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A comparison between wood quality and growth in planted and naturally regenerated Scots pine (*Pinus sylvestris* L.) stands in Sweden and in Poland

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Master Thesis no. 213

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Streszczenie

Sosna zwyczajna to jeden z głównych gatunków lasotwórczych, którego drewno jest podstawowym materiałem wykorzystywanym w przemyśle drzewnym, zarówno w Szwecji, jak i w Polsce. Celem hodowli sosny jest produkcja drewna o wysokiej jakości. W niniejszej pracy magisterskiej porównany został wpływ różnych metod odnowienia, więźby sadzenia, oraz materiału sadzeniowego pochodzącego z wyłączonych drzewostanów nasiennych na przyrost i cechy jakościowe sosny. Badania terenowe zostały przeprowadzone w drzewostanach południowej Szwecji (Linnebjörke i Värnamo), oraz zachodniej Polski (Nadleśnictwo Potrzebowice). Wyniki przedstawiają charakterystykę badanych drzewostanów oraz jakość ich drewna .
Przeciętnie, drzewostany posadzone na powierzchniach pozrębowych miały większe wysokości (34%), pierśnice (39%),oraz większy przeciętny przyrost roczny (242%) w porównaniu do powierzchni odnowionych naturalnie. Ponadto miąższość drzewostanów sosnowych posadzonych pod luźnym okapem drzew matecznych wynosiła (121%) tych, które posadzone zostały pod gęstym okapem drzew matecznych. Również, miąższość drzewostanów odnowionych naturalnie pod luźnym okapem drzew matecznych wyniosła (346%) tych, które zostały odnowione naturalnie pod gęstym okapem drzew matecznych. Powierzchnie pomiarowe w Värnamo i w Potrzebowicach odnowione w najgęstszych więźbach (10.000/ha i 13.000/ha) miały największa średnia wysokość, miąższość, oraz największy przeciętny przyrost roczny. Posadzone drzewostany, pochodzące z materiału sadzeniowego z wyłączonych drzewostanów nasiennych charakteryzowały się wysoką jakością i przyrostem. Przeciętnie odznaczały się 5 i 4%, większym przyrostem wysokości i miąższości w porównaniu do posadzonych drzewostanów lokalnej prowenienсji.
Naturalnie odnowione drzewostany sosnowe będą cechowały się lepszą ogólną jakością, w porównaniu do drzewostanów odnowionych sztucznie. Przeciętnie, średnia wielkość najgrubszych gałęzi była (20%) mniejsza w naturalnych odnowieniach. Ponadto, mniej szczególnie krzywych strzał sosnowych, eliminujących je do dalszego przemysłowego wykorzystania zanotowanych zostało w drzewostanach sosnowych odnowionych naturalnie. Sosny posadzone pod długo trwającą osłoną drzew matecznych, odznaczały się lepszą jakością. Jakość starzał sosen posadzonych w bardzo luźnych więźbach (1600/ha) była bardzo niska, a średnica gałęzi znacząca, w porównaniu do powierzchni posadzonych w gęstych więźbach 10.000/ha i 13.000/ha). Współczynnik korelacji liniowej pomiędzy średnicą najgrubszej gałęzi a pierśnicą drzew był niższy w naturalnych odnowieniach. A zatem, drzewostany naturalnie odnowione cechują się większymi możliwościami selekcji.

Słowa kluczowe: jakość drewna, krzywizna, miąższość, odnowienie naturalne, osłona górna, przyrost, sadzenie, Sosna zwyczajna, sęki zrośnięte, średnica najgrubszej gałęzi, więźba sadzenia, zrąb zupełny.

Abstract

Scots pine *Pinus sylvestris* L. is one of the most important trees species for wood industry in Sweden and in Poland. The silviculture is aiming for high quality timber. This study compares different regeneration methods, initial densities, improved planting material and their impact on wood quality and growth. The study areas were located in Linnebjörke and Värnamo Forests (southern Sweden) and in Potrzebowice State Forest district (western Poland). In total 30 circular plots were set up in Sweden and 8 in Poland. The results shows stand characteristics such as height, diameter, mean annual increment, volume and timber quality traits, *i.e* diameter of the thickest branch, crookedness, spike knots occurrence, damages and judged overall quality .

Planted stands had on average greater mean heights (34%), diameters (39%), mean annual increment (242%) compared to the naturally regenerated stands. The volume of pines planted under the normal shelter was on average (121%) of those planted under the dense shelter. Similarly the volume of the naturally regenerated pines under normal shelter was (346%) of the ones regenerated under the dense shelter. In Värnamo and Potrzebowice the plots planted in the lowest spacing (10.000/ha and 13.000/ha respectively) had the highest mean height, total volume per ha and MAI. The trees originated from improved planting material characterized high external quality and good growth. On average the growth of height and volume was 5% and 4% greater compared to the not improved plots planted on the clear cut.

Naturally regenerated pine stands will have superior overall quality compared to the planted stands on the clear cut. On average the mean branch diameter was (20%) lower in the naturally regenerated plots compared to the planted ones. In general, fewer severely crooked stems were recorded in the natural regeneration. Longer shelter period improved the quality of planted pines. The stem straightness was considerably poorer and diameter of branches higher in the wide planting (1600/ha) compared to the closer planting (10.000 and 13.000/ ha). According to the linear correlation between the diameter of the thickest branch and the diameter at breast height the naturally regenerated stands will give higher selection possibilities than the planted stands.

Keywords: Clear cut, crookedness, diameter of the thickest branch, growth, Scots pine, *Pinus sylvestris*, natural regeneration, planting, shelter, spacing, spike knots, volume, wood quality.

