Forestry Advance Access published September 10, 2012

Forestry An International Journal of Forest Research

Institute of Chartered Foresters

Forestry 2012; **0**, 1–8, doi:10.1093/forestry/cps065

The effect of mechanical site preparation methods on the establishment of Norway spruce (*Picea abies* (L.) Karst.) and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) in southern Sweden

Kristina Wallertz[1]* and Cecilia Malmqvist[2]

[1]*SLU, Asa Experimental Forest and Research Station, SE-36030 Lammhult, Sweden*
[2]*School of Engineering, Linnæus University, SE-351 95 Växjö, Sweden*

*Corresponding author Telephone: +46(70)2050453; kristina.wallertz@slu.se

Received 31 January 2012

The aim of this study was to gain a deeper knowledge of the effects of mechanical site preparation on the survival and growth of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and Norway spruce (*Picea abies* (L.) Karst.) seedlings in southern Sweden. The experiment was conducted on a fresh clearcut at the Asa experimental forest (57° 10′ N). The effects of five different site preparation treatments were investigated: control, patch, mound, invert and mix. In each treatment, 40 seedlings of Norway spruce and 40 of Douglas fir were planted in each of four blocks. Site preparation had little or no effect on the survival and growth of Norway spruce: only a few seedlings died during the first 2 years. For Douglas fir, however, all site preparation treatments increased survival compared with the control, where mortality was high. The most intensive soil preparation treatment, mix, significantly increased root growth and total biomass. Pine weevils caused more severe damage to Douglas fir seedlings than to Norway spruce and targeted different locations in the two species, causing comparatively more damage to the leading shoots of Douglas fir seedlings.

Introduction

Norway spruce (*Picea abies* (L.) Karst.) is the most common tree species in Sweden.[1] However, the increasing warmth and length of the Swedish growing season due to climate change is likely to provide opportunities for growing additional species such as Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco). Douglas fir is one of the premier timber trees worldwide, mainly because of its combination of desirable wood properties and yield.[2] In its natural range, Douglas fir grows under various climatic conditions, from maritime climates in the coastal regions to continental climates in mountainous areas.[3] It can currently grow well in southern Sweden, but the establishment of young seedlings is hampered by problems such as frost sensivity, browsing and pine weevil damage.[4,5] While Douglas fir have been planted in Sweden over the last century, this has only been done on a very small scale why there is relatively little information available on its establishment.

When planting on a clearcut, it is important to maintain a high initial growth rate in order to minimize the length of the establishment period during which the seedlings are exposed to stress factors. Rapid early root growth facilitates the uptake of nutrients and water and thereby increases seedling growth rates.[6,7] Mechanical site preparation has been demonstrated to greatly improve seedling establishment and is widely used in Sweden.[8] Importantly, it increased soil temperature, which is essential for improving the root growth in northern latitudes.[9] There are a variety of methods of mechanical site preparation that can be used, each of which affects seedling growth in different ways. Patch scarification increases soil temperature and reduces competition from undesired vegetation but may also decrease access to nutrients due to the removal of the humus layer.[10] Mounding creates elevated spots with increased soil temperatures but also presents an increased risk of drought.[11] Inverting creates planting spots at the same level as the surrounding ground.[12] Despite their differences, the latter two preparation methods both create spots where the humus layer is buried under a covering of mineral soil. If the seedling is planted correctly, the roots will have access to a loose nutrient-rich layer, which should facilitate the root growth. In addition, the covering of pure mineral soil surrounding the seedling will reduce the damage caused by pine weevils.[13] The purpose of mix (see *Materials and methods*) was to create loose spots with elevated soil temperatures and rates of mineralization. In addition to the above-mentioned effects, all of the different site preparations methods reduce competition from field vegetation.[11]

The aim of this study was to investigate the effects of different mechanical site preparation methods on the survival, growth and biomass of newly planted Douglas fir and Norway spruce seedlings on a fertile site in southern Sweden. The hypotheses tested were: (i) site preparation reduces mortality and promotes shoot development; (ii) the site preparation mix increases the soil temperature and enhances root growth to a greater extent than alternative treatments; (iii) the growth of Douglas fir is more heavily affected by site preparation than that of Norway spruce.

Materials and methods

Site properties and experimental design

The experiment was established in 2010 on a mesic, fertile site (SI H100:34 m) with a sandy silt soil structure at Asa (57° 10′ N, 14° 47′ E) in southern Sweden. The previous stand on the site had been cut during the winter of 2009–2010 and post-harvested wood residues were removed. The location on a gentle slope implied low risk of frost damage and browsing by moose and deer was prevented by fencing. During the study years of 2010 and 2011, there were favourable growth conditions in June, July and August with higher temperature and more precipitation than normal. The mean temperatures at the site was 15.8°C (2010) and 15.5°C (2011) which is >1°C higher than normal (14.4°C). Similarly, the average precipitation was 104 mm (2010) and 120 mm (2011) compared with a long-term annual average of 69 mm per month during June, July and August.

The experiment followed a split plot design with five site preparation treatments randomly assigned to each of the four replicate blocks, which were divided into half and planted with either Norway spruce or Douglas fir.

