



Regeneration of Norway spruce in conversion forest management

Analysing natural regeneration in the conversion
phase from a single layered to a multi-layered
forest structure

Kerstin Fersters



Independent project • 15 credits
Swedish University of Agricultural Sciences, SLU
Southern Swedish Forest Research Centre
Forest and Landscape
Alnarp 2025

Regeneration of Norway spruce in conversion forest management. Analysing natural regeneration in the conversion phase from a single-layered to a multi-layered forest structure

Föryngring av gran i omställningsbestånd. Analys av naturlig föryngring i omställningsfasen från enskiktad till flerskiktad skog.

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Credits:	15
Level:	First cycle, G2E
Course title:	Independent project in Forestry science
Course code:	EX1012
Programme/education:	Forest and Landscape
Course coordinating dept:	Southern Swedish Forest Research Centre
Place of publication:	Alnarp
Year of publication:	2025
Cover picture:	Natural regeneration of Norway spruce in Hästhagen (Photo: Kerstin Fersters)
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Keywords:	Continuous cover forestry, Forest conversion, Norway spruce, Natural regeneration, Selective cutting, Multi-layered forest, Thinning strategies

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Abstract

Swedish forestry is dominated by even-aged, single-layered stands managed through the clear-cut system, a practice that has increased timber yields but also led to the decline of complex forest structures and associated biodiversity. Alternative management methods are being promoted which implies conversion of a large proportion even-aged Norway spruce (*Picea abies*) stands to multi-layered structures. However, practical knowledge about effective conversion methods is scarce.

This thesis investigates how different thinning strategies, site preparation and fertilization affect natural regeneration during the early phase of converting even-aged Norway spruce stands to multi-layered forests. The study is based on a unique long-term field experiment established at four sites in Sweden, with two sites in the north (Jämtland) and two in the south (Småland). Regeneration was assessed in relation to treatment and site conditions, with focus on seedling abundance, species composition, and ground vegetation.

Results show that heavy thinning was the only treatment that consistently stimulated regeneration, significantly increasing seedling numbers compared to untreated controls. Other treatments, such as different thinning strategies, fertilization, and site preparation, had little or no effect on overall seedling establishment. Regeneration was significantly higher at the northern sites than at the southern sites, a difference that is more likely influenced by site specific factors such as stand age, soil moisture, soil fertility and seed production dynamics. One of the sites showed little or no regeneration regardless of treatment.

The findings highlight the complexity of regeneration dynamics in conversion management and suggest that successful transformation to multi-layered Norway spruce stands depends not so much on silvicultural treatments but rather on a combination of site-specific factors. More long-term field experiments are needed to learn about these factors.

Keywords: Continuous cover forestry, Forest conversion, Norway spruce, Natural regeneration, Selective cutting, Multi-layered forest, Thinning strategies

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1. Introduction

Sweden is a country dominated by boreal forests with a tradition of intense forest management. Out of the total land area of Sweden, 68 % is forest land and 58% (23,5 million hectare) is productive forest land (Riksskogstaxeringen, 2024) (Fig. 1). The predominant silvicultural system in Sweden is clear-cut forestry. This method became widespread in the mid-20th century and has grown to become the dominant approach, with only 3-4 % of the productive forest area being managed differently (Skogsstyrelsen, 2025c). As a result, annual harvests and economical yield has almost doubled since the 1950s (Riksskogstaxeringen, 2024) but it has also resulted in loss and degradation of important habitats in these ecosystems (Naturvårdsverket, 2023) as complex forest structures has undergone a radical change to single-layered, even-aged cohorts that clear-cut forestry creates (Ekholm et al, 2023).

Composition of Swedish land area

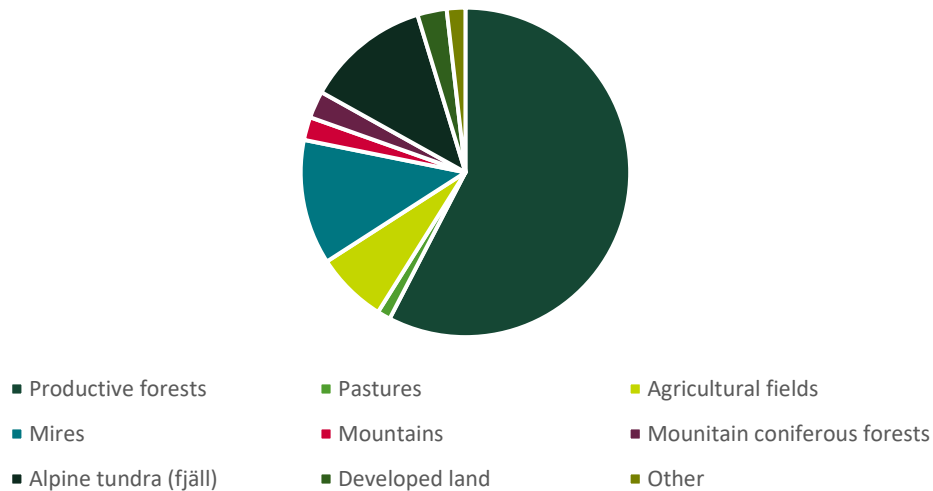


Figure 1: Distribution of major land areas. Source: Riksskogstaxeringen 2024

1.1 Clear-cut forestry in Sweden

1.1.1 History

Before the adoption of clear-cut forestry, Swedish forests were managed primarily through some form of selective cutting, with the basic idea of removing the largest trees, or trees with specific qualities (Ekholm et al, 2023) from a forest that contains all age classes and sizes. These systems need to balance the outtake of

trees to provide conditions for younger trees to grow and seedlings to establish, keeping the forest structure relatively intact. Clear-cut forestry on the other hand, is a cyclic system that undergoes distinct phases from regeneration, typically by planting, pre-commercial thinning (PCT), a few commercial thinnings and clear-felling at the end of the rotation after which this procedure is repeated. This management system produces even-aged stands, with trees of more or less the same size.

The shift to clear-cut forestry was a response to unsustainable harvesting rates in the late 19th and early 20th centuries, which left behind forests that regenerated poorly (Goude et al, 2022). Clear-cut forestry was introduced to increase productivity and has been seen as a more reliable system (Ekholm et al, 2023). As a result, annual harvests have increased from 51 million m³ to 92 million m³ since the 1950s and economic yield has grown in equal proportion (Riksskogstaxeringen, 2024).

1.1.2 Biodiversity issues

The widespread implementation of clear-cut forestry has transformed the forest landscape into a less complex structure, with negative consequences for many species that depend on continuity in the landscape, old trees, and large amounts of dead wood (Ekholm et al, 2023).

Today, forest-dwelling species are the most threatened group of organisms in Sweden due to several factors. The most important factor is the lack of continuity in forests, meaning forests that maintain their structure, followed by the lack of large and old trees, the disturbance from site preparation in the establishment phase of clear-cutting, and the lack of dead wood in these ecosystems (Artdatabanken, 2026)

Efforts are being made to reduce the negative impacts on forest biodiversity within the clear-cut system, including leaving dead wood after clear-felling, maintaining buffer zones along water bodies, minimizing ground disturbance from harvesters, and retaining deciduous trees after harvest (Skogsstyrelsen, 2025b). However, the critical situation for endangered species in forest ecosystems is not improving but rather getting worse (Artdatabanken, 2026).

A recent report by Skogsstyrelsen on the effects of alternative forest management methods on biodiversity shows that most forest-dwelling species would benefit from systems other than clear-cutting (Skogsstyrelsen, 2025a).

1.2 Demand for alternative silvicultural systems

A change in forest policies over the last years can be seen on several levels in society in favour of alternatives to the clear-cut forestry. The EU forest strategy from 2021 states that clear-cut forestry should only be practiced “...in duly justified cases” (EU, 2021). Södra Skogsägarna, Sweden’s largest forest-owner cooperative with over 50,000 members, is now providing training in alternative forestry methods to all its field staff, responding to growing interest among its members (Södra, 2023). The Church of Sweden, the country’s fifth largest forest owner, recently conducted an extensive review of its forest management practices. As a result, it is moving away from traditional clear-cut forestry on a significant portion of its holdings (Svenska Kyrkan, 2024).

