Effects of Different Pre-Commercial Thinning Strategies on Growth in Young Scots Pine Stands.

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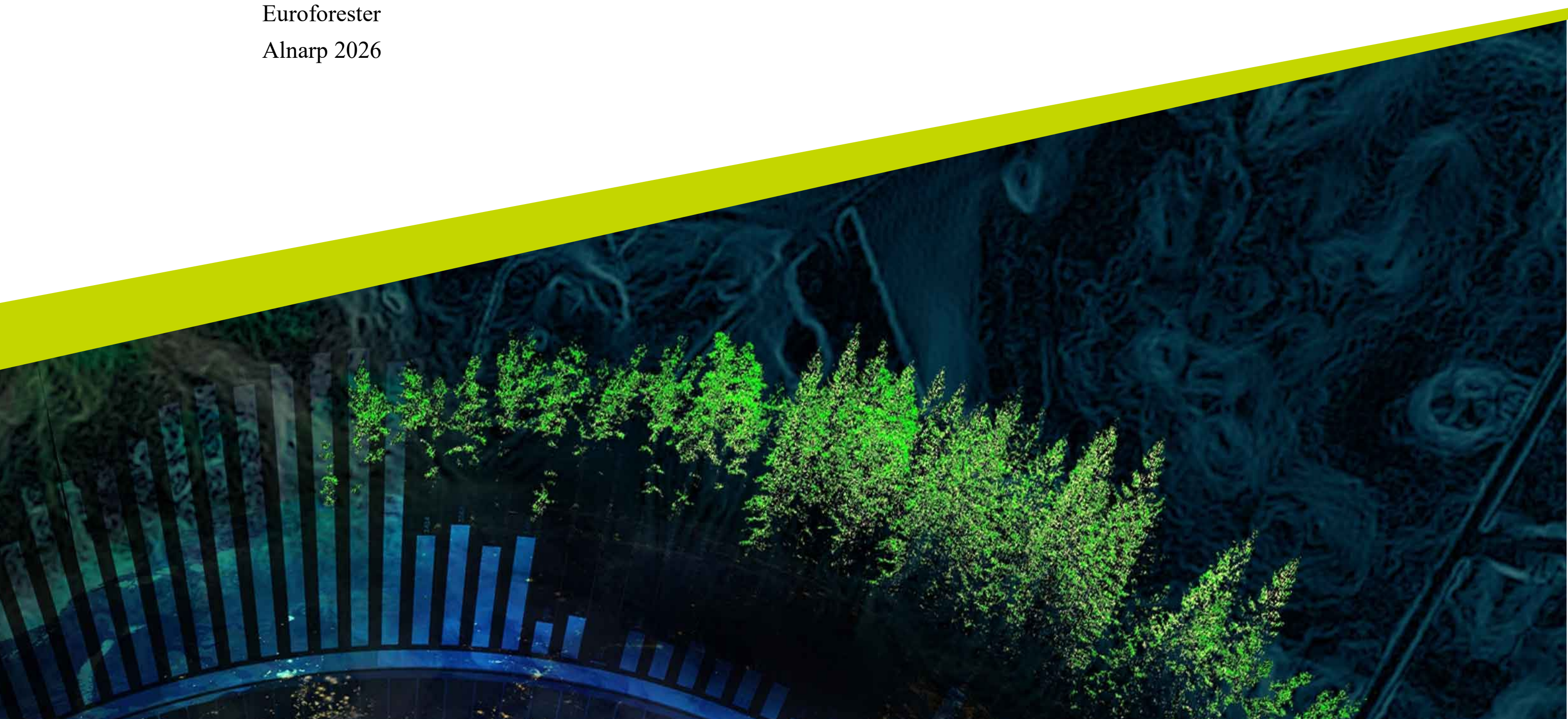

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Abstract

Scots pine (*Pinus sylvestris* L.) is a widely distributed tree species, with a range extending from eastern Europe to far eastern Russia. It is an early-successional, light-demanding species with relatively low shade tolerance, particularly when young. In Scots pine plantations, early competition among seedlings is generally not the main limiting factor in the first years following planting. However, it increases as stand development progresses. Pre-commercial thinning (PCT) is therefore important for regulating stand density and competition, thereby promoting the growth and quality of selected crop trees.

The aim of this thesis was to study early stand growth in young Scots pine plantation under different PCT thinning treatments. To address this aim, the experiment was established at Remningstorp estate in southern Sweden, using a completely randomized block design with four blocks. Each block included three treatments, with one plot assigned to each treatment. The treatments were: Control (no PCT), (Tall) thinning with retention of the 1000 tallest trees ha^{-1}, and (Short) thinning with retention of the 1000 shortest trees ha^{-1}. Treatments were based on tree height.