Site preparation treatments

Site preparation was performed using an excavator to provide planting spots with the following treatments (the name of each treatment is given in parentheses): (1) no treatment (control), (2) scarified mineral soil patch (patch), (3) inverted humus turf deposited on undisturbed forest floor and capped with pure mineral soil (mound), (4) inverted humus turf, reset into the pit from which it had been dug out and covered with pure mineral soil (invert) and (5) complete mixing of mineral soil and humus (mix). The driver of the excavator was instructed to create planting spots of ∼40 × 40 cm for each treatment. The planting spots generated for the patch treatment were located in slight depressions, with their surfaces being ∼1–5 cm below the level of the surrounding undisturbed forest floor. The spots for the mix and invert treatments were on the same level as the surrounding forest floor or slightly elevated, while the surfaces of the mound treatment spots were ∼10–20 cm above the surrounding forest floor. The patch, mound and invert treatments are all relatively common in Swedish forestry, whereas mix is very rare. One seedling was planted in each spot.

Seedling stock and planting procedure

The seedlings were planted at the experimental site on 2 May 2010, and had previously been grown in Hiko 93 ml containers for 1 year. The Norway spruce seedlings originated from the Bredinge seed orchard, while the Douglas fir seedlings were produced from seeds obtained from the Larch Hills area in the interior of British Columbia, Canada. All seedlings were sowed in the same nursery for the same amount of time and were sprayed manually with an insecticide (the systemic neonicotinoid imidacloprid) immediately after planting and in April of experiment's second year. Each seedling was treated with 3–4 ml of a 14 g l^{-1} insecticide solution according to manufacturer's instructions. Forty seedlings each of Norway spruce and Douglas fir were planted in two rows in each treatment and block. The 20 seedlings of each species in the first row were used for *in situ* measurements. The second row consisted of seedlings that were destructively harvested and used for biomass measurements.

Data collection

Seedling and competing vegetation development were followed during two growing seasons.

The seedling height (cm), leading shoot length (cm) and root collar diameter (0.1 mm) were measured at the time of planting and in October of the first year. Observations of the cover of field vegetation were not recorded until the first autumn because after harvesting an old and closed stand in Sweden the cover of field vegetation is almost non-existing or very modest. The competing vegetation development (% cover and mean height) was then assessed in 40 × 40 cm squares surrounding each seedling. Three times during the first season (in early July, August and November of 2010) and once at the end of the second (November 2011), two live seedlings per treatment and species were randomly chosen within each block for biomass determination. The reason for the intensive inventories during the first year was to detect whether there were any early differences between root and shoot growth between tree species or treatments. Due to the cost of the analyses, it was necessary to limit the number of seedlings harvested during the second year. The seedlings were carefully excavated to minimize losses of root material and stored in a freezer until all seedlings had been collected. After thawing, all parts of the seedlings were washed and dried at 70°C for 48 h. Before weighing, the seedlings were separated into the following three fractions: roots, needles and stems + twigs. Damage caused by pine weevil was recorded in the autumns of 2010 and 2011 using a six-level scale (0 = undamaged, 1 = uncertain or hardly damaged, 2 = slightly damaged, 3 = severely damaged, 4 = seedling will probably die and 5 = dead). The percentage of bark that had been removed by feeding was estimated separately for the main stem and the leading shoot.

The root-to-shoot ratio (R/S ratio) was calculated by dividing the dry weight of root biomass by the dry weight of aboveground biomass.

The soil temperature was monitored during the growing season using a CR10 datalogger (Campbell Scientific Inc., North Logan, UT, USA) with two thermocouple (Cu/Co) sensors positioned at a depth of 10 cm in each soil treatment. The sensors were scanned every 10 min and their results were averaged to yield 30-min mean temperatures. The air temperature was measured at 1.3 m above ground.

Analysis

The mean values for the different response variables for each block and treatment were calculated before the analyses were conducted. The general linear model procedure of SAS (SAS Institute, Cary, NC, USA) was then used to perform selected statistical tests. The experiment was treated as a split plot design with tree species as the main plot and the site preparation methods representing the subplots. Block and block × tree species were treated as random factors, and block × tree species was defined as the error for block and tree species. The following model was applied:

$$Y_{ijm} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma_m + (\beta\gamma)_{jm} + \varepsilon_{ijm}$$

where μ is the overall mean, α_i is the block effect ($i = 1$–4), β_j denotes the tree species ($j = 1 - 2$) and γ_m is the site preparation treatment effect ($m = 1 - 5$) and ε_{ijm} is the experimental error.

Comparisons were also made within tree species, focusing on the effect of the site preparation methods on Douglas fir and Norway spruce separately. In this analysis, block was selected as the random factor. Differences with a P-value of <0.05 were considered to be significant. When significant differences were identified, Tukey's test was used to separate individual factors.

Results

Tree species

After one growing season, Douglas fir seedlings had a significantly lower rate of survival (89%) than Norway spruce (99%; $P = 0.043$). The same trend was observed after 2 years (the survival rates of the two species were 84 and 98%, respectively), but the difference was no longer significant ($P = 0.069$). The percentage of Douglas fir seedlings killed or severely damaged by pine weevil (22%) was significantly higher than that for Norway spruce (2%; $P = 0.004$). In addition to suffering more extensive damage from pine weevils in general, the leading shoots of Douglas fir seedlings were much more likely to be attacked by pine weevils than were those of Norway spruce ($P = 0.005$): on average, 9.6% of the Douglas fir leading shoots were debarked by pine weevil while the corresponding figure for Norway spruce was 0.2%.