These decisions to move away from the clear-cut system in Sweden implies that large-scale conversion of even-aged stands into multi-layered forests will be necessary since the majority of Swedish forests have already been clearcut at some point and are currently managed under the principles of clear-cut forestry.

1.3 Continuous cover forestry

1.3.1 Terminology and definitions

Continuous cover forestry (CCF) is an umbrella term for several silvicultural systems that involves maintaining a more or less dense tree canopy at all times. In the discussion about mitigating the negative effects of clear-cut forestry, CCF has been suggested as a solution to some of the biodiversity issues related to clear-cut forestry. In Sweden, the term *clear cut free forestry* is widely used for describing these methods.

The Swedish Forest Agency (SFA) defines clear cut free forestry as such:

“Non-clearcut forestry on forest land intended for wood production implies that the forest is managed in such a way that the land always has a tree cover, without any larger clear-cut areas.” (Skogsstyrelsen, 2021)

The maximum size for a clear cut in the definition from SFA is 0,25 hectares and the forest stand must always have trees above 10 meters present. Further explanations and definitions are thoroughly listed in the SFA report from 2021 (Skogsstyrelsen, 2021).

Examples of management systems that fall under the CCF umbrella are gap cutting, target diameter cutting, shelterwood systems and selective cutting.

- **Gap cutting:** Involves creating canopy openings (of maximum 0,25 ha) to allow light into the stand and stimulate natural regeneration. This method creates a patchy structure in the stand, with several age classes represented.
- **Shelterwood systems:** Establishes a two-storied canopy by leaving a sparse overstory after heavy thinning, which creates a favorable microclimate for seedling establishment beneath. Final removal of the older trees occurs once the new generation has reached a certain height, maintaining continuous forest cover throughout the regeneration cycle. This method creates a diameter distribution as seen in Figure 2B.
- **Selective cutting or target diameter cutting:** Involves harvesting individual trees based on specific criteria such as diameter or quality. This system depends on a multi-layered forest structure, with continual seedling ingrowth being essential. As mature trees are removed, younger trees fill their place, maintaining a relatively stable and diverse forest structure. Target diameter cutting specifically focuses on harvesting trees once they reach a predetermined diameter. The ideal diameter distribution in these stands will resemble an inverted J-curve (Fig 2C)

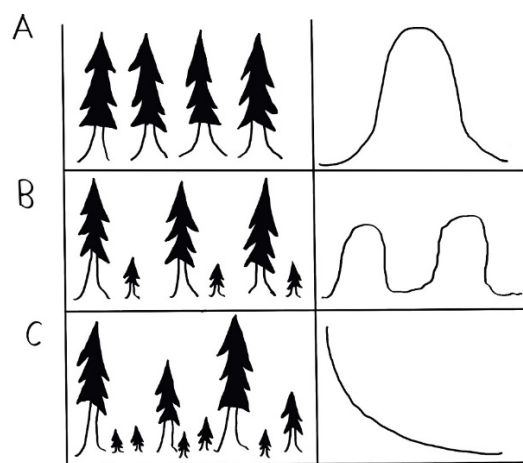


Figure 2: Conceptual sketch of diameter distribution curves for different management systems. The horizontal axis represents the diameter of stems in the stand and the vertical axis represents the number of stems. A= clear-cut forestry. B=shelterwood system C= selection cutting or target diameter cutting.

In uneven-aged management there is no rotation period or specific regeneration phase as in traditional clear-cut forestry. The idea is that new trees establish themselves each year, and harvesting is adjusted so that, in the long term, it balances the regeneration and growth within the stand (Hannerz et al, 2017).

In systems like selective cutting, where forests contain trees of all age classes, the optimal structural composition is often described by a diameter distribution of an inverse-J curve (Fig 2C). In these systems, the success is considered to depend on the constant ingrowth of seedlings that are and ready to grow and fill in the gaps created as the larger trees are removed. This ongoing regeneration is crucial for maintaining sustainable timber production (Vítková et al, 2014). These systems require active management and planning, just as other silvicultural systems do.

1.3.2 Opportunities for CCF in Sweden

In Sweden, the dominant tree species used in forestry are Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), and silver birch (*Betula pendula*) (Fig. 3). These species occupy different ecological niches, which makes them more suited for certain CCF methods and less suited for others. Scots pine and silver birch are pioneer species. These are fast to establish on open sites but not very shade-tolerant, requiring open conditions for successful regeneration. For these species, shelterwood systems or gap cutting are most suitable (Ahlström, 2016).

Norway spruce, on the other hand, is considered a secondary species. It is slower to establish but more shade-tolerant, allowing it to regenerate and grow under an existing canopy. This characteristic makes Norway spruce particularly well-suited to CCF methods like selective cutting or target diameter cutting, where the goal is to maintain a multi-layered forest structure with all age classes present (Ahlström, 2016). Selective cutting is the method that is being pointed out as the most beneficial for forest-dwelling species (Skogsstyrelsen, 2025a)

This study will focus on Norway spruce in the context of selective cutting.

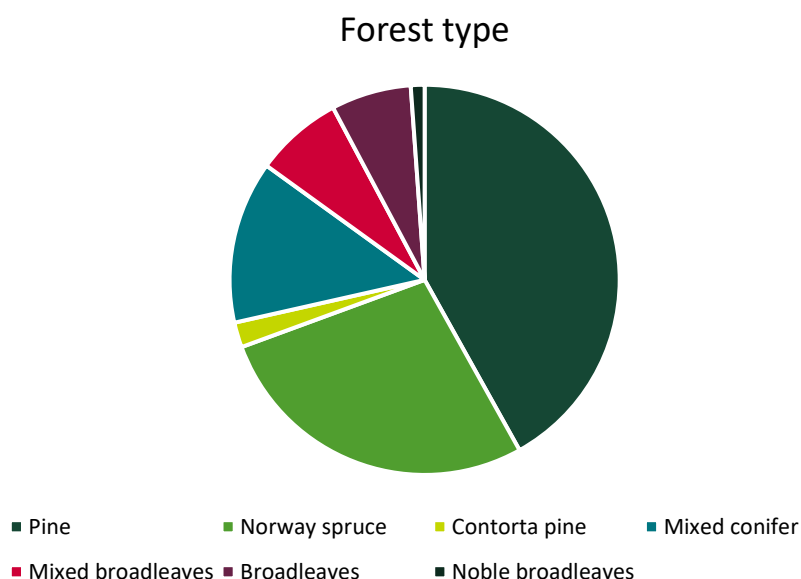


Figure 3: Composition of productive forest land in Sweden. Monoculture Norway spruce stands make up 26.5 % of the total area. Source: SLU Riksskogstaxeringen 2024

1.4 Conversion forestry management

1.4.1 Challenges and opportunities for conversion of Norway spruce

Converting even-aged Norway spruce stands into a multi-layered structure is aiming at creating a diverse diameter distribution that follows the inverted J-curve where the stand contains all age classes. The most suggested method for initiating this transformation is through heavy thinning, which allows more light to reach the forest floor and thereby promotes the ingrowth of seedlings. The process raises fundamental questions, such as when during the rotation it is most appropriate to begin such a transformation, which sites are more likely to be successfully converted, and how to determine when a conversion can be considered “complete” or successful (Vítková et al, 2014).

The timing of a conversion thinning must consider the age of the trees. Norway spruce begins producing seeds at around 30 years of age, with a peak seed production between 50 and 60 years (Vítková et al, 2014). While it is important that trees are mature enough to produce seeds in the conversion process, conducting a thinning later in the rotation also increases the risk of windthrow. Due to the shallow root system of Norway spruce, older trees that lose the wind shelter from neighbouring trees become increasingly vulnerable to wind damage. Thinning early in the rotation process will give the trees a better chance to stabilize but might not produce a sufficient amount of seeds.

The intensity and style of thinning during conversion is a subject of research, not only in relation to wind damage but also regarding other ecological factors. On some sites, increased light availability may lead to competition from ground vegetation, which can become problematic if too much light reaches the forest floor. Another risk is that the next generation of seedlings may become too abundant, forming a dense second canopy that inhibits further regeneration beneath it. This could result in a two-layered forest structure (Fig 2B), rather than the intended multi-layered forest with all age classes represented.

