The ability to create mixed stands by planting Norway spruce and Scots pine every second row

Eva Higgins Andersson

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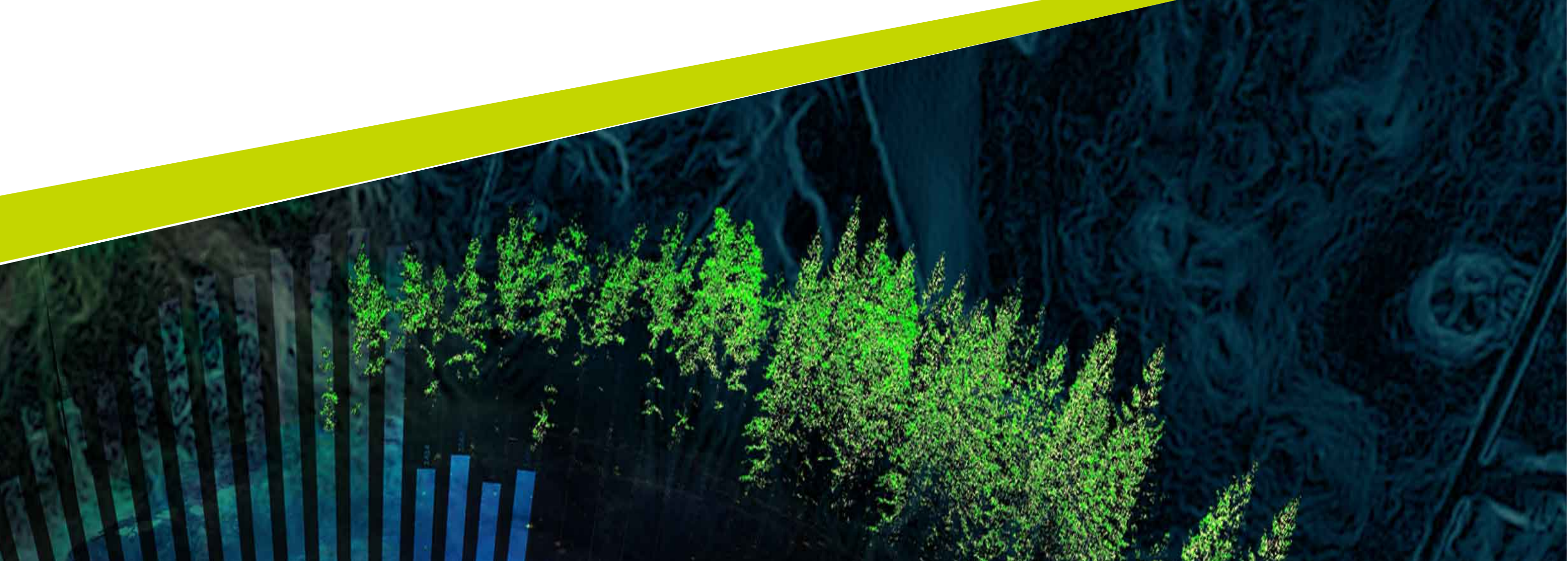

The ability to create mixed stands by planting Norway spruce and Scots pine every second row

Möjligheten att skapa blandskogar genom plantering av tall och gran varannan rad

Eva Higgins Andersson

Supervisor:	**Karin Hjelm, Swedish University of Agricultural Sciences, Southern Swedish Forest Research Centre**
Assistant supervisor:	Stefan Mattsson, Sveaskog
Assistant supervisor:	Erik Nyberg, Sveaskog
Examiner:	Martin Goude, Swedish University of Agricultural Sciences, Southern Swedish Forest Research Centre

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Swedish University of Agricultural Sciences
Faculty of Forest Sciences
Southern Swedish Forest Research Centre

Abstract

Swedish forests primarily consist of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.). Scots pine grows in stands with lower site index and Norway spruce in stands with higher site index. Despite the differences both tree species can co-exist naturally in Sweden. Pine and spruce mixed stands have a higher biodiversity than monocultures. Pests and pathogens usually spread from one tree to another of the same species. A mixed forest is more resistant to pests and pathogens due to the mix of tree species, making it more difficult for pests and pathogens to spread through the stand. The disadvantages with mixed stands could be the decrease in volume production and increase of cutting costs. Important to remember is that mixed stands can spread financial risks and help forest managers move decision making into the future depending on the development of the stand.

The main purpose of the thesis was to examine if Scots pine and Norway spruce planted every second row could be a way to create mixed stands in central Sweden. Ten stands owned by Sveaskog planted every second row with 2 000-2 300 pine and spruce seedlings ha^{-1} were examined. The stands were planted 2009-2012 in Hälsingland and Dalarna, the site index varied from T19 to T24 and G18 to G27. A goal was set to reach 2 000 stems ha^{-1} after pre-commercial thinning. A regression analysis showed that the number of pine stems was gradually decreasing as site index increased. Spruce stems were gradually increasing as site index was increasing. The correlation was only 5-10% however the decrease in pine stems and increase in spruce stems was significant for both tree species. Breaking point seemed to be at approximately T22 and G22 where the number of pine stems increased below T22, and the number of spruce stems increased above G22.

When site index varied within the stands, it showed in number of stems per tree species selected to create future stands. Spruce was higher in number of stems in plots with higher site index and pine was higher in number of stems in plots with lower site index. Height difference between pine and spruce needed to be less than one meter for one tree species not to take over in the future stand. The mean height for all stands were within the one-meter span. In summary, planting Scots pine and Norway spruce every second row in central Sweden to create mixed species stands was successful within the site index variation in this study.

Keywords: Local site index, seedlings every second row, regeneration, biodiversity, climate change and establishment.

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Abbreviations

DBH	Diameter at Breast Hight
IPCC	Intergovernmental Panel on Climate Change
PPS	Probability Proportional to Size
SI	Site index
SLU	Swedish University of Agricultural Sciences

1. Introduction

Swedish forest industry has been very important both historically and today to the Swedish economy. The demand for wood products in Europe increased at the end of the 18th century. Swedish forests became interesting at the time to fulfil the demand. The forest industry increased rapidly, and the wood products exported from Sweden increased ten times during 1828 to 1958 to 5 million m^3 (Fryk & Nylinder 2017). Numerous people were employed by the forest industry and it was looked upon as the backbone for the industrialisation of Sweden.

The Swedish land area is 40,7 million hectares of which 23,5 million hectares is production forest (SLU 2022). The standing volume has increased from 1 720 million m^3sk in mid 1920s to 3 551 million m^3sk today. Forests in Sweden are dominated by Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.). More than 80% of the standing volume consists of these species, approximately 40% of pine and 40% spruce. Monocultures of Norway spruce and Scots pine are the most common forests in Sweden (Felton et al. 2016). Commercial forests are usually monocultures all over the world to maximize the standing volume (Morag et al. 2017). However, pine-spruce forests are one of the most common mixed forest types in Europe. Both tree species are very important for wood supply (Drössel et al. 2018).

1.1 Scots pine and Norway spruce Biology

Scots pine is a pioneer species that needs a lot of light especially in the early stage as small seedlings (Skogsstyrelsen 2013). It is also tolerant to frost and grow well in sites with low site index. Site index is a way to classify the quality of a site/stand, how much standing volume the site can produce over a 100-year span (Skogsstyrelsen 2017). For example, a pine seedling planted on site index T-20 reach the height of 20 m after 100 years. Scots pine has a deep root system and ability to stop respiration to prevent water loss, that enables Scots pine to grow in areas with a wide range of site conditions. The deep roots protect the tree from falling during hard winds and the thick bark protects it from forest fires.

