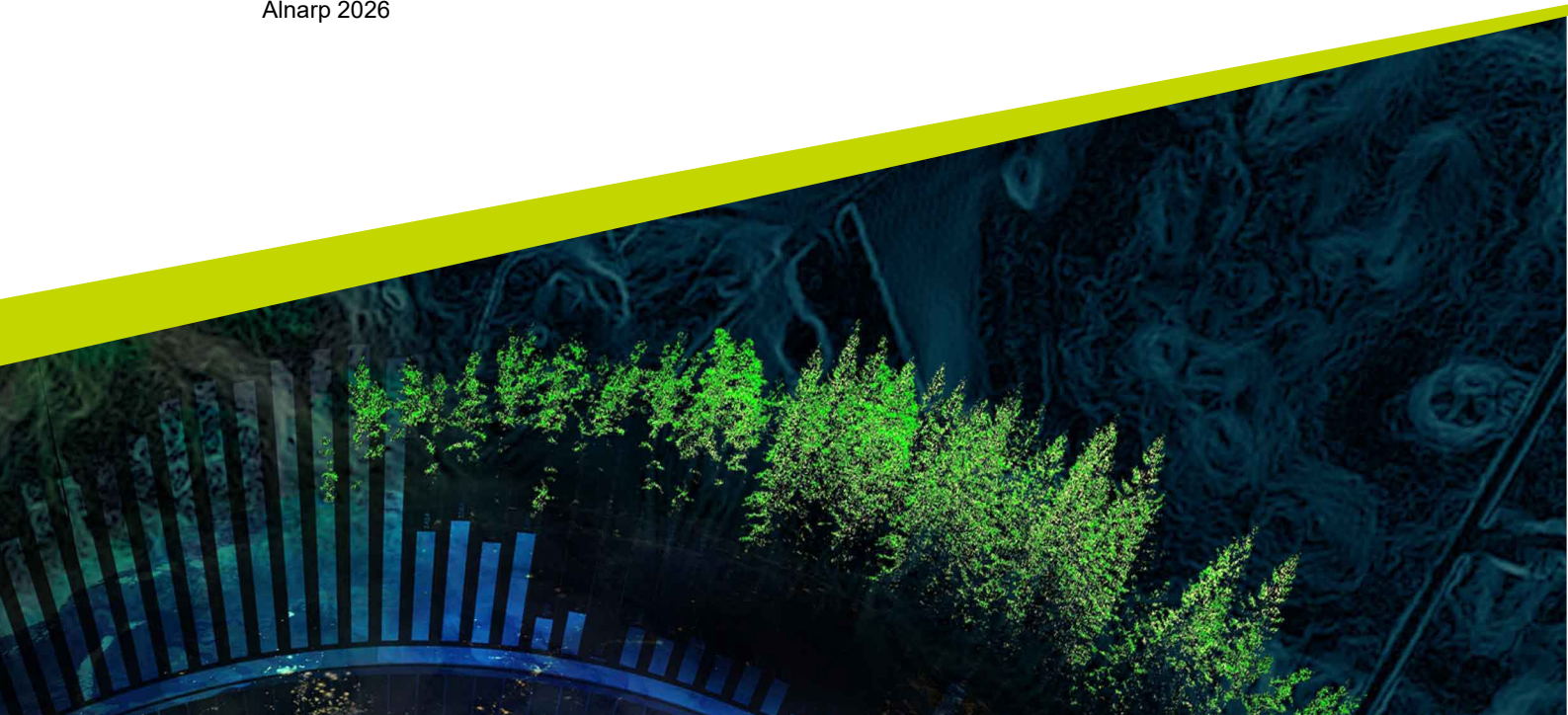




Effects of Mechanical Site Preparation on Seedling growth Across a Latitudinal Gradient

Elvira Löwenadler

Degree project/Independent project • 15 credits
Swedish University of Agricultural Sciences, SLU
Southern Swedish Forest Research Centre
Alnarp 2026



Effects of Mechanical Site Preparation on Seedling growth Across a Latitudinal Gradient

Markberedningens effekt på tillväxt längs en latitudgradient

Elvira Löwenadler

Supervisor: Jonatan Klaminder, Swedish University of Agricultural Sciences, Department of Forest Ecology and Management

Examiner: Urban Nilsson, Swedish University of Agricultural Sciences, Southern Swedish Forest Research Centre

Credits: 15
Level: First cycle, G2E
Course title: Independent project in Forestry Science
Course code: EX1012
Programme/education: Forest and Landscape bachelors' program
Course coordinating dept: Southern Swedish Forest Research Centre
Place of publication: Alnarp
Year of publication: 2026

Copyright: All featured images are used with permission from the copyright owner.