The leading shoots of Norway spruce seedlings grew more rapidly than those of Douglas fir during both year 1 (9.7 and 5.2 cm, respectively; $P = 0.002$) and 2 (21.0 and 16.3 cm, respectively; $P = 0.001$). Conversely, the mean root collar diameter of Douglas fir seedlings at the end of the first growing season (6.3 mm) was significantly greater than that for Norway spruce (5.9 mm; $P = 0.006$). After two seasons, the mean root collar diameter for both species was 11.3 mm and there was no significant difference between the two ($P = 0.49$). However, the Douglas fir seedlings exhibited substantially greater variation in root collar diameter: the number of Douglas fir seedlings having a root collar diameter above 15 mm or below 8 mm was more than twice than that for Norway spruce.

On average, regardless of treatment, there was no significant difference between the dry weight of the roots or total biomass for the Douglas fir and Norway spruce seedlings on any sampling occasion.

R/S ratio

There was a difference between the two species considered in terms of the R/S ratio on the first occasion of sampling, in July 2010 ($P = 0.04$). For Douglas fir seedlings, the mean R/S ratio for all treatments was 0.24 for the July measurement while the corresponding figures for Norway spruce were 0.18. In August and November 2010 as well as November 2011 no differences between species were found.

Mechanical site preparation

Mechanical site preparation significantly increased the likelihood of survival for Douglas fir seedlings ($P = 0.0005$): 60% of the seedlings survived under the control treatment, compared with 89–94% of those planted on mechanically prepared sites (Figure 1). This high mortality under the control treatment was partly due to damage caused by pine weevils, which accounted for 17% of seedling deaths, and partly due to unidentified factors, which accounted for 26% of all seedling deaths. Control plots had the highest levels of Douglas fir mortality due to pine weevils, with most of the damage occurring during year 1. Conversely, only a few Norway spruce seedlings died under any treatment and there were no significant differences between the treatments in terms of mortality for this species.

The lowest mean growth was recorded for Douglas fir seedlings planted in control plots, but the difference was not significant compared with the other treatments (Figure 1). During the second year, the mean growth of the leading shoot for Douglas fir seedlings planted in control plots was 14.3 cm when compared with 18.2 cm in the mix treatment plots, which yielded the highest mean growth (Figure 2). For Norway spruce, the mean length of the shoot in the second year varied between 19.1 and 22.4 cm among treatments. The differences between treatments were not significant for either Norway spruce ($P = 0.633$) or Douglas fir ($P = 0.262$).

There was a significant difference in root collar diameter between treatments for Douglas fir seedlings after one season ($P = 0.002$) (Figure 3). The smallest diameter, 5.6 mm, was observed for seedlings planted in control plots. Douglas fir seedlings planted in the other treatments had significantly larger diameters, ranging from 6.3 to 6.5 mm. In the second year, the root collar diameters for Douglas fir seedlings ranged from 10.6 to 12.0 mm, with no significant differences between treatments. Norway spruce showed no significant differences between treatments after one season: the diameter was, on average, 5.8 to 6.0 mm. After the second year, however, there was a significant difference between treatments ($P = 0.013$): seedlings planted in Mound treatment plots had greater root collar diameters (12.1 mm) than those planted in patch, mix or control plots.

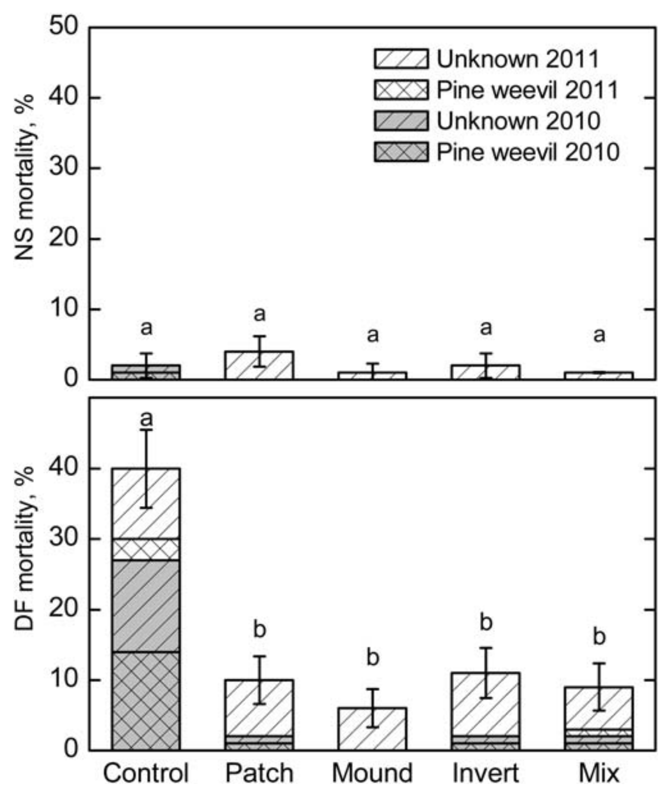

Figure 1. Mortality (%) of Norway spruce (NS) (upper panel) and Douglas fir (DF) (lower panel) during 2010 and 2011. There were five different site preparation treatments (control, patch, mound, invert and mix).