Norway spruce is a late successional species that can grow in shade (Skogsstyrelsen 2013). However, it is possible to plant seedlings of Norway spruce in open scarified stands and expect the seedlings to grow well if the climate is not too cold with frosty nights during the growth period. Norway spruce needs water continuously to grow well and produce most stem volume on higher site index where for example bilberries are growing. The root system is normally shallow which makes Norway spruce sensitive to wind throw and difficulties to reach water deep down in the ground. Norway spruce can look very different in different locations due to its ability to adjust the shape of the crown to snow, wind and sun angle. The crown is large and has a shape of an umbrella to absorb the sunlight in southern Sweden where the sun is high in the sky. In the northern parts of Sweden Norway spruce is tall and thin due to the low sun angel, snow and wind. The thin trees make it easier for the snow to fall off and the wind cannot blow over the trees as easy as if the trees were wider.

1.2 Mixed forests

Rotation period for trees and stands are from 70 to 100 years. Mixed species stands are a way to spread the risks over the rotation period. Forest managers can leave decision making further in the future depending on the condition of the stand due to abiotic, biotic and financial risks. During pre-commercial thinning and commercial thinning, the forest manager can decide which tree to remove and to keep. Homogeneous stands are not as flexible, forest managers can decide which tree to remove and keep however the forest manager only has one tree species to choose from. Mixed species stands give more flexibility in forest management and can help create a more resistant forest to prepare for future climate change, biotic and-, abiotic damage and financial risks.

Volume production
Scots pine and Norway spruce can co-exist in a wide range of sites with different site index. Both species can grow naturally in same sites with mediocre site index in Sweden (Drössler 2018). Research in Vindeln situated in northern Sweden showed that mixed Scots pine and Norway spruce stands had similar volume as homogeneous stand. However, the basal area weighted mean was 30% higher in mixed stands than pine monocultures, in 43-year-old stands on site index T27 (Jonsson 2010). It is now important to remember that pine and spruce grow better in different site conditions. Mixed stands on a dry location naturally bring down the production if Norway spruce is mixed with Scots pine in a stand not suitable for spruce. Spruce grows well in stands high in moisture content with easy access of nutrition. Adding pine would also bring down the average production in a stand not suitable for pine.

Jonsson (2013) examined an experiment in central Sweden (Sandviken) showing that 43-year-old Scots pine was growing faster in height and diameter than Norway spruce in mixed stands (site index T26,9 and G24,6). Scots pine in monoculture were taller than in mixed stands due to lack of light competition from other trees. However less competition for nutrients in mixed stands lead to larger diameter (DBH) for the Scots pine. Total volume yield was higher in mixed stands than average yield in Scots pine and Norway spruce monocultures, mainly due to the larger Scots pine trees in the mixed stands. Larger diameter brings in more revenue. However, total volume in mixed stands was lower than total volume in Scots pine monocultures. Norway spruce had a slow start, volume growth was increasing later. Scots pine had an early start and culminated according to Jonsson (2001). Nilsson (2020) found that Scots pine in monoculture plots after 57 years generated 126% more standing volume than Norway spruce during his research in Fremlingshem. There are other studies done all over Europe showing that mixed pine and spruce stands do not generate higher volume than monocultures, and most sites in Sweden in the study did not produce higher volume according to Drössler et al. (2018).

Financial security and logging costs
Logging costs depend primarily on methods used and size of the trees harvested (Brunberg & Arlinger 2001). Normally a harvester and a forwarder are used to cut and bring the logs to the forest road. The logs are placed in timber rolls according to assortment. Increased cost per assortment was approximately 1% during harvesting and 3-4% during forwarding. According to Felton et al. (2016) the additional assortment for Scots pine and Norway spruce mixed stands was expected to increase logging costs during thinning with approximately 0-2% and at final felling by 0-6%.

It is very difficult for forest managers today to predict the future timber prices (Felton et al., 2016). Trees are harvested approximately 70-100 years after they were planted. Mixed stands can reduce the economic risk. If the price is going up for one species and down for the other the forest manager has a chance to favour the more profitable tree species in the management regime during the growth period. Pests, pathogens, windthrow, forest fires and climate change are all difficult to predict and mixed species stands could be a way to spread the risks

Biodiversity
There have not been many studies looking at mixed forests in Sweden. However, Felton et al. (2016) studied the difference between Norway spruce monocultures in southern Sweden and mixed pine-spruce forests. The biodiversity was higher in mixed forests than Norway spruce monocultures due to a wider range of environmental conditions that lead to a variety of habitats. Norway spruce and Scots pine are both conifer species similar in terms of shape, the way they grow and genetic background, which can make it more beneficial for the biodiversity to mix conifer species with broad leaf species. A positive effect for the biodiversity is expected by mixing Scots pine and Norway spruce due to the differences in bark and the property of dead wood. The crown structure also differs between the species, affecting the soil conditions and micro-climate. Scots pine let through more light and precipitation than Norway spruce, mixing the species changes the amount of light and precipitation reaching the ground. Older Scots pine and Norway spruce trees host different lichens and bryophytes. Mixed Scots pine and Norway spruce stands also had higher bird species diversity (Felton et al., 2016).

Climate change, biotic and abiotic risks
Climate change is expected to bring elevated temperatures, approximately 7,8 °C in Europe by year 2100 according to Intergovernmental Panel on Climate Change (2013). The climate change is not only expected to bring higher temperatures and changes in precipitation, it can also affect frosts and storms (Blennow & Olofsson 2008). Increase in temperature and CO_2 in the atmosphere can lead to an increased growth rate by 15-55% in Sweden by the end of this century according to process-based models (Subramanian, 2015). The climate change can also bring pests, pathogens and storms that we have not had previously in Sweden (Skogsstyrelsen 2006).

Pests and pathogens are usually species or genus specific (Morage 2017). By planting different species, the forest manager is spreading the risks if pests and pathogens infest the forest stand. Research has shown that local tree diversity can decrease fungal pathogen infestations and species richness has shown higher resistance to insect pests. The probability that a pathogen will infect a suitable tree is lower if the tree is in a stand mixed with trees that the pathogen does not infest. However, Drössler et al. (2018) found that browsing has shown to be higher or similar in mixed stands than in spruce monocultures.

2. Thesis aims

Stands with mixed species are beneficial for biodiversity and more resistant to forest fire, wind throw, pests and pathogens. It is also important to spread the risks climate change might bring. Financially it is also a good idea to spread the risks over more species.
Seedlings planted today are expected to grow for the next 70-100 years, and it is difficult to predict the future conditions for these plants.

The goal of the thesis was to examine if Scots pine and Norway spruce planted every second row could be a way to establish mixed stands in central Sweden. Sometimes it is difficult to decide if Scots pine or Norway spruce will grow better on a mediocre site index, therefore a mixed spices stand could be a good start. It is almost impossible for a forest manager to know how a stand develop over the next 70-100 years. If one tree species gets infested by pests and pathogens or if the price goes up for one tree species and not the other. When the stand reaches later stages it is possible to choose species composition during pre-commercial thinning and commercial thinning. Mixed stands are a way to prepare for future risks and push decision making further into the future when the forest manager has more knowledge of how the stand has developed.