Content

Abbreviations

Dbr - branch diameter
d.s - dense shelter
Dbh - diameter at breast height
i. - improved planting material
MAI - mean annual increment
nat. reg - natural regeneration
n.s - normal shelter
p.l - planting on the clear cut
PCT - pre-commercial thinning
R - the linear correlation coefficient

1 Introduction

The primary aim in Scots pine (Pinus sylvestris L.) silviculture is high quality timber. Therefore this study focuses on the different regeneration methods, whether they effects the production and wood quality of Scots pine. Also a comparison regarding Swedish and Polish stands was made.

Pine is an important species with a share of the standing stock of around 50% in Sweden and around 67% in Poland. The timber is used for pulp and construction wood but mainly as a high quality material for indoor products, such as flooring and furniture.

Silviculture

Regeneration of Scots pine is done through planting or natural regeneration. The silviculture differs in both countries. The initial density is much lower in Sweden (2000-4000 per ha) compared to in Poland, (8000-10.000 per ha). (Zasady hodowli lasu, 2003. In English: The guidelines to forest silviculture). Moreover, considering the whole rotation the thinning operations are carried out more frequently in Poland than in Sweden. Also the rotation cycles varies, in Poland it is 100 years or more, while in Southern Sweden it is between 80-100 years depending on the site fertility.

Planting is done in the following steps: after the clear cut the site is scarified, often 2 years old seedlings are planted, later on a pre-commercial thinnings are done to remove undesired species, such as birches. Finally the stand is fenced to prevent it from browsing damages.

Natural regeneration is done using a shelter of seed trees (50-150 per ha), (Karlsson, 2000). However on fertile sites 100-200 seed trees are recommended, (Ekö&Agestam,1994). In southern Sweden compared to the northern there is no need to wait for a mast year. On the south, pines produce seeds abundantly every second year. During winter clear cuts one can observe cones on the felled trees. The soil is scarified (disk trenching) in the autumn before the seed fall. The seed trees are kept as a shelter until the regeneration is well established (0,5-1m in height) and clear felled after. When the stand reaches 2-3 m in height is pre-commercially thinned. Bad quality and wolf trees, as well undesired species like birch are removed. In some areas there is a tradition to leave the shelter trees (150) until the regeneration height is 1-2 m. To keep the regeneration vital the shelter is thinned down to approximately 75 tress. Poorly regenerated patches and gaps are sometimes planted.

In Poland compared to the Scandinavian countries this regeneration method is less common, (Andrzejczyk&Żybura, 2012). Currently in Poland natural regeneration is done through strip regeneration in the following steps: the soil is scarified in the autumn before the clear cut, the stand is clear felled during winter in a mast year in 50-60 meters wide clear cuts. The site is regenerated by the adjacent edge trees. The seeds are spread by the wind. Unsuccessfully regenerated patches are filled by planting, (Puchalski, 2000).

Timber quality

The quality of pine wood is an important issue. In Sweden as a consequence of sparse planting densities and a lack of interest for valuable timber on the market one can observe a deterioration of the quality during the past years, (Agestam et al., 1998). However in contrast to spruce timber, valuable pine saw logs are well paid on the market which could be an incentive for a forest owner.

The most important traits affecting the wood quality are: crookedness, branch diameter, spike knots and stem damages.

Crooked stems often contain compression wood which weakens the timber strength, (Warensjö&Rune, 2004), (Krzysik, 1978). Moreover less amount of saw wood can be obtained from crooked stems, and such logs might be used only for pulp.

Thick branches deteriorate as well the wood strength and might decay inside. Furthermore the branches die off late and have an visual impact on saw timber, (Fahlvik et al., 2005), (Agestam et al., 1998).

Spike knots are side branches which took over the apical growth when the leading shoot has been damaged by frost. The side branches are often bended and ingrown in stem and bark. As a result of spike knots the strength, value and beauty of saw goods decrease, (Ståhl et al.,1990), (Ståhl&Prescher, 1986).

Damaged stems might decay, (Krzysik, 1978) and be infected by a pathogens.

Besides the external quality traits one can investigate internal ones such as, spiral grain, tracheid dimensions, juvenile wood content, basic density and ring width, (Pape,1999).

Ways and reasons of impact on wood quality

A forester can influence on the production of high quality timber, for instance through a regeneration method. Open planting (3000-4000/ha) gives best results in volume production, (Malinauskas, 1999), whereas leaving shelter trees decreases stand production but protects the understory from frost damages and improve their quality, (Agestam et al., 1998), (Ekö&Agestam, 1994).

Natural regeneration can give high quality timber, (Andrzejczyk&Żybura, 2012), (Huuskonen et al., 2008), (Agestam et al., 1998). As concluded by Agestam et. al (1998) the naturally regenerated pines have better quality because their root system is more stable and the selection possibilities are higher compared to the planted stands. Also trees in such stands grow in high heterogeneity and competition from shelter trees, which supports formation of quality timber. Another aspect is choosing the proper site for natural regeneration. The best sites are warm, moderately fertile, and with low frequency of frosts, (Tegelmark, 1999).

Also a forester can choose the site and initial densities for planting. In closer spacings and on less fertile soils pines are straighter and have better quality, (Malinauskas, 2003), (Malinauskas, 1999). In denser stands the natural cleaning of branches runs faster, because there is less light, (Fahlvik et al.2005). As a result of competition, trees growing in dense spacings are less taper than the ones in open planted stands, (Pape, 1999). Moreover one can use longer rotation periods and manual pruning which are essential to achieve quality wood, like veneer.

