Effects of stand structure on natural regeneration in uneven-aged mixed forest

– a case study from Tranemåla, Blekinge

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Abstract

The growing conditions in southern Sweden can support a wide range of native broadleaf and coniferous tree species, which all are important for biodiversity and provision of ecosystem services. However, forest management in southern Sweden has for the last century been dominated by planted even-aged stands of Norway spruce or Scots pine, with a main focus on production of pulp and timber. Ecosystem resilience and biodiversity are often low in even-aged monocultures and there is an increasing interest in developing the management of uneven-aged mixed forest.

Tranemåla forest in Blekinge is one of relatively few areas that during the last century have been managed with less focus on the traditional rotational forestry that is dominating in Sweden. Due to this, more heterogeneous forest and structures have developed, offering a unique possibility to do research within the field of continuous cover forestry that can provide insight with regard to both challenges and opportunities for future forest management in Sweden.

The purpose of this case study was to examine how stand structure influences natural regeneration in Tranemåla forest. Two spruce (*Picea abies*) dominated, uneven aged mixed stands were selected and 24 circular sample plots of 10-meter radius were established systematically and examined for tree species composition, stem density, basal area and natural regeneration. The results show that the current diameter distribution provides a good potential for uneven-aged mixed forest management, although there is still a relatively low stem density in the smallest diameter classes. The results also indicate that natural regeneration is increasing with decreasing basal area, regardless of tree species. Other factors than overstory density, such as nutrient and water availability, may also affect regeneration outcomes, and further research is needed to include more aspects. The understory development of the two selected stands is recommended to follow up in the future.

Keywords: Close-to-nature forestry, Continuous cover forestry, *Fagus sylvatica*, Natural regeneration, *Picea abies*, Swedish NFI, Thinning

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Abbreviations

Abbreviation	Description
BA	Basal Area
CCF	Continuous Cover Forestry
DBH	Diameter at Breast Height (130 cm)
HA	Hectare (1 ha=10 000 m^2)

1. Introduction

The forest industry in Sweden has for the last century been dominated by the rotational forest management with planting of monocultures of mainly Norway spruce (*Picea abies*) or Scots pine (*Pinus sylvestris*) and harvested through clear cutting of large areas. Harvesting and management practices have mainly been driven by resource demands and technological innovations developed to intensify forest production (Kuuluvainen et al., 2012). Approximately two thirds of the land area in Sweden are covered by forest (Roberge et al., 2020) and through this management system, Sweden is today one of the biggest exporters of pulp and timber in the world, generating 185 billion SEK in 2024 (Swedish Forest Industries Federation, 2025). However, as climate change progresses, this system could potentially be vulnerable to future weather challenges and increased biodiversity loss (Felton et al., 2024) as clear cutting is the main reason that species connected to forest ecosystems are becoming increasingly rare and threatened (Sterkenburg et al., 2019, SLU Artdatabanken 2020). Alternative forest management systems are still underdeveloped in Sweden and more research is needed to find solutions to keep generating a strong bioeconomy while increasing forest resilience and halting biodiversity loss in the forest ecosystem (Felton et al., 2024). These management systems are closer to mimicking natural forest disturbances and are often based on creating a mix of structures and dynamics in the forest through different management methods (Berglund & Kuuluvainen, 2021). The heterogeneity of these forests creates a variation of habitats, which is crucial for species diversity and ecological processes (Kuuluvainen, 2002). A commonly used term for these systems is continuous cover forestry (CCF).

1.1 Continuous cover forestry

Continuous cover forestry is an umbrella term for several systems that refers to managing the forest in a way that the land remains continuously tree-covered, without the creation of large clear-cut areas (Skogsstyrelsen, 2021). In Sweden, this concept is commonly known as clear-cut free forestry and it includes several systems, such as selective, gap cutting, and shelterwood systems. There are many benefits deriving from CCF, e.g. recreational values from a landscape perspective, resilience to climate challenges, reduced carbon emissions, and increased biodiversity values. For instance, with a continuous tree cover, chances of mycorrhiza survival in the ground increase (Tomao et al., 2020). Also, an intact forest micro-climate is maintained, which can benefit biodiversity in general, especially in terms of survival for the more desiccation sensitive species that are sensitive to clear-cutting. However, it should be mentioned that CCF does not always equal more ecological sustainability. For this purpose, it is important to make sure that enough dead wood and old habitat trees are still retained and that there is a mix of substrates (e.g. dead wood and living trees from different tree species and structures, standing and laying dead wood) in the forest (Kuuluvainen, 2009).

1.1.1 Selective system

The selection system is based on the harvest of individual trees and maintaining a multi-layered stand structure (Brunner et al., 2025). This method is generally more suited for shade tolerant species, like spruce and beech (*Fagus sylvatica*) due to the lack of large openings in the stand where enough light can reach the ground layer. However, other factors also play a role in the regeneration of other tree species, such as soil type and water availability. Selection cutting can also focus on modifying tree species composition. For example, reducing the share of spruce, that otherwise can largely dominate a stand due to its shade-tolerant characteristics, can be a good idea to promote growth and increase chances of regeneration of more light demanding species. A better understanding of the conditions under which selective cutting is suitable for maintaining mixed-species stands, while ensuring the continuous regeneration of less shade-tolerant species, is needed (Brüllhardt et al., 2022).

