Can precommercial thinning be used to create more diversity after planting spruce?

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Abstract

Mixed forests will harbour other ecosystem services than a planted coniferous monoculture. This study used early results from a long-term experiment to examine if different precommercial thinning treatments can be used to increase diversity in planted stands of Norway spruce (*Picea abies*) mixed with high densities of natural regeneration of birch (*Betula spp.*).

Precommercial thinning treatments are standard in the Swedish even-aged clear-cut silvicultural system and are used to shape the future commercial thinning stand. Three different precommercial thinning strategies were applied as treatments in planted stands of Norway spruce (*Picea abies*). Used selection strategies were I) spruce monoculture with an even diameter distribution and the largest stems, II) mixed stand with an uneven diameter distribution and only the largest 1/8 of stems, combined with the smallest trees and III) mixed stand an even diameter distribution and the largest stems. The treatments were tested with densities of 1200 and 1500 stems hectare^{-1} after treatment. Investigated parameters after treatment were quadratic mean diameter, diameter distribution, mixed species ratio and the development over two years after treatment.

The experiment was established on two sites with three blocks on each site. Precommercial thinning was performed in 0.08-hectare sized plots with a buffer zone of 5 m. All trees within the treatment plot were measured directly after precommercial thinning and two years after treatment, as a part of a long-term experiment. Measurements were taken by cross-calipering all trees at 1.3 m and registering tree species. Sample trees were selected from the whole diameter distribution and used for height measurements.

Results showed that increased stand diversity could be created through a mixed species strategy in precommercial thinning. The diameter and height distributions were largely unaffected by treatment. Planted spruce had a larger diameter than the naturally regenerated birches, which were more slender and less dominant. Overall, the results were in line with previous studies in southern Sweden. The study was concluded with practical applications and suggestions for future research.

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1. Introduction

1.1 Increasing diversity in production forests

Production forestry provides certain ecosystem services, with timber production as the most important (Felton et al. 2016). In Sweden, production forestry entails clear-cut silviculture, characterized by homogenous stands with diversity provided mainly on landscape level. To avoid a certain negative bias against the name clear-cut silviculture in comparison with other silviculture methods, the name rotational silviculture will be used in this text (see for example Amsalu et al. 2014 and Mason et al. 2021). The main ecosystem services in a rotational system are timber production and carbon storage (Högberg et al 2021).

In rotational forestry, plantation after site preparation is a common practice to aid regeneration and increase production (Hjelm et al. 2019). Even though most stands are planted with only one species, the site preparation is contributing to abundant natural regeneration of broadleaves in the young stands (Holmström et al. 2017). This natural regeneration often provides increased species diversity and some ecosystem services, for example forage for ungulates (Ara et al. 2022b). The natural regeneration in the stand can be either maintained or removed, through the use of different precommercial thinning strategies (Fahlvik 2005).

1.2 Precommercial thinning strategies

In rotational silviculture with focus on timber production, precommercial thinning is performed in the young stand, to shape future stand characteristics (Fahlvik 2005). Desired stand characteristics after precommercial thinning are diameter evenness and large future commercial stems, with well-developed crowns (Rytter & Werner 2007; Hallsby et al. 2015). So-called "wolf trees" which are larger than the others are removed, to give more space and light to the other stems (Fahlvik 2005). According to the National Forest Inventory, the mean annual area that was precommercially thinned was almost 10 % of the managed forest land in Götaland (southern Sweden), during the period 2017 to 2021 (Skogsdata 2023).

Strategies can be designed to promote certain qualities or species (Fahlvik et al. 2015) In the even-aged rotational silviculture system, the aim is to maintain large and even stems, for rationality and profitability in management. Smaller stems are harvested in commercial thinnings, and the undergrowth is normally removed in previous stages, to increase the visibility and productivity of the machine operator (Kärhä 2006).

1.3 Species

In southern Sweden, Norway spruce (*Picea abies* (L.) Karst.) is the dominant tree species (Skogsdata 2023). Norway spruce, hereafter denoted as "spruce", has a large commercial value as timber and is normally established through planting after regeneration cuts ("clearcuts"). Spruce is a semi shade-tolerant species, which can grow also under shelterwood and be tended with different silvicultural methods.

Birch (*Betula* spp.) is the most abundant broadleaved species in Sweden (Skogsdata 2023).The two species *Betula pendula* (Roth), and *Betula pubescens* (Ehrh.) are combined in the National Forest Inventory data and are also in this study denoted as "birch". The growth pattern of the primary species birch differs from spruce, it has a fast initial growth and require lots of light and a well-developed crown (Hynynen et al. 2010).

During precommercial thinning, birches and other broadleaves are often removed due to the risk of whipping damage on the slower-growing spruces (Holmström et al. 2016a). If outgrown, birch has a lower survival when under a dense canopy of spruce (Nilsson et al. 2002). This means that after an initial removal in precommercial thinning, the light-demanding birches have small chances of competing with the shadowing spruces, even though stump sprouting occurs (Holmström et al. 2016a). Therefore, the future species mix is decided with the precommercial thinning strategy.