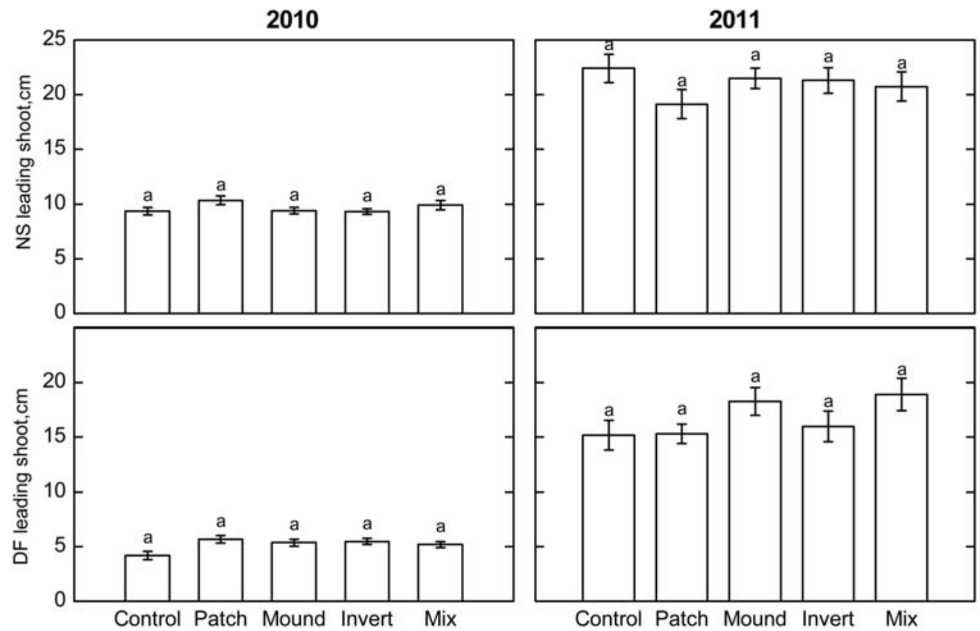

Figure 2. Mean length of leading shoot of Norway spruce (NS) 2010 (upper left panel) and 2011 (upper right panel) and Douglas fir (DF) 2010 (lower left panel) and 2011 (lower right panel). There were five different site preparation treatments (control, patch, mound, invert and mix).

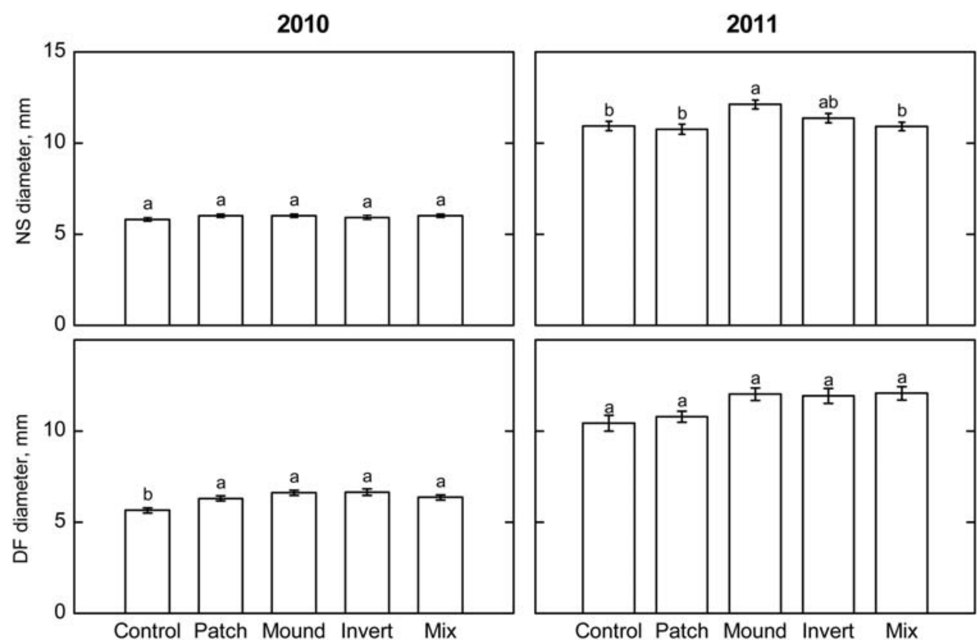

Figure 3. Mean root collar diameter of Norway spruce (NS) (upper panel) and Douglas fir (DF) seedlings planted in different site preparation treatments (control, patch, mound, invert and mix).