1.1.2 Gap cutting system

Gap cutting refers to the creation of openings in the forest by harvesting all trees within a relatively small area, usually no more than 0.25 ha (Skogsstyrelsen, 2021). This method is not commonly used in Sweden and further research is needed. The aim is to create gaps that promote the establishment of light demanding species, such as pine, birch (*Betula* spp.) and oak (*Quercus* spp.). The size of the area required for successful regeneration of the light demanding pioneer species varies, but chances can be enhanced through site preparation (Skogsstyrelsen, 2023). Additionally, pine also generally grows better where the belowground competition from mature trees is reduced (Häggström et al., 2024), indicating that gap cutting is more suitable for successful pine establishment. The number of gaps in a stand should not be so extensive that the average stand density is below the 5§-curve according to the Swedish Forestry Act (Skogsstyrelsen, 2021).

1.1.3 Shelterwood system

This system refers to stands initially thinned regularly and developed to having individual trees with long crowns, evenly distributed over the whole stand as seed trees and shelter for regeneration (Brunner et al., 2025). To count as CCF, these trees should not be removed until seedling establishment has been ensured and preferably grown above 2.5-meters in height (Skogsstyrelsen, 2023).

1.1.4 Close-to-nature forestry

The term close-to-nature forestry is based on the concept of mimicking natural processes in the forest. Guidelines on how close-to-nature forestry should be managed have been developed by different actors, such as environmental organisations and researchers at universities (Skogsstyrelsen, 2023). In these guidelines, the general advice is to look at different natural processes and use them as inspiration for management and harvesting trees, to minimize unnatural damage on surrounding environment. However, some discords occur when it comes to the use of non-native species where some stakeholders are very strict with only using plants and/or seeds from local provenances. Larsen et al., (2022) suggest that we need to adapt the use of tree species to a new climate and are even open to use species from other continents that could be suitable for certain sites and conditions, e.g. using more drought tolerant species. This is commonly referred to as *closer*-to-nature forestry as opposed to *close*-to-nature forestry.

1.2 Regeneration in continuous cover forestry

A common concern when it comes to CCF is the natural regeneration of trees. A dense canopy in a spruce forest often limits seedling establishment as light availability is an important factor (Lula et al., 2025). Understory temperature, which can also be determined by tree density and the species composition can also influence tree regeneration (Díaz-Calafat et al., 2023). Planting is of course an option even in CCF, but it is usually only used when the natural regeneration on the site is very low (Skogsstyrelsen, 2023). To increase chances of seedling establishment, site preparation can be beneficial. However, in the guidance from the EU-commission (2023) on close-to-nature forestry, site preparation should be carefully executed when needed, and not causing any damage more than necessary. Another issue could be browsing pressure on the established seedlings, especially in southern Sweden. This thesis will, however, only focus on the effects of stand structure on natural regeneration.

1.3 Tranemåla Forest as a case study

The management of the Tranemåla property is done by a foundation commonly known as "Tranemålastiftelsen" which has recently initiated a shift to close-to-nature forestry and CCF over the whole property. On the Tranemåla estate there is a larger amount of mixed species forests than in other forests surrounding the area. This is due to the forest being managed more carefully through thinning and with less large clearcuts during the 20th century (Brunet, 2024). These conditions make it suitable for implementing CCF as it already has some within-stand diversity in species and age classes. The emphasis on promoting noble broadleaves on the estate has been of great importance since the start of the foundation (Brunet, 2024).

1.3.1 Strategic goals

In an unpublished manuscript by Brunet (2024), there are some strategic goals set for Tranemåla forest. The goals are based on the implementation of close-to-nature forestry and CCF on the whole property of forest land. When it comes to the production, the long-term focus is on producing more quality timber. The goal is to achieve this through natural regeneration and having a timber production of spruce, pine, birch, beech and oak (with an emphasis on high quality oak timber). Oak and beech of good timber quality are present in several pure and mixed stands (Brunet, 2024). 20% of the productive forest land are intended to be set aside for nature conservation and a careful selection of retention trees should be carried out. In the management strategy, also the social aspects of recreational values as well as cultural values should be taken into consideration. Having diversity in the forest increases the ecological resilience (Felton et al., 2024) and in Tranemåla forest the intention is to create resilient forests for both short- and long-term purposes, and to use it for future research in this subject.

1.3.2 Aim of research

The purpose of this study is to present two contrasting mixed stands and to examine how stand structure influences natural regeneration in these stands (no 58 and 61) in Tranemåla forest. Looking at species composition and stand density, the research aims to get a better understanding of natural regeneration dynamics and provide insights for future CCF management. The main research question examined is "How do tree species composition and stand density affect the abundance and diversity of natural regeneration?" A basic hypothesis for the present study is that tree species composition will influence regeneration patterns, with no regeneration or only shade-tolerant species dominating under closed canopies, and light-demanding species establishing in more open areas.

2. Material and Methods

Tranemåla forest is located in the northern part of Karlshamn municipality in Blekinge län, Sweden. The property holds 250 ha of land, where 230 ha is productive forest land (Brunet, 2024). This paper will focus on two stands on this property, stand 58 and stand 61.