The results showed that dominant trees were not influenced by neighbouring smaller trees in terms of mean diameter. In contrast, suppressed trees responded positively to release from larger neighbours, exhibiting a greater increase in both mean diameter and mean diameter growth, than suppressed trees in the unthinned control. Meaning that the release of competition for supressed stems increased the mean diameter and mean diameter growth, compared to stems staying supressed by dominant trees.

Keywords: Pre-commercial thinning, Stand development, Spatial distribution, Juvenile growth, Competition, Silviculture, *Pinus sylvestris*.

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Abbreviations

DBH	Diameter at breast height
H	Height
PCT	Pre-commercial thinning
GPS	Global Positioning System

1. Introduction

1.1 Characteristics of Scots Pine

Scots pine (*Pinus sylvestris* L., hereafter referred to as pine) is a conifer native to Fennoscandia, with a broad natural distribution. Its natural range spans from Western Europe (including Scotland, France, and Spain) across Eurasia to eastern Russia (Larsen et al., 2005, Figure 1). Pine grows across a wide range of sites and displays a relatively high tolerance to abiotic stress (Larsen et al., 2005). It occurs on diverse soil types, from nutrient-poor, dry sandy substrates to peat and shallow soils (Brichta et al., 2023; Spathelf & Ammer, 2023; Larsen et al., 2005). Pine is an early-successional species that typically regenerates well on open, disturbed sites, such as fire events and windthrow (Larsen et al., 2005; Spathelf & Ammer, 2023). During establishment, pine develops a deep taproot, which enhances drought tolerance in well-drained, coarse-textured soils. As the tree matures, resource uptake becomes increasingly dominated by lateral and fine roots, while the deep rooting system continues to play an important structural role in anchorage against wind damage and in buffering against drought (Praciak, 2013).

Pine is widely utilised across its range and is of major economic importance. Its timber is used for sawn wood and engineered wood products such as cross-laminated timber (CLT) and panelling, while lower-grade logs are used for pulpwood and bioenergy (Brichta et al., 2023).

Figure 1. Distribution of Scots pine (Pinus sylvestris L.). Green indicates the native range, while yellow indicates areas where the species has been introduced and naturalised (Caudullo, G., CC BY 4.0 (https://creativecommons.org/licenses/by/4.0), via Wikimedia Commons.

1.2 Pine in Sweden

In Sweden, forestry is governed by the Forestry Act, which sets multiple objectives, including timber production, provision of recreational values, and the conservation of biodiversity and ecosystem services (Swedish Forestry Act 1993:553; Felton et al., 2020). Swedish forests are dominated by pine 40.1 % of total volume, Norway spruce (*Picea abies* (L.) H. Karst.) 38.0 % of total volume and birch (*Betula spp*.) 13.2 % of total volume (SLU Riksskogstaxeringen, 2025). Sweden is one of the world's top exporters of pulp, paper and sawn timber, with export values of 185 billion SEK in 2024 and 184 billion SEK in 2023 (Swedish Forest Industries Federation, 2026).

Effective forest management has been essential for achieving the production goals, requiring managers to account for both production objectives and the environmental requirements of the Forestry Act to achieve the management objectives (Albrektson et al., 2012; Swedish Forestry Act 1993:553).

1.3 Forest management in Sweden

The predominant forest management system in Sweden is rotational clear felling, typically of either Norway spruce or Scots pine (Felton et al., 2018; SLU Riksskogstaxeringen, 2025). The rotation usually begins with the planting of nursery grown seedlings at a mechanically site prepped clear cut. Planting density of pine in Swedish production forestry varies depending on the site productivity, however the number of seedlings is usually 2000-3000 seedlings ha^{-1} (Pettersson et al., 2012; Skogsstyrelsen, 2025). The initial planting stock ensures sufficient seedling survival until the pre-commercial thinning (Pettersson et al., 2012).

Pre-commercial thinning (PCT) intends to regulate stand density and promote uniform development of tree height and diameter. There could be a need to adjust the number of stems ha^{-1} if natural regeneration increased the stand density above target levels, or if there is a need to remove wolf trees (Fahlvik, 2005). After the PCT, thinnings and final felling are carried out during which timber is extracted from the stand (Albrektson et al., 2012).

Selective PCT is the most established method in Sweden, meaning that the operator selects which stems to remove. The decision is based on individual stem characteristics and their spatial distribution within the stand (Fahlvik, 2005; Fällman, 2005; Södra, 2026). The operations are carried out using motor-manual brush saws (Fällman, 2005; Södra, 2026).