This study investigated the mix of Scots pine, Norway spruce and birch. The mix could vary over the stand depending on the local site index. As an example, pine could dominate a dry area, spruce the moist and a more wet part could have 100 % birch. Scots pine and Norway spruce have different biology and co-exist naturally in Sweden. There has not been much research on how to create mixed species stands in Sweden. It is therefore important to examine if the method to plant pine and spruce every second row is a way to create mixed species stands. Mixed species stands are higher in biodiversity, a way to spread risks and could be a way to prepare for expected climate change. Following research questions RQ 1. and RQ 2. were examined.

RQ 1. Is it possible to successfully plant Scots pine and Norway spruce seedlings every second row on site index from T19-24 and G18-27 in central Sweden?

RQ 2. Will Norway spruce and Scots pine seedlings planted in central Sweden every second row become mixed stands?

3. Material and Methods

3.1 Material and Methods

A forest manager at Sveaskog harvested a mixed forest with Scots pine and Norway spruce, and the idea was to recreate a similar forest again in the same area by planting Norway spruce and Scots pine every second row according to Nyberg (2022). Ten stands owned by Sveaskog, planted every second row with Scots pine and Norway spruce from 2009 to 2012 were measured in November 2021. At the establishment, the stands were scarified and planted. The stands had not been pre-commercially thinned at the time of measurements. They were situated in Hälsingland and Dalarna, latitude 61-62° (see table 1). The altitude varied from 120-385 m above sea level. Site index varied from T19-T24 and G18-G27, the stand sizes were from 4,0 ha to 46,2 ha. Figure 1 shows one of the stands planted every second row with Scots pine and Norway spruce.

Table 1. Stand data from Sveaskog.

Stand	Stand size [ha]	Hight above sea level [m]	Latitude [°]	Site Index (SI)	Pine Planted Seedlings	Spruce Planted Seedlings	Seedlings planted [year]
Lillsjöberget	9,5	349	62	T20S	1000	1000	2012
Galven	26,7	264	61	T22S	1000	1000	2012
Rakvägen	46,2	345	62	T22H	1150	1150	2009
Linbodarna	4,0	254	61	G22H	1100	1000	2011
Trollmossberget	9,1	383	61	G22H	1000	1000	2010
Ore mitt	4,4	284	61	G22H	1100	1000	2012
Enskogen N	43,1	359	62	G22H	1100	1100	2012
Enskogen S	5,7	358	62	G22H	1100	1100	2012
Gäddtjärnen	14,5	316	62	G22H	1100	1100	2009
Lottefors	5,7	120	61	T26S	1100	1100	2012

S = Phytocentric, composition-based

H= Dendrocentic method

Figure 1. Scots pine and Norway spruce planted 2012 every second row in Galven. Picture taken 2021.

Sample plots were randomly spread out over the stands using probability proportional to size sampling, usually called PPS sampling (Kershaw 2017). Since the stands had different sizes Sveaskogs inventory instruction was used to establish the number of sample plots needed for each stand (Mattsson 2020) (table 2). The distance between the sample plots depended on the size of the stand.

Table 2. Sample plots per stand.

Stand size [m²]	Sample plots	Square side [m]
≤ 0,9	3	40
1,0-2,9	5	60
3,0-4,9	6	80
5,0-9,9	8	100
10,0-19,9	10	120
20,0-29,9	12	140
30,0-39,9	13	160
≥40,0	13	180

Circular plots with a radius of 3,99 m ($r^2\pi=50$ m²) were placed as a squared pattern over the stand (see figure 2). The circular plots were situated where the vertical and horizontal lines cross each other. The first circular plot was situated one square side from the edge of the stand. The distance was measured by counting steps and the direction was pointed out by a compass. The next plot was placed along the compass line and so on until the edge of the plot was reached. At the edge of the plot a 90° angel turn was done, and one more square side measured thereafter another 90° angle to start the next line going opposite direction (Kershaw 2017). If the centre of the plot landed outside the designated area, the plot was moved forward along the compass line to the nearest suitable area. If the centre of the plot landed on the edge of the examined area the plot was simply halved and the data was doubled as Kershw (2017) and Mattsson (2020) describes in their work.

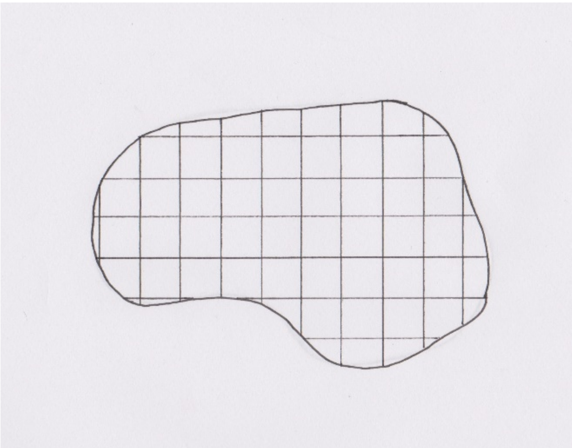

Figure 2. Square pattern over a stand. Circular plots situated in each line crossing.

Within each circular plot the height for the 10 most suitable trees was measured. The selected trees were the five tallest Norway spruce and five tallest Scots pine. Birch was added to reach the amount of 10 trees if there was a lack of Scots pine and Norway spruce. Selected trees needed to be healthy and well suited for the site condition. Minimum distance between the stems was 0,6 m (Mattsson 2020). If two trees of same species where closer than 2 m the height could differ a maximum of 1 m. Pine stems had to be minimum half the height of the arithmetic mean of the two highest stems and spruce needed to be minimum one third of the arithmetic mean of the two highest stems. If there was more than 3 m to the nearest stem shorter stems could be selected if they seemed suitable to fit in the future stand. 2 000 trees ha^{-1} (10 000m²/50m²=200) was the goal after pre-commercial thinning. Each circular plot needed 10 trees (10*200=2 000) to reach a total of 2 000 stems ha^{-1}.

To decide the local site index a phytocentric, composition-based method (bonitering) was used for each circular plot according to Skogsstyrelsen (2013). Species composition in the understory vegetation, underlying soil relationships, water accessibility and flow were examined. Latitude and the hight over sea level were also needed to establish site index using a table from Skogsstyrelsen (1985).

Top shot deformation and insect infestations were also registered for each circular plot. Notes were taken for stems selected to create the future stand. The number of stems with top shot deformation and infested with insects was counted in each circular plot.

3.2 Statistical Analysis

Variance shows how far from the mean a value is. Equation 1 shows how to calculate the variance according to Olofsson (2012).

Variance = $\frac{1}{n-1}\sum_{i=1}^{n}(Xi-m)^2$ (Equation 1.)

m = sample mean
Xi = the ith observation in the sample
n = observations

Standard deviation describes how far from the arithmetic mean each value is on average. It is interesting to see how much the height differ from the arithmetic mean to get a better understanding of the height difference between the different species within the same stand. Standard deviation was also used to show the difference in stems per species to get an idea how much the species differs from the arithmetic mean. Standard deviation was calculated according to equation 2.

Standard deviation = √Variance (Equation 2.)

