Sievi, Vaala and Simo experimental sites

At all sites the sample plots were delineated in the field and the retained 50 seed-trees per hectare were marked before seed-tree cutting. Cuttings were done at Parkano, Sievi and Vaala in October 2005 and at Simo in April 2006. Site preparation treatments included mounding and scalping, except at Simo, where only scalping was applied. The study design included also unprepared control treatment. In all areas scalping was done with the scoop of an excavator by removing a very thin layer of the top soil aiming to achieve a similar amount of prepared soil area as possible during practical site preparation. The mounding was done by digging a shallow ditch and lifting the peat onto the soil surface in low

Crop trees (dominant competitive seedlings of good quality able to form commercial stems in thinning or the final cut) were selected in each sub-sample plot. Aiming at 2,000 crop trees per ha led to accepting one seedling in each sub-sample plot. The selected crop seedling was preferably a Scots pine, but if there were no Scots pines or their condition was estimated visually to be too poor, e.g. due to moose browsing, a Norway spruce or seed originated birch seedling was selected if available on the sub-sample plot. The height of the crop seedlings was measured with accuracy of one cm.

Statistical methods

Mean seedling numbers (for total and crop seedlings) by species were calculated according to the experimental sites and site preparation treatments. The differences in the seedling numbers per ha according to the site preparation treatments in each location were tested with a one-way analysis of variance with treatment as the fixed effect and block as the random effect. The treatment means were compared using Tukye's multiple range test at a significance level of $p < 0.05$. Additionally, the following linear mixed-effects model including all of the locations was constructed to test the fixed treatment effects:

$$Y_{ijk} = TRMT + \delta_i + \gamma_{ij} + \varepsilon_{ijk}, \quad (1)$$

where Y_{ijk} is the total number of trees or the number of crop trees by species, *TRMT* is the site preparation treatment (control, scalping or mounding expressed as dummy variables), and δ_i , γ_{ij} , and ε_{ijk} are the random effects of site, block within the site, and the residual error, respectively.

Results

All seedlings

The total number of all seedlings (species combined) was high on all sites and in all treatments. The lowest number of seedlings (9,600 ha^{-1}) was found in control plots at Parkano and the highest number of seedlings (51,000 seedlings ha^{-1}) were in mounded plots at Sievi (Figure 3).

The average number of pine seedlings was 4,552 ha^{-1} (Table 1). According to the mixed model including all locations, mounding had a highly significant ($p < 0.001$) and scalping a nearly significant ($p = 0.062$) effect on the total number of pine seedlings. According to the experiment-specific models, both scalping and mounding equally improved the pine seedling emergence at Parkano, but only mounding did so in the Vaala experiment. At Sievi and Simo the number of pine seedlings was high also on unprepared soil and thus the site preparation did not have a significant effect (Figure 3, Table 1). The total number of birches was nearly three times higher than the number of pines, on average (Table 1). Due to the large variation in birch seedling numbers, there were no significant treatment effects according to experiment-specific tests. The mean seedling numbers of both species were, however, higher with site preparation and a very high number of birch seedlings existed especially in scalped plots at Vaala and in some mounded plots at Sievi (Figure 3). According to the mixed model including all experiments, scalping turned out to have a significant ($p = 0.038$) and increasing effect on the number of birch seedlings (Table 1).

The number of Norway spruce seedlings was clearly the highest at Simo (1,200–2,800 ha^{-1}), while at Sievi and Vaala there were 200–800 and 60–260 spruces ha^{-1}, respectively. At Parkano there were only some spruce seedlings (0–50 seedlings ha^{-1}).

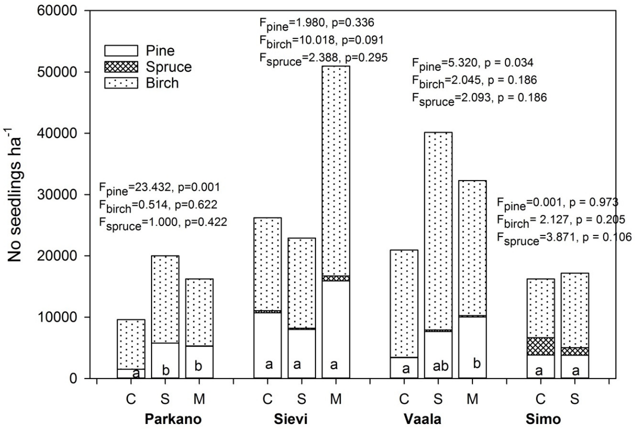

Figure 3. The total number of seedlings in the study areas. C = control, no soil preparation, S = scalping, M = mounding. Means (all species combined) marked with the same characterr do not differ from each other according to Tukey's test at a significance level of $p < 0.005$)