1.4 Pre-commercial thinning

In Scots pine plantations, early competition among seedlings is generally not the main limiting factor in the first years following planting. However, it increases as stand development progresses (Spathelf & Ammer, 2023) and it is during the juvenile phase that the greatest chance exists to influence the stand structure, composition and quality (Fahlvik, 2005). Recommendations from researchers to optimize the productivity of pine production, varies depending on the geographical location and site fertility. Stand density after pre-commercial thinning, are recommended to be 2000 stems ha^{-1} on low fertility sites, 2300 on medium fertility sites and 2500 on more fertile pine sites (Varmola & Salminen, 2004). The forest owners' association Södra provides similar advice, although slightly adjusted to 2200 stems ha^{-1} on low fertility sites, 2500 on the medium fertility sites and 2800 on the most fertile pine sites (Södra, 2026).

The juvenile phase hence forms the foundation for future stand development. Uniformity in tree height and diameter after PCT is desirable in forests managed for wood production, leading to higher production (Pettersson et al., 2012; Fahlvik, 2005). Stand density and height uniformity are also important factors influencing canopy closure, that often result in self-pruning of the pine stems (Praciak, 2013; Pettersson et al., 2012). This means that branches die off when being shaded by the upper canopy of surrounding trees, resulting in tree trunks free from live branches (Praciak, 2013). Although the timing of canopy closure is strongly site dependent, the competition can have a significant impact on growth, that ultimately leads to self-thinning. Besides self-pruning, browsing risk is also a considerable factor in management strategies, as pine is a preferred winter forage species for moose and roe deer (Kolstad et al., 2018). Therefore, silviculture must be adapted to account for both competition and browsing damage in stands managed for timber production (Fahlvik et al., 2018; Fahlvik, 2005; Ruha & Varmola, 1997).

1.5 Pre-commercial thinning strategies in Scots pine

Different strategies could be applied regarding PCT depending on the goals. Conventionally, in production forests, PCT is conducted ones or twice during the rotation period. This depends on whether the young plantations (mean height below 1.3m) require a release cutting, to reduce competition from spontaneous ingrowth of other species e.g. birch (Södra, 2026; Fahlvik, 2005). This first PCT is sometimes referred to as cleaning and is primarily used for increasing seedling survival.

PCT carried out at a mean height of 2-3 m is intended to increase stand stability and growth. However, it may also negatively affect stem wood quality (e.g., by promoting development of thick branches, increased stem taper, and lower wood density) (Pettersson et al., 2012; Huuskonen & Hynynen, 2006; Varmola & Salminen, 2004). Furthermore, it may increase the risk of browsing damage on remaining stems as well as reduce future selection possibilities (Fällman, 2005).

Delaying thinning until a mean stand height of 4-5 m rather than 2-3 m may improve overall timber quality. The delayed PCT, may decrease branch diameter, size of a living crown and stem diameter at breast height (DBH) (Ahnlund Ulvcrona, 2011; Pettersson et al., 2012). Upon canopy closure, most pine stands become structured by dominant stems and suppressed trees, as competition for light initially affects diameter growth more than height growth (Jäghagen & Albrektson, 1996; Nilsson & Albrektson, 1993). This was evident in a thinning experiment from The Svartberget Experimental Forest (ID 2182).[1] The experiment used heavy thinning from above and below in a pine stand, to study competition. The plots were thinned to either 300 or 600 stems ha^{-1}, retaining the largest or the smallest trees at plot level. By comparing the treatments with an equivalent number of trees from the unthinned control plots, the thinning response could be studied. The results showed a thinning response in the 300 largest trees being 24% and 4.5% for the 600 largest tress ha^{-1}. For the 300 smallest trees and 600 smallest trees, the corresponding responses was 293% and 190%, respectively.

In practical forestry, managers often allow pine stands to grow beyond the browsing window and reach heights of 4-6 m before PCT, with the aim of reducing browsing damage and maintaining high selection possibilities. However, this approach has not been tested scientifically (Bergquist, 2017; Pettersson et al., 2012). The drawbacks that come with postponing PCT's are increased labour cost compared to conventional approach with earlier PCT's (Ahnlund Ulvcrona, 2011). Nevertheless, despite the higher initial costs, PCT intends to increase DBH, which later lowers the costs of harvesting at first thinning (Södra, 2026; Karlsson, 2013).

[1] Urban Nilsson, Professor, Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences (SLU), lecture during field excursion to Svartberget Experimental Forest, 2023-09-20.

1.6 Thesis aim

The aim of this study was to evaluate the effects of heavy pre-commercial thinning from above and below, on growth in young Scots pine stands. By comparing retention of either the tallest- or the shortest trees with untinned control stands.

The hypothesises are:

1. Pre-commercial thinning treatments significantly affect stand growth compared with unthinned control plots.
2. The growth of larger trees is not significantly affected by competition from smaller trees.
3. The growth of smaller trees is significantly influenced by competition from larger trees.