Keywords: Mechanical site preparation, MSP, Latitude, Production, Growth

Swedish University of Agricultural Sciences

Faculty of Forest Sciences

Southern Swedish Forest Research Centre

Acknowledgement

This work has been carried out during my final course and represents my last project at bachelor's level at the Swedish University of Agricultural Sciences. This project is sprung from my strong interest in mechanical site preparation and productivity-enhancing efforts, which has developed from having had the opportunity to participate in forestry courses at all of SLU's main campuses. It is also through that knowledge and contacts that this project has been possible.

I would therefore like to extend my sincerest thanks to my supervisor, Jonatan Klaminder, for all his help and support throughout the project.

Abstract

Successful forest regeneration is essential for a sustainable future and a strong forest industry. Mechanical site preparation (MSP) is a common method used to improve seedling establishment, but effects may vary between tree species. My study investigated the effects of soil inversion on height and volume growth of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) at three sites along a latitudinal gradient in Sweden. Growth data from the Övergaards tree species experiment were analysed using Linear mixed-effects models. Mechanical site preparation significantly increased both height and volume growth in both species. Scots pine showed a stronger positive response than Norway spruce, notably in volume growth, indicating species-specific responses to soil inversion. The results suggest that soil inversion is an effective method for improving early seedling growth, especially for Scots pine, although additional studies are needed to evaluate long-term and climatic effects.

Keywords: Mechanical site preparation, MSP, Latitude, Production, Growth

Table of contents

List of tables	6
List of figures.....	7
Abbreviations	8
1. Introduction	9
1.1 Aim and scope	11
1.2 Delimitations.....	11
2. Materials and methods	12
2.1 Övergaards tree species experiment.....	12
2.2 Data collection.....	13
2.3 Hypothesis testing.....	13
3. Results	14
4. Discussion	16
4.1 Conclusion	17
5. References.....	19

List of tables

Table 1: analysis done with Type III Tests of Fixed Effects with height being the dependent variable.	14
Table 2: Result of my Linear mixed-effects model and the effect of tree volume (spruce and pine) as a function of site preparation.	15

List of figures

Figure 1. Illustration of the Mechanical site preparation method Soil inversion.....	10
Figure 2. Illustration of the plot design used in the experiment	12
Figure 3: Average heights for Scots pine and Norway spruce on soil without site preparation (control) and with site preparation (site. prep).....	14
Figure 4: Average tree volume (dm ³) for Scots pine and Norway spruce on soil without site preparation (control) and with site preparation (site. prep)	15

Abbreviations

Abbreviation	Description
SLU	Swedish University of Agricultural Sciences
MSP	Mechanical site preparation
LMMs	Linear mixed-effects Models
REML	Restricted maximum likelihood

1. Introduction

Greenhouse gases from using fossil fuels are the biggest factor in the ongoing global warming (IPCC 2021). Forests play an important role in transitioning from fossil products to renewable options. For this transition to be functional, successful regeneration of forest following harvest plays a key role. Production enhancing methods will therefore be important, to make sure that forest production continues. Yet, forests are declining due to human land-use (UNEP 2026) and the European union has developed forest protection strategies for preserving forest for 2030 (European commission 2021). Nevertheless, there is currently a strong demand for forest products around the globe, highlighting the need for sustainable forestry practices.

Sweden remains one of the largest forest industries in the world, with one of the largest exports of pulp, paper and sawn timber (Skogsindustrierna 2026). Historically, Swedish forestry is mostly focused on producing raw material for the industry, typically sawn timber, packaging, construction wood, and paper products (Sandberg et al. 2014). To meet the heavy market demands and have an economically viable forestry, the traditional forest management has been even-aged silviculture, with clear-cutting and planting regulated by the Swedish laws (Skogsvårdslagen (SFS 1979:429)).

Swedish forest ecosystems are important in facilitating the shift towards a bioeconomy and sustainable world. However, it is important to recognize that there is both a need for more raw materials and energy for being able to limit the usage of fossil fuels but also to minimize risks in the forests. In 2025, Göran Örlander published a Swedish government's official report called "*En robust skogspolitik för aktivt skogsbruk*", promoting an increased forestry production to minimize the risks of damages (SOU 2025:93). To make sure that there is raw material to use, reestablishment of harvested forestland is important. The most common practice of establishing new forestland is to plant.