Norway spruce undergoes mast years, during which it produces a large quantity of seeds, but these events are hard to predict. If mast years could be predicted, thinning and soil scarification could be timed accordingly to facilitate for seedlings to establish. However, this approach also carries the risk of creating a two-layered structure instead of a truly multi-layered one.

In addition to timing, the specific conditions of the site are considered important for the outcome of the conversion attempt. Some sites are easier to assess than others. Very windy sites are likely to entail higher risks of economic loss due to storm damage. Wet and fertile sites promote the growth of Norway spruce seedlings but comes with a higher risk of windthrow because wet soils are less stable. Sites that are more difficult to judge can be those with medium fertility and a thick humus layer. Water availability is a factor that apart from soil moisture and groundwater levels, can also refer to precipitation or air humidity (Appelqvist et al, 2021).

1.4.2 Conversion experiments and studies

As a result of the long tradition and domination of clear-cut forestry in Sweden, research on alternative silvicultural systems is scarce. Out of 4000 long-term field experiments in the country, 140 of them are about CCF methods and the majority of them are established after the 1980s (Goude et al, 2022) which in terms of forestry is a relatively short perspective. Only one of these experiments deals specifically with the issue of converting a forest stand from even aged to uneven aged management.

A number of simulation studies on the conversion phase has been conducted to gain insight into different aspects of conversion forest management and try to answer some of the questions of how economy is affected and what treatments could stimulate regeneration (Fahlvik et al, 2024) (Ekholm et al, 2023) (Hanewinkel et al, 2000).

Most studies conclude that it is hard to deliver any “one size fits all” guidelines to forest managers, based on the scarce experiments that exists. Therefore, uncertainty and risk of failure must be weighed in when attempting to make a conversion. A study by Fahlvik et al, 2024 based on the long-term conversion experiment mentioned above, simulated different scenarios where conversion management was started and abandoned at different stages in a rotation of Norway spruce. The study concluded that attempting a conversion does not have to come with any greater economical risk since the management can easily be converted back and clear-felled if it shows little potential.

In attempting conversion from single layered to multi-layered forest, studies have identified the regeneration as the key factor that will determine the success of the conversion (Hanewinkel et al, 2001)

1.5 Aim of study and hypothesis

This study is interested in how regeneration is affected by different thinning methods and treatments conducted in a long-term field experiment on conversion of even aged Norway spruce.

The experiment that the study has focused on is the only long-term field experiment in Sweden about the process of conversion of Norway spruce.

The aim of this study is to compare how different thinning strategies, site preparation and fertilization have affected the regeneration in the sites, using the following research questions:

- *Does heavy thinning stimulate regeneration and has different thinning strategies had any effect?*
- *Is it possible to say if the experiments are successful or not in creating a multi-layered structure?*

The main hypothesis is that a heavy thinning will stimulate regeneration in a Norway spruce stand. A second hypothesis is that different thinning strategies and treatments will not have a significant effect on regeneration.

2. Materials and Methods

2.1 Description of study sites

The sites investigated in this study are part of a research project called “*Omföring till flerskiktad skog*” (Conversion to multi-layered forest), which was established between 2010 and 2013. Four sites in different parts of Sweden have been thinned and subjected to different treatments in an attempt to convert the forest to a multi-layered structure. Two of the sites were located in Jämtland (1511 Halåsen and 1512 Mordviksbodarna), while the other two are found in Småland (1513 Moboda and 1514 Hästhagen) (Fig 4). The purpose of this experimental series was to study how management practices can influence the stratification of middle-aged, homogeneous Norway spruce stands.

At each of the four sites, several 50×50 meter plots were assigned to different thinning strategies and treatments (see complete list of plots and treatments in appendix), while one or more plots at each site were left as untreated controls. Across all sites, the basal area was reduced by 60% using three distinct thinning approaches: (1) thinning to maintain the full range of diameter classes by removing trees from the most common diameter classes (Fig. 5A); (2) thinning to create a more uniform diameter distribution by removing both the largest and smallest trees (Fig 5B); and (3) uneven thinning, where the diameter



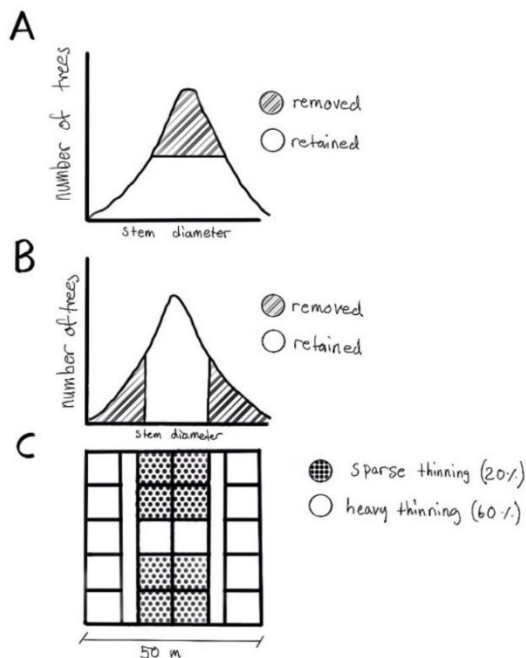
Figure 4: Location of the study sites.

Table 1: Compilation of site data.

	Halåsen (1511)	Mordviksbodarna (1512)	Moboda (1513)	Hästhagen (1514)
Age of trees (at experiment establishment)	45	41	29	28
Site index	G24-G27	G24-G27	G34	G31-G41
Soil moisture class	Moist	Mesic	Mesic/Moist	Mesic
Number of plots	7	17	9	13
Region	Jämtland	Jämtland	Småland	Småland
Year of establishment	2010	2010	2011	2013

distribution was retained but thinning was conducted in sections, leaving some areas more open than others (Fig 5C). In addition, certain plots received fertilization and mechanical site preparation.

During a review of the experiment in 2022, it was decided that the design of



the southern sites (Moboda and Hästhagen) should be modified, as these locations did not deliver any regeneration at all after around 10 years. It was decided to proceed with a second thinning at these sites, using two different strategies across the plots: one that removes 50% of the basal area and another with a 25% reduction. As of this writing, only the plots at site Hästhagen had undergone the second thinning, which was carried out in autumn 2023. Moboda was still only thinned once.

Figure 5: Conceptual sketch of the different thinning strategies conducted in the experiment "Omföring till flerskiktad skog). Thinning strategy A= retain diameter distribution, B= limit diameter distribution and C= retain diameter distribution but thinning is conducted unevenly across the stand.

2.2 Inventory design

A plant and ground vegetation inventory was conducted at the southern sites in March 2025. Within each 50×50 m plot, two diagonal transects were established—one oriented north–south and the other east–west. Along each transect, circular subplots (10 m^2 each) were systematically placed at ten-meter intervals (see figure 6), resulting in 13 subplots per plot and a total of 260 subplots surveyed across both sites.

Within each circular subplot, all seedlings were counted and classified by species (Norway spruce, birch, other broadleaves and Scots pine) and height class (10–19 cm, 20–49 cm, and 50–130 cm). Each subplot was further divided into quarters, and ground vegetation cover in each quarter was visually estimated by type (grass, shrubs, heather, and wild raspberry) using cover classes of 0–5%, 5–25%, 25–50%, and 50–100%.

The following tools were used during data collection:

- Two 50 m measuring tapes for laying out transects
- A 1.785 m stick to measure subplot radii
- Folding rule for measuring seedling height
- Compass for orientation along transects
- Pen and paper for field notes

A similar plant inventory was conducted in 2022 at the northern sites where data was collected from 20 circular plots (radius 1.785 m) within each 50×50 m plot. The same height classes and species categories were used as in the inventory of the southern sites; however, ground vegetation data were not collected at these locations.

Data from both inventories were subsequently organized in Excel and analyzed in R Studio. Mean seedling densities per hectare, treatment, and site were calculated based on these two inventories, and the percentage of ground vegetation cover was calculated based on the 2025 inventory.