2. Material & methods

2.1 Study site

The experiment was established in a five-year-old Scots pine plantation at the Remningstorp estate in southern Sweden (58.46° N, 13.64° E, elevation of 141 m.a.s.l). The previous stand was a pine dominated (80%) mixed species stand that was clear felled in 2013. The following year of 2014, 2-year-old seedlings of Scots pine were planted. The estate is located in the Götaland region, in-between lake Vänern and lake Vättern, see Figure 2.

The field layer was classified as thin-layered grass type, and the soil type was classified as podsol. Between the years 1990-2020 the average annual temperature was +4°C at the study site and during 2016-2025, the average annual rainfall was 661mm (SHMI 2026, SMHI 2026a). Weather data were collected at the Remningstorp weather station located approximately 2km from the experiment. The estimated site index was 28m, defined as the mean height of the 100 thickest trees at breast height at the reference age of 100 years (Hägglund & Lundmark, 1977).

Figure 2. Location of the experiment. Map from OpenStreetMap (https://www.openstreetmap.org/?mlat=58.46372&mlon=13.64026#map=15/58.46372/13.64026&layers=VN).

2.2 Experimental design

The experiment followed a complete randomized block design consisting of four blocks and three treatments per block, yielding a total of 12 experimental plots (Figure 3). Each plot measured 30x30m, with data collected from a central net plot measuring 20x20m. The treatments were: Control (no pre-commercial thinning), (Tall) thinning with retention of the 1000 tallest trees ha^{-1} and (Short) thinning with retention of the 1000 shortest trees ha^{-1}. The treatments were defined based on tree height, see Table 1.

Table 1. Data from measurements at revision 1 represent the initial values of the experiment for height and number of trees per hectare across all three treatments: Control (no pre-commercial thinning), thinning with retention of the 1000 tallest trees ha^{-1} (Tall), and thinning with retention of the 1000 shortest trees ha^{-1} (Short). Values are presented as mean ± standard error.

Treatment	Control		Tall		Short	
Block	Mean height	Nr of trees ha^{-1}	Mean height	Nr of trees ha^{-1}	Mean height	Nr of trees ha^{-1}
1	1.71	2125	1.67	1000	1.43	1000
2	1.57	1725	1.71	975	1.45	1000
3	1.55	2275	1.81	1000	1.46	1000
4	1.64	2025	1.67	1000	1.43	1000

Each tree was assigned a unique identification number that was maintained throughout the experiment, enabling repeated measurements over time for the individual trees. Prior to thinning, each plot was divided into four equal sections. The purpose was to ensure the uniformity of spatial distribution regarding retained trees.

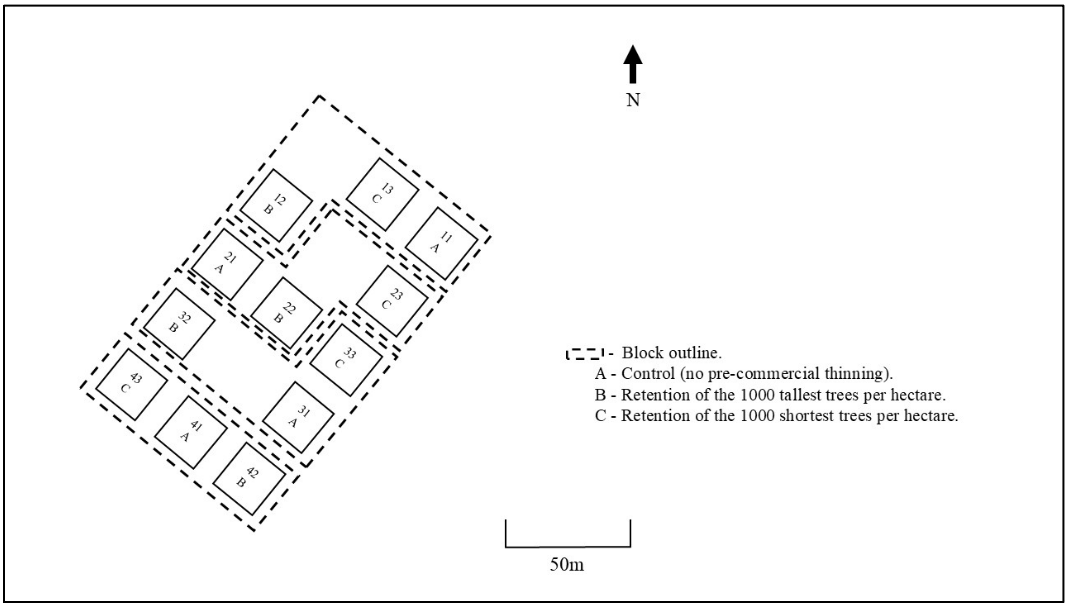

Figure 3. Schematic spatial distribution of the experiment. Plots are shown as black squares and identified by a two-digit code, where the first digit indicates the block number and the second digit indicates the treatment. Blocks are outlined with dashed lines. Each block contains one replicate of each treatment: control (A: no pre-commercial thinning), thinning with retention of the 1000 tallest trees ha^{-1} (B: Tall) and thinning with retention of the 1000 shortest trees ha^{-1} (C: Short). Squares represent gross plots (30 × 30 m), including a 5 m buffer zone.