1.4 Mixed forest

Stand diversity can be maintained through mixed forests. A mixed forest is defined as a stand with a threshold share of the dominant tree species, for example that 75 percent of the basal area is one species and the rest consists of one or more other species (Lee et al. 2023). In southern Sweden, mixed forests make up almost 40 percent of the forest area, with spruce-birch mixtures being the most common coniferous-deciduous mixture (Lee et al. 2023).

Previous studies have shown that there are different precommercial thinning strategies to maintain a tree species mixture into the commercial thinning stage in production stands (Fahlvik et al. 2015; Holmström et al. 2021, 2016a; b). However, studies also shows that the share of birch basal area in the mixed stands decreases with increasing age (Holmström et al. 2021).

The ecosystem services that are gained from mixed spruce-birch stands are primarily more biodiversity compared to a spruce monoculture (Felton et al. 2016; Holmström et al. 2021; Huuskonen et al. 2021). Felton et al. (2016) conclude that mixed forests provide regulating services in the landscape regarding for example soil, water, and fire. Risks are spread out through pest management and resistance, and cultural values are increased (Felton et al. 2016). The increased benefits from creating mixed stands seem to be applicable throughout Fennoscandia (Huuskonen et al. 2021) and both production and profitability could be maintained in a mixed stand of spruce and birch in southern Sweden, when compared to a spruce monoculture (Ara et al. 2022a).

1.5 Height and diameter diversity

Another way to create stand diversity is through a wide height distribution. Height diversity provides habitats and biodiversity (Lei et al. 2009). Stem height can be linked to stem diameter, and there are several models used for predicting height based on diameter, i.e. Näslund (1947). Precommercial thinning is performed manually, normally in dense stands with bad visibility of the crowns. Therefore, a practical way of creating height diversity is through creating diameter diversity at breast height.

1.6 Other silvicultural systems

The long-term aim of the treatment Mix-Uneven in the field experiment is to create a stand with the potential to be managed with types of continuous cover forestry. Continuous cover forestry (CCF) entails different silvicultural systems, where the two most important characteristics are a maintenance of constant canopy coverage and a larger diversity in tree diameter distribution than in a rotational stand (Pommerening & Murphy 2004). Important ecosystem services from CCF are habitat continuity for shade-dependent species and soil preservation, together with timber production and some amenity values (Hertog et al. 2022).

CCF entails single tree selection with shade-tolerant species, which in Fennoscandia means spruce (Lundqvist 2017). Trees are harvested based on cutting classes, commonly based on diameter. A full-storied stand has a diameter distribution of an inversely shaped J-curve, with a large number of small trees and a few large trees (Ahlström & Lundqvist 2015). Harvest is dependent on ingrowth levels, to maintain a continuous state in the forest and decrease neither the standing volume nor the production.

One management system within CCF is non-clearcut silviculture. Non-clearcut silviculture is defined per Swedish forestry authorities as land managed with a long-term intention a continuous tree cover and gap sizes of maximum 0.25 hectares (Appelqvist et al. 2021). Different types of shelterwood are included in the definition, with a minimum density regulated by §5 in the Swedish Forestry Act (SFS 1979:429). This theoretically allows the use of primary species also within the non-clearcut silvicultural system. A potential conversion to non-clearcut forestry using a mixed stand will be tested long term with the Mix-Uneven treatment. The short-term diversity changes after PCT will be presented and discussed in this study.

1.7 Thesis aim

The aim of my study is to investigate if more stand diversity can be created through different strategies of precommercial thinning. Three precommercial thinning strategies were applied as treatments in stands of planted Norway spruce mixed with high densities of naturally regenerated birch. Used selection strategies were I) spruce monoculture with an even diameter distribution and the largest stems, II) mixed stand with only the largest 1/8 of stems, combined with the smallest trees and III) mixed stand an even diameter distribution and the largest stems. Stem densities were 1200 or 1500 stems hectare^{-1} after treatment.

My research questions are:

1. Does the selection strategy change the diameter distribution?
2. Does the selection strategy change the quadratic mean diameter?
3. Is the structure of the mixed forest different in strategies II and III?
4. Has the answers to question 1-3 changed after 2 years growth?

2. Methods

2.1 Experimental sites and treatments

A precommercial thinning experiment on two sites in southern Sweden was used in this study (Figure 1), site 1 in Remningstorp Experimental Forest [Lat: 58.455367, Long: 13.630042, altitude 130 m], and site 2 in Släne [Lat: 57.199040, Long: 12.532439, altitude 150 m]. Mean annual temperature was 6.8°C and 8.3°C, mean precipitation was 651 mm year^{-1} and 853 mm year^{-1} (SMHI, 2022). Average growing season in the region is 237 days year^{-1} (SMHI, 2022). The stands were planted with Norway spruce, site 1 in 2008 and site 2 in 2010, after which spontaneous natural regeneration occurred. At the time of the establishment of the experiment, the natural regeneration consisted mainly of birch. The experiments were established during summertime, site 1 in 2020 and site 2 in 2021.