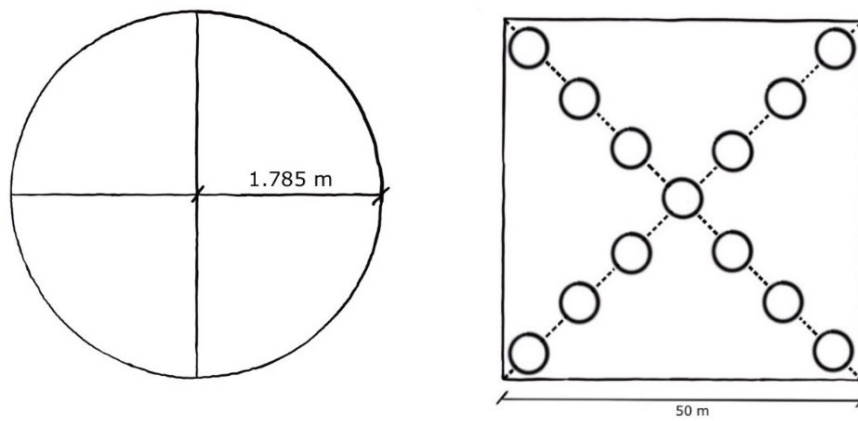


Figure 6: Schematic overview of the plant inventory method. Left: 10 m² circular subplot divided into quarters for visual ground cover assessment. Right: Layout of the 50 × 50 m main plot, showing the arrangement of 13 subplots established along diagonal transects.

3. Results

3.1 Seedling numbers

Seedling number varied considerably between plots and sites (see Fig. 7). The plot with the highest seedling number was plot 17 in 1512 Mordviksbodarna with 17 700 seedlings/ha and the lowest numbers were found in 1513 Moboda where five out of nine plots lacked seedlings completely. The most notable difference was observed between seedling numbers in the northern sites (1511 Halåsen and 1512 Mordviksbodarna) and the southern sites (1513 Moboda and 1514 Hästhagen). The average number of seedlings in all the thinned plots in Halåsen was 8150 for all species, 4690 for Mordviksbodarna, 58 in Moboda and 1769 in Hästhagen (Table 2).

Table 2: Average seedling numbers from thinned and unthinned plots of all sites per hectare.

	Seedlings all species (thinned plots)	Norway spruce (thinned plots)	Control (all species)	Control (Norway spruce)
Halåsen	8150	1350	2300	1150
Mordviksbodarna	4690	947	1400	125
Moboda	58	0	0	0
Hästhagen	1769	595	38	0

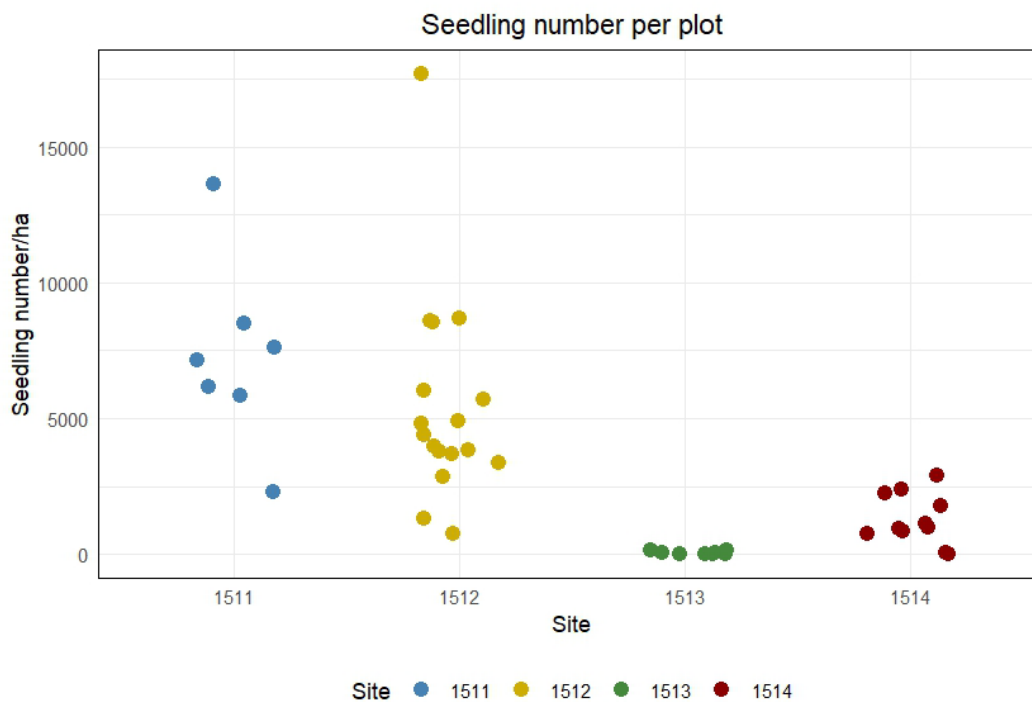


Figure 7: Total seedling number of each plot inventoried. Each point represents a plot.

The seedling abundance across different thinning strategies showed no consistent pattern when analysed by treatment type (Fig. 8). The numerical differences that were observed between strategies (e.g., "Retain uneven" vs. "Limit"), were not statistically significant. However, a two-way ANOVA showed two statistically verified findings (Table 3). First that a heavy thinning (grouped treatments) significantly increased seedling numbers compared to unthinned controls ($p = 0.0049$), explaining 35% of the observed variance in regeneration. Secondly, site differences accounted for 45% of variance ($p = 0.0077$), exceeding the thinning effect in magnitude. This analysis excluded Moboda due to a complete lack of regeneration, which skewed variance estimates.

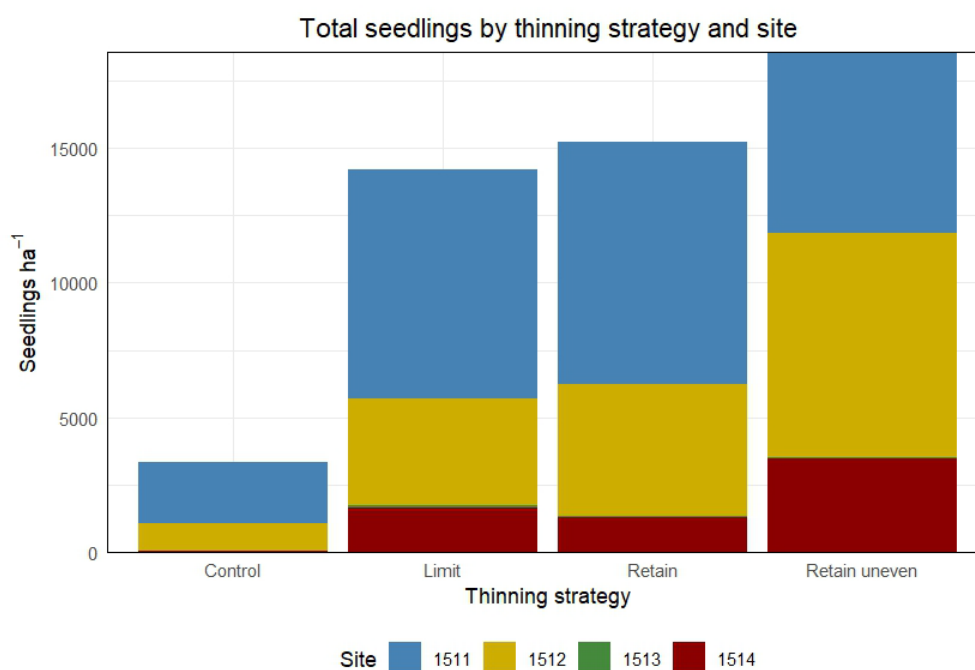


Figure 8: The three thinning strategies shows insignificant differences compared to each other. Control= unthinned control, Limit= thinning to limit diameter distribution (Fig. 5b), Retain = thinning to retain full diameter distribution (Fig 5a), Retain uneven= thinning to retain full diameter distribution, leaving sections of the plot more open than others (Fig. 5c).

Table 3: Results of two-way ANOVA testing the effects of thinning treatment and site on seedling abundance. **Bold = statistically significant difference.**

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Thinning	1	39427886	39427886	14.798	0.00490**
Site	2	50697688	25348844	9.514	0.00768**
Residuals	8	21314629	2664329		

3.2 Species composition

The species composition of regeneration was dominated by broadleaved species across all four sites. In the southern sites, birch was the most abundant species, while the northern sites also showed a high proportion of other broadleaved species in addition to birch. The highest seedling numbers are represented by birch or other broadleaves and Scots pine are rare in all sites (Fig. 9).