2.3 Data collection

All the plots were inventoried during three revisions: 2019, 2022, and 2025. Diameter at breast height (DBH) was measured using a calliper at 1.3 m above ground level on all occasions except in 2019. Diameter growth was hence measured between 2022 and 2025. Tree height was measured in 2019 and 2022 using a wooden measuring stick (Table 1).

In addition, during the winter of 2026, Global Positioning System (GPS)-mapping of all trees within the experiment was conducted. An Emlid Reach RS3 GNSS receiver mounted on a survey pole was used in all plots, including buffer zones, to record data on spatial distribution of stems (see Figure 4). The purpose was to better visualize the spatial distribution of trees for the treatments, across the entire experiment (see Figure 5).

Figure 4. The Emlid Reach RS3 GNSS GPS- receiver in use during field work.

The GPS-receiver gave each tree an individual position throughout the experiment, that made it possible to visualise stand density and spatial distribution (Figure 5).

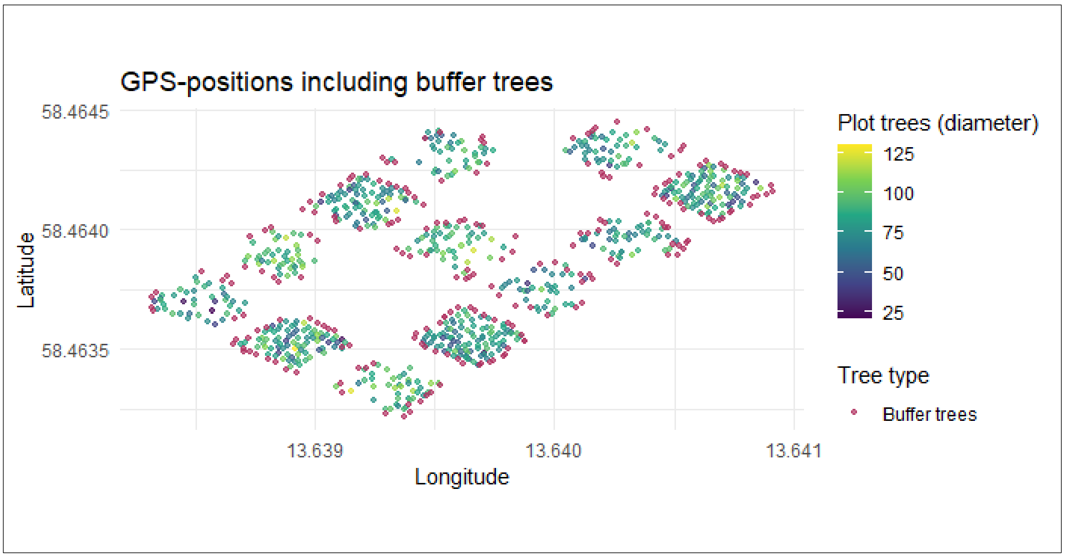

Figure 5. Spatial distribution of stems in the experiment. Global Positioning System (GPS)-positioned trees within the net plot (squares, 20 × 20 m) are coloured according to diameter (mm), as indicated in the legend. Trees located in the 5 m-wide buffer zone are shown in maroon.

2.4 Statistical analyses & calculations

The analyses were conducted in Microsoft Excel 365. Mean height (revision 1), mean height (revision 2), diameter (revision 2- revision 3), mean diameter (revision 3) and diameter growth (revision 2- revision 3), were analysed for each treatment. Treatment effects were assessed using analyses of variance (ANOVA). Mean height at revision 1, as well as mean diameter and diameter growth at revision 3, were analysed using analyses of variance (ANOVA) with a significance level of $p = 0.05$. Significant effects were further explored using Tukey's HSD post-hoc test for pairwise treatment comparisons.

In addition, a separate analysis was conducted to compare mean diameter at revision 3 and mean diameter growth between revision 2 and revision 3, using a subset of the data from the Control. The 1000 largest trees ha^{-1} in the Control (Control Tall), was compared to Tall. The 1000 smallest trees ha^{-1} in Control (Control Short), was compared to Short. The selection of the 1000 largest and smallest trees in Control respectively, was based on height measurements taken at revision 1.