Confidence interval shows the degree of confidence in the estimates (Olofsson 2012). In this study the probability was chosen to be 95% (constant 1,96), which means that the estimated value was within the interval with 95% confidence. The confidence interval was calculated as shows in equation 3.

Confidence interval = arithmetic mean ± 1,96 * standard error (Equation 3.)

Standard error shows the precision in the measurements and was calculated as shows in equation 4.

Standard error = Standard deviation/√N (Equation 4.)

N = population size

Regression analysis, analysis of variances and ANOVA was done in Excel for the stems per plot for spruce, pine and site index. Regression analysis was done according to equation 5.

$Y = ß_0 + ß_1X$ (Equation 5.)

Y = Amount of stems
X = Site index
$ß_0$ = Intercept
$ß_1$ = A constant

4. Results

Site index

The site index did not change much between most of the circular plots within the same stand. Rakvägen och Linbodarna had highest variation from T20 to T24 and G21 to G26 within the same stand. Lowest difference was no variation at all in four of the stands. The stands that had a variety in site index was mainly due to topography. Lower parts were more wet than higher parts, resulting in lower site index. The overall examined site index was higher than the given mean site index per stand from Sveaskog. The differences in site index were observed but not statistically proven and probably a result of the differences in assessment method of the site index in this study and Sveaskogs system.

Half of the examined plots had higher mean site index than Sveaskogs mean site index, three of the plots had same mean site index and two of Sveaskogs mean site index was higher than the examined plots. Table 3 shows mean stand site index from Sveaskogs register and the interval of site index measured in the study for each circular plot. Site index was measured for both pine and spruce using only a phytocentric composition-based method in the study.

Table 3. Shows site index examined in this study and the given site index by Sveaskog.

Stand	Site index Circular plot Study	Mean stand Site index Sveaskog
Enskogen N	T19-23 G18-22	G22H
Rakvägen	T20-24 G19-22	T22H
Ore mitt	T20-23 G21-26	G22H
Enskogen S	T23 G22	G22H
Gäddtjärnen	T22-24 G21-22	G22H
Galven	T23 G25	T22S
Linbodarna	T20-24 G21-26	G22H
Lillsjöberget	T24 G23	T20S
Trollmossberget	T23-24 G25	G22H
Lottefors	T26 G26	T26S

S = Phytocentric, composition-based
H= Dendrocentic method

Table 4 shows the mean number of stems ha^{-1} for each species per stand. The total was 2 000 stems ha^{-1} divided over pine, spruce and birch. Mean height per stand per species with confidence interval also shows in table 4 (minimum and maximum mean height per each stand with 95% confidence). The table starts with stands from lowest site index to the highest. The lowest and highest site index within the stands were also presented in table 4. Figure 2-5 shows four different stands planted every second row with Scots pine and Norway spruce. Galven, Lottefors, Enskogen S planted 2012 and Rakvägen planted 2009.

Enskogen N had the greatest number of pine stems ha^{-1} and lowest site index of all stands, from T19 to T23 and from G18 to G22. Lillsjöberget (T24, G23), Trollmossberget (T23-24, G25) and Lottefors (T26, G26) were the three stands with highest site index and the greatest number of spruce stems ha^{-1}.

Pine was in general shorter than spruce. Lottefors (T26, G26) and Galven (T23, G25) had a taller mean of pine than spruce. Lottefors had 1 000 stems ha^{-1} of pine and 1 000 stems ha^{-1} of spruce and Galven had 1 100 stems ha^{-1} of pine and 900 stems ha^{-1} of spruce. Trollmossberget had the lowest number of pine stems, only 520 ha^{-1}. 1 000 pine and 1 000 spruce seedlings were planted ha^{-1} in Trollmossberget, it means that 480 pine seedlings did not grow well enough to be selected to be part of the future stand. The pine stems also seemed suppressed by the taller spruce.

Table 4. Number of stems for each stand after an imaginary pre-commercial thinning. Mean height for each tree species with confidence interval.

Stand	Mean Stems Pine ha^{-1}	Mean Stems Spruce ha^{-1}	Mean Stems Birch ha^{-1}	Mean height Pine [m]	Mean height Spruce [m]	Mean height Birch [m]	Site index
Enskogen N	1080	740	180	1,9 ± 0,2	2,1 ± 0,3	1,9 ± 0,3	T19-23 G18-22
Rakvägen	940	900	120	2,4 ± 0,3	2,7 ± 0,3	2,8 ± 0,3	T20-24 G19-22
Ore mitt	1040	840	140	1,4 ± 0,2	1,6 ± 0,3	2,0 ± 0,0	T20-23 G21-26
Enskogen S	900	760	360	1,9 ± 0,1	2,6 ± 0,1	2,6 ± ,04	T23 G22
Gäddtjärnen	960	980	60	2,8 ± 0,4	2,9 ± 0,4	2,6 ± 0,4	T22-24 G21-22
Galven	1100	900	-	2,7 ± 0,2	2,5 ± 0,2	-	T23 G25
Linbodarna	1020	900	100	1,7 ± 0,5	2,2 ± 0,4	2,1 ± 0,0	T20-24 G21-26
Lillsjöberget	860	1060	100	2,1 ± 0,3	2,9 ± 01	2,3 ± 0,0	T24 G23
Trollmossberget	520	1380	100	1,5 ± 0,1	1,9 ± 0,2	1,9 ± 0,5	T23-24 G25
Lottefors	1000	1000	-	3,3 ± 0,2	2,9 ± ,03	-	T26 G26

Figure 3. Galven planted 2012, picture taken 2021.

Figure 4. Lottefors planted 2012, picture taken 2021.

Figure 5. Enskogen S planted 2012, picture taken 2021.

Figure 6. Rakvägen planted 2009, picture taken 2021.

Regression analysis
Number of pine stems per plot gradually decreased as the site index increased (see figure 6). Site index only explained approximately 5% of the change in pine stems however, the p-value found in table 5 was lower than 0,5 and shows that the decrease of pine stems was significant as the site index increased.

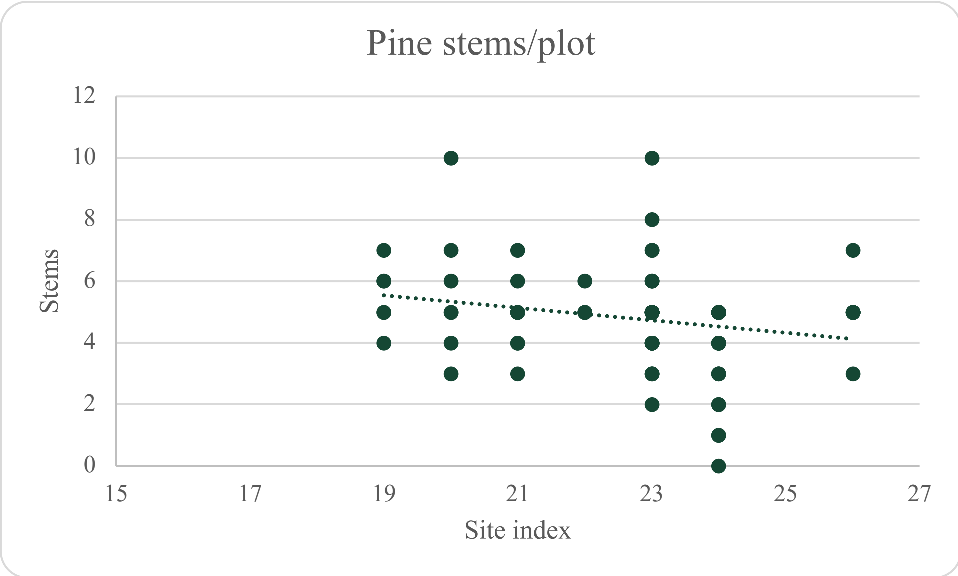

Figure 7. Correlation between site index and number of Scots pine stems.