In Sweden during past years there has been a change in pine management. As a consequence of favoring planting instead of natural regeneration many stands are severely browsed by moose (Alces alces) and the quality of the trees is bad. It has been investigated that the naturally regenerated stands have less damages caused by moose, because of the greater seedlings number. In Poland pine plantations are browsed mainly by red deer (Cervus elaphus). In both countries fencing is a common practice to reduce the damages.

The diameter of the thickest branch is one of the decisive parameter regarding timber quality and strength, and can be controlled by a forester. As concluded by Fahlvik et al. (2005) branch diameter is strongly correlated with the growth, therefore dense spacings could decrease the diameter of branches.

The naturally regenerated stands could have less spike knots. Because of higher selection possibilities and the shelter effect, which protects the understory from frost damages, (Agestam et al., 1998), (Ekö&Agestam, 1994). One can influence spike knots formation through initial density and breeding. As investigated by Ståhl et al. (1990) higher initial density and the provenance of the planting material can reduce the frequency of spike knots.

What has been done so far?

Previous studies focused on the different regeneration methods found that the quality of pine wood is much better in the naturally regenerated stands. The studies conducted by Andrzejczyk&Żybura (2012) found that the external quality of the naturally regenerated young Scots pines will be much better, since the branches will die off more rapidly and the growth of the trees will be slower compared to the unsheltered stands. Agestam et al. (1998) studied natural regeneration in Tönnersjöheden Experimental Forest. It was a controlled experiment; as well the compared stands had similar genetic settings. They found superior quality on the naturally regenerated trees compared to the planted ones.

The aim of this study was to investigate whether the Scots pine production and external quality are affected by:

- the different regeneration methods,
- different initial spacing,
- improved planting material.

The study compares the stands in Sweden and in Poland.

2 Materials and methods

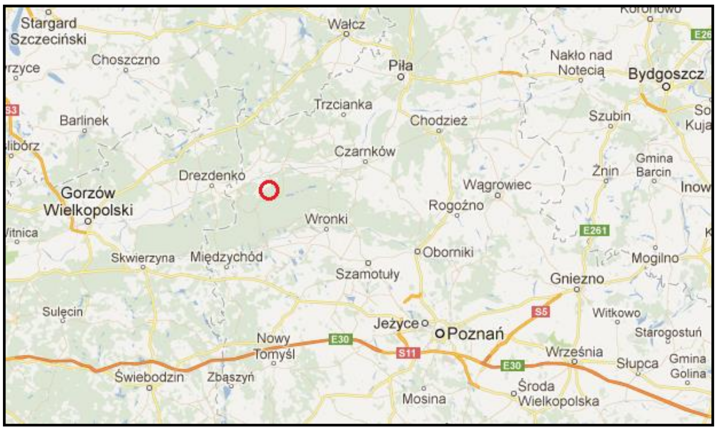
The thesis is based on the field work which was conducted in Scots pine stands varied from 14 to 21 years old. The diameter on breast height of measured trees was equal or higher than 5 cm. Studies have been carried out in experimental forests in southern Sweden, as well as in north-west Poland in Potrzebowice State Forest district.

Table 1. Plots locations

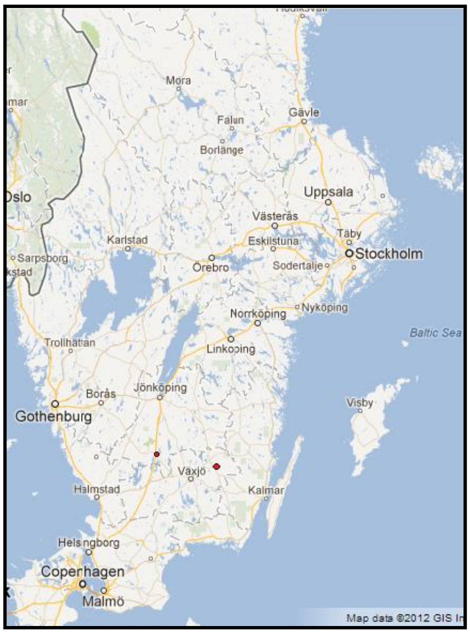
Country	Location	Latitude °N	Longitude°E
Sweden	Linnebjörke	56° 59.190'	15° 09.139'
	Värnamo	57° 14.779'	14° 03.217'
Poland	Potrzebowice		
	75d	52° 51.220'	16° 10.895'
	21g	52° 50.078'	16° 01.757'
	43b	52° 49.744'	16° 02.773'
	11a	52° 50.412'	16° 01.539'

The approximate location of the sites was presented on maps *(Map 1, 2, 3, 4, 5).*

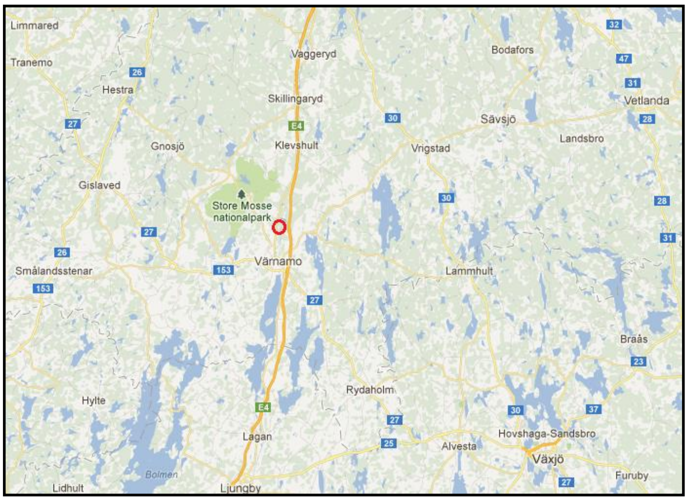
Map 1. General view.(Google Maps,2012)



Map 2. Detailed view.(Google Maps, 2012)



Map 3. General view.(Google Maps, 2012)



Map 4. Detailed view.(Google Maps, 2012)

Map 5. Detailed view.(Google Maps, 2012)

2.1 Materials

The field studies in Sweden comprised Linnebjörke and Värnamo forests belonging to the Swedish University of Agricultural Sciences. Both mentioned places are fenced preventing the grazing damages from deer and moose. The main component of the stand is *Pinus sylvestris* L. trees. The area was also covered by *Picea abies* L. and *Betula pendula* occurred as an admixture. The studied plots were unthinned.