The experiment was originally created as a randomized block design. However, early analysis demonstrated that the ANOVA for comparisons of general treatments, showed how block had low statistical effect. Therefore, block was excluded as a fixed effect and a one-way ANOVA was used to analyse the treatments as the only factor. There was a slight overlap in the data subset for the second block, that contained 69 trees. 80 trees or more was needed to avoid an overlap, making the current dataset containing the same trees within both groups with 11 trees, or 15.9%.

Lastly, the GPS-mapped data were visualised in R version 4.5.2 (R Core Team 2025), see Figure 5.

3. Results

3.1 Treatment effects

3.1.1 Revision 1

At the establishment of the experiment (2019), statistically significant differences in height were observed among the tested treatments after PCT (Table 2). Revealing that the three treatments differed at establishment. The Tukey HSD post-hoc test, showed that Control and Tall did not differentiate significantly in height. But that Tall differed from Short and that Control differed from Short.

3.1.2 Revision 2

The DBH at revision 2 was for Control 60.76 ± 1.53mm, Tall 68.73 ± 2.51mm and Short 54.41 ± 1.14 mm.

Table 2. Data from the revision 1 are presented as block means for height (m) ± standard error. Statistical significance was set at $p \leq 0.05$.

Revision 1			
Treatment	Height (m)	SE	P-value
Control	1.62	±0.04	
Tall	1.71	±0.03	
Short	1.44	±0.01	
ANOVA			**0.004172**
Tukey HSD	Control – Tall		0.196018
Tukey HSD	Control – Short		**0.028573**
Tukey HSD	Tall – Short		**0.003585**

3.1.3 Revision 3 - General comparison of treatments

At revision 3, mean stem diameter ANOVA showed statistically significant difference among treatments (p = **0.01109628**). Control had a mean diameter of 80.37 ± 0.88mm, Tall 91.35 ± 2.71mm and Short 76.92 ± 1.87mm. The post-hoc Tukey HSD tests showed that Tall was significantly different from Control (p = **0.036301661**) however, no significance was found between Control and Short (Figure 6; Appendix 1).

Mean diameter growth between revision 2 and revision 3 did not show any statistically significant differences among treatments. The diameter growth for Control was 18.93 ± 1.08mm, Tall 22.61 ± 0.74mm and for Short 22.32 ± 1.49mm. The post-hoc Tukey HSD tests confirmed that no pairwise differences were present (Appendix 1).

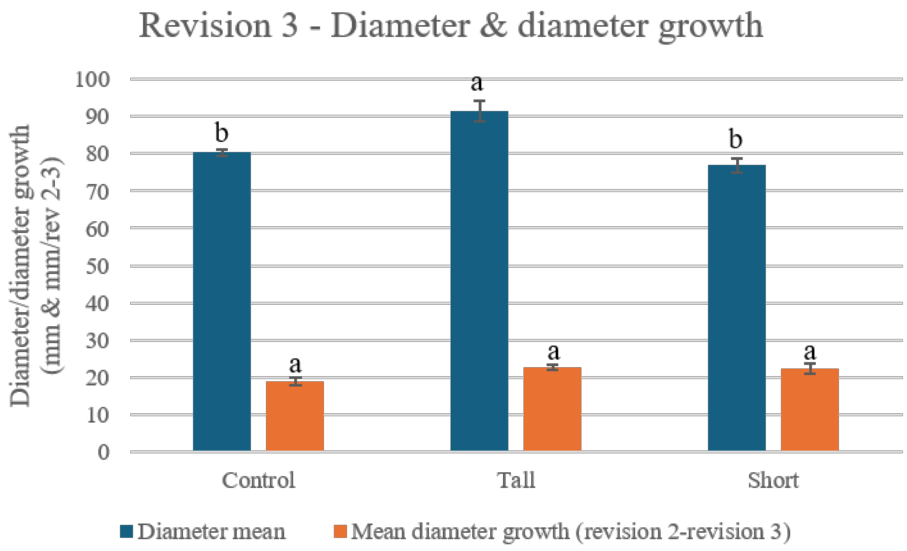

Figure 6. Mean diameter (mm) at revision 3 and mean diameter growth (mm) between revision 2 - revision 3 in the respective treatments: Control (no pre-commercial thinning), thinning with retention of the 1000 tallest trees ha^{-1} (Tall), and thinning with retention of the 1000 shortest trees ha^{-1} (Short). Error bars represent standard errors of the mean. Letters above the bars indicate statistically significant differences among treatments. Statistical significance was obtained at $p \leq 0.05$.