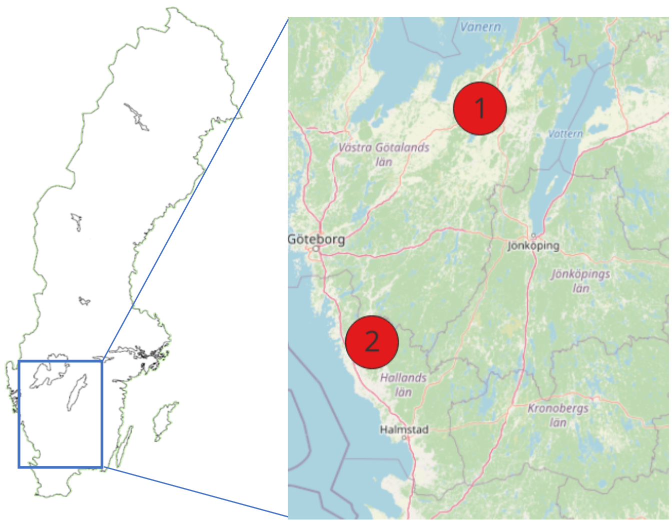

Figure 1. Site location in southern Sweden. Maps from Wikimedia Commons and OpenStreetMap.

Precommercial thinning (PCT) treatments were distributed in a randomized block design, with six blocks placed with minimised variation in site properties within the block (Figure 2). PCT was done manually using a brushsaw, by forest workers with proper training and safety equipment. Treatment plots of 0.08 ha were surrounded by a 5-meter buffer zone with PCT to a mixed forest with stems of both spruce and birch. The target stem density after treatment was 1200 stems ha^{-1} on block 1-3 and 1500 stems ha^{-1} on block 4-6 (Figure 2). The following treatments were assigned randomly within a block:

- Monoculture of spruce, where the largest spruce stems were retained. The strategy aimed for a pure spruce stand within a rotational silviculture system into the commercial thinning stage, and eventually a final harvest of all trees.
- Mix-Uneven. Here only the largest 1/8 of the stems were retained, regardless of species. Then the smallest stems filled up to the target stem density, with a total stem mixture of 1/3 birch. The strategy aimed for a mixed stand with a wide diameter distribution that could convert into a multi-storied forest without a final harvest of all trees.
- Mix-Even. Here the largest trees of both spruce and birch were retained. The strategy aimed for a mixed stand with a narrower diameter distribution within a rotational silviculture system, a maintained species mixture into the commercial thinning stage, and eventually a final harvest of all trees.

In the long-term field experiment, the plan for future stand development is commercial thinning and rotational silviculture in the even-distributed stands. The strategy for treatment Mixed-Uneven had the intention of retaining only a few of the fast-growing spruce trees, which would then grow up without too much of competition and eventually become more wind stabilized, with a cohort of lower understory trees. The aim was that trees could be more easily be harvested in thinnings and non-clearcut silviculture, without creating a risk of windthrow.

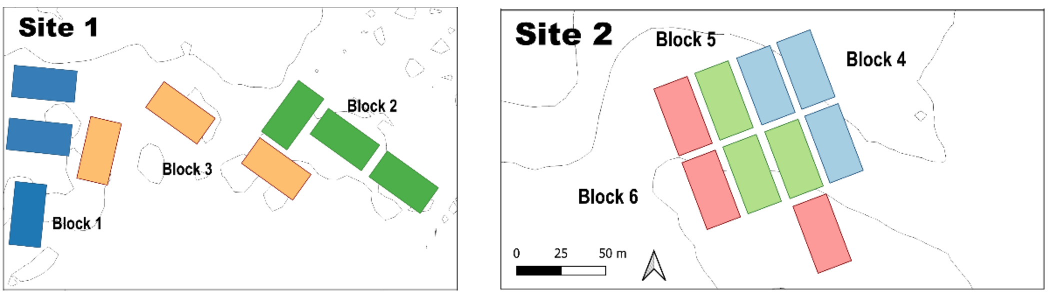

Figure 2. The block layout. Equidistance of 10 m is marked; the scale is consistent over both maps. The buffer zone is 5 meter around the treatment plots.

2.2 Measurements

The sites were measured before and after treatment, and after two growing seasons. Stand data before treatment is presented in Table 1. Measurements before treatment was only used to assess the variance between treatment plots within blocks, which assured that every treatment could be performed in each plot, and that diameter distributions and tree species composition were similar within each block.

After PCT, all stems on the plot were numbered. Diameter was cross-measured with a caliper at breast height and stem height was measured with a Haglöfs Vertex V hypsometer. The breast height diameter will hereafter be written as “diameter”. Height was measured on 20 stratified sample trees per species per plot. The two-year measurements were taken in the end of the growing season 2022 for block 1-3 and in the end of the growing season 2023 for block 4-6. No distinction was made between *Betula pendula* and *Betula pubescens* in the data, they were both recorded as birch.

Table 1. The blocks before treatment. Stem density (N ha^{-1}), mean diameter (d) and standard deviation (sd) per species. Birch percentage (%) was based on stem number. The diameters are rounded off to centimeters to give an easier overview.