2.1.1 Linnebjörke forest

The experiment was well described in the study done by M.Bèland et al. (1994). The stand grow on sandy loam moraine, which fertility was estimated as T27. (site index= 27 m dominant height at age 100 yrs). (Hägglund, 1974 see M.Bèland et al., 1994 p.248). Current age of the stand is approximately 20 years. On the 10ha area following experiments has been done:

- Natural regeneration of Scots pine under dense shelter amounted 200 shelter trees ha, $^{-1}$
- Natural regeneration of Scots pine under normal shelter amounted 160 shelter trees ha, $^{-1}$
- Planting on the clear cut area in densities 1600/ha, 3000/ha, 10.000/ha,
- Planting under the two shelter variants in densities 3000/ha and 10.000/ha,
- Planting 3000 trees per hectare using the best breeding material.

Scots pine trees were the main component of the stand and admixture with Norway spruce was present.

The age of the shelter trees in time of establishment was about 78 years old and its number amounted 573 stems per ha. The trees started to be felled down between January and February in 1992. All spruces were cut down, unless there was no shelter of pines, spruces remained. After shelterwood establishment the number of Scots pines and Norway spruces decreased. In the normal shelter to (150 and 4 respectively), in the dense shelter to (189 and 19 respectively). The shelterwoods were prepared to the seed fall by preparatory cuttings, as well as soil was scarified by disk trenching three times during autumn between the years 1992 to 1995. Furthermore, the number of seedlings was sampled every year starting from 1992 till the end of 1996, (M.Bèland et al., 1994). The naturally regenerated plots were cleaned from birches up to 1 meter in height and pre-comercially thinned in 2011. Among the planted stands only 10.000 planted was subjected to PCT treatment in 2011.

2.1.2 Värnamo forest

The experiment on the following area was carried out using the same patterns as in Linnebjörke pine stand. The artificial regeneration of Scots pine was done by planting, applying following densities 1600, 3000, and 10.000 seedlings per hectare. The natural regeneration appeared under approximately 80 shelter trees in 1996. According to the Swedish Site index curves the site fertility is T20, (Hägglund, 1974). The soil type is fine sand. Both naturally regenerated stands and planted were not pre-commercially thinned. Current age of the stand is 16 years old.

2.1.3 Potrzebowice State forest

The measurements on above mentioned area were done on two sites with naturally regenerated Scots pine trees, as well as on two planted stands. The soil type in all cases was classified as podsols. All of the stands were unthinned.

One of the studied planted site was established on the former burned area. The fire appeared in summer 1992 and 6000 hectares were totally burned.

On the investigated pine stand which size is 22.08 hectares all damaged trees were clear felled, then trees residuals were fragmented and dispersed by the "Seppi" machines, finally during autumn soil was plowed in perpendicular passes. Next, artificial regeneration has been done and 13.000 seedlings per hectare were planted. After some years one pre commercial thinning was carried out. Currently, the area is covered in great majority by Scots pine trees with Silver birch admixture and is ready for the second last pre commercial thinning. The site fertility is classified as bonitation I, (BULiGL, 2012) and was estimated by using the Swedish Site index curves as T25, (Hägglund, 1974). The age of the stand is 19 years old, and the average height amounts 6 meters.

The another planted site is 3.40 hectares and its age is 15 years old. The stand is formed by Scots pine trees, with component of Silver birch and Grey alder. The described land was prepared for regeneration following general patterns mentioned in above paragraph. The planting was carried out using distances 0.8×1.3m which is 9615 trees per hectare. The average height of the stand is 5 meters. Planted material originated from seeds collected on best phenotypes of Pinus sylvestris L. tress occurring on the local area. The local ecotypes characterize best quality meaning straight stems and well developed tree crowns. The stand in early growing stages was fenced to prevent from grazing damages. Currently, the age of it is 15 years. The site fertility was classified as bonitation II, (BULiGL, 2012) and was estimated according to the Swedish Site index curves as T25, (Hägglund, 1974).

Natural regeneration was studied on two sites labeled as 21g and 43b which size is 4.52 and 4.34 hectares. The age of 21g stand is 14 and 16 years old in 43b. Site fertility was classified as bonitation II, (BULiGL, 2012) and was estimated according to the Swedish Site index curves as

T23, (Hägglund, 1974). The average height amounts 5 meters. The seed fall begun in 1996 and lasted till 1999. The history of establishment of the areas is similar. At the beginning of the regeneration process the seed trees were 98 and 104 years old respectively. Before it, field inspection was conducted which aim was to select best seed trees. Two features has been considered, such as crown size and its development and the external quality of stem, focusing on straightness and branchiness. Next, on the two described areas the selection of trees was done. On the first site 87 pines per hectare were selected, whereas on the second site 120 pine trees were selected. The rest of trees which were not selected as seed trees have been clear felled, and the slash was spread out by “Seppi” machines. During autumn before the mast year the soil was prepared by shallow plowing in perpendicular passes. Seed trees were stimulated for seed production by preparatory cuttings. There are some differences between the two stands. The 21g is characterized by big heterogeneity. Height and diameter differs significantly between trees on the described area, whereas in 43b the diversity is not so easily observed. The reason for it is that on the first area regeneration started spontaneously in four small gaps caused by windthrow, by this pine trees which grow there are 25 years old, while the surrounding pines are 14 years old. Furthermore, some of the trees on this area were planted to refill gaps where natural regeneration was not as successful. The regeneration in 43b was very good, all the land was covered by high number of seedlings. Finally, in both stands seed trees were cut down at the age of 115 and 109. The pre commercial thinning has been carried out two times so far and was less intense compared to the planted sites.