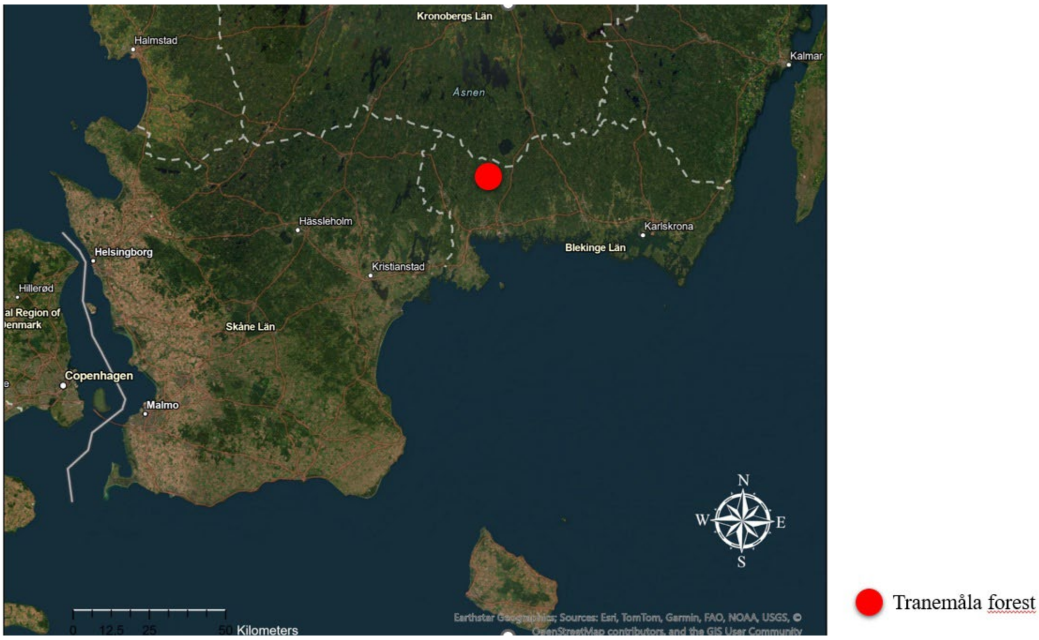

Figure 1: Location for Tranemåla forest in Blekinge län, Sweden. Map: ArcGIS, SWEREF 99 TM.

2.1 The stands

The studied stands are separated by a gravel road, which is used as a baseline for the study transects that lead into the two forests. Both stands have been dominated by spruce, but a thinning operation was conducted in stand 58 in the winter of 2023/24 with a focus on removing mainly spruce. Stand 61 has had no active management for more than 20 years. To estimate the diameter at breast height (DBH) for the cut trees in stand 58, the DBH and the stump diameter (at ca 30 cm height) from 20 trees in the same stand were measured to calculate a linear regression model. The resulting function, DBH = stump diameter x 0,7695 was used to estimate DBH of the cut trees.

2.2 Sample plot distribution

From the road, five transect lines were established extending into each stand (Figure 2). The distance between each transect is 30 meters, measured with a 50-

meter measuring tape and marked out by the road. From these marks, a compass was used to walk in a straight line into the forest stands, in a 90-degree angle from the road. On each transect there are between 1-3 plots in each forest stand, depending on stand borders. The plots closest to the road are located 20 meters into the forest, measuring from the road edge (the edge closest to the respective forest) to the centre point of the first plot on the transect. Thereafter, it is 30 meters between every centre point of the plots (if more than one on that transect).

Figure 2: Drone image over stand 58 (left side of the road) and stand 61 (right side of the road) with five transect lines, including plot numbers. Note that this is a visualisation of plot distribution and not the exact placement of the plots. Photo: Author

2.2.1 The sample plots

The tree located closest to the 30-meter mark along the transects is chosen as a centre tree, marked as such, and measured of DBH. All DBH were measured with a diameter measuring tape (or two-way measurement with callipers in case of double stems with tight gaps) and rounded down to the closest quarter decimal (e.g., .00, .25, .50, .75). From the centre tree, two circular sample plots with a radius of 3.5-meter and 10-meter are outlined with measuring tapes and examined, mainly following the methodology of the Swedish National Forest Inventory (2022) for permanent plots. In the 3.5-meter radius plots, trees with DBH between 4-10 centimetres are measured and identified to species, as well as counting and identifying tree saplings ranging from >10 cm in height to <4 cm DBH. In the 10-meter radius plots, trees ≥10 cm DBH are measured and identified. Additionally in stand 58, the circumference of the recently cut stumps is measured and identified in the 10-meter radius plot. Plots 1-10 are located in stand 61, with plot 1 starting from transect 1, then counting from the road with plot numbers increasing into the forest (Figure 2). Plots 11-24 are located in stand 58, starting with plot 11 on transect 1. Plots 21-24 were added a posteriori and distributed on transect 1, 2, 3 and 5.

2.3 Statistics and calculations

For data analysis and calculations, Excel was used to compile the data from the sample plots and do basic calculations such as basal area (BA) from stem diameter, stems per hectare, and seedlings per hectare. Pie charts of species composition based on basal area in percentages, and graphs showing diameter distribution were also created in Excel. To investigate the relationship between basal area and number of seedlings found on each plot, a linear regression analysis was performed in Minitab.