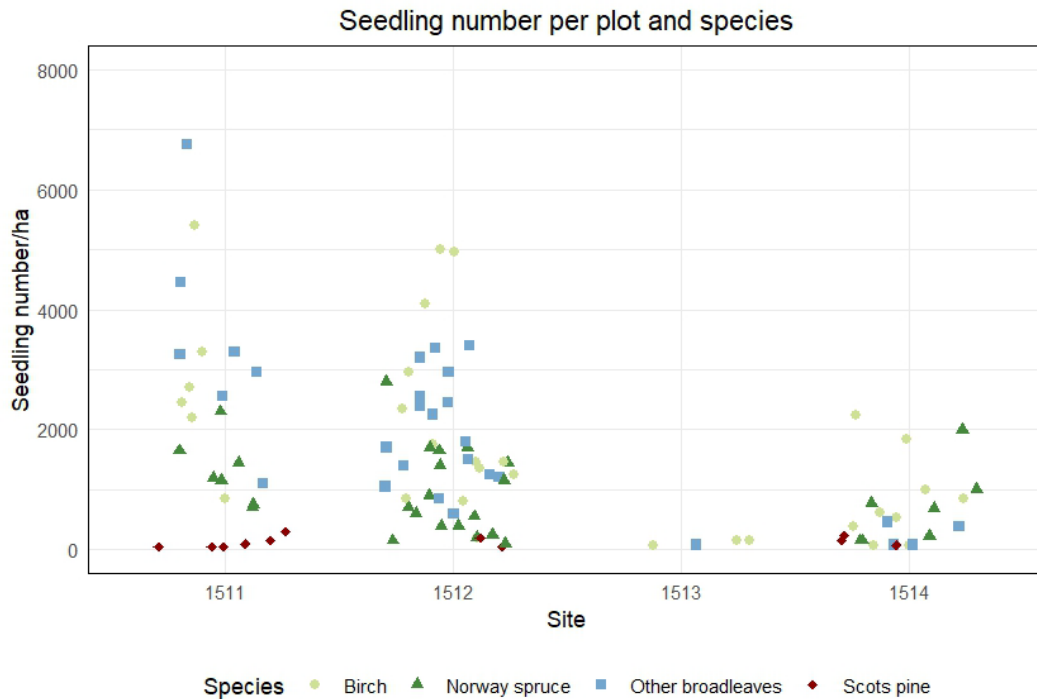


Figure 9: Each point represents seedling counts (per hectare) for Norway spruce, birch, Scots pine and other broadleaves. Data from plot 17 (Mordviksbodarna, 14,300 birch seedlings/ha) were excluded to improve scale readability.

The proportion of different species did not show any clear trend in relation to the different thinning strategies or in comparison to the control plots (Fig. 10). The proportion of Norway spruce among total seedlings was relatively low in most sites: 18% in Halåsen and 17% in Mordviksbodarna, while Hästhagen had a higher proportion (41%), and Moboda lacked spruce regeneration entirely.

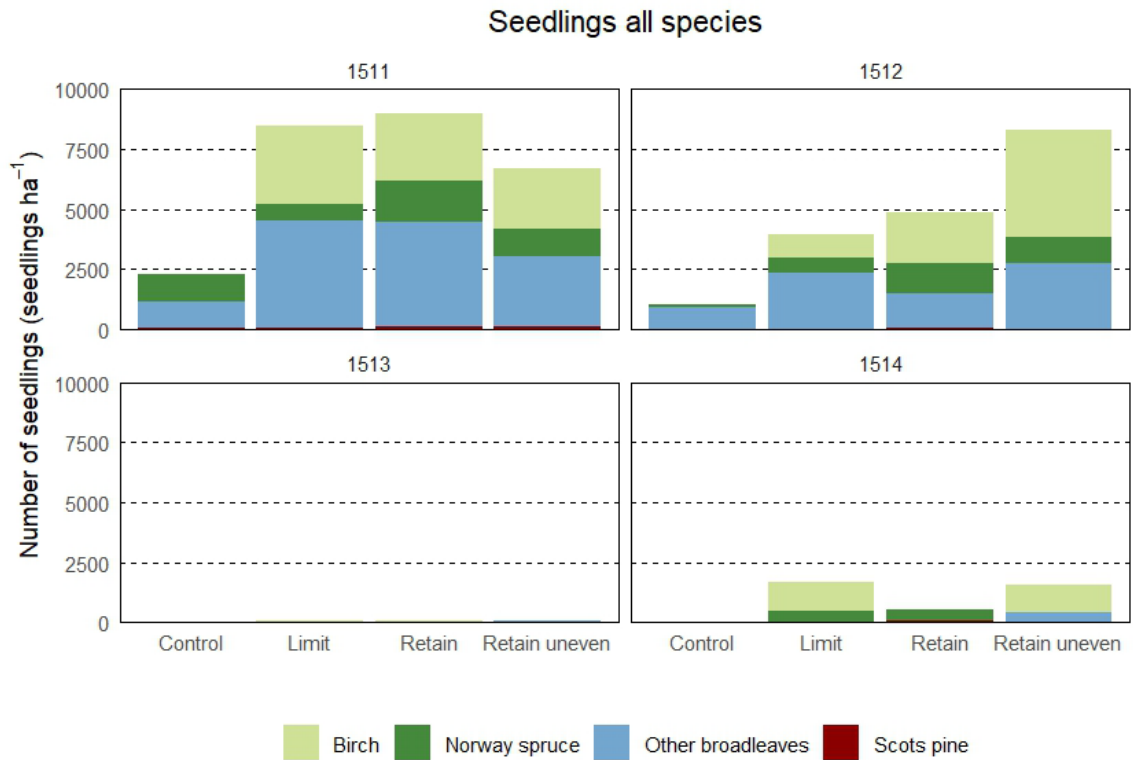


Figure 10: Total seedling number across all sites and treatments. Control= unthinned control, Limit= thinning to limit diameter distribution (Fig. 3b), Retain = thinning to retain full diameter distribution (Fig 3a), Retain uneven= thinning to retain full diameter distribution, leaving sections of the plot more open than others (Fig. 3c).

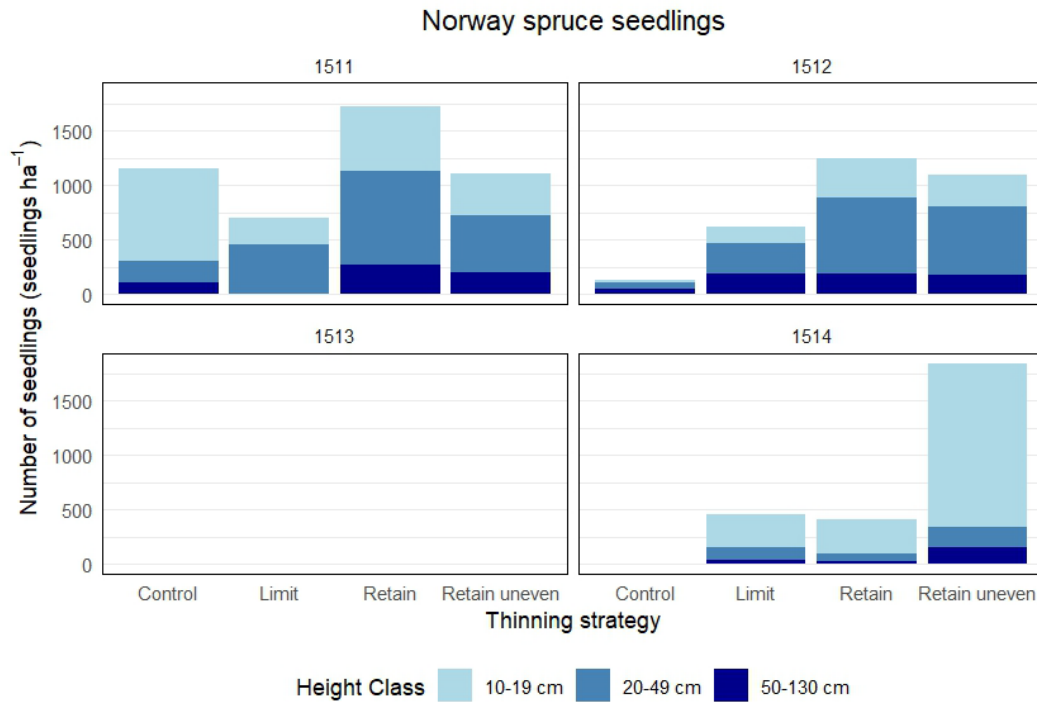


Figure 11: Norway spruce seedlings across treatments, grouped by sites with height classes visible. Control= unthinned control, Limit= thinning to limit diameter distribution (Fig. 3b), Retain = thinning to retain full diameter distribution (Fig 3a), Retain uneven= thinning to retain full diameter distribution, leaving sections of the plot more open than others (Fig. 3c).