2.2 Methods

The data was collected by establishing circular plots within each stand. The radius of the plots used in Swedish forests was 10 m, whereas in Poland thanks to higher planting densities 8 m radius was applied. Finally, the amount of trees per each plot was similar, so the aspect of comparability is maintained. Next the procedure of data collection was uniform in Polish and Swedish conditions, and it has been done as following; the area which has been covered by the radius was marked by ribbons. Next, all the trees which had 5cm or more in diameter were callipered at 1.3m of breast height. Then, two biggest trees plus 25 trees were selected as sample trees. On the mentioned individuals diameter at breast height was measured, as well as other traits were investigated, such as:

- Height measured by Vertex IV hypsometer (P offset 0,3; Trp height 1,3)
- growth intercept on the distance between 2,5 m in height to the last visible whorl,
- distances to overstory trees if they were closer than 10m,
- overall quality in 4 point scale (1 the best ; 4 the worst) ,
- crookedness: straight, relative deviation < 1; slightly crooked 1-2; crooked 3; very crooked 4;reject crooked (r.c) represents substantial crooks, relative deviation > 4 (Agestam et al., 1998)
- the number and height on which spike knots were observed,
- diameter of the thickest branch below 2 m of stem height, the branches were callipered in 3cm distance from tree trunk,

- narrow branches,
- the distance between the three closest whorls below and above 1,3 m of stem height, and number of branches which are more than 1cm in diameter,
- mechanical damages,
- position of the tree in the stand in 4 point scale* (dominants, co-dominants, dominated, suppressed).

D - Dominant trees were the highest and formed biggest crowns.
CD - Co-dominant trees a bit lower than the dominants, formed the canopy of the stand.
DD - Dominated lower and suppressed by surrounded trees.
S - Suppressed totally by the other individuals.

Consequently, above described procedure was repeated to other sample trees counted as every 5^{th} or every 3^{th} tree to obtain the result of 25 sample trees in total within one parcel. The other tree species than Scots pine were recorded only if they had 5cm or more in dbh. Finally, highly crooked individuals, its crookedness were not measured instead of it they were described as "reject crooked". The diameter at breast height and branch diameters were determined in millimeters, intercepts were described in centimeters, while heights were noted in decimeters.

Following parameters were calculated to show the differences between the measured stands. They are top height, Lorey's height, arithmetic height, square quadratic mean diameter, arithmetic average diameter, basal area, volume and mean annual increment.

Top height [dm] -calculated as the average of the highest sampled trees within one plot.

Lorey's height [dm]

$$\frac{\sum hi * di^2}{\sum di^2}$$

hi - heights of sampled trees [dm]
di-diameters of sampled trees [mm]

Arithmetic height [dm]- average height of sampled trees.

Square quadratic mean diameter [mm]

$$\sqrt{\frac{\sum di^2}{n}}$$

di-diameters of all trees [mm]
n-number of all measured trees

Arithmetic average diameter [mm] – counted as the average of the diameters of all measured trees.

Basal area [m^2 ha^{-1}]

$$\frac{\sum d^2}{4} * \pi * \frac{10000}{r^2 * \pi}$$

d-diameter of all trees [mm]
r-radius[m]

Volume [m^3 ha^{-1}]

$V=10^{-1,38903}*D^{1,84493}*(D+20,00)^{0,06563}*H^{2,02122}*(H-1,3)^{-1,01095}$ (Brandel, G. 1990.)

D-diameter of all trees [cm]
H-height of all trees for each plot was estimated by using polynomial function in relation to dbh of all trees [m]

Mean annual increment [m^3 ha^{-1} yr^{-1}]

$$\frac{\text{Volume}}{\text{Stand age}}$$

Volume-[m^3 ha^{-1}]
Stand age- [years]

3 Results

3.1 Stand characteristics and growth

Calculated means for the different stand characters are shown in the Table 2 and commented on in the following paragraphs.

Tabell 2 Overview of stand data

Site	Plot	Treatment	Age (years)	Top height (dm)	Lorey's height (dm)	Arith-metic height (dm)	Square quadratic mean diameter (mm)	Arith-metic average diameter (mm)	Basal area (m^2 ha^{-1})	Volume (m^3 ha^{-1})	MAI (m^3 ha^{-1} yr^{-1})
Linnebjörke	F	pl.1600	21	116	108	106	142	140	12,0	129	6,1
	G	pl.3000	21	112	109	106	130	127	13,5	149	7,1
	E	pl.10.000	21	112	105	102	98	96	12,1	134	6,4
	C	pl.3000i *	21	122	118	112	126	121	12,4	143	6,8
	R	pl.3000n.s**	21	101	93	87	114	110	9,2	89	4,3
	Z	pl.3000d.s***	21	114	102	97	98	95	7,9	83	3,9
	Å	pl.10.000d.s	21	107	94	90	86	84	6,4	64	3,0
	U	pl.3000i.d.s.	21	120	105	102	98	95	7,6	79	3,8
	O	nat.reg. n.s	19	92	83	81	84	81	6,9	63	3,3
	Ö	nat.reg. n.s	19	65	69	63	67	66	3,1	27	1,4
	V	nat. reg.d.s	19	71	62	60	63	62	1,7	13	0,7
Värnamo	B	pl. 1600	16	64	56	53	65	64	2,7	19	1,2
	C	pl. 3000	16	65	60	57	67	66	4,0	29	1,8
	A	pl.10.000	16	70	64	59	73	70	5,3	40	2,5
	D	nat. reg.	16	59	53	52	60	59	0,8	5	0,3
Potrzebowice	A	pl.10.000i	15	81	75	73	67	66	9,8	84	5,6
	D	pl.13000	19	94	87	84	83	81	12,8	122	6,4
	B	nat. reg.	16	70	62	60	65	64	6,4	48	3,0
	G	nat. reg.	14	67	60	56	70	68	6,5	47	3,4