Site	Block	N ha^{-1}	Spruce		Birch		
			Mean d ± sd (cm)	N ha^{-1}	Mean d ± sd (cm)	N ha^{-1}	Birch (%)
1	B1	5 666	4 ± 2	1 433	2 ± 1	4 233	75%
1	B2	6 500	4 ± 2	1 367	2 ± 1	5 133	79%
1	B3	12 466	5 ± 2	1 833	2 ± 1	10 633	85%
2	B4	6 733	4 ± 3	2 700	3 ± 1	4 033	60%
2	B5	6 933	3 ± 2	3 667	3 ± 2	3 266	47%
2	B6	6 433	3 ± 2	1 600	3 ± 2	4 833	75%

2.3 Data analysis

To evaluate the performance of the PCT strategies three different central tendencies were compared; quadratic mean diameter (QMD), arithmetic mean diameter (AMD) and median diameter. A linear mixed-effect model was developed for statistical analysis of stand characteristics as a result of PCT treatments. Analysis of variance (ANOVA) with $\alpha = 0.05$ was used species-wise per the different years (Function 1).

$$y_{ijk} = \mu + b_i + c_j + d_k + \varepsilon_{ijk} \quad (1)$$

Where y_{ijk} is the response variable, μ the mean value, b_i the treatment effect of precommercial thinning strategies, c_j the density effect, d_k the random block effect and ε_{ijk} a random error term for observation ijk. The tested response variables were QMD, AMD, median diameter, basal area and stem taper.

2.3.1 Quadratic mean diameter and species mixture

Quadratic mean diameter (QMD) was used for the diameter comparison. QMD is the diameter corresponding to the mean basal area tree and basal area is defined as the sum of area per hectare that is covered by trees. Basal area (m^2 $hectare^{-1}$) was calculated for each treatment plot as the sum of the basal area of all calipered trees (BAtree). The BAtree was calculated with the measured diameter (Function 2) and divided with the stem density (N $hectare^{-1}$) to calculate the QMD (Function 3).

$$BAtree = \pi \times (d/2)^2 \times 0{,}0001 \quad (2)$$

Where BAtree is the basal area per tree (m^2) and d is the calipered diameter (mm)

$$QMD = \sqrt{\frac{\sum BAtree \times 4}{N \times \pi}} \quad (3)$$

Where QMD is the quadratic mean diameter, BAtree is calculated in Function 2 and N is the stem density per hectare.

The structure of the mixed forest was described as the relative size between the two species spruce and birch, and here calculated as the proportion of the QMD of birch divided by the QMD of spruce (QMDratio). The QMDratio was used as an indicator for differences in the structural species mixture between treatments. A high QMDratio (above 1) indicates that the birch stems are thicker than the spruce and more dominant. A QMDratio below 1 indicates the opposite.

2.3.2 Basal area growth

To estimate the stand basal area growth, the difference in total basal area per treatment and block was calculated between after treatment (Year 0) and after two years (Year 2). To harmonise the values with forestry practise, the basal area in m^2 was divided by the treatment plot and block size respectively, to get m^2 $hectare^{-1}$ values. Function 1 was used and analysis of variance (ANOVA) was performed species-wise, with treatment, density and block as factors ($\alpha = 0.05$).

2.3.3 Height estimation

Stand heights were estimated from measured diameters using Näslunds height function (Function 3, Näslund 1947). The height and diameter of the sample trees were used to acquire the needed parameters a and b per species, (Holmström et al. 2016a). All functions were visually evaluated comparing estimated and measured heights for the sample trees. After constructing height to diameter functions for species, treatment plots and years respectively, based on the sample trees, all calipered trees were given an estimated height.

To evaluate the stem taper, a height-diameter ratio was calculated per sample tree through dividing the measured height in meters with the measured diameter in cm, and then summarised per species, block, and treatment.

$$EstHeight = 1.3 + \frac{d^2}{(a + b * d)^2} \tag{3}$$

Where EstHeight is the estimated height, d is diameter (cm) and a and b are coefficients.

3. Results

3.1 Diameter distribution

Different selection strategies in the precommercial thinning did not change the range of the diameter distribution in two planted stands of Norway spruce with natural regeneration of birch (Figure 3, page 20). There were more small stems of spruce in the monoculture than in the mixed species strategies, where the small stems were birch. Spruce diameter was higher than birch diameter, independent of treatment or stem density. Diameter tendencies are presented species-wise in Table 2 and 3. The results are converted from millimetres to centimetres for increased readability and connection to practical forestry. See Table 6 (page 19) for p-values from the ANOVA.

Selection strategies did not significantly change the spruce quadratic mean diameter (QMD) or arithmetic diameter (AMD) directly after treatment (Table 2, Table 6). Diameter tendencies were significantly higher in the density 1500 stems ha^{-1} than 1200 stems ha^{-1} across all treatments, which is likely a site effect and will be further commented in the discussion.