3. Results

The result section includes a descriptive analysis of stand 58 (before and after thinning), stand 61, and linear regression analysis of tree saplings in relation to basal area in the two stands. From the inventory of stumps from harvested trees in the thinning operation of winter 2023/24 in stand 58 we could see that the stand structure and species composition before the thinning differed from stand 61.

3.1 Stand 58

Stand 58 is an open and light stand with a great variation of species. Because of the recent thinning operation, residues of branches are still present and cover strip roads and some other parts of the ground. The thinning mainly focused on harvesting spruce, resulting in a more even species mixture. In Figure 3, species composition before thinning and after thinning is presented in percentages based on BA.

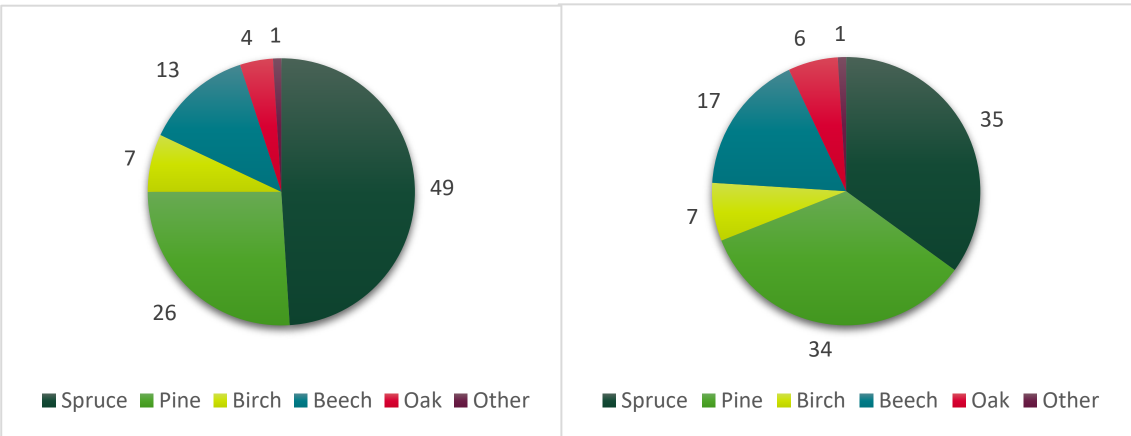

*Figure 3: Species composition of spruce (*Picea abies*), pine (*Pinus sylvestris*), birch (*Betula *spp.), beech (*Fagus sylvatica*), oak (*Quercus *spp.) and other tree species (e.g.* Populus tremula*) in stand 58 before thinning (left) and after thinning (right) in percentages, based on basal area (m^2/ha).*

3.1.1 Stand 58 before thinning

The stand was approximately consisting of 75% conifers where almost 50% were spruce. 25% were of different broadleaves with the largest proportion being 13% beech. BA was around 28.2 m^2/ha excluding standing dead wood. Stand density was 576 stems per hectare. The diameter classes in stems/ha presented in Table 1 shows the largest proportion of spruce in diameter class 20-29.9 cm while most pine trees in the stand belong to diameter classes >30 cm. Broadleaf species are mainly present in the smaller diameter classes. The overall diameter distribution before thinning shows an increasing stem density with decreasing DBH, except for the smallest DBH class which only contained few trees (Figure 4).

Table 1: DBH distribution (stems/ha) for each tree species before thinning in stand 58.

DBH	4–9,9 cm	10–19,9 cm	20–29,9 cm	30–39,9 cm	40–49,9 cm	≥50 cm
Spruce	9	57	105	71	9	0
Pine	0	0	5	14	11	16
Birch	0	27	25	5	0	0
Beech	56	77	30	9	0	0
Oak	0	32	9	2	0	0
Other	0	5	2	0	0	0

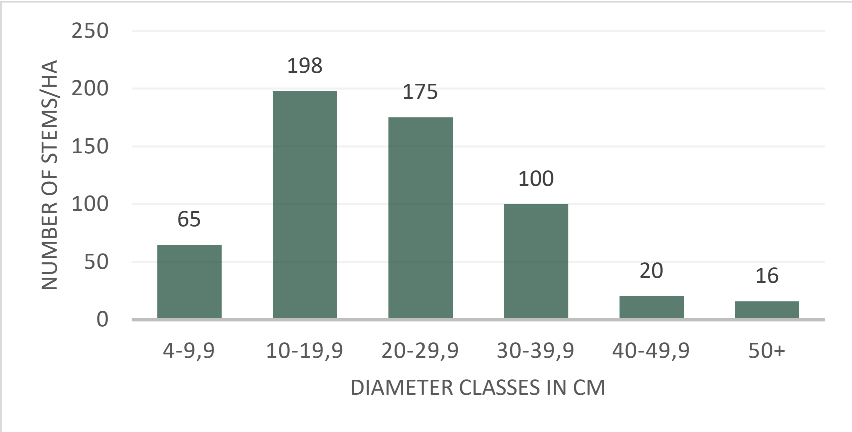

Figure 4: DBH distribution in stand 58 before thinning in winter 2023/24.