Table 1. Mixed model results on the effect of site preparation treatments on the number of all seedlings and the number of crop seedlings by species. Estimate standard errors are given in parentheses

Variable	Number of all seedlings, ha^{-1}			Number of crop seedlings, ha^{-1}		
	Scots pine	downy birch	Norway spruce	Scots pine	downy birch	Norway spruce
Control	4,552 (1642) *p*=0.010	12,763 (3773) *p*=0.002	913 (506) *p*=0.083	1,035 (150) *p*<0.001	543 (92) *p*=0.000	222 (148) *p*=0.145
Scalping	+1,929 (990) *p*=0.062	+6,629 (3025) *p*=0.038	-524 (285) *p*=0.078	+476 (127) *p*=0.001	-200 (103) *p*=0.065	-135 (56) *p*=0.025
Mounding	+4,871 (1170) *p*<0.001	+5,883 (3562) *p*=0.111	-178 (337) *p*=0.602	+686 (150) *p*=<0.001	-395 (120) *p*=0.003	-79 (67) *p*=0.253
Std (Site)	2,854.8	6,135.1	913.4	211.3	108.7	267.2
Std (Site (block))	1,446.2	0.9	250.4	211.0	0.2	197.9
Residual	2,886.8	8,819.9	831.3	370.9	302.2	165.5

At Parkano the height of the pine seedlings was 50–54 cm, at Sievi it was 57–69 cm, at Vaala it was 48–55 cm, and at Simo it was 45–36 cm (Figure 4). The treatments did not affect the height of pine and birch seedlings except at Vaala, where birch seedlings were tallest in the scalped plots. Birch seedlings were much taller than pine seedlings and were the tallest at the southernmost experimental site at Parkano (Figure 4). Birch height according to the different treatments varied between 210–248 cm, 174–223 cm, 143–200 cm and 127–131 cm at the Parkano, Sievi, Vaala, and Simo sites, respectively.

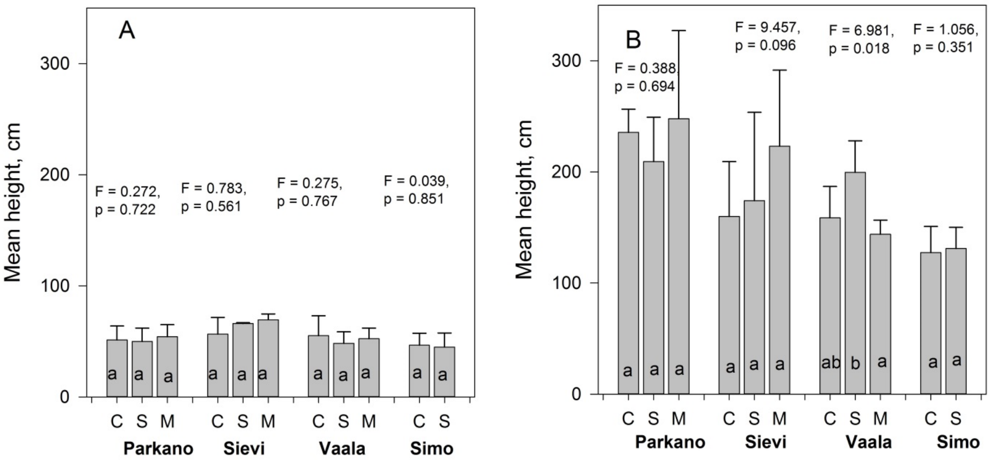

Figure 4. Mean height and standard deviation of the tallest Scots pine (A) and birch (B) seedlings on the sub-sample plots. Means marked with the same character do not differ from each other according to Tukey's test at a significance level of $p < 0.005$