The number of Norway spruce seedlings showed no statistically significant differences between control and thinned plots, and no clear trends were observed among the different thinning strategies (Fig. 11, Table 4).

Table 4: The analysis shows no statistically significant effects of thinning on Norway spruce regeneration.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Thinned	1	799642	799642	2.632	0.143
Site	2	535996	267998	0.882	0.451
Residuals	8	2430558	303820		

3.3 Height classes

Across almost all sites, the number of seedlings in the 10-19 cm height class was the lowest, and the northern sites had more seedlings in the two taller height classes overall (Fig. 12). At Mordviksbodarna, the number of seedlings in each height class showed a pattern across the different thinning strategies, with the fewest seedlings in the control plots and the most in the “Retain uneven” treatment. At the other sites, there was no clear trend to suggest that the thinning strategies had any effect.

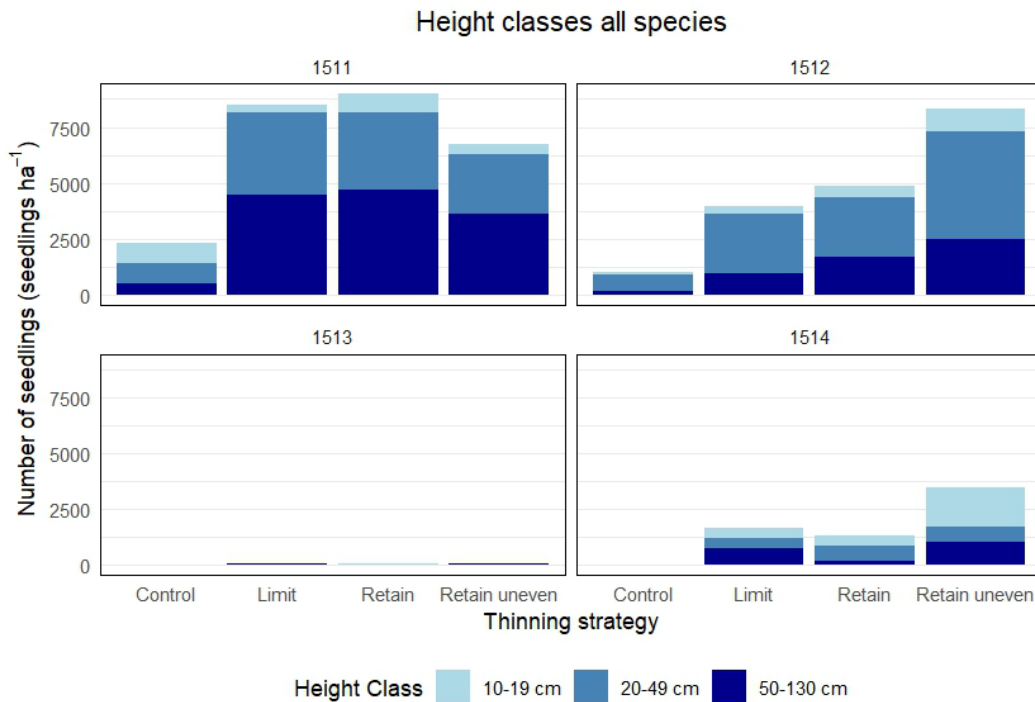


Figure 12: Seedlings categorized in different height classes and species. Control= unthinned control, Limit= thinning to limit diameter distribution (Fig. 3b), Retain = thinning to retain full diameter distribution (Fig 3a), Retain uneven= thinning to retain full diameter distribution, leaving sections of the plot more open than others (Fig. 3c).

3.4 Fertilization

Fertilization was applied as a treatment at three of the sites, but no statistically significant effect on seedling numbers was detected. Seedling densities tended to be lower in the fertilized plots (Fig. 13), although this trend was not significant. Birch as the only species was found more abundant in the fertilized plots.

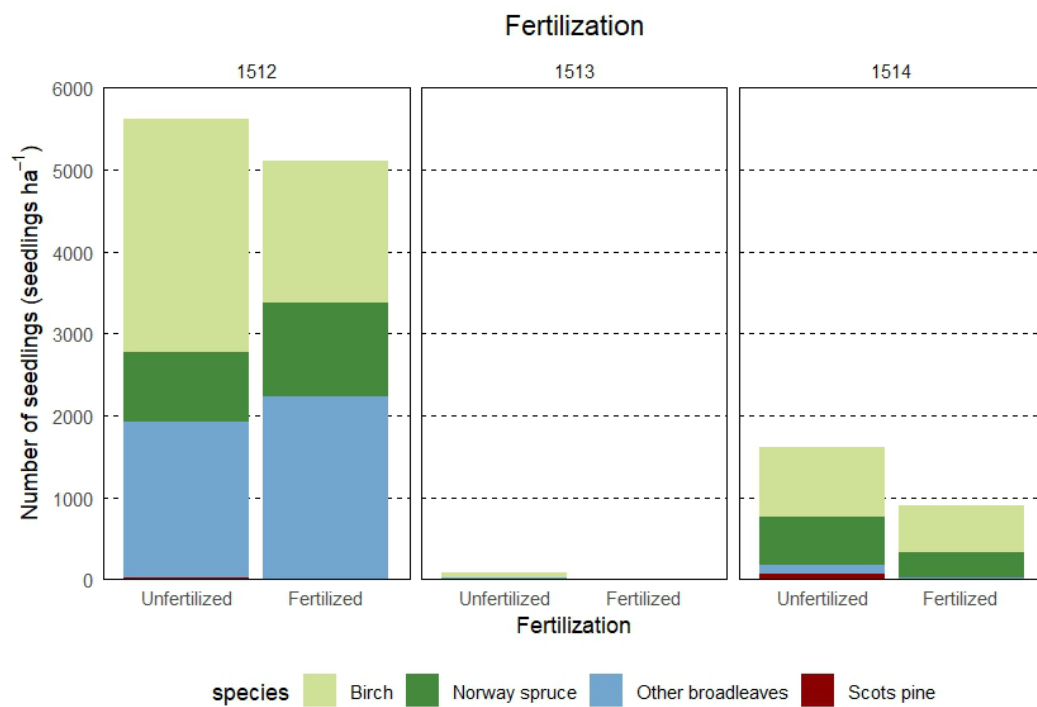


Figure 13: Comparison of fertilized vs. unfertilized plots indicates a slight positive trend for birch and a negative trend for other species.

3.5 Site preparation

Seedling numbers in plots treated with mechanical site preparation showed a positive trend, with higher birch seedling densities observed in these areas compared to untreated plots (Fig. 14). This suggests that site preparation may stimulate regeneration, particularly for birch. At Halåsen, only one plot received this treatment, making it difficult to draw reliable conclusions for this site due to the limited sample size.