*improved material- best breed planting material from local pine ecotypes

** normal shelter 160 trees/ ha

***dense shelter 200 trees/ ha

3.1.1 Height

Differences between regeneration methods

On average stands on planted plots were higher than on the naturally regenerated plots. The greatest difference was noticed in Linnebjörke (51%), followed by Potrzebowice and Värnamo (33 and 13%, respectively), (Table 2, Figure 9).

The effect of shelter

On average, naturally regenerated pines under the dense shelter were smaller (23%) compared to under the normal shelter, contradictory planted 3000 under dense shelter was higher than 3000 under the normal shelter (10 %), (Table 2, Figure 9).

The effect of spacing

There were no obvious differences in height between stands planted at different densities in Linnebjörke, but in Värnamo and Potrzebowice the height in the densest planted stands were greater by (11 and 16%) compared to the plot with improved material, (Table 2, Figure 9).

The effect of improved material

In Linnebjörke stands originated from improved material both under shelter and on the clear cut were taller (5%)than the local provenance established in the same way. However, the result was not consistent over sites. In Potrzebowice the improved stands was lower (16%) compared to the local material, (Table 2, Figure 9).

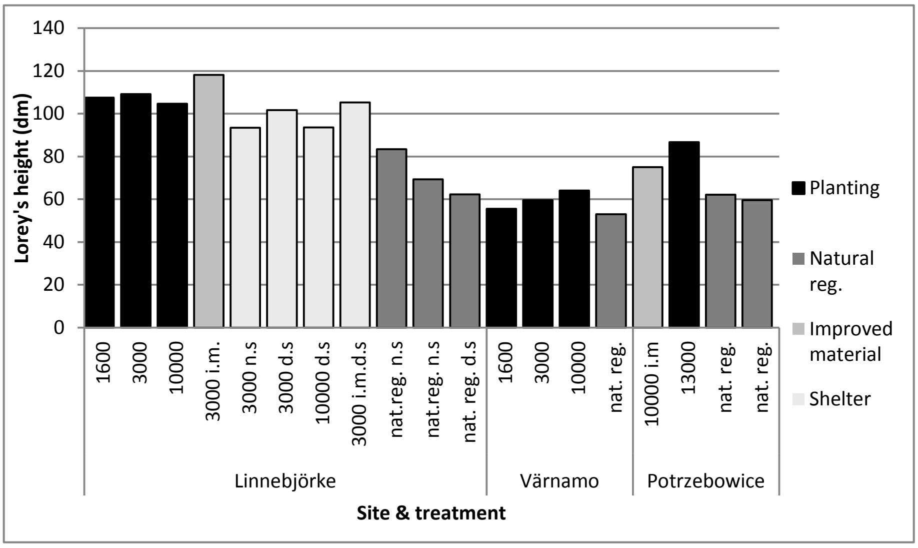


Figure 9. Comparison of Lorey's height between the sites.

3.1.2 Diameter

Differences between regeneration methods

The planted stands on the clear cut had on average bigger mean diameters compared to naturally established stands. The greatest contrast was recorded in Linnebjörke (73%). In Värnamo and Potrzebowice the corresponding differences were 14% and 11% respectively, (Table 2, Figure 10).

The effect of shelter

Together naturally regenerated and planted stands under normal shelter had on average 16 and 20 % larger diameters in comparison to the same treatments under dense shelter, (Table 2, Figure 10).

The effect of spacing

On average the closest spacing had the greater diameters, in Värnamo, Potrzebowice (11 and 24%) higher compared to the more open spacings, however in Linnebjörke the densest planted stand had 39% smaller mean diameter compared to the others planted plots, (Table 2, Figure 10).

The effect of improved material

A slightly positive influence of improved material was observed in Linnebjörke where on the clear cut a 2% greater diameter was found compared to the local material. Contradictory in Potrzebowice the average diameter was 24% smaller compared to the local material. No obvious difference was found studying the sheltered stands, (Table 2, Figure 10).