According to the forest agency, 88% of reestablished forest stands are planted (Skogsstyrelsen n.d). In Swedish context, there are two common types of seedlings, containerized seedling and bareroot seedling. Containerized seedlings are the most common seedling type regarding both pine and spruce, although the usage of spruce bareroot seedlings increases in the south of Sweden (Berglund et al 2026). There are also hybrid options between containerized and bareroot seedlings, commonly described as plug-plus (Skogskunskap 2024). However, successful regeneration does not solely depend on the preferred seedling type, but rather multiple factors beyond seedling morphology.

Mechanical site preparation, MSP, is a common component in establishing forest stands. The Swedish Forest agency reports that 86% of the forest land that is planted with MSP. This can be done regardless of the type of seedling. Using MSP is more common in the northern parts of Sweden compared to the southern parts (Skogsstyrelsen n.d). MSP is used to enhance the productivity of the site. It is reported to have a positive effect on both the plants survival and establishment as well as the growth in early stages (Hallsby & Örlander, 2004). By modifying the soil and the microenvironment, both the soil temperature and nutrient availability increase, which has a positive effect on early root development. MSP also decreases the density of the soil, since the soil is shaken up, which has a positive effect on plant establishment (Örlander, Gemmel & Wilhelmsson 1991).

There are several methods of MSP, the most common methods in Sweden are Disc trenching and mounding where disc trenching is the most dominating method due to its cost-effectiveness and productivity (Skogsstyrelsen 2026). Data from 2025 shows that approximately 50% of MSP in Sweden is done with disc trenching (Berglund et al 2026). Although disc trenching is the most common practice, researchers are emphasizing the benefits of more methods. One of the methods is soil inversion, where the turf is lifted, and turned over, placed back at the same place. The humus layer is now covered in mineral soil, which minimizes the soil disturbance as well as suppressing the competing vegetation (Hansson et al 2014; Örlander et al 1990). The roots then get access to nutrients from the humus layer do not risk drying out since the planting spot is not elevated (ibid).

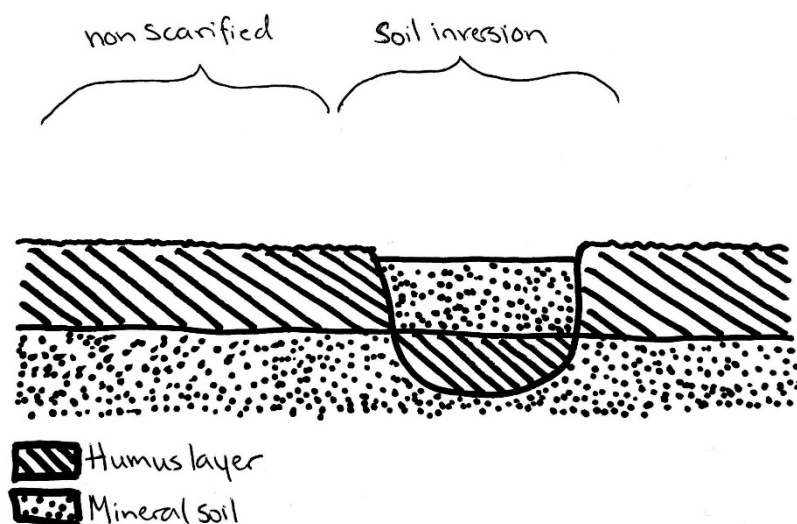


Figure 1. Illustration of the Mechanical site preparation method Soil inversion. Non-scarified, untreated soil on the left and soil inversion on the right. Illustration by: Elvira Löwenadler.

In 2012, a study showed that spruce planted with MSP had a higher survival rate and higher height growth compared to spruce planted without MSP (Hjelm, Nilsson & Örlander 2012). Karlstrand (2022) did a study on SCA's planting methods that did not show any significant differences regarding MSP. Specifically, the inversion method and the positive effects of it have been studied in northern Sweden, showing a positive effect on survival rate and height growth (Örlander et al 1998).

The most common species in Swedish forestry is Scots pine (*Pinus sylvestris*), which grows throughout Sweden (Åslund 2020). Norway Spruce (*Picea abies*) is the second most abundant species and grows all over Sweden (Lindbladh 2022). According to Skogsstyrelsen (2026) about 59% of all planted seedlings in Sweden during 2025 were Scots pine. Norway spruce was about 40% of all planted seedlings and the rest were a mix of broadleaves and other conifers. However, there are researchers suggesting that the long-term viability for Norway spruce in the southern parts of Sweden is compromised due to the ongoing climate changes (Greiser & Eggers 2026).