Crop seedlings

The average number of crop seedlings was almost 2,000 ha^{-1} in all treatments (Figure 5). The lowest numbers of crop seedlings were on the unprepared soil at Parkano (1,550 seedlings ha^{-1}) and at Vaala (1,780 seedlings ha^{-1}). The average number of pine crop seedlings on unprepared plots was 1,034 ha^{-1} (Table 1). The mixed model indicated a significant increasing effect of both scalping (+476 seedlings ha^{-1}, $p = 0.001$) and mounding (+686 seedlings ha^{-1}, $p < 0.001$) on pine crop seedlings (Table 1). Site preparation also increased the share of pines among all the crop seedlings especially in the Parkano and Vaala experiments, where the proportion of birch remained very high on unprepared soil (Figure 5). Inversely this means that soil preparation significantly reduced the number of crop birch seedlings (scalping by -200 ha^{-1} and mounding by -395 ha^{-1}, on average) and the share of birch on prepared soils, because on treated plots there were more pine seedlings to choose as crop seedlings. However, the same could not be statistically verified in the Sievi and Simo experiments when examining by experiment-specific models. The number of pine seedlings was also high on unprepared soil and thus the share of pine was almost the same as for the scalped and mounded soils. In the Simo experiment the number of spruce crop seedlings on unprepared soil was almost the same as for pine and only one third were found on scalped soil. This probably indicates that most of the spruce seedlings originated before the site preparation.

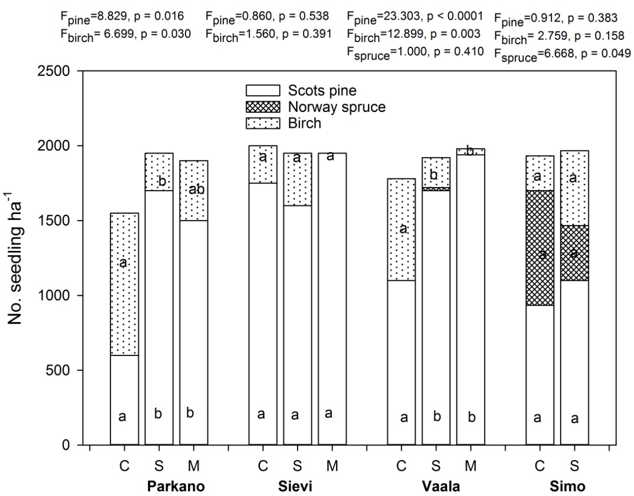

Figure 5. The number of crop seedlings in the study areas. C = control, no soil preparation, S = scalping, M = mounding. Means marked with the same character do not differ from each other according to Tukey's test at a significance level of $p < 0.005$)

The mean height of pine crop seedlings per location and treatment varied between 45 to 69 cm being highest in the southernmost location (Parkano) and decreasing towards the northernmost one (Simo). The mean height of pine crop seedlings was similar to that for all the pine seedlings. Within the experiments there were no significant differences between treatments in terms of mean height. This was true also for birch and spruce crop seedlings.

The share of crop seedlings growing on the prepared scalp-surfaces on the scalped plots was only 22-61 % in all other experimental sites except at Parkano (Figure 6), where almost equal shares of crop seedlings

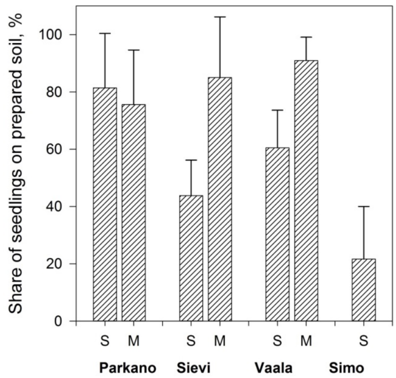

Figure 6. The share of crop seedlings growing on prepared soil

(81% and 76 %) were growing on scalped or mounded surfaces. However, at Parkano scalps covered half of the total area of the scalped treatment plots whereas at Simo and Sievi the figures were only 20% and 30%, respectively. Thus, at Simo the share of seedlings growing on scalped soil was the lowest (22%). At Sievi, 44% of the seedlings grew on scalped soil and 85% on mounds. There were also some (5%) seedlings growing on mounds even on the control treatment (unprepared soil) at Simo. This was due to seedlings growing on soil excavated from an additional ditch.