Vegetation

The most common species at the site was raspberry (*Rubus idaeus*). Various herbs and sedges were also present, but no detailed inventory of the different species was prepared. There were significant differences between the treatments in terms of the level of vegetation cover at the end of the first growing season ($P = 0.0001$). The most extensive vegetation cover (16%) was observed for the patch and control treatments; the other treatments yielded vegetation cover levels of 8–10%. After the two seasons, the relationship between treatment and vegetation cover was much less readily apparent; the mean level of cover ranged from 46 to 61%. However, there was a significant difference between the various treatments, with the Patch treatment yielding significantly more vegetation cover than the alternatives ($P = 0.0001$). The height of the vegetation did not differ between treatments ($P = 0.101$).

Biomass

The different soil preparation methods affected both root and aboveground biomass growth for both species during the first year. Douglas fir seedlings growing in the mix treatment had significantly greater root dry weight ($P = 0.04$) and total biomass ($P = 0.05$) than seedlings growing in Control plots as early as the August measurement (Table 1). The total biomass at that time was 12.05 g for the mix treatment and 6.12 g for the control treatment; the corresponding dry root weights were 2.06 and 1.3 g, respectively. The same trends were observed in November of the first year (Table 1). The results for Norway spruce seedlings were less straightforward, and it was not until November of the first year that a clear difference became apparent, with seedlings in the control plots having a lower dry root weight than those in the mix plots. In November of the second year, the Douglas fir seedlings planted in the control plots tended to have a lower total biomass than those grown in the mix plots (33.9 and 48.6 g, respectively), but the differences were not significant. No difference between the treatments was observed on this measurement occasion for Norway spruce seedlings. The R/S ratio did not differ between treatments for any of the tree species at any occasion.

Soil temperature

When measurements began in June 2010, the weekly mean soil temperature was 12.6°C for the control treatment and 13.2°C for the mix treatment (Figure 4). During the following weeks, the soil temperature rose rapidly in the mix treatment plots reaching a weekly mean of 20°C by the first week of July. The mean soil temperature in the control plots at that point was 17.9°C, making July 2011 the month with the most pronounced difference between the mean soil temperatures for the two treatments. The maximum weekly soil temperature during July of the first year was 26.3°C for the mix treatment and 21.5°C for control. The air temperature dropped below zero on a couple of occasions in the beginning and middle of April and also in the beginning of May 2011, with a minimum temperature of −6°C. The soil temperature never fell below zero during the measurement period.

Discussion

The survival rate for Norway spruce was much greater than that for Douglas fir: only a few Norway spruce seedlings died during the first two seasons after planting. Several studies have

Table 1: Root and total biomass (g) and R/S ratio for Norway spruce and Douglas fir seedlings, in different site preparations: control, patch, mound, invert and mix, measured at four different occasions during the first and second growing season (2010 and 2011)

	Douglas fir			Norway spruce		
	Roots	Total biomass	R/S ratio	Roots	Total biomass	R/S ratio
July 2010						
Control	1.06	5.47	0.24	0.89	5.94	0.18
Patch	1.25	6.92	0.22	0.3	6.76	0.18
Mound	1.29	7.37	0.21	1.00	6.19	0.19
Invert	1.6	8.18	0.24	0.9	6.54	0.17
Mix	1.69	7.67	0.28	0.96	7.25	0.16
	$P = 0.587$	$P = 0.653$	$P = 0.46$	$P = 0.600$	$P = 0.397$	$P = 0.48$
August 2010						
Control	1.3c	6.12b	0.27	1.32	8.95	0.17
Patch	1.98ab	9.7ab	0.26	1.95	10.63	0.22
Mound	1.35c	8.45ab	0.19	1.89	9.76	0.24
Invert	2.02a	10.02ab	0.25	1.99	9.80	0.25
Mix	2.06a	12.05a	0.21	1.55	8.35	0.23
	$P = 0.04$	$P = 0.05$	$P = 0.31$	$P = 0.19$	$P = 0.44$	$P = 0.16$
November 2010						
Control	2.17b	8.66b	0.33	2.80a	11.77	0.31
Patch	3.02ab	10.97ab	0.38	3.24ab	12.79	0.34
Mound	2.83ab	11.56ab	0.32	3.56ab	13.48	0.36
Invert	2.72ab	12.81ab	0.27	3.31ab	13.90	0.31
Mix	3.86a	15.08a	0.34	4.06b	14.67	0.38
	$P = 0.05$	$P = 0.04$	$P = 0.37$	$P = 0.05$	$P = 0.68$	$P = 0.23$
November 2011						
Control	6.12	33.94	0.22	9.63	48.28	0.25
Mix	8.40	48.55	0.21	8.76	48.03	0.22
	$P = 0.28$	$P = 0.24$	$P = 0.62$	$P = 0.50$	$P = 0.98$	$P = 0.68$