1.1 Aim and scope

My study investigated the effect of mechanical site preparation on height and volume growth on seedlings at three different sites distributed along a latitudinal gradient. The studied species are Norway Spruce and Scots Pine.

My hypothesis for this thesis was: Effects of mechanical site preparation on seedling height performance differ between tree species (Scots pine and Norway spruce).

My hypothesis was tested using data extracted from a long-term tree species experiment.

1.2 Delimitations

The analysis was done with only one site per latitude and with two different species, in Sweden. The method of MSP was soil inversion at all sites.

2. Materials and methods

2.1 Övergaards tree species experiment

The material used in this thesis is an experiment called Övergaards tree species experiment. In the experiment there is a total of 15 trials spread over Sweden. The sites were established between 2012 and 2015, with the same experimental design. The experiment focuses on growth differences between species as well as the effects of fertilization and mechanical site preparation. The different sites have different species, depending on what region of Sweden the site is placed in. The experiment is established on forestland and on agricultural land.

In this analysis only three of the sites are analyzed, Gideå at latitude 63, Leksberget at latitude 60 and Tagel at latitude 56. All three sites were established during 2013 and planted with spruce, pine and hybrid aspen. There are four unfertilized plots with each species on each site. The plots are 24x24 m and contain 11 rows, six with MSP, soil inversion, and five without. The rows treated with MSP have 11 seedlings and the untreated rows have six seedlings. All the sites are fenced, and each plot is both treated with MSP and without. The plots are established on forestland, previously clear-cut. Plots treated with fertilizer are not used in this analysis.

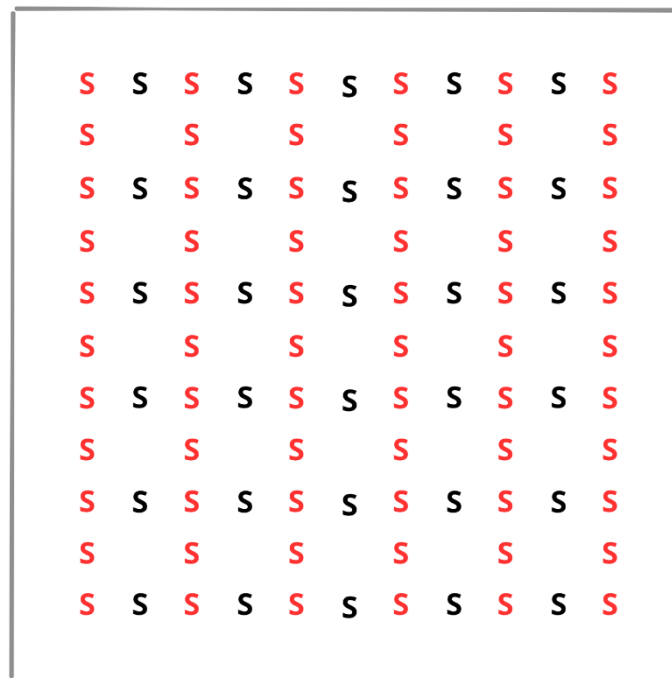


Figure 2. Illustration of the plot design used in the experiment. S = Seedling. Red means mechanical site preparation, black means no mechanical site preparation.

2.2 Data collection

For this analysis, data collection was done between seven and 11 years after planting. Measurements of height and diameter were collected on each site. Height was measured in meters (m) and diameter were measured in millimeter (mm).

Tree volume (including bark and measured in dm^3) was provided from one of the contact persons for the experiment Martin Goude, Experiment group leader at Tönnersjöheden, SLU. Volume was estimated using small tree functions based on tree hight, diameter at 1.3 m and the distance between the tree crown and the ground as described in detail by Karlsson, Mossberg & Ulvcrona (2012).

2.3 Hypothesis testing

The effects of soil scarification and tree species on tree volume and height were analysed using linear mixed-effects models (LMMs). Treatment (control and soil scarification), tree species, and their interaction were included as fixed effects. To account for the hierarchical experimental design, site and blocks nested within site were included as random effects.

Models were fitted using restricted maximum likelihood (REML). The significance of fixed effects was evaluated using F-tests. When significant treatment $\times$ species interactions were detected, pairwise comparisons were performed to assess treatment effects within individual tree species.

Model assumptions were evaluated by visual inspection of residual diagnostics. Normality of residuals was assessed using histograms and normal Q–Q plots, and homogeneity of variance was evaluated by examining plots of residuals against fitted values. Residual diagnostics indicated no substantial deviations from model assumptions.