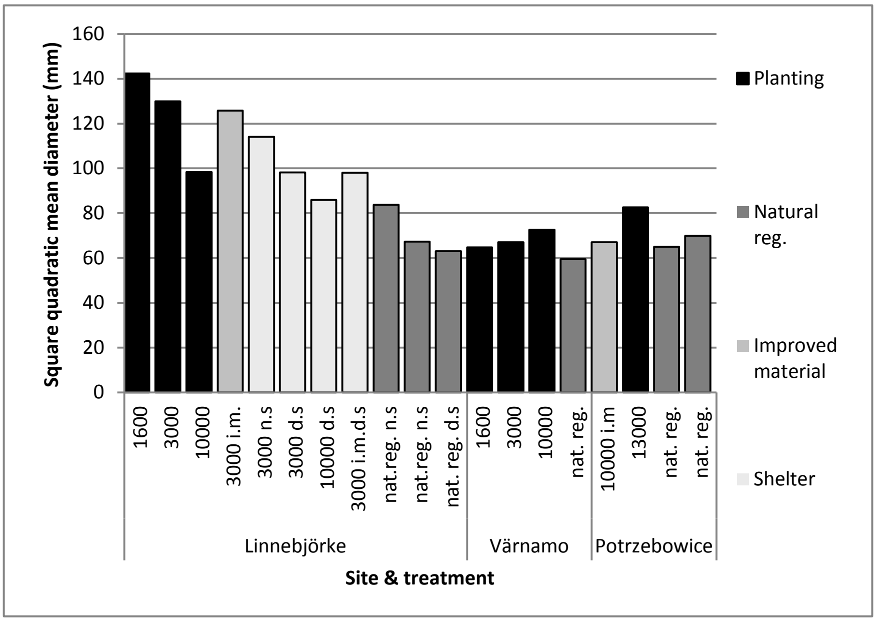


Figure 10. Comparison of Square quadratic mean diameter between the sites.

3.1.3 Volume

Differences between regeneration methods

Planted stands had substantially greater volume than the naturally regenerated. The greatest mean difference was found in Linnebjörke 103 m^3 ha^{-1}, followed by Potrzebowice 56 m^3 ha^{-1} and Värnamo 24m^3 ha^{-1}, (Table 2, Figure 11).

The effect of shelter

The planted stand under the normal shelter had on average 16 m^3ha^{-1} higher volume compared to the stand under the dense shelter. Also the naturally regenerated stands below the close canopy had 32 m^3ha^{-1} lower volume than under the normal shelter, (Table 2, Figure 11).

The effect of spacing

In Linnebjörke the differences among the plots established on the clear cut were not consistent, however in Värnamo and Potrzebowice trees developing in closest spacing were on average superior in volume (16 and 38m^3ha^{-1} respectively), (Table 2, Figure 11).

The effect of improved material

On average, the improved material in Linnebjörke planted on the clear cut had 5,6m^3ha^{-1} greater volume than the other plots planted at the same density on the clear felled area but in Potrzebowice it was 38m^3ha^{-1}lower, (Table 2, Figure 11).

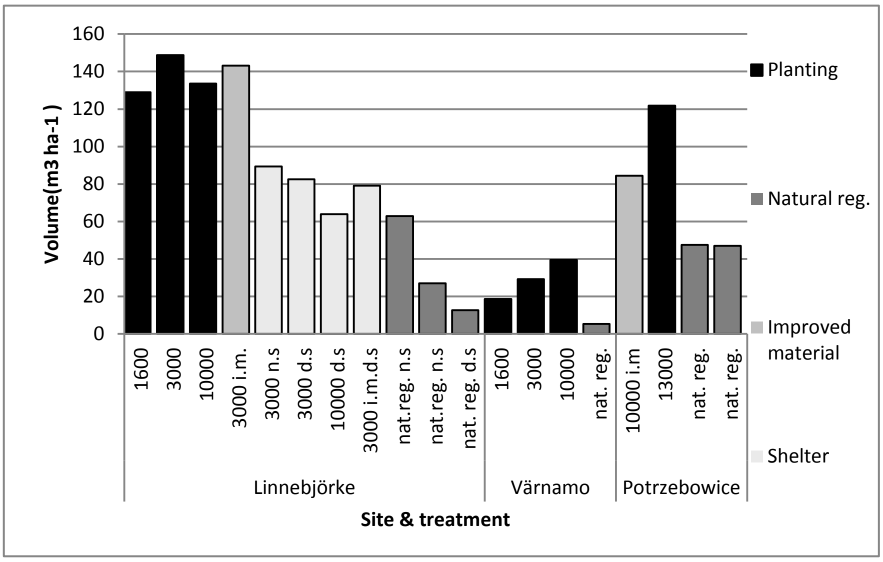


Figure 11. Comparison of Volume between the sites.

i.m - improved material
n.s - normal shelter
d.s - dense shelter
nat. reg - natural regeneration

3.1.4 Mean annual increment

Differences between regeneration methods

The MAI between naturally regenerated stands and planted varied noticeably. Planted stands in Linnebjörke, Värnamo and Potrzebowice had on average 4,7, 1,5 and 2,8 $m^3ha^{-1}yr^{-1}$ higher growth.

The effect of shelter

Not only the presence or absence of shelter, but also the shelter density affected the increment. Among the two shelter types; 3000ns to 3000ds the difference was 0,4$m^3ha^{-1}yr^{-1}$, whereas among naturally regenerated stands, 1,7$m^3ha^{-1}yr^{-1}$, (Table 2.). Comparing the average values of MAI between planted trees on the clear cut and below shelter the difference was 2,8$m^3ha\text{-}^1yr^{-1}$, (Table 2.)

The effect of spacing

In Värnamo and Potrzebowice the closer spacing had highest MAI. However it was not consistent with the results in Linnebjörke where 3000 planted grew 0,7 m^3 ha^{-1} yr^{-1} more than in 10.000 planted, (Table 2.)

The effect of improved material

In Linnebjörke the improved 3000 planted on the clear felled area had 0,3 $m^3ha^{-1}yr^{-1}$ lower increment than the not improved 3000 planted on the same area. In Potrzebowice the improved stand planted in 10.000 density per ha $^{-1}$ had 0,8 m^3 ha^{-1} yr^{-1} smaller MAI than 13.000. The influence of breeding was not decisive under shelter, (Table 2.)