3.1.2 Stand 58 after thinning

The thinning operation focused on the harvesting spruce and left the stand with a more even mixed species composition, decreasing the share of spruce down to almost 35%. BA is currently 21 m^2/ha, excluding standing dead wood. BA of standing dead wood is 1.1. Stand density is 448 stems per hectare. In the diameter classes presented in Table 2 we can see the large reduction of spruce in all diameter classes and only a slight reduction for the other species. In Figure 5 we can see that the overall diameter distribution pattern has not been changed by the thinning.

Table 2: DBH distribution (stems/ha) for each tree species after thinning in stand 58.

DBH	4–9,9 cm	10–19,9 cm	20–29,9 cm	30–39,9 cm	40–49,9 cm	≥50 cm
Spruce	0	34	75	36	0	0
Pine	0	0	2	14	11	16
Birch	0	20	18	5	0	0
Beech	56	77	27	9	0	0
Oak	0	30	9	2	0	0
Other	0	5	2	0	0	0

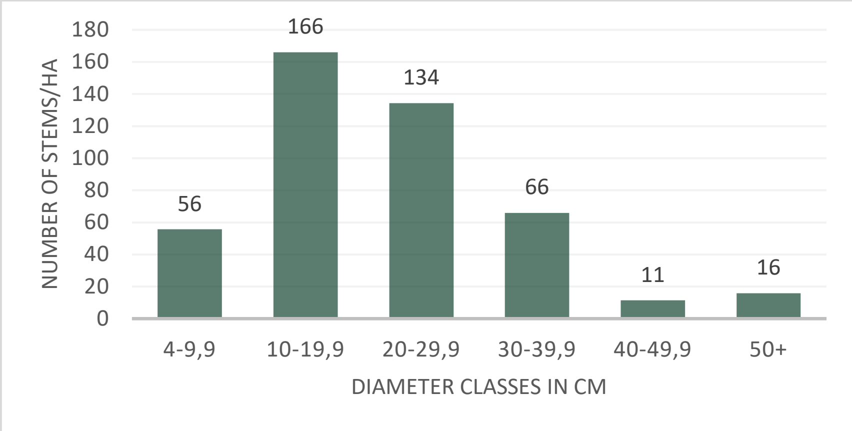

Figure 5: DBH distribution in stand 58 after thinning in winter 2023/24.

3.2 Stand 61

Stand 61 has had no active management for over 20 years. The stand consists of approximately 80% spruce. Remaining trees consist of retention pines, some beech and oak, and other broadleaves mainly found in moister parts of the stand (Figure 6). BA excluding standing dead wood is 40.5 m^2/ha. Standing dead wood has a BA of 1.3. Stand density is 863 stems per hectare. Table 3 shows that spruce dominates all diameter classes, while pine is only found in class 40-49.9 cm. Similar to stand 58, broadleaves are only found in the smaller DBH classes. The overall diameter distribution shows a wide but rather unimodal distribution with the highest stem density in DBH class 20-29.9 cm (Figure 7).

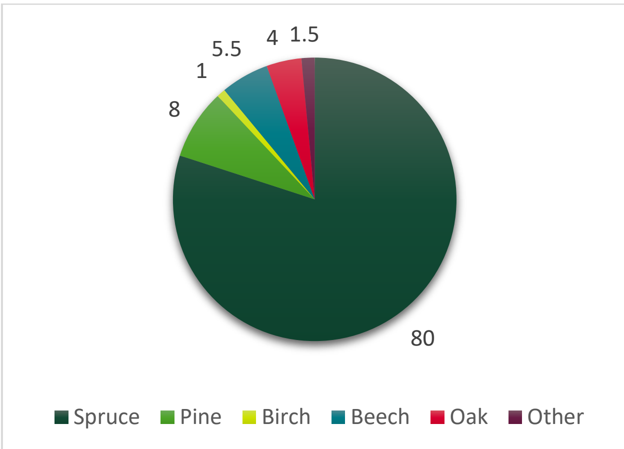

*Figure 6: Pie chart showing species composition of spruce (*Picea abies*), pine (*Pinus sylvestris*), birch (*Betula *spp.), beech (*Fagus sylvatica*), oak (*Quercus *spp.) and other tree species (e.g.* Alnus *spp.) in stand 61 in percentages, based on basal area (m^2/ha).*

Table 3: DBH distribution (stems/ha) for each tree species in stand 61.

DBH	4–9,9 cm	10–19,9 cm	20–29,9 cm	30–39,9 cm	40–49,9 cm	≥50 cm
Spruce	78	102	248	131	29	6
Pine	0	0	0	0	19	0
Birch	0	32	0	0	0	0
Beech	52	45	29	0	0	0
Oak	26	41	10	3	0	0
Other	0	3	6	3	0	0