Discussion

We studied the result of natural regeneration after seed tree cutting and site preparation in four Scots pine stands growing on drained peatlands. We were interested in the overall regeneration result and the main objective was to assess the number of crop trees after eight years from seed tree cutting. In this study, a sufficient regeneration result was obtained at all sites and with all of the treatments when compared to the minimum requirement specified in Finnish forest legislation. According to the Forest Act and Government Decree, the forest regeneration obligation is fulfilled when the number of seedlings with a mean height of 0.5 m exceeds 1,500 ha^{-1} in ten years in southern and central Finland and 1,200 ha^{-1} in 20 years in northern Finland. However, the number of Scots pine crop seedlings was low on non-prepared plots in two of the sites we tested, Parkano and Vaala, and the target density of crop seedlings (2,000 ha^{-1}) was achieved only when 500 – 1,000 birch seedlings (i.e. 30 – 60%) were accepted as crop seedlings. According to the legislation, downy birch is an acceptable species in regeneration of peatland forests (Valtioneuvoston … 2013). However, such a high admixture means that after tending an established seedling stand, the proportion of birch still remains quite a bit higher than recommended for pine seedling stands in medium productive sites like these (ca. 10 %, Äijälä et al. 2014). Thus, a significantly higher birch admixture accepted in regeneration may lead to stands of lower value which reduces the financial outcome of the next generation of trees.

Weather conditions during the growing season, moisture in the peat, development of vegetation, and seed crops during the first years after seed tree cutting all influence the natural regeneration result. Different soil preparation treatments may have different impacts on the moisture of the prepared soil depending on the prevailing weather conditions. Since the establishment of seedlings after seed tree cutting and soil preparation takes place over several years, extreme weather conditions during some of the years, such as the warm and very dry first summer in this study, do not affect regeneration as much as they do when sowing or planting.

Scalping increased the total number of seedlings and the number of crop seedlings in two sites, but failed to do so in the two other sites. This may be due to scalps filled with water during the third, especially wet growing season. In well-humified *Carex*-dominated peat, as in the study sites, water conductivity is low which may transform scalps into water ponds after longer periods of rain. In scalping the water table may also be too close to scalp surface for young seedlings to grow efficiently (Mueller-Dombois 1964, Lieffers and MacDonald 1990, Pearson et al. 2011, 2013). However, increased moisture has a positive impact on natural regeneration by providing better conditions for seed germination in peat soil (Satoo and Goo 1954, Kamra 1968, Larson and Schubert 1969). In spite of a good germination result, rainy late summer months have been shown to be a high-risk period for young seedlings, which are growing their roots at the same time (Saarinen et al. 2013, Saarinen 2013). In pristine peatlands seeds germinate, but seedlings do not establish on lawns, where the water table is closer to soil surface than in hummocks where seedlings can establish (Holmgren et al. 2015). Furthermore, a high ground water table increases not only the total coverage of vegetation but also colonization of species such as *Eriophorum vaginatum*, which strongly reduces the seedbed receptivity of the scalps and furrows (Saarinen et al. 2009).

Mounding and scalping produced similar results in this study when the regeneration results were assessed by the number of crop seedlings. In mounding, seeds establish themselves on an elevated surface, which is generally not too moist for seedling germination. The mound surface can, however, become too dry and be an unfavourable substrate for seeds to germinate. Well-humified *Carex* peat especially is prone to extensive drying and is also resistant to rewetting when dry. Therefore, making both scalps and mounds during site preparation would be an option: during wet growing seasons mounds would be optimal for germination and during drier seasons scalps would have an advantage. Combined mounding and scalping might also be solution. This requires a new type of digger bucket which would be able to make very light and superficial scalps and also mounds.

Vegetation which changes from *Sphagnum* dominated communities to moss species commonly found in upland sites, hinders seedling establishment on old drainage areas. Site preparation is generally carried out to expose soil that is more favourable to seed germination. The prepared soil is also colonized by weeds after some years, but there are very few research results on the development of vegetation following soil preparation on peatlands (Saarinen 1997). For example, soil prepared by surface rotavation with shallow furrows has been shown to become covered by vegetation within a few years (Saarinen 2002). A high-water table may enhance the development of ground vegetation. For example, in the study by Saarinen (2013) vegetation colonized 70 % of scalped surface within 5 years when the ground water table was close to the surface (<20 cm), whereas the coverage of ground vegetation remained under 30 % when the ground water table was deeper than 40 cm. In the study by Moilanen and Issakainen (1981), six years from site preparation the coverage of shrubs and *Eriophorum vaginatum* was similar on unprepared and prepared soil. The development of vegetation is probably the reason why the most rapid seedling number increase takes place within three years of treatment (Hökkä et al. 2016), but pine seedlings can emerge even 6-7 years from seed tree cuttings and site preparation (Saarinen 2002). More intensive site preparation, such as mounding, restricts competition of ground vegetation more effectively and for a longer time (Mannerkoski 1975, Moilanen and Issakainen 1981, 1984, Saarinen et al. 2009). On unprepared soil Silfverberg et al. (2010) did not find any correlation between the total vegetation coverage and the number of naturally regenerated Scots pine seedlings six year after clearcutting on unprepared soil.