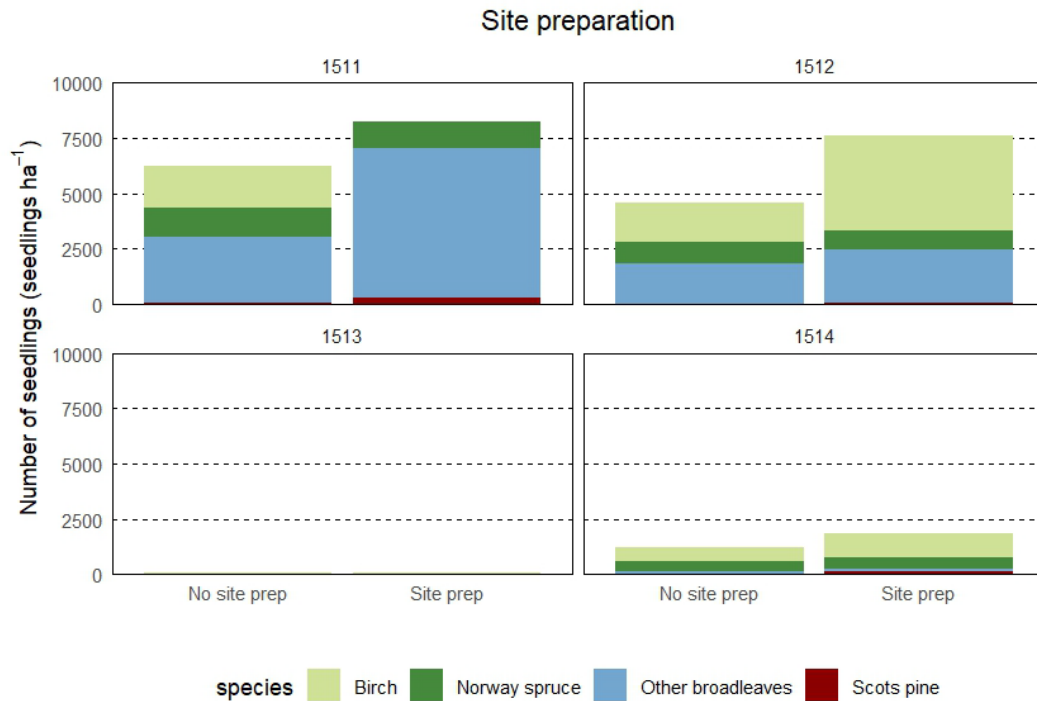


Figure 14: Seedling numbers in relation to fertilized vs. unfertilized plots across all sites and treatments.

3.6 Ground cover

Vegetation cover was notably higher in Hästhagen compared to Moboda, with Hästhagen also showing greater species diversity (Fig. 15, Fig. 16). Grass was the dominant ground vegetation type at both sites, but the overall abundance and variety of ground cover species were more pronounced in Hästhagen. This pattern mirrored the seedling numbers, which were also higher in Hästhagen than in Moboda. No clear trends in ground cover composition or percentage were observed among the different thinning strategies. Vegetation cover was not inventoried in the the northern sites.

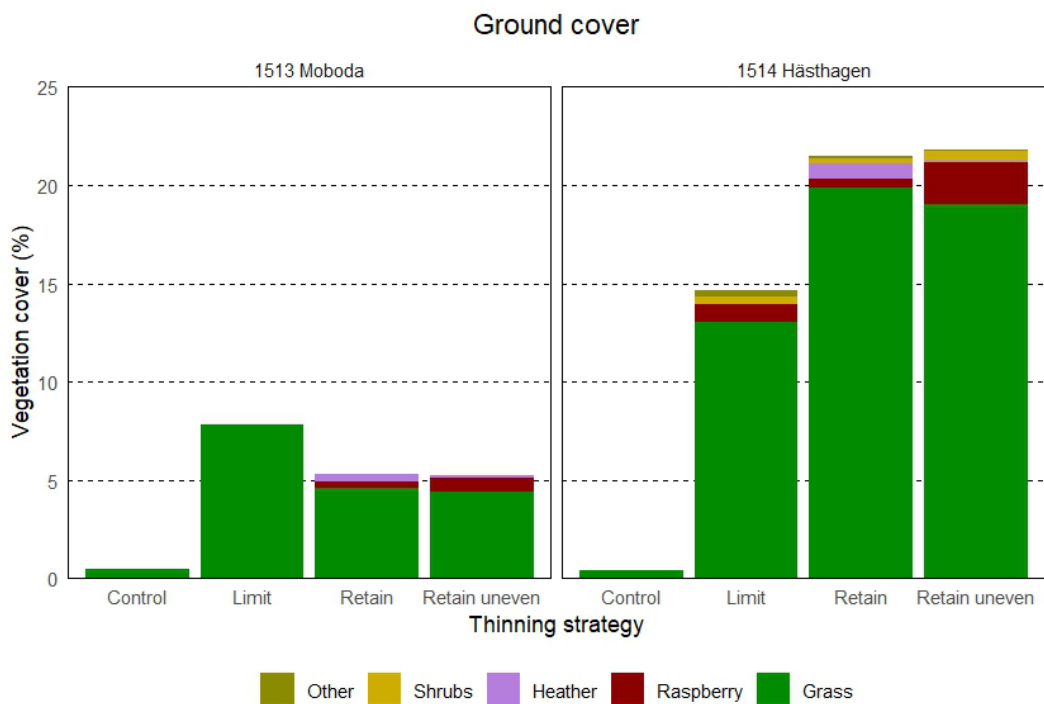


Figure 15: Vegetation cover is more abundant and more diverse in Hästhagen (1514). Control= unthinned control, Limit= thinning to limit diameter distribution (Fig. 5b), Retain = thinning to retain full diameter distribution (Fig 5a), Retain uneven= thinning to retain full diameter distribution, leaving sections of the plot more open than others (Fig. 5c).

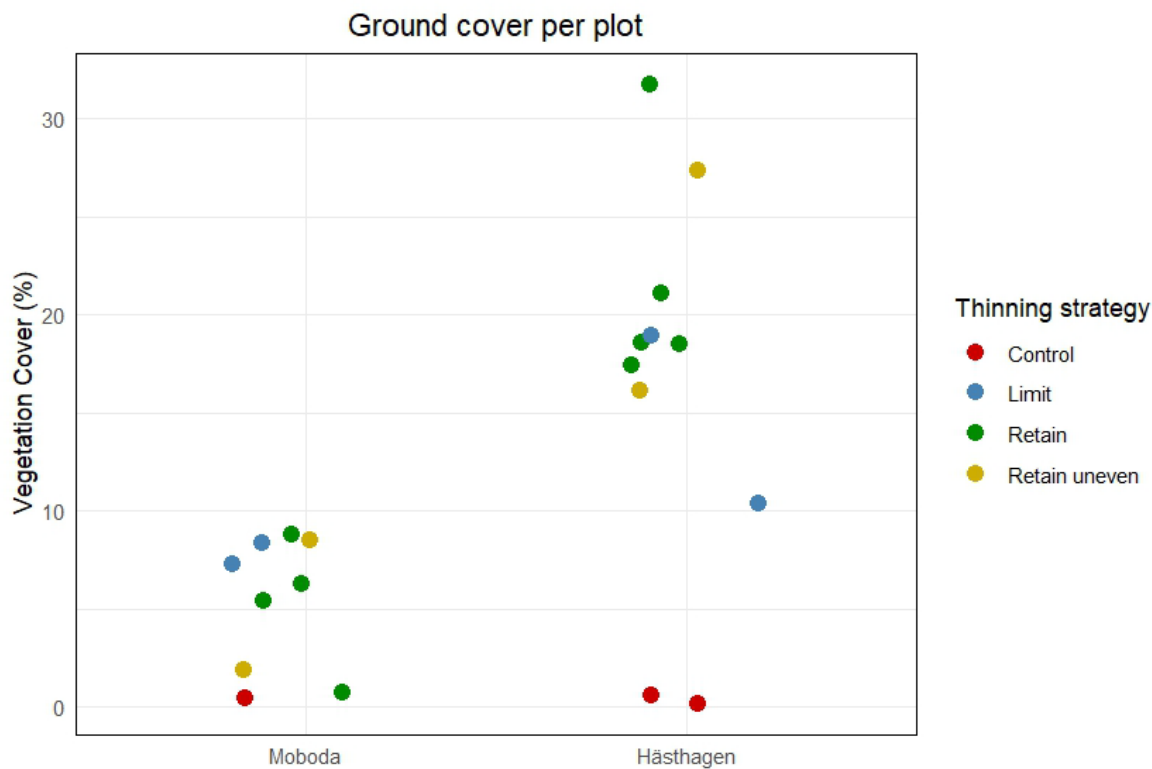


Figure 16: The percentage of vegetation cover of all inventoried plots in the southern sites. Control= unthinned control, Limit= thinning to limit diameter distribution (Fig. 5b), Retain = thinning to retain full diameter distribution (Fig 5a), Retain uneven= thinning to retain full diameter distribution, leaving sections of the plot more open than others (Fig. 5c).