Table 2. Quadratic mean diameter (QMD), arithmetic mean diameter with standard deviation (AMD ± sd), and median diameter for spruce per treatment and stem density

Spruce	Density (N ha^{-1})	QMD (cm)	AMD ± sd (cm)	Median d (cm)	QMD (cm)	AMD ± sd (cm)	Median d (cm)
		Year 0			Year 2		
Monoculture	1200	5.0	4.8 ± 1.4	4.7	8.8	8.6 ± 1.6	8.3
	1500	6.5	6.3 ± 1.4	6.2	9.1	8.9 ± 1.9	8.7
Mix-Uneven	1200	5.6	5.4 ± 1.5	5.2	8.0	7.8 ± 1.9	7.8
	1500	6.3	6.1 ± 1.7	6.0	9.2	9.0 ± 2.0	9.0
Mix-Even	1200	5.8	5.7 ± 1.2	5.6	9.0	8.9 ± 1.7	8.9
	1500	6.8	6.6 ± 1.5	6.7	9.5	9.3 ± 1.8	9.4

Birch diameter tendencies QMD and AMD were not significantly different, but the median diameter was larger in the 1500 stems ha^{-1} treatment (Table 3, Table 6). After two years, there were no differences in QMD, AMD or median diameter.

After treatment, the QMDratio differed between Mix-Uneven (0.8) and Mix-Even (0.7), but after two years the birch QMDratio was 0.8 in both treatments. Since it is below 1, it indicates that the birches were smaller and less dominant.

Table 3. Quadratic mean diameter (QMD), arithmetic mean diameter with standard deviation (AMD ± sd), and median diameter for birch per treatment and stem density

Birch	Density (N ha^{-1})	QMD (cm)	AMD ± sd (cm)	Median d (cm)	QMD (cm)	AMD ± sd (cm)	Median d (cm)
		Year 0			Year 2		
Mix-Uneven	1200	4.1	3.9 ± 1.4	3.7	6.6	6.3 ± 2.0	5.9
	1500	5.2	4.8 ± 1.5	4.7	7.6	7.4 ±2.0	7.2
Mix-Even	1200	4.0	3.9 ± 1.2	3.7	6.4	6.3 ± 1.5	6.0
	1500	4.8	4.7 ± 0.8	4.6	7.1	7.0 ± 1.2	6.9

3.2 Basal area growth

Basal area per species did not vary significantly between treatments or densities after treatment or after two years (Table 4, p-values in Table 6). When combining the values of the separate species in Table 4 for the basal area and growth of the entire stand, there were no significant differences between treatments in stand basal area at Year 0 ($p>0.731$), basal area at Year 2 ($p>0.720$) or mean annual basal area growth ($p>0.072$). There were significant differences between stem densities in stand basal area at Year 0 ($p<0.023$), basal area at Year 2 ($p<0.027$) and mean annual basal area growth ($p<0.041$). Basal area for the total stand is presented in the appendix.

Table 4. Basal area per species and year for different treatment and densities. Mean annual basal area growth over the two-year period.

	Density (N ha^{-1})	Spruce basal area (m^2 ha^{-1})		Growth (m^2 ha^{-1} $year^{-1}$)	Birch basal area (m^2 ha^{-1})		Growth (m^2 ha^{-1} $year^{-1}$)
		Year 0	Year 2		Year 0	Year 2	
Monoculture	1200	2.36	6.03	1.83			
	1500	4.93	9.99	2.53			
Mix-Uneven	1200	2.04	4.93	1.45	0.55	1.39	0.42
	1500	3.07	6.42	1.68	1.05	2.25	0.60
Mix-Even	1200	2.16	5.28	1.56	0.52	1.31	0.40
	1500	3.66	7.25	1.79	0.88	1.94	0.53

3.3 Height distribution and stem taper

The mean estimated heights and standard deviation were the same among all treatments and species (Table 5). The birches in the Mix-Even treatment were not higher than the ones in Mix-Uneven, however the distribution was slightly narrower (Figure 4, page 20). The stem taper differed between species and the mean measured height-diameter ratio was lower for the spruces than for the birches, showing that the birches were more slender. For spruce, the stem taper was 1 in Monoculture and Mix-Uneven and 0.9 in Mix-Even. There was no significant difference between treatment but a significant density effect. After two years, the ratio was lowered to 0.8 in Monoculture and Mix-Even and remained 0.9 in Mix-Even, however the difference was not statistically significant.

For birch, the mean measured height-diameter ratio was 1.3 for both treatments, with a significant density effect. After two years, the stem taper was lowered to 1, with no significant differences for either density or treatment.

Table 5. Mean estimated height and standard deviation per treatment and species directly after treatment (Year 0) and after two years growth (Year 2).

	Mean estimated height ± sd (m)			
	Spruce	Birch	Spruce	Birch
	Year 0		Year 2	
Monoculture	5 ± 1	-	7 ± 1	-
Mix-Uneven	5 ± 1	5 ± 1	7 ± 1	7 ± 1
Mix-Even	5 ± 1	5 ± 1	7 ± 1	7 ± 1

Table 6. P-values from ANOVA of the effect of treatment and density on tested parameters per year, divided by species. Statistically significant (p<0.05) values are marked in bold.