All statistical analyses were performed using R studio (Posit 2026).

3. Results

Table 1: analysis done with Type III Tests of Fixed Effects with height being the dependent variable.

Source	Numerator df	Denominator df	F	Sig.
Mechanical site preparation	1	2187	79.426	<.001
Tree species	1	2187	5.250	.022
MSP * Tree species	1	2187	11.591	<.001

a. Dependent variable: height

Height responded positively to site preparation ($p < 0.001$) (Table 1). Scot pine trees were generally taller (on average 4.3 m) than spruce (on average 3.6 m) on site with soil inversion (Table 2) and the difference between species was significant ($p = 0.022$). Interestingly, the analysis also showed a significant interaction between site preparation and tree species ($p < 0.001$), suggesting that pine grew slower than spruce in the control (average 2.9 m) in comparison to spruce (average 3.0 m) seen for spruce (Table 2).

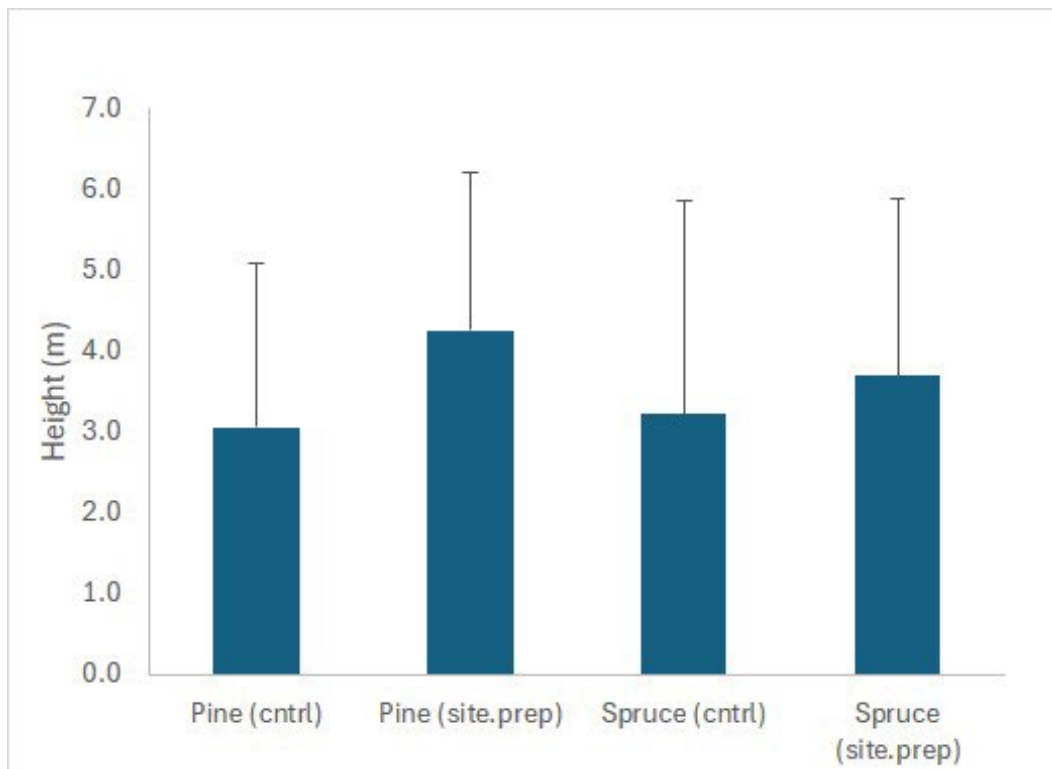


Figure 3: Average heights for Scots pine and Norway spruce on soil without site preparation (control) and with site preparation (site. prep). Error bars indicated standard deviation.

Table 2: Result of my Linear mixed-effects model and the effect of tree volume (spruce and pine) as a function of site preparation.

Source	Numerator df	Denominator df	F	Sig.
Mechanical site preparation	1	2187	357.787	<.001
Tree species	1	2187	282.310	<.001
MSP * Tree species	1	2187	140.455	<.001

Result for volume largely resembled that of tree height, but with some differences. Tree volume increased as result of site preparation ($p < 0.001$) (Table 2). There was also an effect ($p = 0.001$) of tree species where pine had a more than three times higher volume than spruce, both in the control and in the treatment with site preparation (Figure 4). Again, there was an interaction effect suggesting that pine volume and spruce volume responded differently to site preparation (Table 2). This effect was mainly explained by a much more dramatic increase in pine volume following site preparation in comparison to spruce (Figure 4).