3.1.4 Revision 3 - Comparison using a subset of the data from Control

The analyses revealed no statistically significant differences in either diameter or diameter growth between Control Tall and Tall, respectively (Table 3).

Table 3. Comparison using a subset of the data from Control Tall, containing only the 1000 tallest trees ha^{-1} compared to Treatment B. The values of diameter (mm) ±standard error (SE) and diameter growth (mm between revision 2-3) ±standard error (SE). Statistical significance was obtained at $p \leq 0.05$. Statistical significance was obtained at $p \leq 0.05$.

	Revision 3					
Treatment	Diameter	SE	P-value	Diameter Growth (Revision 2-3)	SE	P-value
Control Tall	86.95	±0.91		19.69	±1.12	
Tall	91.35	±2.71		22.61	±0.74	
ANOVA			0.175187			0.072088579

However, trees in the Short treatment had a statistically significant higher mean diameter and mean diameter growth, compared with the corresponding subset of the Control Short data (Table 4).

Table 4. Comparison using a subset of the data from Control (Control Short), that contained only the 1000 shortest trees ha^{-1} compared to Treatment C. The values of diameter (mm) ±standard error (SE) and diameter growth (mm between revision 2-3) ±standard error (SE). Statistical significance was obtained at $\alpha \leq 0.05$. Statistical significance was obtained at $p \leq 0.05$.

	Revision 3					
Treatment	Diameter	SE	P-value	Diameter Growth (2022-2025)	SE	P-value
Control Short	71.10	±0.51		17.53	±1.12	
Short	76.92	±1.87		22.32	±1.49	
ANOVA			**0.024047**			**0.042061626**

4. Discussion

4.1 General development of the experiment

At the establishment of the experiment 2019, immediately after treatment application, statistically significant differences in height were observed among treatments. The results indicate that the PCT treatments successfully created distinct stand structures, particularly distinguishing Short from the other treatments.

At revision 3, when comparing Control to Tall and Short, statistically significant differences were observed regarding the mean DBH. The structure was still distinct, however shifted towards Tall being particularly distinguished from the rest of the treatments, in terms of largest DBH. This was not unexpected due to that treatment Tall, completely lacked supressed trees with smaller DBH, after the heavy PCT from below. Mean diameter growth was however not different between the treatments and Control, when the entire dataset from Control was used in the comparison.

4.2 Mean diameter & diameter growth using a subset of data from Control

When sharing the same stem density (ha^{-1}), the comparison between Control Tall and Tall showed no statistically significant difference between them. Indicating that resources or competition, did not appear to be a limiting factor for dominant trees at Remningstorp, with site index 28. Control Short was however affected by the competition, resulting in an increase of both DBH and diameter growth, upon release from a heavy PCT from above. This corresponds with Jäghagen & Albrektson (1996), saying that exposure to competition for light, alters the tree morphology and impacts diameter growth more than height growth. Meaning, that when the supressed trees did not have to fight for light, they started to develop both DBH and diameter growth more than when being supressed. Additionally, the findings from this study are consistent with the result from the experiment at Svartberget Experimental Forest. Both experiments presenting that dominant trees are relatively unaffected by competition from below at stand level. However, upon release from competition from bigger trees, smaller trees increased growth significantly.

4.3 Practical application of the findings

The experiment showed that at stand densities of 2000 stems ha^{-1}, PCT was not necessary for successful development of future crop trees at site index 28. There was little to no competition from natural regeneration at the study site, and planting density followed typical Swedish production forestry standards. This suggests that under local conditions, PCT may act as a cost with limited future stand development as an outcome, under the assumption that the Control reflects a conventional pine production stand. Additionally, the observed benefits of PCT following a heavy thinning from above are generally not considered a rational silvicultural practice, since crop trees tend to be selected from the dominant trees in the stand, having larger DBH (Fahlvik, 2005). Consistent with this, Control Tall performed similarly to Tall in mean DBH, indicating that reducing the number of stems ha^{-1} to Tall-levels, gave no major advantages regarding development of larger DBH. Doing heavy PCT from above affects the timber yield by removing future crop trees and is suboptimal since a share of planted seedlings would be removed without generating economic return.

According to Fahlvik (2005), main stems should be carefully selected first in PCT, followed by secondary stems, with the aim of reaching an even crown canopy and spatial distribution. When selecting secondary stems, consideration should be given to whether supressed trees would benefit from a release from competition. The results of this study suggest that PCT efforts could instead be directed towards clusters of suppressed trees, since smaller diameter trees demonstrated a distinct growth response upon release from competition. By targeting these groups, more stems may develop into future crop trees. Improving resource- and management efficiency in PCT operations, of juvenile pine stands.