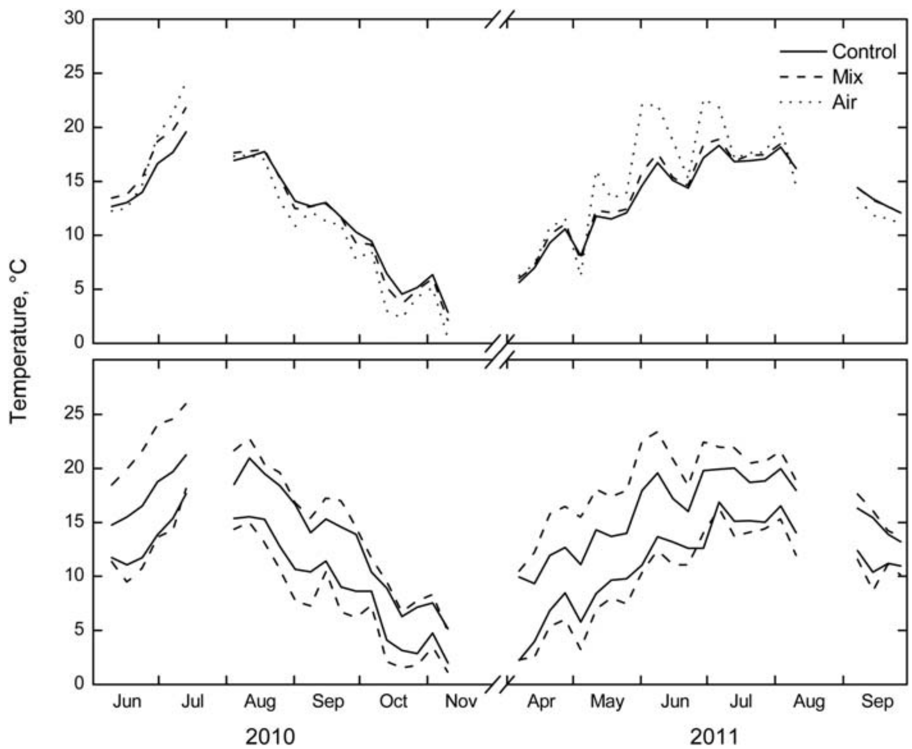

Figure 4. Mean weekly air and soil temperature in control and mix plots during 2010 and 2011 (upper panel). Minimum and maximum soil temperature in control and mix plots during 2010 and 2011 (lower panel).

shown that mechanical site preparation increases survival rates and reduces the damage sustained by Norway spruce seedlings during the first few years after planting.[7,14] However, in this work, there was no significant difference between the control treatment and the various mechanical site preparation techniques with respect to the survival of Norway spruce seedlings. This was probably due to the site being located in an area with favourable growth conditions on a fertile slope with good access to water and protection against pine weevils. The weather during the experimental growing seasons was also very favourable, with fairly high temperatures and sufficient rain. The survival rates for Douglas fir were lower than those for Norway spruce and the different site preparation methods had a clear impact on the survival for this species, with seedlings planted in control plots exhibiting high mortality. A large proportion of the seedlings died of unknown causes; it is possible that the growth of Douglas fir seedlings' roots may have been restricted in unprepared soil. Damage caused by pine weevils was another major cause of mortality among Douglas fir seedlings, even though they were treated with insecticide in the same way as the Norway spruce seedlings. Pine weevils are one of the most common causes of seedling mortality in recent clear-cuts in southern Sweden and it is well known that surrounding the seedlings with pure mineral soil reduces the damage they can cause.[13,15–17] In this study, pine weevil showed a clear preference for Douglas fir. This contradicts the findings of some other studies in which Douglas fir was found to be less attractive than spruce and pine as a weevil food source.[18,19] Weevils that fed on the bark of Douglas fir under laboratory conditions produced smaller eggs and smaller adult weevils than those that fed on several species of spruce and pine, indicating that Douglas fir may not be the weevil's optimum food source.[20,21] However, in this study, the mean debarked area for Douglas fir was greater than that for Norway spruce. In addition, the weevils targeted different locations in the two species: they consumed ∼10% of the bark from the leading shoots of Douglas firs whereas the leading shoots of Norway spruce seedlings were almost untouched. Very few seedlings died as a result of pine weevil damage between the final measurement occasion of the first year and the end of the study. However, almost one-fifth of the seedlings of Douglas fir were considered to be severely damaged by pine weevil, mainly due to weevil feeding on the leading shoots. This damage will most likely result in to a reduced growth in subsequent years. In a study focusing on maritime pine (*Pinus pinaster* Ait.), Zas *et al.*[22] made similar observations, even though most of the seedlings in their study survived pine weevil feeding, the leader loss due to stem girdling resulted in significant growth reductions.

There was a clear difference in growth (in terms of the average length of leading shoot) between the tree species during the first season: on average, the leading shoots of Douglas fir were half as long as those of Norway spruce. Hermann and Lavender[23] claim that the growth of Douglas fir seedlings during the first year is indeterminate but relatively slow. The same authors noted that first-year seedlings on better sites in the Pacific Northwest can develop shoots 6–9 cm long and that the shoot growth may accelerate in subsequent years. The conditions in Sweden are different to those in the Pacific Northwest, which might explain why the average length of Douglas fir leaders was <6 cm long in this case. Shoot growth is affected by temperature and the length of the growing season, as well as the environmental conditions during the previous year.[6] For Douglas fir, the data suggest that mechanical site preparation had some effect on growth in the second year, since the seedlings grown in the mix treatment exhibited the greatest growth at the end of the study, but the difference was not significant.

Soil that has not been mechanically prepared may be more physically resistant to root growth than treated soil.[24] In general, the root dry mass was greater for treatments involving extensive mechanical disturbance of the planting site, with Douglas fir seedlings planted on mixing plots having significantly more massive roots in August of year 1 than did those grown under alternative regimes. In contrast, it was not until November of year 1 that significant between-treatment differences were observed for the dry root mass of Norway spruce seedlings.