Table 5. ANOVA analysis from the regression analysis in Excel for pine and site index.

	fg	KvS	MKv	F	p-value for F
Regression	1	10,773526	10,773526	4,7012507	0,0327495
Residual	91	208,5383	2,2916297		
Totalt	92	219,31183			
	Coefficient	**Standard deviation**	**t-quota**	**p-value**	
Intercept	9,23533	2,07337	4,45427	0,00002	
Site Index	-0,19600	0,09039	-2,16824	0,03275	

The number of spruce stems was increasing as the site index was increasing (see figure 7). The site index explained approximately 10% of the increase however, the p-value found in table 6 was lower than 0,5 and showed that the increase of spruce stems as the site index increased was significant.

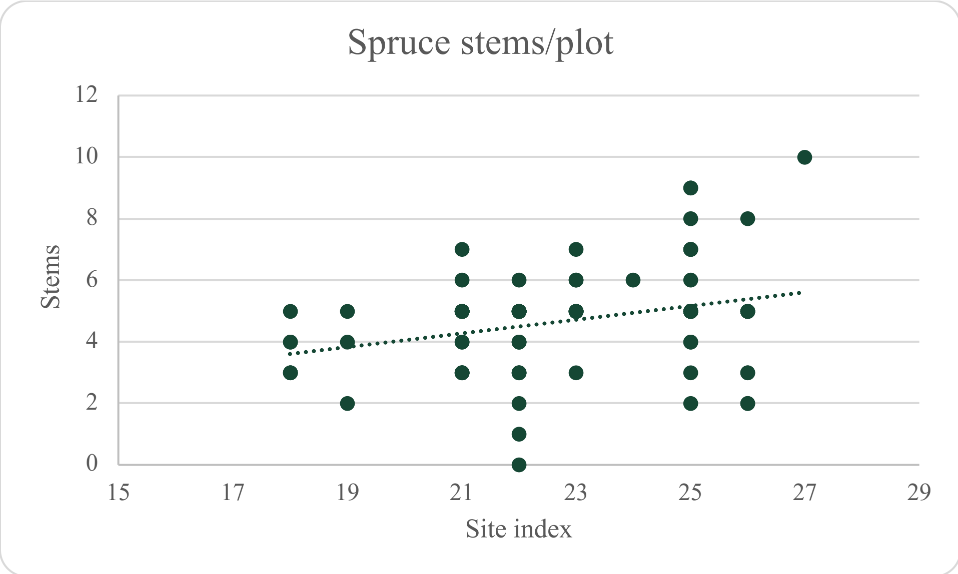

Figure 8. Correlation between stie index and number of spruce stems.

Table 6. ANOVA analysis from the regression analysis in Excel for spruce and site index.

	fg	KvS	MKv	F	p-value for F
Regression	1	24,41210	24,41210	9,97588	0,00216
Residual	90	220,24007	2,44711		
Totalt	91	244,65217			
	Coefficient	Standard deviation	t-quota	p-value	
Intercept	-0,50743	1,66225	-0,30527	0,76087	
Site Index	0,22695	0,07186	3,15846	0,00216	

Height difference between pine and spruce

The maximum height differences (mean height per stand) between pine and spruce varied from 0,6 m to 1,4 m (see Table 5). Lillsjöberget had the largest maximum difference and Galven had the lowest maximum difference in height between pine and spruce. Figure 8 shows the difference between the mean height per stand and species.

Table 7. Maximum mean height difference between Scots pine and Norway spruce per stand.

Stand	Maximum Height difference [m]	Site index Circular plot Study	Mean stand Site index Sveaskog
Enskogen N	0,7 P	T19-23 G18-22	G22H
Rakvägen	0,9 S	T20-24 G19-22	T22H
Ore mitt	0,7 S	T20-23 G21-26	G22H
Enskogen S	0,9 S	T23 G22	G22H
Gäddtjärnen	0,9 S	T22-24 G21-22	G22H
Galven	0,6 P	T23 G25	T22S
Linbodarna	1,4 S	T20-24 G21-26	G22H
Lillsjöberget	1,2 S	T24 G23	T20S
Trollmossberget	0,7 S	T23-24 G25	G22H
Lottefors	0,9 P	T26 G26	T26S

P=Pine highest
S=Spruce highest

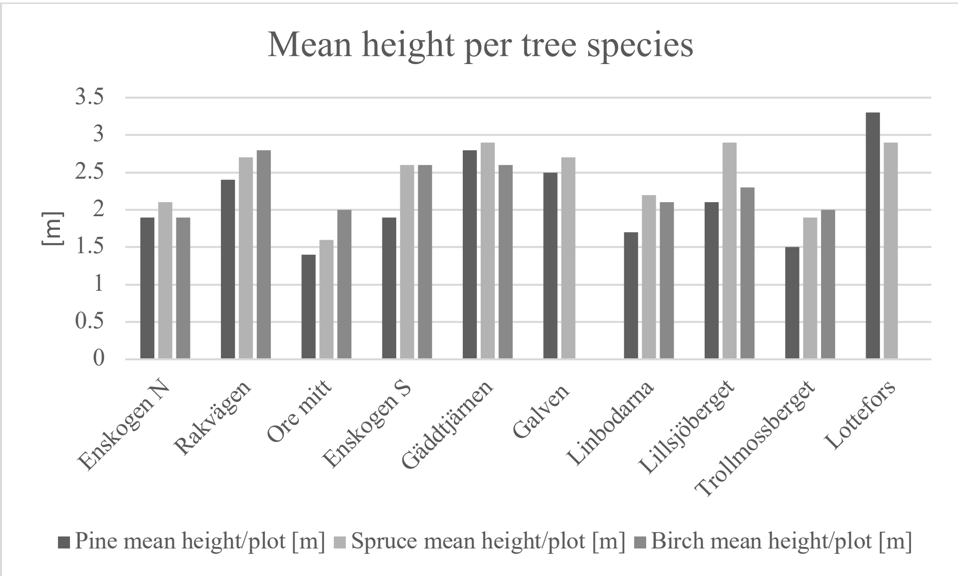

Figure 9. Difference in mean height per tree species for each stand.

Number of stems per hectare

Figure 9 shows the number of tree species per hectare in each stand. Trollmossberget had the largest amount of spruce, 1 380 stems ha^{-1}. 1 000 pine and 1 000 spruce seedlings ha^{-1} was planted in Trollmossberget. Trollmossberget had the second highest site index (T23-24, G25) and 380 spruce stems ha $^{-1}$ were naturally regenerated. Pine did not seem to grow well due to the taller spruce suppressing the pine. Galven had the largest amount of pine stems, 1 100 per hectare. 1 000 pine and 1 000 spruce seedlings ha^{-1} was planted in Galven with site index T23 and G25. 100 pine stems ha^{-1} was naturally regenerated. Enskogen S with site index T23 and G22 had the largest amount of birch, 360 stems ha^{-1} (900 pine stems and 760 spruce stems ha^{-1}). 1 100 pine and 1 100 spruce seedlings ha $^{-1}$ was planted in Enskogen S. Lottefors and Galven did not need any birch stems added to reach 2 000 stems ha^{-1}, all other stands had birch added to reach 2 000 stems ha^{-1}.