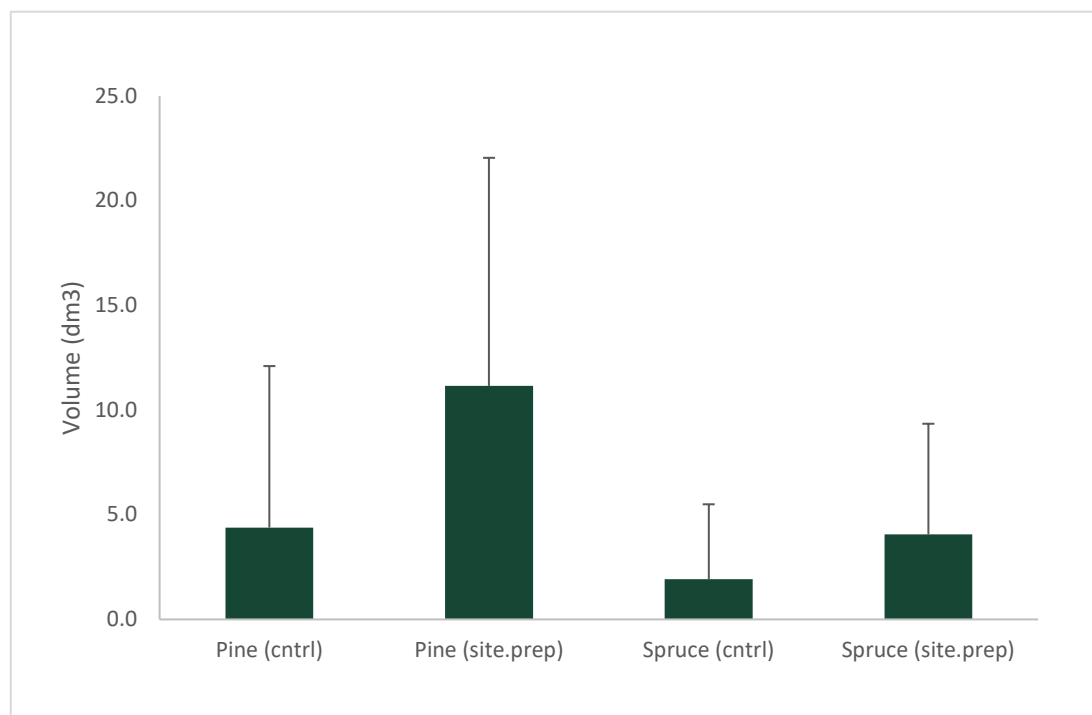


Figure 4: Average tree volume (dm³) for Scots pine and Norway spruce on soil without site preparation (control) and with site preparation (site. prep). Error bars indicated standard deviation. Note that volume estimates are used as provided by the manager of Silva boreal and that the applied volume was not specified by the data provider. Therefore, the results should be treated with caution and results may differ if reanalysed using other volume functions.

4. Discussion

The results of the analysis support the hypothesis that the effects of mechanical site preparation on seedling performance differ between tree species. In the analysis, a significant interaction was found between site preparation and tree species regarding both height and volume. Overall, mechanical site preparation improved the growth of both species, although Scots pine benefitted more from the mechanical site preparation than Norway spruce. This finding is supported by previous studies, which also show a positive effect of mechanical site preparation on conifer species (Sikström et al. 2020).

The differences observed between species in this experiment could be explained by their ecological differences. Scots pine is often considered a pioneer, early successional species sensitive to shading (Skogskunskap 2026a). It adapts to open areas and tolerates light. Norway spruce, on the other hand, is more shade tolerant and less dependent on open areas. The species is also considered a later successional species (Skogskunskap 2026b).

Since mechanical site preparation, soil inversion, improves the growing condition through exposing the mineral soil and sets the humus layer underneath, the nutrient availability is closer to the roots, meaning that the seedlings can access more nutrients faster. The grass that was growing on top of the humus layer dies when turned over and new grass has a harder time competing against the growing seedlings. The soil temperature also increases with mechanical site preparation, which is beneficial for seedlings. These changes are particularly beneficial for a pioneer species, such as pine, which could explain the results.

Both species showed beneficial effects from mechanical site preparation, which also align with previous studies regarding the effects of mechanical site preparation, both Hjelm, Nilsson and Örlander (2012) and Hansson et al. (2014) pointed out the benefits of MSP when planting conifers, regarding establishment, growth and resistance against insects like pine weevil.