		Spruce		Birch	
		Treatment	Density	Treatment	Density
QMD	Year 0	0.359	**0.046**	0.347	0.112
AMD	Year 0	0.309	**0.049**	0.397	0.072
Median d	Year 0	0.161	**0.029**	0.500	**0.048**
Basal area	Year 0	0.333	0.065	0.375	0.096
Stem taper	Year 0	0.550	0.234	0.058	**0.004**
QMD	Year 2	0.319	0.130	0.334	0.148
AMD	Year 2	0.286	0.134	0.459	0.133
Median d	Year 2	0.241	0.107	0.795	0.123
Basal area	Year 2	0.225	0.082	0.351	0.102

Stem taper	Year 2	0.771	**0.003**	0.773	0.365
Basal area growth	Difference	0.142	0.130	0.327	0.110

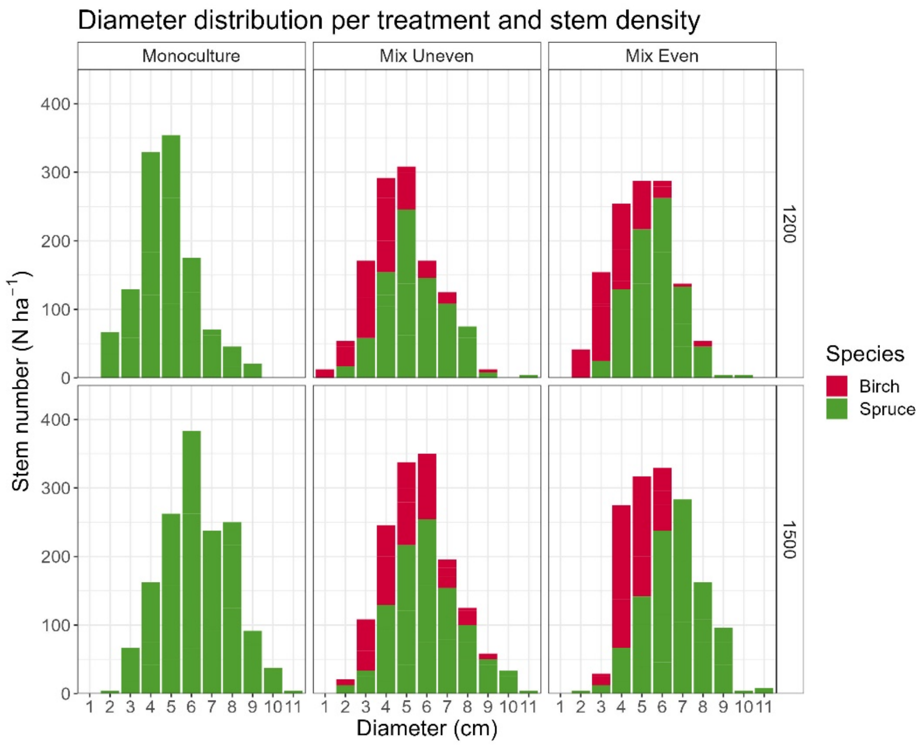

Figure 3. Diameter distribution after treatment per treatment and stem density. The stem number is per hectare values.

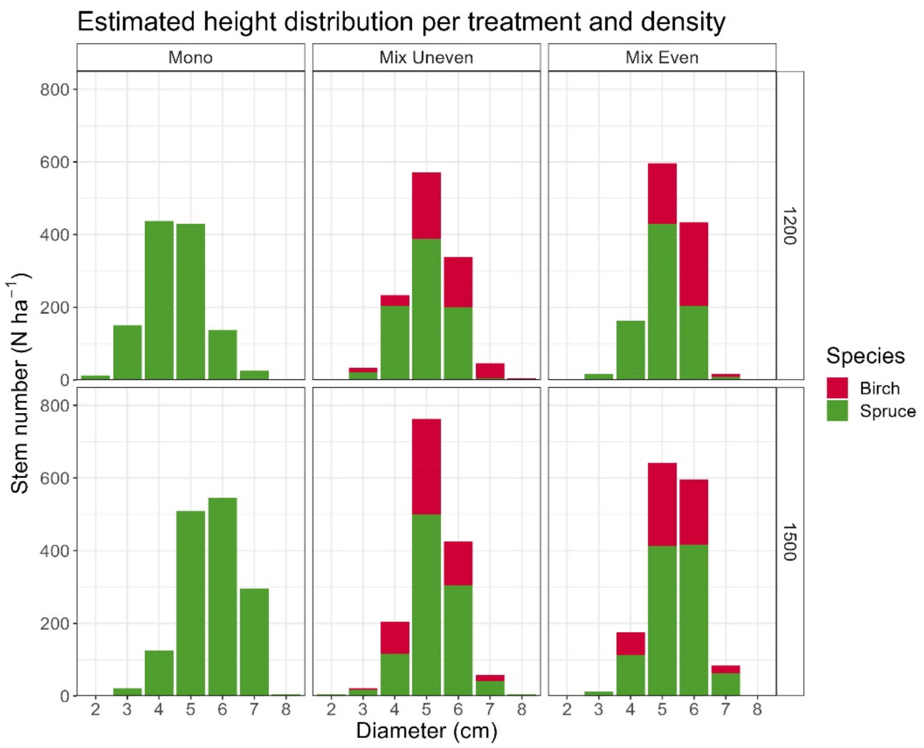

Figure 4. Estimated height distribution after treatment with heights per treatment and stem density.