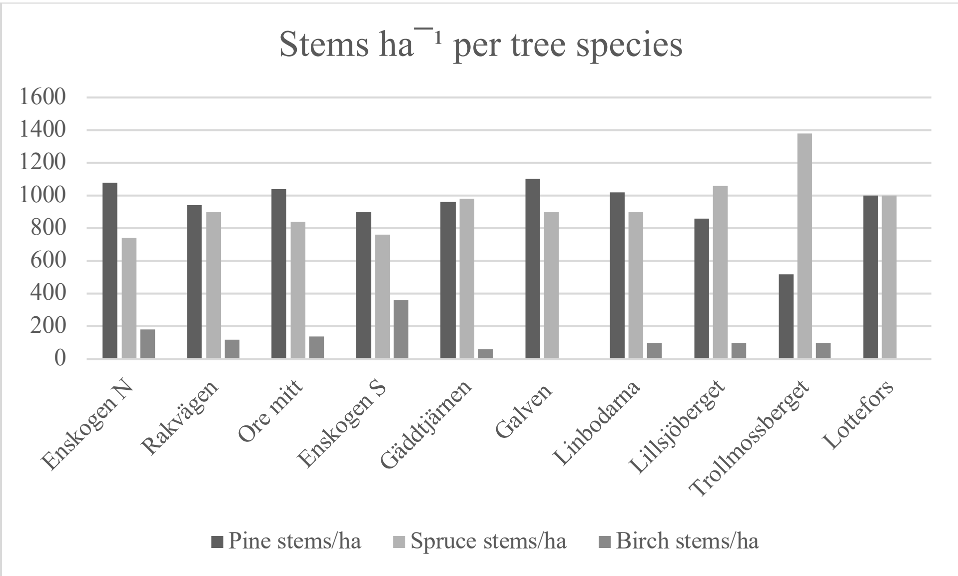

Figure 10. Number of stems per tree species ha^{-1} for each stand.

Browsing and insect infestation

In Enskogen N approximately 6% of all spruce stems were infested by a plant parasite highly likely to be Green spruce bile louse (*Sacchiphantes viridis)* figure 10. The insect also infested Enskogen S, approximately 10% of all spruce was infested. Browsing damage on pine such as top shot feeding was also examined. The damage in all the sites were very low, from 0,0% to 8,7% of the pine stems were browsed. The mean value over all the pine stems was 3,7%.

Figure 11. Green spruce bile louse in Stand 6. Enskogen N, picture taken 2021.

5. Diskussion

5.1 Discussion

The mean site index per stand given by Sveaskog was in general lower than the site index examined in this research. One reason the site index in this research was higher than the mean site index in Sveaskogs system could be the time that has passed between the two measurements. According to Subramanian (2015) climate observations have shown that temperature has gone up 0,8°C since 1900. Warmer soil speeds up decomposition and release more nutrients to the soil and the site could support species with higher demand of nutrients. The site could simply be more nutritious now compared to when the site index was last measured. It is very different how to determine site index in a mature stand than in young stands. Another reason for the difference between Sveaskogs site index and the examined was the probability of faults. It was not optimal to examine site index with snow on the ground even though it was a thin layer. Tree height does not affect site index based on soil properties and therefore has scarification, seedling properties and tree growth minor effect on the site index established in this study.

When site index varied within the stands, it did not seem to have a great effect on the mean height between Scots pine and Norway spruce. The effect was more reflected in tree species distribution since the shorter trees were simply not selected. It seemed like the change in site index effected which tree species grow taller and got selected during pre-commercial thinning. Higher site index had larger number of spruce stems. T 22 and G 22 seem to be the breaking point where pine was growing better below T 22 and spruce was growing better above G22 according to the regression analysis. Holmström et al. (2019) examined an experiment in Främlingshem with 60-year-old pine and spruce stands on mediocre site index. The pre-commercial thinning and commercial thinning was important to maintain the mix of pine and spruce throughout the growth period. The pine needed help to keep developing otherwise spruce would take over. The stands were regenerated by sawing mixed seeds of Sots pine and Norway spruce.

Jonsson (2001) found that spruce had higher volume yield on sites with higher site index than both mixed stands of pine and spruce and homogeneous pine stands. Pine had higher volume yield in sites with lower site index than mixed pine and spruce stands and homogenous spruce stands. In 43-year-old stands on sites with mean site index T 26,9 and G24,6. According to this study it was possible to plant Norway spruce and Scots pine every second row to match local site index from T19-24 and G 18-27 in central Sweden.

Maximum mean height difference per stand between Scots pine and Norway spruce was 0,2-1,4 m. Spruce was taller in three of ten stands. Eight of the stands were within the required hight span of 1 m according to Mattsson (2019). Linbodarna and Trollmossberget was the only two stands that may not fit within the one-meter span. Linbodarna had site index that varied the most for spruce, from G21-26. All other stands were within maximum mean of 1 m difference between pine and spruce, therefore suitable to manage as mixed stands. However, Trollmossberget did not seem to have regenerated well. Many of the pine stems had not survived, only 520 pine stems ha^{-1} was suitable to create a future stand after pre-commercial thinning. The spruce could have been browsed as seedlings. Spruce seemed to grow well in Trollmossberget, 1 380 spruce stems ha^{-1} indicates that 380 spruce sems ha^{-1} were naturally regenerated. Site index in Trollmossberget was one of the highest T23-24 and G25.

The goal was to reach 2 000 stems ha^{-1} after pre-commercial thinning by planting Norway spruce and Scots pine every second row. All stands reached the goal of 2 000 stems ha^{-1}. The regeneration was very successful keeping in mind that 2 000-2 300 seedlings of pine and spruce was planted. There was enough of naturally regenerated broadleaves in all the stands to reach 2 000 stems ha^{-1} even when the regeneration of conifer was less successful.

Mixed stands have a wider range of biodiversity and humans prefer to spend time in this type of forests according to Nilsson (2020). It is also a way to spread financial risks at the same time as logging and harvesting comes with a slightly higher price. Planting spruce and pine every second row could help generating mixed forests in the future to cope better with windthrow, insects, pathogens and drought periods. It is simply a god way for forest managers to spread the risks over more tree species. If one tree species gets infested maybe the other one resists the infestation better. It is also safer with mixed tree species when it comes to volume growth. One tree species might grow better on small hills and the other one in lower or wet parts. According to the local site index, the mix of tree species might vary over the stand.

All stands were still young and had many more years left to grow until harvesting. Holmström et al. (2019) points out the benefit of planting two tree species to be able to select the best growing species in future managing regimes. The stands in this research were young, and more research is needed to find out how the stands develop over time. Pretzsch (2018) highlight the importance of long-term research to follow stands and trees during the whole rotation period.