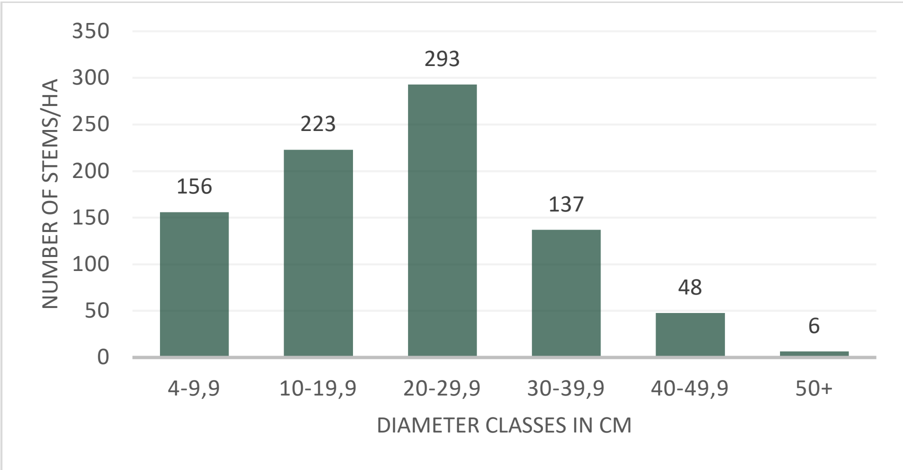

Figure 7: DBH distribution in stand 61.

3.3 Natural regeneration

Regeneration was found in both stands but was higher in stand 58 with approximately 2208 seedlings/ha, compared to stand 61 that had around 780 seedlings/ha. However, the difference between the stands was not statistically significant, due to large between-plot variation in both stands ($p>0.05$, Mann-Whitney U-test). For details of species-wise density of regeneration, see Appendix, Table 4.

The linear regression shows a statistically significant negative relationship between increased BA and number of all tree saplings found ($P=0.003$, $n=23$, Figure 8). Plot 24 is excluded from the analysis because it has an extreme value and did not display a realistic representation of the whole stand 58, due to other factors than BA (see Discussion).

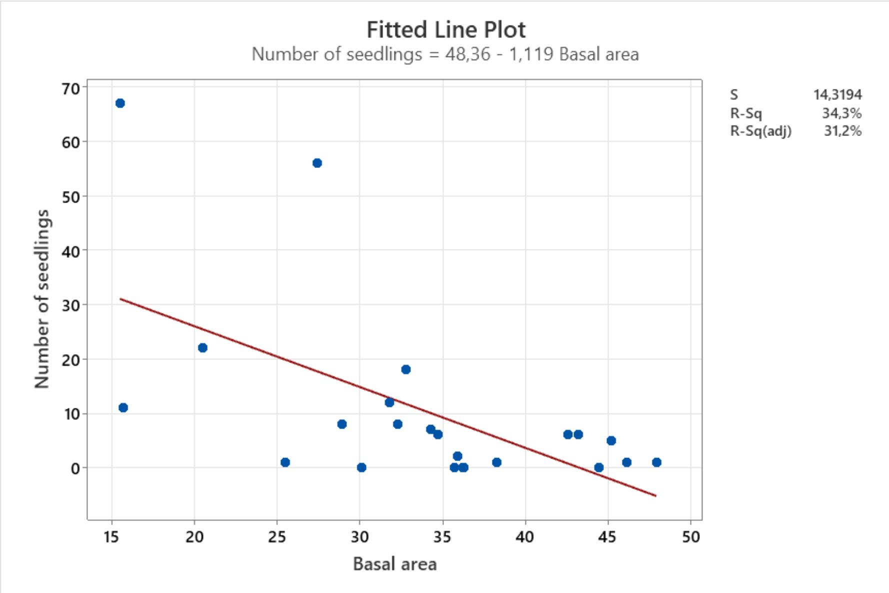

Figure 8: Relation between basal area in sample plots of stand 58 (before thinning) and 61 and number of all tree saplings found in the plots (P = 0.003, n = 23, outlier plot 24 excluded).

In Figure 9 we see a similar pattern with density of tree saplings of only the shade tolerant species spruce and beech also decreasing as BA increases. Plot 24 with its extreme value is excluded from this regression analysis.

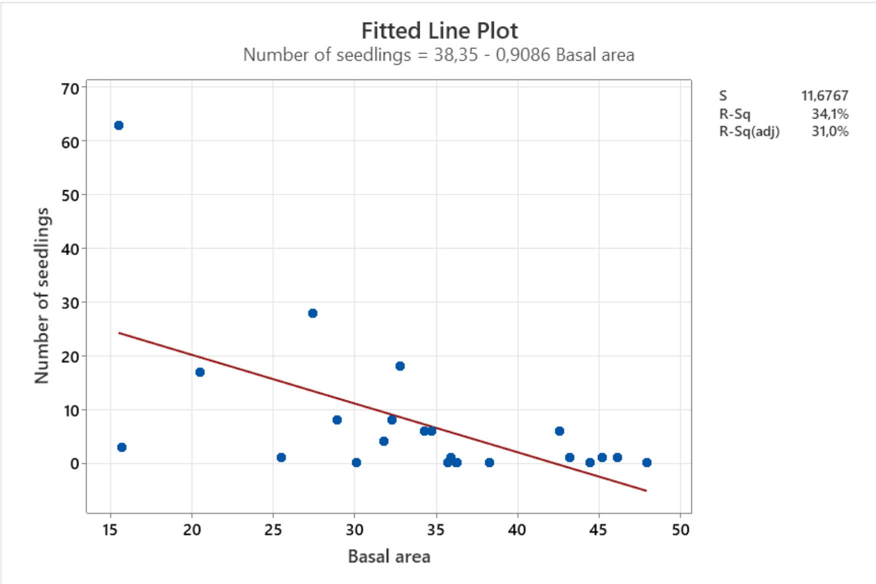

Figure 9: Relation between basal area in sample plots of stand 58 (before thinning) and 61 and number of tree saplings of the shade tolerant tree species spruce and beech found in the plots (P = 0.003, n = 23, outlier plot 24 excluded).