The analysis conducted in my study included sites from three latitudes in Sweden. While the geographic (latitude) spread of study sites increases the generality of my results, the numbers of sites are too few to interpret the result as a difference because of climatic conditions. To exemplify, the reactions per site were not consistent, there were differences in the amount of growth between the sites. This could indicate that temperature or the growing season can also influence the mechanical site preparation effect, but the dataset, however, was not designed to formally evaluate climatic interactions. Yet future studies involving more study sites may be able to resolve possible climatic effects.

Although this study does not compare different MSP methods, it is important to understand that over half of all the MSP done in Sweden is done by disc trenching. One factor for choosing disc trenching is the cost, disc trenching costs around 2300/ha while soil inversion costs around 4200/ha (Sundblad et al 2016). In 2015, Skogforsk published information about soil inversion and how to do it, which is less than fifteen years ago (Skogforsk 2015). It is therefore safe to say that even though the method might be less intense on the ground, it is still quite unused in the Swedish forestry.

There is a need to intensify the forestry in some sites, to be able to protect and enhance biodiversity at other sites. Mechanical site preparation has been proven to increase survival rate as well as improve early height growth in several studies, as well as in this analysis.

The forest ownership in Sweden is broad and with different types of owners and owner structure. Because of this, it is important that the information regarding production enhancement, such as MSP, is researched continuously.

The experiment was design in a similar way in all the sites, improving the comparability between the different sites as well as limiting any methodological errors based on variation of data.

Continuing forward, this analysis shows that there is a need for continuous research. With the increasing demand for raw material and green energy and at the same time, increasing the amount of protected forestland, there is a need to research more about how to increase the growth at each site as well as increasing survival. Mechanical site preparation is shown to have a positive effect on height growth. This thesis is only applicable to two conifer species. There is a need for further research, both regarding locations and forest types in Sweden as well as more species. It is also important to study the long-term effects on height growth, this analysis only applies to the first growth years. There is also a need to study the effects between different MSP methods, and their effects on the forest floor and not only their difference in economic costs.

4.1 Conclusion

Mechanical site preparation, specifically soil inversion, had a positive effect on seedling growth for both Norway spruce and Scots pine, but pine showed a stronger growth response, especially in volume growth. This could be linked to the ecological differences. The results seem to be applicable across Sweden,

although it is not possible to exclude any climatical effects, which would need to be studied further to conclude.

5. References

- Berglund, M., Öhlund, J., Fahlvik, N., Häggström, B., Johansson, F., Hjelm, K., Zyirgzdins, A., Renman, C., Krook, M. & Vestlund, M. (2026). *Föryngringskollen – Resultat 2025*. Uppsala: Skogforsk.
- European Commission (2021). *New EU Forest Strategy for 2030*.
- Greiser, C. & Eggers, J. (2026). *Allt mer gran på klimatmässigt olämpliga områden*. Sveriges Lantbruksuniversitet. <https://www.slu.se/nyheter/2026/02/allt-mer-gran-pa-olampliga-omraden/> [2026-05-08]
- Hallsby, G. & Örlander, G. (2004). *A comparison of mounding and inverting to establish Norway spruce on podzolic soils in Sweden*. Forestry: volume 7 number 2. Oxford university. <https://doi.org/10.1093/forestry/77.2.107>
- Hansson, L., Rappe, M., Annemieke, G. & Gärdenäs, I. (2014). *Markberedning i svenskt skogsbruk nu och i framtiden med fokus på miljökonsekvenser litteraturstudie och expertintervjuer*. Skogsstyrelsen och Skogforsk. Sveriges lantbruksuniversitet.
- Hjelm, K., Nilsson, U. & Örlander, G. (2012). *A comparison of long-term effects of scarification methods on the establishment of Norway spruce*. Forestry: An International Journal of Forest Research. <https://doi.org/10.1093/forestry/cps062>
- Intergovernmental Panel on Climate Change. (2021). *Climate Change 2021: The Physical Science Basis*. Cambridge University Press. <https://doi.org/10.1017/9781009157896>
- Karlsson, K., Mossberg, M. & Ulvcróna, T. (2012). *Fältdatasystem för skogliga fältförsök*. Enheten för skoglig fältforskning, Sveriges Lantbruksuniversitet.
- Karlstrand, A. (2022). *Samband mellan föryngringsresultatet år fem och kvalitetsklassing av markberedning och planteringsåtgärder på SCA:s fasta provytor i norra Sverige*. Master thesis. Sveriges Lantbruksuniversitet.
- Lindblad, M. (2022). *Granens historia: från vild till domesticerad*. Vilda växter. Sveriges lantbruksuniversitet.
- Posit Team (2025). *RStudio: Integrated Development Environment for R*. Boston, MA: Posit Software, PBC.