4. Discussion

4.1 Overall aim

The aim of this thesis was to investigate if increased stand diversity could be created through different strategies of precommercial thinning (PCT) in a planted stand of Norway spruce with natural regeneration of birch. This was done through examining the parameters of diameter distribution, quadratic mean diameter, and mixed species ratio, both directly after treatment and after two years.

4.2 Diameter distribution

Different precommercial thinning strategies did not affect the diameter distribution in a planted Norway spruce stand with natural regeneration of birch. There was variation of the distribution between the densities, but no clear trends could be distinguished in Figure 3. Density was site-wise, so the effect is likely from site rather than spacing, since the mean diameters were larger in the denser spacing.

Spruce diameter distribution was generally unaffected, and the bar charts show similar distribution patterns across all treatments per density. The mean diameter per species was not affected by treatment. There is little previous research on PCT strategies in mixed stands to create a multilayered forest to compare with, but that the diameter of planted spruce is not affected by PCT treatment is consistent with previous research on spruce growth in mixed stands after precommercial thinning (Fahlvik et al. 2005, 2015; Holmström et al. 2016a).

Since there is limited previous research on the topic of precommercial thinning strategies to create diameter distribution in mixed stands, this result is interesting. Nilsson et al (2002) showed that the survival of birch is negatively correlated with the density of spruces in a two-storied stand. The young stands in this study were in one story so the results are not entirely comparable. The larger birches might persist and add ecosystem services to the future thinning stand, which would be in accordance with previous studies (Fahlvik et al. 2005), however the small birches might die due to competition.

When only looking at small diameter trees, below 5 cm, the distribution was similar between treatments, but the monoculture had more small stems of spruce than the mixed species treatments, where small stems were birch. This could be explained with the limited possibilities for stem selection in the monoculture strategy, where small spruces were retained that might have been removed in favour for a birch in the mixed treatments. Therefore, diameter distribution could be created through a species selection strategy, through a stem density goal.

4.3 Mean diameter tendencies

That the quadratic mean diameter (QMD) did not differ within species after treatment is in line with previous studies (Holmström et al. 2016b). Using basal-area weighted diameters is common in the forest research field, due to better providing the commercial stem data which is interesting for practical forestry. There were only small differences between QMD, arithmetic mean diameter (AMD) and median diameter. Since one of the treatments had the aim of creating large diversity, the small differences were captured through the usage of three different diameter tendencies.

4.4 Basal area growth

Neither the stand basal area growth nor the mean height growth was affected by PCT strategy. The birches gave a smaller stand basal area increase than spruces, likely due to fewer trees with smaller basal area at the start, but the stand growth was the same when combining both species. That the growth was not decreased by the retention of birches and small trees gives management opportunities of increasing ecosystem services after PCT without growth loss. However, this can also only be because of the short time since treatment and has to be further evaluated in the coming years.

Nonetheless, that the growth was not impacted by the strategies in this study also shows that there are small chances of quickly shaping a conversion to continuous cover forestry using PCT strategies.

4.5 Height distribution

As seen in Table 4 and Figure 4, the mean heights and height distributions did not differ between treatments. Heights were estimated based on the diameters; therefore, the distribution was expected to follow diameter distribution. The stem taper, calculated as the height-diameter ratio, differed for spruce and birch. That the birches were more slender than the planted spruces might give future stability differences, which should be further examined.

4.6 Limitations and suggestions for future research

The choice of method is similar to other studies in precommercial thinning, but most studies span over more than two years after growth. The short time frame can be explained with the need to investigate early results and an opening up of new research questions for future studies. For example, previous studies about mixed forests and precommercial thinning have used the data after PCT to simulate future growth (Holmström et al. 2016b; Rytter & Werner 2007). The early revision results used in this study could further strengthen the study design in future simulation studies.

When further revisions are made in this experiment, birch crown length would be an interesting parameter, especially in combination with stem taper. The crown lengths can be used to be able to predict the competitiveness of the broadleaves in a future mix, since they regulate the birch growth capacity and indicate growing space. Small crowns on slender stems are an indicator for too dense stands and might give stability issues after commercial thinning. Whipping damage is another parameter that have been included in previous studies (Fahlvik et al. 2015; Holmström et al. 2016a). To investigate whipping damage in the mixed stands along a slope gradient could impact the practical application of the different PCT strategies. Browsing damage could also be examined to nuance the findings in this study, and also the possibilities of the different PCT strategies to create food for ungulates, an important ecosystem service (Holmström et al. 2016b; Ara et al. 2022b).

4.6.1 Conversion to non-clearcut silviculture

In the report by Appelqvist et al. (2021), the precommercial thinning stage is stated as the earliest possible stage to define non-clearcut silviculture, and the long-term intention of management is a part of the definition. The Mix-Uneven strategy has the long-term objective of a multi-storied stand where non-clearcut silviculture could be used. The Mix-Uneven treatment could therefore be classified as non-clearcut silviculture, despite not showing any differences in the examined parameters from strategies aimed at rotational silviculture strategy after two years.