Sveaskogs goal is to have 10% of broadleaf species in their conifer stands. The method of planting 2 000-2 300 seedlings ha^{-1} of Scots pine and Norway spruce every second row could also be used to reach Sveaskogs goal. If 2 000 stems ha^{-1} is the goal and if the planting is as successful as in this study, pine or spruce stems might need to be removed during pre-commercial thinning to make room for 10% broadleaf species. Broadleaf species usually regenerate naturally without costs and Sveaskog would prefer not to remove planted pine and spruce during pre-commercial thinning. Damaged and naturally re-generated stems need to be removed. Another possibility would therefore be to plant less spruce and pine seedlings. One could keep in mind that it might be safe to have extra pine and spruce stems to choose from while creating a future stand due to risks such as pests, pathogens and browsing. It might be wise to accept some removal of pine and spruce during pre-commercial thinning. A third option would be to increase the number of stems ha^{-1} and simply add more broadleaf species. However, that would have a negative effect on the diameter increment and lead to slimmer trees and less income. All birch and other broadleaf species were not counted in this study and therefore one cannot answer the question whether or not there are enough birch stems in the examined stands to reach 10% broad leaf.

A weakness in this study was fieldwork executed in November when a thin layer of snow was on the ground. The snow made it more difficult to see all the species growing on the ground and might have affected the result of site index. The stands were also not planned for research purposes and did not have pine and spruce planted every second row all over the stand. Sometimes the circular plots had to be moved along the compass line to find a suitable location. The studies strength was that the forest managers and not scientists planted the stands. The study was executed in forests effected by browsing, insects and natural regenerating seedlings in the way forests grows. Future studies could be designed as a mixed species research project where the purpose is to study different ways of planting mixed stands. Mixed stands with more species could be interesting, for example pine and broad-leaf trees in the same stand.

5.2 Conclusion

It was possible according to this study to plant Norway spruce and Scots pine every second row in central Sweden in sites with site index from T19-T24 and G18-G27 to create mixed species stands. Tree height depend on local site index. The tallest trees were selected during an imaginary pre-commercial thinning to form a future stand. The breaking point for the site index was approximately T22 and G22. Higher site index favoured Norway spruce and lower site index favoured Scots pine.

The goal of 2 000 stems ha^{-1} was reached in all stands. Broad-leaf species was added in eight of ten stands. It is important to plan for a mixed species stand throughout the entire rotation period from regeneration to, pre-commercial thinning and commercial thinnings.

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Popular science summary

The ability to create mixed forests by planting spruce and pine every second row

Eva Higgins Andersson

It is possible to create vital mixed forests by planting spruce and pine every second row. Mixed forests spread the risks and resists pests and pathogens better than monocultures.

Pine and spruce have different biology and grow well in different conditions. A mix of the two tree species can match the soils fertility with the trees biology and create a vital mixed forest. A vital mixed forest is more resistant to climate change, pests and pathogens.

A forest manager at Sveaskog harvested a mixed species forest with spruce and pine. The forest was very pleasant, and the forest manager wanted to recreate a similar forest again. After the harvesting was pine and spruce seedlings planted every second row to recreate a mixed forest. The forests were planted 2009-2012. Ten of these forests were examined to find out if this method was working. The hight difference between pine and spruce cannot be too large. Pine lives in open areas and need sunlight. Spruce can live in shade however it is possible to plant spruce in open areas. Main purpose of the thesis was to examine if Scots pine and Norway spruce planted every second row would be a way to create mixed forests in central Sweden. Mixed forests have higher biodiversity and humans prefer to spend time in this type of forests. Different forests have different ability to support different tree species. It was also interesting to see if planting the two tree species every second row could match different soil conditions with the biology of the tree species. A goal was set to 2 000 stems per hectare.

The study showed that the amount of pine stems was gradually going down as the ground was less fertile. Spruce stems were gradually going up as the ground was more fertile. Matching local soil properties with biology of the tree species was possible. Hight difference between pine and spruce was not too large and planting pine and spruce every second row to create mixed forests was possible.

2 000 stems per hectare was reached in all stands. Birch is increasing biodiversity by adding a broadleaf species to the mixed forests and Sveaskog has a goal to reach 10% of broad leaf species in their stands. The forests in this study where stil young and it is important to plan for mixed species forests during forest management in the future to maintain a mixed forest. The benefit of planting two tree species is the ability to spread the risks over more tree species. Make the forest manager able to select the best growing species in future managing regimes, create a more resistant forest for pathogens, insects and climate change.

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Appendix

Appendix 1. Shows data from stand 6. Enskogen N

Circular plots	Pine stems/plot	Spruce stems/plot	Birch stems/plot	Pine mean hight/plot [m]	Spruce mean hight/plot [m]	Birch mean hight/plot [m]	Site Index
1	5	5	0	2,0	2,6	0,0	T23 G21
2	6	4	0	1,8	2,2	0,0	T19 G18
3	4	3	3	1,8	2,0	1,6	T19 G18
4	6	4	0	1,8	2,3	0,0	T19 G18
5	7	3	0	1,7	1,4	0,0	T19 G18
6	5	5	0	1,2	1,5	0,0	T19 G18
7	5	5	0	1,5	2,5	0,0	T23 G22
8	3	3	4	1,9	2,1	2,5	T23 G22
9	5	5	0	2,0	1,8	0,0	T23 G22
10	5	3	2	1,9	1,4	2,2	T19 G18
11	5	2	3	1,9	2,3	1,5	T23 G22
12	4	6	0	2,5	2,9	0,0	T23 G22
13	10	0	0	2,6	0,0	0,0	T23 G22
Mean	5,4±0,9	3,7±0,7	0,9±1,1	1,9±0,2	2,1±0,3	1,9±0,3	T21 G20
St.deviation	1,7	1,2	2,6	0,4	0,5	0,5	

Appendix 2. Shows data from stand 10. Rakvägen

Circular plots	Pine stems/plot	Spruce stems/plot	Birch stems/plot	Pine mean hight/plot [m]	Spruce mean hight/plot [m]	Birch mean hight/plot [m]	Site Index
1	5	5	0	2,1	1,9	0,0	T21 G21
2	6	4	0	3,3	2,8	0,0	T20 G19
3	5	3	2	2,7	3,2	3,3	T21 G21
4	3	2	3	2,7	3,7	3,3	T20 G19
5	5	5	0	3,0	3,6	0,0	T24 G22
6	4	6	0	1,8	3,7	0,0	T21 G21
7	5	5	0	3,0	2,6	0,0	T21 G21
8	6	4	0	1,8	1,8	0,0	T21 G21
9	5	3	2	1,9	1,7	2,3	T21 G21
10	3	7	0	2,0	2,5	0,0	T21 G21
11	4	5	1	2,4	2,6	2,1	T21 G21
12	5	5	0	2,1	2,3	0,0	T20 G19
13	5	5	0	2,4	2,7	0,0	T24 G22
Mean	4,7±0,5	4,5±0,7	0,6±1,8	2,4±0,3	2,7±0,3	2,8±0,3	T21 G21
St.deviation	0,9	1,3	1,8	0,5	0,6	0,6	