Douglas fir seems to give a higher priority to root growth than Norway spruce during the first spring and summer, but the latter species attains parity thereafter. Spruce species have a seasonal root growth pattern, with root growth peaking just before the bud starts to develop, followed by a reduced growth after bud break.[6] It may be that Douglas fir has a somewhat different pattern, in which root growth is dependent on the current photosynthate[25] meaning that the seedlings could start root growth at an early stage if there is early flushing. The Douglas fir seedlings used in this study originated from the interior of British Columbia, and are known to exhibit early flushing. Soil temperature is another factor that strongly influences seedling establishment in northern latitudes.[14,26] Vapaavuori *et al.*[27] found that root temperature affected the growth and development of spruce and pine roots, and Grossnickle[6] claims that low soil temperatures in the spring often restrict the root growth of Norway spruce. The mix treatment yielded higher soil temperatures than were observed in unprepared soil, which might partially account for the relatively poor root growth observed in control plots, particularly for Douglas firs. Although the total seedling biomass was lower in the control plots than in the mix plots, the R/S ratio was similar for both, suggesting that root growth is heavily dependent on shoot growth and vice versa.[28] It is unlikely that root development in this study would have been restricted by either water deficiencies or by soil water saturation due to the location of the experimental site.

Nilsson and Örlander[11] found that mounding was as effective as an intensive herbicide treatment at reducing vegetation cover during the first years after planting. In this study, the patch treatment was the least effective at reducing field vegetation. The mean extent of vegetation cover in the patch plots was the same as that in the control plots after one growing season; after the second growing season, the patch treatment yielded the highest field vegetation cover. The mean percentage of vegetation cover was high in all treatments after two growing seasons, greatly reducing the impact of site preparation on pine weevil damage.[29] The presence of grass is commonly regarded as a severe limiting factor during tree regeneration[30] and reducing the vegetation cover around seedlings tends to decrease seedling mortality and to improve seedling growth after planting.[31] Nilsson and Örlander[11] argue that differences in the growth of Norway spruce seedlings between undisturbed ground and vegetation control treatments may have been due to allelopathy. The vegetation at the experimental site examined in this study consisted primarily of raspberry plants, herbs and sedges; it is possible that these species might be less competing or less toxic towards newly planted seedlings.

Overall, the results presented herein indicate that on a fertile slope like the one studied, site preparation has little or no effect on the survival and growth of Norway spruce. For Douglas fir, however, all site preparation methods increased survival compared with the control and mortality was high when seedlings were planted in unprepared soil. The most intense site preparation treatment, mix, significantly increased root growth and total biomass. In addition, pine weevils caused more severe damage to Douglas fir seedlings than to Norway spruce and also targeted different locations in the two species, causing more extensive damage to the leading shoots of Douglas fir seedlings.

Funding

The research was funded through Future Forests, a multi-disciplinary research programme supported by the Foundation for Strategic Environmental Research (MISTRA), the Swedish Forestry Industry, Swedish University of Agricultural Sciences (SLU), Umeå University, and the Forestry Research Institute of Sweden (Skogforsk).

Acknowledgements

The authors gratefully acknowledge the contributions of Professor Urban Nilsson, who was actively involved in designing the trial. Karin Johansson and Urban Nilsson also provided valuable comments on the manuscript. Thanks are also due to the staff of the Asa Research Station, who provided assistance with the fieldwork and with separating and drying the different parts of the harvested seedlings. The authors are particularly thankful to Ola Langvall who helped out with the logger and designing of the figures. Finally, special thanks also to the English editing service, Sees-Editing Ltd., for invaluable help in improving the language of the paper.

Conflict of interest statement

None declared.

References

1 Skogsdata, 2011. *Aktuella uppgifter om de svenska skogarna från Riksskogstaxeringen*. Fakulteten för skogsvetenskap, Institutionen för skoglig resurshushållning, Umeå. ISSN 0280-0543.

2 Hermann, R.K. and Lavender, D.P. 1999 Douglas-fir planted forests. *New Forest*. **17**, 53–70.

3 Larsen, B. 2010 The dynamics of Douglas-fir stands. Berichte Freiburger Forstliche Forschung, Nr 85.

4 Lemoine, K. and Wirtén, H. 1988 *Examensarbete I skogshushållning*. Institutionen för skogsskötsel, Sveriges lantbruksuniversitet, Umeå.

5 Svensson, J. 2011 Survival and growth of Douglas fir in southern Sweden. Kandidatarbete i skogshushållning (Elektronisk publicering: http://stud.epsilon.slu.se). In Swedish with English summary.

6 Grossnickle, S.C. 2000 *Ecophysiology of Northern Spruce Species: the Performance of Planted Seedlings*. NRC Research Press, Ottawa.

7 Nordborg, F., Nilsson, U. and Örlander, G. 2003 Effects of different soil treatments on growth and net nitrogen uptake of newly planted *Picea abies* (L.) Karst. seedlings. *For. Ecol. Manage.* **180**, 571–582.