4. Discussion

The mixed species composition in stand 58 before the thinning in the winter 2023/24 was a good starting point for the implementation of CCF. The combination of species composition and site conditions due to this, e.g. higher light availability, is likely a key factor contributing to the higher number of established seedlings observed in the sample plots of stand 58. The thinning will presumably lead to even higher seedling establishment, including more light demanding species, in the coming years. The stand currently exhibits a high degree of canopy openness and increased light availability, left with an even greater mix in species composition, an uncommon characteristic in contemporary Swedish forests. There is still a lot of residues and slash from the thinning operation laying on the ground. This could influence the number of seedlings found in the sample plots, but when looking at the species distribution of the seedlings (see Table 4 in Appendix), there is still a significant part of light demanding species, such as birch and oak regenerating. Species composition, gaps in the canopy and water accumulation seems to have more effect on seedling establishment in both stands. Some elevation differences and wet parts occurred in both stands and there were some rocky parts, especially in stand 61, close to the north edge of the study area.

The hypothesis that tree species composition will influence regeneration patterns only partly answers the research question posed in the introduction: "How do tree species composition and stand density affect the abundance and diversity of natural regeneration?". In stand 58, the diversity of tree species was already before the thinning 2023/24 influencing the species regenerating, showing higher numbers of the light demanding species birch, pine and oak establishing (see Table 4 in Appendix). Because the stand was more open (less stem density) and heterogeneous, it provided good prerequisites for these seedlings to establish. In stand 61, the shade-tolerant species totally dominated seedling establishment, as stated in the hypothesis. In general, the results confirm the hypothesis, but the large variation of seedling density in plots with a low basal area suggests that other factors than light availability influence local regeneration patterns.

4.1 Regeneration patterns

In the linear regression model, we could see that the number of seedlings decreased with increased basal area as this limits light availability, which affects seedling establishment. However, basal area is not the only determinant when it comes to regeneration patterns. Dănescu et al. (2018) suggest that the traditional ways of investigating the relationship between stand density and regeneration is not always sufficient in uneven stands and that you need to consider both the horizontal and vertical layers of the forest, e.g. gaps between the crowns and that the multiple layers can influence the temperature, light, and moisture, which are all factors that can affect seedling growth. The distance to seed sources will also play an important role in species composition (Skogsstyrelsen 2023, Skogskunskap 2024) and in Tranemåla, older seed trees of all species regenerating are found within the stand or relatively close. Oak trees are valuable for both economic purposes when harvested as high-quality timber, and for biodiversity reasons when left as retention trees. However, to ensure continuous oak seedling establishment, it is crucial to perform active forest management and adjust these to specific site conditions, which is important for both production and biodiversity purposes (Stimm et al., 2022). After a mast year, oak seedlings can grow abundantly, but without an opening in the canopy that allows enough light, a lot of those seedlings are not able to survive (Tinya et al., 2020). Further, nutrient availability is also crucial for seedling survival and growth, assuming they are not exposed to herbivory or pathogens (Lula et al., 2025). This became apparent when comparing the different plots in this study. For example, plot 24, that was excluded from the regression analysis, located in stand 58 had an extremely high value in regeneration numbers. This plot was located beneath a slope, where it was semi-wet and in connection to an older gap in the canopy in the south direction. These conditions are probably the main factors causing the high number of established seedlings, even if there could be additional aspects not investigated in this research.

4.2 Conversion to CCF and possible risks

Because of the rotational forestry system in Sweden (and Fennoscandia) where we have a large majority of even-aged, single-species forests with low individual tree stability, it can be challenging to convert to a CCF system (Brunner et al., 2025). Risks of wind damage increase as stands go through intense thinning in the conversion phase, and possible challenges of ensuring sufficient natural regeneration are still in need of more research. It may be particularly difficult if you are converting to a selection cutting system where you need to develop multi-layered stand structures. In these forests you typically aim to create the “inverted J-curve”, referring to having higher numbers of stems/ha in the smaller diameter classes and fewer in the large diameter classes. This is to ensure a continuous regeneration in the stand. The research of conversion try-outs in practice is very much lacking in Nordic environments and simulations are still not reliable due to their inability to include risks, such as windthrow (Brunner et al., 2025) along with natural regeneration and ingrowth of additional species (Pukkala et al., 2014).