Appendix 3. Shows data from stand 4. Ore mitt

Circular plots	Pine stems/plot	Spruce stems/plot	Birch stems/plot	Pine mean hight/plot [m]	Spruce mean hight/plot [m]	Birch mean hight/plot [m]	Site Index
1	5	5	0	1,5	1,4	0,0	T23 G25
2	5	5	0	1,3	2,3	0,0	T20 G26
3	6	4	0	1,4	1,4	0,0	T22 G21
4	4	2	4	1,2	1,9	2,0	T23 G26
5	7	3	0	1,3	1,2	0,0	T20 G21
6	4	6	0	1,7	1,7	0,0	T20 G24
Mean	5,2±1,0	4,2±1,2	0,7±0	1,4±0,2	1,6±0,3	2±0	T21 G24
St.deviation	1,2	1,5	0	0,2	0,4	0	

Appendix 4. Shows data from stand 7. Enskogen S

Circular plots	Pine stems/plot	Spruce stems/plot	Birch stems/plot	Pine mean hight/plot [m]	Spruce mean hight/plot [m]	Birch mean hight/plot [m]	Site Index
1	3	3	4	1,6	2,2	2,6	T23 G22
2	5	4	1	2,2	2,7	1,7	T23 G22
3	4	1	5	1,9	3,3	2,6	T23 G22
4	4	3	3	2,1	2,6	2,7	T23 G22
5	4	5	1	1,6	2,5	3,3	T23 G22
6	5	5	0	1,8	2,7	0,0	T23 G23
7	5	5	0	1,7	2,2	0,0	T23 G22
8	6	4	0	2,0	2,6	0,0	T23 G22
Mean	4,5±0,6	3,8±1,0	1,8±1,3	1,9±0,1	2,6±0,1	2,6±0,4	T23 G22
St.deviation	0,9	1,4	1,9	0,2	0,1	0,5	

Appendix 5. Shows data from stand 9. Gäddtjärnen

Circular plots	Pine stems/plot	Spruce stems/plot	Birch stems/plot	Pine mean hight/plot [m]	Spruce mean hight/plot [m]	Birch mean hight/plot [m]	Site Index
1	5	5	0	2,4	2,6	0,0	T22 G21
2	5	5	0	2,2	2,7	0,0	T24 G22
3	5	5	0	2,7	2,3	0,0	T24 G23
4	5	5	0	2,2	2,3	0,0	T24 G22
5	4	5	1	2,2	1,9	2,2	T24 G22
6	5	5	0	2,4	2,7	0,0	T22 G21
7	4	4	2	2,8	3,5	3,0	T24 G22
8	5	5	0	3,8	3,8	0,0	T22 G21
9	5	5	0	3,2	2,9	0,0	T24 G23
10	5	5	0	4,3	4,1	0,0	T24 G22
Mean	4,8±0,2	4,9±0,2	0,3±1,1	2,8±0,4	2,9±0,4	2,6±0,4	T23 G22
St.deviation	0,4	0,3	1,8	0,7	0,7	0,6	

Appendix 6. Shows data from stand 1. Galven

Circular plots	Pine stems/plot	Spruce stems/plot	Pine mean hight/plot [m]	Spruce mean hight/plot [m]	Site Index
1	6	4	2,7	3,3	T23 G25
2	5	5	2,7	2,4	T23 G25
3	5	5	2,7	2,0	T23 G25
4	5	5	3,1	2,8	T23 G25
5	7	3	3,3	2,7	T23 G25
6	4	6	2,5	2,8	T23 G25
7	5	5	2,6	2,6	T23 G25
8	5	5	2,8	2,6	T23 G25
9	8	2	2,5	2,3	T23 G25
10	6	4	2,4	2,1	T23 G25
11	5	5	2,2	1,9	T23 G25
12	5	5	2,3	2,4	T23 G25
Mean	5,5±0,6	4,5±0,6	2,7±0,2	2,5±0,2	T23 G25
St.deviatin	1,1	1,1	0,3	0,4	

Appendix 7. Shows data from stand 2. Linbodarna

Circular plots	Pine stems/plot	Spruce stems/plot	Birch stems/plot	Pine mean hight/plot [m]	Spruce mean hight/plot [m]	Birch mean hight/plot [m]	Site Index
1	7	3	0	2,0	1,7	0,0	T23 G26
2	5	5	0	1,8	2,8	0,0	T24 G25
3	7	3	0	1,6	1,9	0,0	T21 G21
4	10	0	0	1,5	0,0	0,0	T20 -
5	3	8	0	1,5	1,9	0,0	T23 G26
6	5	5	0	1,8	2,0	0,0	T23 G26
7	4	2	4	1,4	1,9	2,1	T24 G26
8	0	10	0	0,0	3,0	0,0	T24 G27
Mean	5,1±1,8	4,5±1,9	0,5±0,0	1,7±0,5	2,2±0,4	2,1±0,0	T23 G25
St.deviation	2,4	2,8	0	0,2	0,5	0,0	

Appendix 8. Shows data from stand 8. Lillsjöberget

Circular plots	Pine stems/plot	Spruce stems/plot	Birch stems/plot	Pine mean hight/plot [m]	Spruce mean hight/plot [m]	Birch mean hight/plot [m]	Site Index
1	5	5	0	2,0	2,7	0,0	T24 G23
2	3	7	0	2,1	2,7	0,0	T24 G23
3	4	6	0	1,4	2,9	0,0	T24 G23
4	4	6	0	3,1	3,1	0,0	T 24 G23
5	5	5	0	2,1	3,2	0,0	T24 G23
6	5	5	0	2,2	2,6	0,0	T24 G23
7	5	5	0	1,6	3,0	0,0	T24 G23
8	3	3	4	2,3	2,7	2,3	T24 G23
Mean	4,25±0,6	5,25±0,8	0,5±0,0	2,1±0,3	2,9±0,1	2,3±0,0	T24 G23
St.deviation	0,9	1,2	0	0,5	0,2	0	

Appendix 9. Shows data from stand 3. Trollmossberget

Circular plots	Pine stems/plot	Spruce stems/plot	Birch stems/plot	Pine mean hight/plot [m]	Spruce mean hight/plot [m]	Birch mean hight/plot [m]	Site Index
1	2	5	3	1,2	2,0	2,2	T23 G25
2	3	7	0	1,9	1,9	0,0	T24 G25
3	1	9	0	1,8	2,3	0,0	T24 G25
4	2	8	0	1,5	1,8	0,0	T24 G25
5	2	7	1	1,5	1,8	1,7	T24 G25
6	5	5	0	1,3	1,6	0,0	T24 G25
7	1	9	0	1,4	2,0	0,0	T24 G25
8	5	5	0	1,5	1,5	0,0	T24 G25
Mean	2,6±1,3	6,9±1,2	0,5±1,7	1,5±0,1	1,9±0,2	2±0,5	T24 G25
St.deviation	1,9	1,7	2,5	0,2	0,3	0,4	

Appendix 10. Shows data from stand 5. Lottefors

Circular plots	Pine stems/plot	Spruce stems/plot	Pine mean hight/plot [m]	Spruce mean hight/plot [m]	Site Index
1	7	3	2,5	2,7	T26 G26
2	5	5	3,1	2,9	T26 G25
3	3	7	3,3	3,1	T26 G25
4	5	5	4,0	3,2	T26 G26
5	5	5	3,2	2,8	T26 G26
6	5	5	2,7	2,7	T26 G26
7	5	5	3,5	2,0	T26 G26
8	5	5	3,8	3,5	T26 G26
Mean	5±0,8	5±0,8	3,3±0,2	2,9±0,3	T26 G26
St.deviation	1,1	1,1	0,3	0,4	

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