Sandberg, D., Vasiri, M., Tricshler, J. & Öhman, M. (2014). *The role of the wood mechanical industry in the Swedish forest industry cluster*. Scandinavian Journal of Forest Research. [Doi: 10.1080/02827581.2014.932005](https://doi.org/10.1080/02827581.2014.932005).

SFS 1979:429

Sikström, U., Hjelm, K., Holt Hanssen, K., Saksa, T. & Wallertz, K. (2020). *Influence of mechanical site preparation on regeneration success of planted conifers in clearcuts in Fennoscandia – a review*. Silva Fennica. <https://doi.org/10.14214/sf.10172>

Skogforsk (2015). Skonsam och produktiv markberedning. <https://www.youtube.com/watch?v=cPTkUqgZJDo> [2026-05-18]

Skogsindustrierna (2026). *Facts and figures*. <https://www.forestindustries.se/forest-industry/statistics/facts-and-figures/> [2026-04-13]

Skogskunskap (2024). *Olika planttyper*. <https://www.skogskunskap.se/skota-skog/foryngra/plantering/olika-planttyper/> [2026-04-28]

Skogskunskap (2026a). *Tall (Pinus Sylvestris)* <https://www.skogskunskap.se/aga-skog/fakta-om-skogen/tradslag-i-vara-skogar/tall---pinus-sylvestris/> [2026-07-13]

Skogskunskap (2026b). *Gran (Picea Abies)*. <https://www.skogskunskap.se/aga-skog/fakta-om-skogen/tradslag-i-vara-skogar/gran-picea-abies/> [2026-07-13]

Skogsstyrelsen (2026). *Levererade skogsplantor*. <https://www.skogsstyrelsen.se/statistik/skogssktsel/levererade-skogsplantor/> [2026-05-16]

Skogsstyrelsen. (2026). *Markberedning*. <https://www.skogsstyrelsen.se/bruka-skog/ny-skog-efter-avverkning/markberedning> [2026-05-01]

Skogsstyrelsen (no date). *Statistik om återväxternas kvalitet*. <https://www.skogsstyrelsen.se/statistik/skogssktsel/atervaxternas-kvalitet/> [2026-04-13]

SOU 2025:93. *En robust skogspolitik för aktivt skogsbruk*.

Sundblad, L-G., Sikström, U., Gålnander, H., Hajek, J., Hjelm, K. & Friberg, G. (2016). *Bilaga 4: Kalkyler*. Kostnadsoptimering av beståndsanläggningskedjan. Skogforsk.

United nations environment programme (2026). *Facts about the nature and crisis*.
<https://www.unep.org/facts-about-nature-crisis> [2026-05-08]

Åslund, M. (2020) *A window to the future of Sweden's pine forestry? Development of declining Scots pine after a severe drought and the presence of Diploдия sapinea*. Master thesis. Sveriges Lantbruksuniversitet.

Örlander, G., Gemmel, P. & Wilhelmsson, C. (1991). *Markberedningsmetodens, planteringsdjupets och planteringspunktens betydelse för plantors etablering i ett område med låg humiditet i södra Sverige*. Sveriges Lantbruksuniversitet, Institutionen för Skogsskötsel (Rapporter nr 33).

Örlander, G., Hallsby, G., gemmel, P., & Willhelmsson, C. (1998). *Inverting improves establishment of Pinus contorta and Picea abies - 10-year results from a site preparation trial in northern Sweden*. Scandinavian Journal of Forest Research.

Örlander, G., Hunt, J.A. & Gemmel, P. (1990). *Site preparation: a Swedish overview*. Forestry Canada.

Publishing and archiving

Approved students' theses at SLU can be published online. As a student you own the copyright to your work and in such cases, you need to approve the publication. In connection with your approval of publication, SLU will process your personal data (name) to make the work searchable on the internet. You can revoke your consent at any time by contacting the library.

Even if you choose not to publish the work or if you revoke your approval, the thesis will be archived digitally according to archive legislation.

You will find links to SLU's publication agreement and SLU's processing of personal data and your rights on this page:

- <https://libanswers.slu.se/en/faq/228318>

☒ YES, I, Elvira Löwenadler, have read and agree to the agreement for publication and the personal data processing that takes place in connection with this