8 Nilsson, U., Luoranen, J., Kolstrom, T., Örlander, G. and Puttonen, P. 2010 Reforestation with planting in northern Europe. *Scand. J. For. Res.* **25**, 283–294.

9 Landhäusser, S.M., DesRochers, A. and Lieffers, V.J. 2001 A comparison of growth and physiology in *Picea glauca* and *Populus tremuloides* at different soil temperatures. *Can. J. For. Res.* **31**, 1922.

10 Hallsby, G. 1995 Influence of Norway spruce seedlings on the nutrient availability in mineral soil and forest floor material. *Plant Soil.* **173**, 39–45.

11 Nilsson, U. and Örlander, G. 1999 Vegetation management on grass-dominated clearcuts planted with Norway spruce in southern Sweden. *Can. J. For. Res.* **29**, 1015–1026.

12 Örlander, G., Hallsby, G., Gemmel, P. and Wilhelmsson, C. 1998 Inverting improves establishment of *Pinus contorta* and *Picea abies*: 10-year results from a site preparation trial in northern Sweden. *Scand. J. For. Res.* **13**, 160–168.

13 Petersson, M., Örlander, G. and Nordlander, G. 2005 Soil features affecting damage to conifer seedlings by the pine weevil *Hylobius abietis*. *Forestry.* **78**, 83.

14 Örlander, G., Gemmel, P. and Hunt, J. 1990 Site preparation. A Swedish overview. FRDA Report 105, 1–62. BC Ministry of Forests. ISSN 0835-0752.

15 Björklund, N., Nordlander, G. and Bylund, H. 2003 Host–plant acceptance on mineral soil and humus by the pine weevil *Hylobius abietis* (L.). *Agric. For. Entomol.* **5**, 61.

16 Petersson, M. and Örlander, G. 2003 Effectiveness of combinations of shelterwood, scarification, and feeding barriers to reduce pine weevil damage. *Can. J. For. Res.* **33**, 64.

17 Petersson, M. 2004 Regeneration methods to reduce pine weevil damage to conifer seedlings. Vol. 33. Doctoral thesis, Swedish University of Agricultural Sciences [Acta Universitatis Agriculturae Sueciae Silvestria]. pp. 1–34.

18 Kuziemska-Grzeczka, G. 1986 Studies of food preference by *Hylobius abietis*. *Folia Forest. Pol. A (Lesnictwo).* **26**, 113–126.

19 Zumr, V. 1989 Responses of the large pine weevil (*Hylobius abietis* L.) (Coleoptera, Curculionidae) to different food attractants. *Lesnictvi.* **35**, 607–620.

20 Wainhouse, D., Ashburner, R. and Boswell, R. 2001 Reproductive development and maternal effects in the pine weevil *Hylobius abietis*. *Ecol. Entomol.* **26**, 655–661.

21 Thorpe, K. and Day, K. 2002 The impact of host plant species on the larval development of the large pine weevil *Hylobius abietis* L. *Agric. For. Entomol.* **4**, 187.

22 Zas, R., Sampedro, L., Prada, E., Lombardero, M.J. and Fernández-López, J. 2006 Fertilization increases *Hylobius abietis* L. damage in *Pinus pinaster* Ait. seedlings. *For. Ecol.Manage.* **222**, 137.

23 Hermann, R.K. and Lavender, D.P. 1990 *Pseudotsuga menziesii* (Mirb.) Franco. In *Silvics of North America. Vol. 1. Conifers*. Burns, R.M., Russell, M. and Honkala, B.H. (Technical coordinators). U.S. Department of Agriculture, Agricultural Handbook 654. pp. 527–554.

24 Hildebrand, E.E. 1983 Der einfluss der bodenvirdichtung auf die bodenfunktionen im forstlichen standort. *Orstw. bl.* **102**, 111–125.

25 Philipson, J.J. 1988 Root growth in sitka spruce and Douglas-fir transplants: dependence on the shoot and stored carbohydrates. *Tree Physiol.* **4**, 101.

26 Örlander, G. 1984 Some aspects of water relations in planted seedlings of *Pinus sylvestris*. Doctoral thesis, Department of Silviculture, Swedish University of Agricultural Sciences, Umeå.

27 Vapaavuori, E.M., Rikala, R. and Ryyppö, A. 1992 Effects of root temperature on growth and photosynthesis in conifer seedlings during shoot elongation. *Tree Physiol.* **10**(3), 217–230.

28 Hawkins, B.J., Henry, G. and Kiiskila, S.B.R. 1998 Biomass and nutrient allocation in Douglas-fir and amabilis fir seedlings: influence of growth rate and nutrition. *Tree Physiol.* **18**, 803–810.

29 Petersson, M., Nordlander, G. and Örlander, G. 2006 Why vegetation increases pine weevil damage: bridge or shelter? *For. Ecol. Manage.* **225**, 368–377.

30 Davies, R.J. 1985 The importance of weed control and the use of tree shelters for establishing broadleaved trees on grass-dominated sites in England. *Forestry.* **58**, 167.

31 Lindström, A., Hellqvist, C., Gyldberg, B., Långström, B. and Mattsson, A. 1986 Field performance of a protective collar against damage by *Hylobius abietis*. *Scand. J. For. Res.* **1**, 3.