4.2.1 Management proposal in stand 61

Stand 61 consists of 80% spruce (based on BA) and is relatively single layered in the part where the plots are distributed. Transitioning from this type of forest into a CCF stand increases risks of storm damages during the transition period (Skogsstyrelsen, 2021). When choosing future activities in stand 61, it is important to minimize these risks. However, if the transition is successful and the stand develops into a multi layered and mixed structure forest, the prerequisites will probably increase ecological resilience, i.e. against storm damages, pests and pathogens, drought, etc. (Felton et al., 2024). In a webinar hosted by Martin Jentzen from Plockhugget (2023), he talked about different aspects to consider when transitioning a spruce plantation into a close-to-nature managed stand. Some of these aspects could work as suggestions for stand 61. One of the first things suggested is to look at the ecological history of the site and assess the previous land use, the soil type (presence of podzols indicates that there has been long-term coniferous forest on the site), and what tree species are best suited to establish in the stand. He also suggested making site-specific adaptions within the stand, and assess wet areas, slopes, etc. When harvesting, the suggestions focus on diversifying the stand and creating different structures, e.g. creating gaps of different sizes and gaps connected to stand borders, and selection cutting with focus on stems with DBH between 35-40 cm. He also emphasizes the importance of having skilful contractors operating the harvesters. The overall regeneration in stand 61 is quite low (Skogsstyrelsen, 2021), which could be an argument to perform gap cutting in the stand to promote more seedling establishment (Pukkala, 2018). Within the stand, there are elevation differences (a slope), wet areas, and broadleaves. One suggestion is to adapt management locally within the stand, e.g. create space around younger broadleaves to stimulate crown development, in particular future crop trees of oak, include buffer zones and no management around wet areas, small gap cutting close to edges in the south part of the stand, leave or perform careful thinning in the denser spruce area in the northern part of the researched area of the stand. In this way, a more heterogeneous structure can be promoted in the future.

4.3 Potential errors and limitations

In the Swedish National Forest Inventory (2022) methodology, tree saplings ranging from >10 cm in height to <4 cm DBH are counted within a circle of 1-meter radius in two opposite directions within the outer edges of the 3.5-meter radius circle. Initially, this resulted in almost no regeneration data, which did not give a realistic description of the two stands from what could be visually observed. Due to this, a modified methodology was applied, where all tree saplings within the 3.5-meter radius circle were counted. One exception was plot

24 with its extreme number of seedlings that was not representative of the stand as a whole. In this plot, the original methodology with the two 1-meter circles, placed in each respective north-east and south-west direction was applied. This modified methodology could possibly showcase a different result than if the original methodology was followed.

Additionally, when measuring stumps ≥10 cm within the 10-meter radius plots, it was not accounted for where in the plot they were placed, i.e. if they were inside the 3.5-meter radius plot. This means that stumps with stump diameter close to above 10 cm, would count as below the 10 cm diameter limit after the linear regression model, resulting in a possible error since it affects what formula is used when calculating stems/ha.
The predominant limitation of this study is that it is a case study, concentrated to just two stands in Tranemåla forest, with no replicates conducted.

5. Conclusion

This research represents the first documented investigation of stand 58 and 61 in Tranemåla forest. The data provides an overview of the current status and work as a baseline for future research and development of the stands. Tranemåla forest is a prominent estate with a unique possibility to implement and develop alternative strategies, such as close-to-nature forestry management. Because of their differences in stand structure, stand 58 and 61 represents two types of forests and how management could be performed in these. The statistical analysis shows that with increased basal area the number of seedlings decreases, even for the shade tolerant species spruce and beech. However, other factors like water, nutrients and surrounding species composition are important to consider when it comes to regeneration. The recently thinned stand 58 will probably develop an increased number of seedlings over the coming years, including more light demanding species. Further investigations are recommended. For stand 61, the data collected can be used to compare and analyse development in the stand after the upcoming management operations.

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Appendix

Table 4: Number of seedlings found in each plot, calculated to seedlings per hectare.

Stand	Plots	BA Now	BA Before	Seedlings/ha Total	Spruce	Birch	Pine	Beech	Oak	Other
61	1	43	N/A	1558	1039	0	0	519	0	0
61	2	46	N/A	260	0	0	0	260	0	0
61	3	30	N/A	0	0	0	0	0	0	0
61	4	33	N/A	4675	4675	0	0	0	0	0
61	5	38	N/A	260	0	260	0	0	0	0
61	6	44	N/A	0	0	0	0	0	0	0
61	7	34	N/A	1819	1299	260	0	260	0	0
61	8	43	N/A	1558	0	779	0	260	0	519
61	9	48	N/A	260	0	260	0	0	0	0
61	10	40	N/A	1299	0	1039	0	260	0	0
58	11	8	16	2857	0	1299	0	779	779	0
58	12	29	42	520	260	0	0	0	260	0
58	13	13	24	5974	0	260	0	4675	1039	0
58	14	34	37	0	0	0	0	0	0	0
58	15	9	16	17662	15584	779	260	1039	0	0
58	16	19	36	0	0	0	0	0	0	0
58	17	22	35	1559	260	0	0	1299	0	0
58	18	28	32	3117	1039	779	0	0	1299	0
58	19	21	29	2338	0	0	0	2338	0	0
58	20	25	27	14806	7273	7273	260	0	0	0
58	21	19	32	2078	0	0	0	2078	0	0
58	22	21	38	0	0	0	0	0	0	0
58	23	22	27	260	0	0	0	260	0	0
58	24	18	19	125796	58917	66879	0	0	0	0

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