For a conversion to non-clearcut silviculture, the Monoculture strategy could be argued to be a better option than the Mix-Uneven. This is due to more small spruces with good possibilities to survive and create a wider future height distribution. On the other hand, the gaps after dying suppressed birches in the mixed stands could provide some additional light which might favour a secondary spruce regeneration, compared to a dense spruce monoculture. This way, a very wide diameter distribution might be created long-term, and the Mix-Uneven treatment might be a suitable strategy to create a long-term conversion to non-clearcut silviculture. Further revisions of this field experiment are advised. This study shows that there are small chances of a short-term conversion to non-clearcut silviculture using precommercial thinning strategies. Both the time aspect of a conversion to non-clearcut silviculture and the definition of what entails a conversion stand needs to be further examined.

Conclusions

In this study, three types of precommercial thinning strategies were compared to evaluate the possibilities to create a more diverse stand from a planted spruce monoculture.

- Different PCT strategies did not create more diversity in stand structures in a planted stand of Norway spruce directly after treatments or after two years. The indicators diameter distribution, height distribution, mean diameter and growth were unaffected by the PCT strategies. There were some small differences after PCT, for example small stems constitution, that could give increased ecosystem services, but the overall stand followed the same distribution.

- The mixed species PCT treatments provided birches in the mix, which provides increased ecosystem services compared to monocultures.

That there were no visible effects of treatment is interesting from a forestry perspective.

- Since the diameter distribution and growth were not affected by PCT strategy, monocultures could be replaced with mixed species stands for increased ecosystem services without production losses.

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Röj fram fler olikheter!

Går det att röja fram en mer varierad skog ur en granplantering? Det var frågan jag hade som utgångspunkt i min examensuppsats på Jägmästarprogrammet. Jag har tittat på hur man kan skapa större skillnad inom ett planterat granbestånd med olika typer av röjning. Ett röjningsexperiment på två platser i Götaland var utgångspunkten, med väl växande gran och självföryngrad björk som röjdes på tre olika sätt. Resultatet var intressant. I medeltal blev det nämligen ingen skillnad i vare sig trädens storlek eller tillväxt, trots att röjningarna skilde sig åt markant.

De tre röjningsstrategierna som använts var att röja fram: 1) en granmonokultur genom björksanering, 2) en blandskog med bara 1/8 av de största träden kvar och resten mindre stammar av både gran och björk, och 3) en blandskog med jämna, stora stammar sparade. Tätheterna 1200 och 1500 stammar/ha testades. För ögat såg bestånden olika ut, men mätvärdena visade att tillväxten faktiskt var precis densamma och att medelvärdena på träden var lika stora sett till både diameter och höjd.

Syftet med att skapa en blandskog med gran och björk är att få in andra värden än vad man får av en ren monokultur. Det finns forskning från både Sverige och Finland som visar att det finns många fördelar med ett blandbestånd av gran-björk. Till exempel skapas fler livsmiljöer och motståndskraften mot enskilda skadegörare ökar. Riskerna sprids ut, viltet gynnas och marken utnyttjas bättre genom att en dålig gran kan ersättas av en bättre björk. Det låter ju bra, eller hur? En aspekt som jag inte har tagit upp i arbetet är att skogen dessutom blir ljusare och vackrare. Nog så viktigt för den privata markägaren!

Eftersom tillväxten inte sänktes av en ojämn röjning så finns det goda möjligheter att med röjsågens hjälp skapa mer variation. Det kan alltså ske både inom ramen av en produktionsskog och för andra mål. Förutom trädslagsblandningen kan man skapa en större diameterfördelning, genom att spara vissa stammar som man annars hade tagit bort. Av det kan man få lite olika fördelar. Till exempel var det långsiktiga målet med en av röjningarna i fältförsöket att möjliggöra en omställning till hyggesfritt skogsbruk. Min studie löpte bara över två år, och kan därför inte ge några direkta svar på hur en omställning kan ske. Men en intressant sak med definitionen av hyggesfritt är att den omfattar den långsiktiga intentionen. Så trots att det inte fanns några mätbara skillnader mellan en

Slutsatsen som jag drog i min uppsats är att det är de grövsta stammarna av det dominerande trädslaget som också utgör det mesta av tillväxten i beståndet. Eftersom tillväxten faktiskt inte påverkades så finns det utrymme att röja fram olikheter. Det går att spara björkar och små träd, utan att huvudstammarna eller grundytan påverkas. Piskskador och kronlängd var två aspekter som jag inte mätte, det vore intressant att studera i framtida projekt. Det här försöket gjordes i planterad granskog på höga boniteter i Götaland, och det vore spännande att testa vad som händer i Svealand och Norrland, där förutsättningarna är annorlunda. De planterade granarna hade ett tydligt försprång mot björkarna. Därför vore det intressant att undersöka förutsättningarna även i ett naturligt föryngrat bestånd.

Min uppmaning till markägare och bolag är att våga röja fram mer olikheter i sina bestånd!

Appendix

		Total stand		
	Density (N ha^{-1})	Year 0	Year 2	Mean annual difference m2/ha/year
Monoculture	1200	2.36	6.03	3.67
	1500	4.93	9.99	5.06
Mix-Uneven	1200	2.59	6.32	3.73
	1500	4.12	8.67	4.55
Mix-Even	1200	2.68	6.59	3.91
	1500	4.54	9.19	4.65

Table 1. Basal area per year and mean annual basal area growth of both spruce and birch combined per treatment and density.

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