4. Discussion

The results of this study highlights the complexity of regeneration dynamics during the conversion of even-aged Norway spruce stands to multi-layered structures. Most notably, the thinnings that were made in these experiments stimulated seedling establishment across the sites, but did not differ between the three strategies that were applied. The findings correspond well to both hypothesis for this study and also aligns with previous research, which has shown that reducing stand density through intensive thinning improves understory conditions for seedling establishment.

The different thinning strategies, fertilization, and site preparation had little or no measurable effect that can be seen yet on seedling numbers in this experiment.

A striking pattern was found in the regional differences between the northern and southern sites. The northern sites showed much higher regeneration rates compared to the southern sites.

This difference appears to be more related to specific site conditions than to the management treatments applied. Known factors that relate to regeneration rates for Norway spruce are for example soil moisture and humus layer thickness. Further studies should investigate the specific conditions of the four sites.

Moboda seemed to fit the description from the Swedish Forest Agency of sites that are challenging for regeneration - medium moisture and a thick humus layer (Skogsstyrelsen, 2021).

Hästhagen had an overall higher seedling number and a richer and more abundant ground flora than Moboda, indicating that there is a difference in conditions that better support plant establishment.

Seed production dynamics is a factor that influences regeneration. Norway spruce produces a quantity of seeds during mast years which occur irregularly and vary between regions. There can be many years between these events and they are hard to predict. It is possible that the northern sites experienced a mast year at some point after the experiment was established, and the southern sites have not yet.

Additionally, the age of trees also affects the production of seeds. Older trees produce more seeds, and while the northern sites were around 41 and 45 years old at time of experiment establishment, the southern sites were only 28 and 29. However, the fact that the northern sites have more regeneration is also seen in species other than spruce, which suggests that something other than just Norway spruce seed production. The mast years also would not explain the contrast

between Moboda and Hästhagen which are both located in the south and would likely have experienced the same mast year if there had been one.

The second thinning that was conducted in Hästhagen is something that could be considered as a potential clue to the difference in seedling numbers between Moboda and Hästhagen. However, this thinning was conducted in autumn 2023 which means that by the time of the plant inventory in March 2025 was conducted, only one growing season had passed (summer of 2024). Given that it typically takes at least two to four growing seasons for regeneration to respond (SkogForsk, 2001) to a thinning, the observed differences in seedling abundance between Moboda and Hästhagen cannot be attributed to this recent thinning.

Soil moisture is another factor worth considering. Norway spruce generally regenerates better on moist sites, and the northern sites may have benefited from higher soil moisture levels. The plots at Halåsen (1511) are located on moist soil while the other plots are either mesic or mesic/moist. Halåsen has the highest seedling number of all plots which could indicate that water availability has a role to play for the outcome of regeneration, although it is impossible to single out a single factor from the results of this study.

Neither fertilization nor site preparation showed a significant effect on Norway spruce regeneration in this experiment. This suggests that, at least under the conditions of this study, these treatments do not seem to be an effective tool for promoting regeneration during conversion management. That is to say, if it is preferable to get a rapid influx of regeneration at the start of a conversion attempt. A risk with *too much* regeneration in the conversion phase is that it could create a second canopy layer and a two-storied structure instead of the intended inverted J-curve diameter distribution. The aim of the conversion should perhaps be to have a steady and more gradual ingrowth rather than a rapid one. If this idea holds some bearing, the lack of regeneration in the southern sites should not be considered a failure yet since the experiment is still relatively young.

The lack of clear trends among the different thinning strategies together with the fact that the northern plots that had the least seedling count (the control plots) was similar to the southern plots that showed the most abundant seedling count underlines the complexity of the regeneration process in conversion forest management. The results in this study put further emphasis on the need for more long-term field experiments to understand which methods and site conditions are most conducive to successful conversion.

Given the limited number of studies on conversion we have today, it is important to take the uncertainties and risk of failure into account when attempting a conversion. These four sites may be representative of the range of outcomes that can be expected under different conditions. However, since the stands remain within the normal rotation period, the option to return back to rotation forestry and clear fell the stand is possible at any given moment, the risks involved in making these attempts are relatively low as (Fahlvik et al, 2024) shows in their study on the economical consequences of attempting and abandoning a conversion.

Further studies should focus on site-specific factors such as soil moisture, annual precipitation, soil type, and vegetation cover at all sites. Investigating the occurrence and timing of Norway spruce mast years in both regions since the experiment was established would also provide valuable insights. Additionally, a second thinning in Moboda should be conducted as soon as possible to keep the comparability between the sites.

This long-term field experiment is unique in its focus on the conversion of monoculture spruce stands into structures suitable for alternative silvicultural systems which is an area of growing interest among both forest owners and the public. Given the growing demand for knowledge in this area, continued monitoring of these sites should be prioritized to improve our collective understanding of effective conversion strategies.

5. Conclusion

This study shows that heavy thinning is effective in stimulating regeneration during the conversion of even-aged Norway spruce stands to multi-layered structures. Other treatments, including alternative thinning strategies, fertilization, and soil scarification, did not have a significant impact on seedling establishment.

The pronounced differences in regeneration between northern and southern sites highlight the importance of site-specific factors, such as stand age, soil moisture, and local seed production dynamics.

While the conversion attempts cannot be considered a failure or a success at this stage, the results underline the complexity of regeneration processes and the need for continued monitoring of these sites and conducting additional long-term field experiments focusing on conversion forest management.

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7. Appendix

SITE	PLOT	FERTILIZED	SITE PREP	FIRST THINNING 60% (STRATEGY)	SECOND THINNING
1511	1			Retained diameter distribution with spatial consideration (C)	
1511	2			Limited diameter distribution (B)	
1511	3		Site prep	Retained diameter distribution (A)	
1511	4			Retained diameter distribution (A)	
1511	5			Retained diameter distribution (A)	
1511	6			Retained diameter distribution with spatial consideration (C)	
1511	7			Control	
1512	1			Retained diameter distribution (A)	
1512	2			Control	
1512	3			Retained diameter distribution with spatial consideration (C)	
1512	4	Fertilized	Site prep	Retained diameter distribution with spatial consideration (C)	
1512	5	Fertilized	Site prep	Limited diameter distribution (B)	
1512	6	Fertilized	Site prep	Retained diameter distribution with spatial consideration (C)	
1512	7	Fertilized	Site prep	Retained diameter distribution (A)	
1512	8		Site prep	Retained diameter distribution with spatial consideration (C)	
1512	9		Site prep	Retained diameter distribution (A)	
1512	10			Retained diameter distribution with spatial consideration (C)	
1512	11			Control	
1512	12	Fertilized		Retained diameter distribution (A)	
1512	13			Retained diameter distribution with spatial consideration (C)	
1512	14			Limited diameter distribution (B)	
1512	15		Site prep	Retained diameter distribution (A)	
1512	16			Retained diameter distribution (A)	
1512	17		Site prep	Retained diameter distribution with spatial consideration (C)	
1513	1			Retained diameter distribution (A)	
1513	2		Site prep	Retained diameter distribution with spatial consideration (C)	
1513	3			Limited diameter distribution (B)	
1513	4	Fertilized		Limited diameter distribution (B)	
1513	5	Fertilized	Site prep	Retained diameter distribution (A)	
1513	6		Site prep	Retained diameter distribution (A)	
1513	7			Retained diameter distribution with spatial consideration (C)	

1513	8	Fertilized		Retained diameter distribution (A)	
1513	9			Control	
1514	1			Retained diameter distribution (A)	50%
1514	2			Control	
1514	3	Fertilized		Limited diameter distribution (B)	25%
1514	4		Site prep	Retained diameter distribution (A)	25%
1514	5	Fertilized	Site prep	Retained diameter distribution (A)	25%
1514	6		Site prep	Retained diameter distribution with spatial consideration (C)	25%
1514	7			Limited diameter distribution (B)	50%
1514	8			Retained diameter distribution (A)	50%
1514	9	Fertilized		Retained diameter distribution (A)	50%
1514	10			Control	
1514	11			Retained diameter distribution with spatial consideration (C)	50%

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