Saarinen (2002) studied the effect of vegetation and site preparation on the natural restocking of Scots pine and birch in ten dwarf-shrub and *Vaccinium vitis-idaea* type peatland forests for 4-16 growing seasons from seed-tree cutting and site preparation (mounding or light site preparation by surface rotavation). The ground vegetation on the unprepared surfaces was divided into “mire moss” communities predominated by *Sphagnum* and *Polytrichum* species, and the vegetation commonly found in transformed peatland forests. The latter represents the final phase of typical post-drainage vegetation succession. According to Saarinen (2002), communities of *Sphagnum* often promoted the restocking of Scots pine; on half of the experiments the number of pine seedlings was at its highest in patches dominated by *Sphagnum*, with or without site preparation. However, some experiments had a statistically significant interactive effect between the vegetation and site preparation; the rotavation furrows in both types of plant community had become equally restocked, but there was a significant difference between *Sphagnum* and *Pleurozium* on the non-treated surfaces. Rotavation can be applied to achieve fully-stocked stands of Scots pine when combined with natural regeneration. This encourages the use of alternative surface-treatment methods instead of mounding. Saarinen (2002) also concluded that because tree seedlings tend to be concentrated on the surface of the furrows, scalping can also produce similar regeneration result than making furrows. In this case, the required machinery is usually already present at the site for ditch network maintenance.

Based on five regeneration experiments, Kaunisto (1984) concluded that due to the poor results of natural regeneration and sowing on untreated peat, site preparation should be done more often than it has been anticipated earlier to secure good regeneration result in medium and poor drained peatland forests. However, these results were mostly from an inventory made two years after seed tree cutting. This study strengthened the evidence of the positive effects of both scalping and mounding in the natural regeneration of Scots pine trees. In this study, the number of Scots pine crop seedlings were low on untreated soil (equal or less than 1,100 ha^{-1}) at all of the sites other than Sievi. At the Simo site, pine seedlings were established on untreated soil, but because of serious moose damage the best growing pine seedlings were severely browsed and could not be ranked as crop seedlings. However, the pine seedlings were well complemented by natural Norway spruce seedlings.

Our main results show that natural regeneration can yield good regeneration results even on old drainage areas and that site preparation can considerably increase the probability of successful regeneration. If a high number of downy birch seedlings are accepted as crop seedlings, a satisfactory result was obtained on all sites even without site preparation. Besides Scots pines, site preparation seems to also increase the number of downy birch seedlings, as observed in other studies as well (e.g. Moilanen and Issakainen 1981, 1984, Silfverberg 1995, Saarinen 2002). Dense stocking of downy birch increases the need for young stand treatment and if not done, further development of pine regeneration is hampered. Both scalping and mounding significantly increase the total number of crop seedlings, but mounding offers a slightly higher probability of achieving a larger share of pine seedlings. This is partly due to the fact that downy birch regenerates much better on moist scalps compared to drier mounds. Scalps are also prone to becoming overly moist substrates especially for Scots pine seedlings, which suffer from excess water during rainy growing seasons. Such is the case particularly in years when a fluctuating water table level in a scalped regeneration area rises during a late summer (Saarinen 2013). This is probably more general in the cooler and more humid climate of northern Finland than in the southern and this also affects the difference observed in the regeneration result between scalps and unprepared soil. Thus, the need for site preparation could be smaller in northern Finland.

In line with some other studies (e.g. Saarinen 2002, 2013), attempts to generalize the results of site preparation effects come up against the uncertainty inflicted by the variation in soil moisture. Due to the random variation in the water table level in scalps and the sensitivity of the peat to desiccation in mounds, forest regeneration success via natural seeding is highly susceptible to weather conditions. In spite of these facts, site preparation has increased the number of Scots pine seedlings on drained peatlands, but there seems to be high variation among locations in the results. On that basis site preparation could be recommended to obtain a good density in pine seedling stands. However, on unprepared sites rise of water table by regulating water flow in ditches has been suggested to increase the success of regeneration (Grigaliūnas and Ruseckas 2005). In Finland the average costs of scalping and mounding in 2014 were 324 and 360 € ha^{-1} (Metsätilastollinen vuosikirja 2014). Thus, a financial analysis is needed to show whether the additional number of pine crop seedlings achieved by scalping or mounding would cover the additional costs caused by the treatment.

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