Larger-diameter trees reduce harvesting costs per stem during first thinning, making the harvested stems often yielding a greater volume (Södra, 2026; Fällman, 2005; Fahlvik, 2005). This would improve the profitability of forest management.

4.4 Suggestions for future research & limitations of the study

The experiment at Remningstorp was pre-commercially thinned when the stand was five years old, with a dominant height of 1.7 m and approximately 2000 stems ha^{-1}. This is slightly earlier than the recommended timing of PCT, which is when stands reach at least 2 m in height (Fahlvik, 2005; Fällman, 2005).

However, the experimental site was fenced, reducing the risk of browsing damage.

The intention was to get an even spatial distribution by dividing the plots into four equal shares. However, impediments made gaps in the distribution of trees, that may have affected the results.

According to management guidelines, the stand density was lower at Remningstorp than recommended, instead suggesting approximately 2800 stems ha^{-1} (Pettersson et al., 2012; Varmola & Salminen, 2004; Södra, 2026). This could be considered if replicating the experiment in the future. Further, the lack of not having more replications of the experiments at additional sites in Sweden is also a limitation. To expand the use of the findings, it could be valuable to conduct the experiment in other locations in the country, such as Northern Sweden.

5. Conclusion

In this study, an experiment was studied to determine whether competition from tall or short trees affects the mean diameter and diameter growth, by doing heavy pre-commercial thinning from above or below. Treatments were made including either only the 1000 tallest trees ha^{-1}, or the 1000 shortest trees ha^{-1}. The two treatments were compared to a subset of data from control plots to make a fair comparison with an equal number of stems per hectare.

The results showed that neither mean diameter nor diameter growth was affected by a heavy PCT from below, excluding competition from supressed trees. However, when heavy PCT from above was conducted, the response on supressed trees showed that they developed both larger DBH and mean diameter growth compared to Control.

The study could provide knowledge on how the variation in stem selection at PCT, affects tree growth of pine. The outcomes from PCT affects both thinnings and final felling. To determine the long-term effects of the treatments in this study, further research is needed.

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Popular science summary

In Sweden, the typical forest rotation consists of regeneration, pre-commercial thinning, thinnings and lastly final felling. This system has been the dominating practice since the 1950s and is the time during the rotation, at which the forester can affect the stand dynamics the easiest. Pre-commercial thinning is, however, a cost for forest owners, which must later be offset by income from subsequent thinnings and final felling. With that in mind, it is financially beneficial to achieve as much positive stand development as possible with as little costly labour as possible. But to come to a sound strategy of how the stand will react, research must be carried out to test the response of the thinning operations.

In this thesis, diameter was measured to see how different release cuttings from pre-commercial thinning influenced the development. To properly test this, an experiment was established in Remningstorp, Västra Götaland. Containing a randomized complete block design with four blocks, each block included three treatments, with one plot assigned to each treatment. The treatments were: Control (no pre-commercial thinning, (Tall) thinning with retention of the 1000 tallest trees ha^{-1} and (Short) thinning with retention of the 1000 shortest trees ha^{-1}. The treatments were categorized based on tree height.

By using subsets of data from Control corresponding to 1000 stems ha^{-1}, comparisons could be made directly to the treatments with either the 1000 tallest trees ha^{-1} (Tall) or the 1000 shortest trees ha^{-1} (Short). This ensured that only the representative trees were used in the analysis. The results showed that at stem densities of roughly 2000 stems ha^{-1}, taller trees are unaffected by competition from shorter trees. However, shorter trees are favoured if being released from competition of taller trees, which results in larger mean diameter and larger mean diameter growth.

The results indicate that focus in pre-commercial thinning, could be shifted towards the suppressed trees. By allocating time and resources to releasing only secondary stems during pre-commercial thinning, operational costs should be lowered. Meanwhile more trees per hectare may have the opportunity to develop into larger trees at the time of first thinning.

6. Appendix 1.

Mean diameter and diameter growth (mm) in the third revision in the following treatments: control (no pre-commercial thinning), thinning with retention of the 1000 tallest trees ha⁻¹ (Tall), and thinning with retention of the 1000 shortest trees ha⁻¹ (Short). Data are presented as mean ± standard error (SE). Statistical significance was determined at $p \leq 0.05$.

	Revision 3					
Treatment	Diameter	SE	P-value	Diameter Growth (Revision 2-3)	SE	P-value
Control	80.37	±0.88		18.93	±1.08	
Tall	91.35	±2.71		22.61	±0.74	
Short	76.92	±1.87		22.32	±1.49	
ANOVA			**0.01109628**			0.154436003
Tukey HSD	Control – Tall		**0.036301661**			0.181699
Tukey HSD	Control – Short		0.578100088			0.222702875
Tukey HSD	Tall – Short		**0.011105198**			0.985720496

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