3.2 Effects on wood quality

3.2.1 The relationship between diameter of the thickest branch and diameter at breast height

Differences between regeneration methods

On average the linear correlation coefficient between the diameter of the thickest branch and the diameter at breast height was for planted stands higher than for the naturally regenerated ones. The greatest variation was observed in Värnamo, mean R for planted stands was 0,6 compared to 0,2 for naturally regenerated stand. Similarly in Linnebjörke the average R was 0,6 for planted and 0,4 for naturally regenerated stands. Contradictory, a weaker relationship between the two studied variables was found in the planted plots in Potrzebowice compared to the naturally regenerated stands (0,6 and 0,8 respectively), (Fig. 12, 13, 14).

The effect of shelter

A significant difference was found between naturally regenerated plots under shelter in Linnebjörke. Under normal shelter there was a strong linear correlation between branch diameter and dbh (R=0,7), while under dense shelter this relationship was very weak (R=0,06). Between planted stands below overstory pines no decisive differences were noticed, (Fig. 12, 13, 14).

The effect of spacing

The mean R between Dbr and Dbh for planted stands in the different spacing on the clear cut did not vary much and ranged from (0,5 to 0,6), (Fig. 12, 13, 14).

The effect of improved material

The stands originated from the improved material showed the strongest relationship between studied variables. In Linnebjörke both improved planted stands on the clear felled area and under dense shelter had on average a R of 0,8 compared to a R of 0,6 in the local provenance. However in Potrzebowice this difference was not decisive (Fig. 12, 13, 14).

Linnebjörke

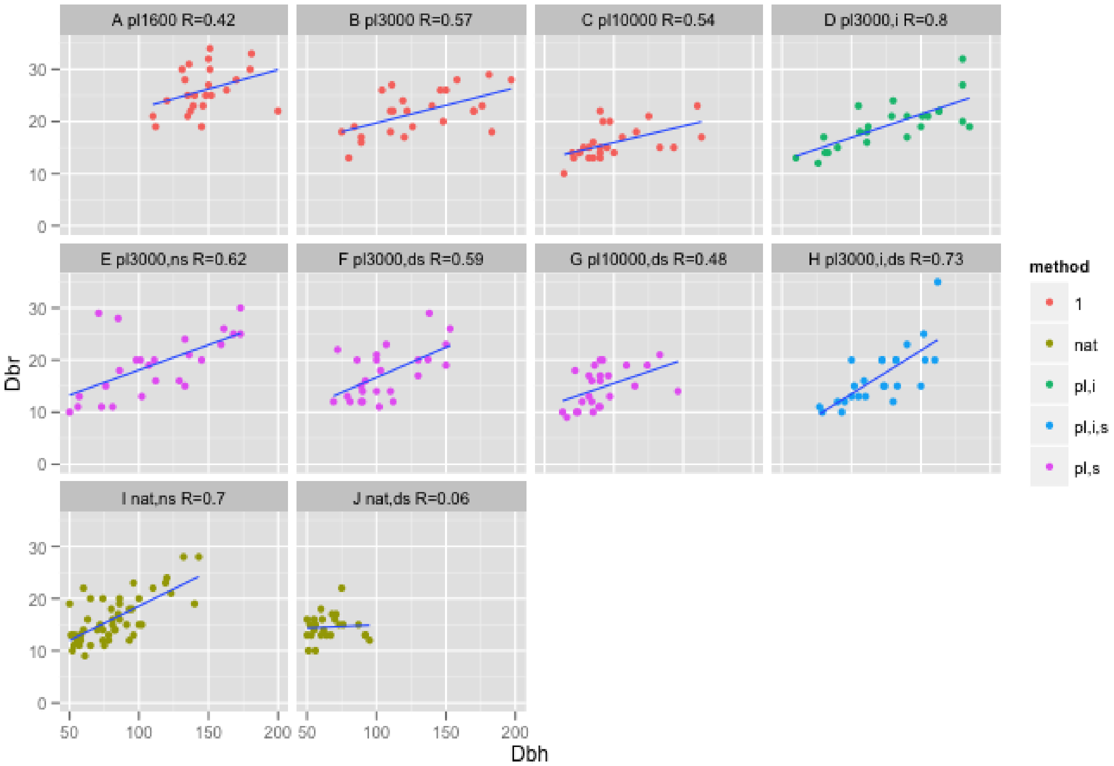


Figure 12. Diameter of the thickest branch related to the tree diameter.

Värnamo

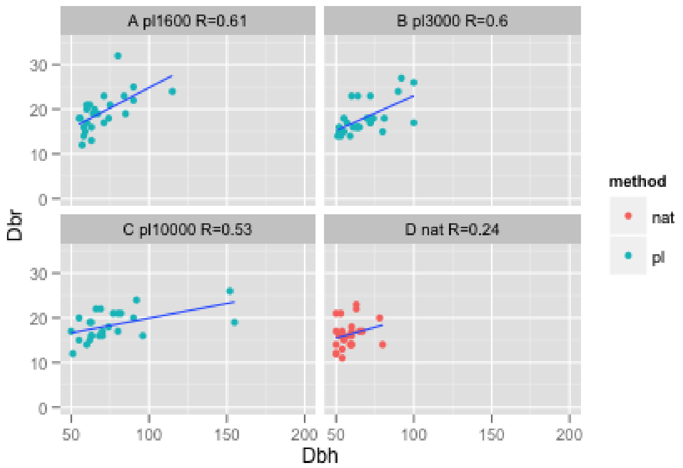


Figure 13. Diameter of the thickest branch related to the tree diameter.

Potrzebowice

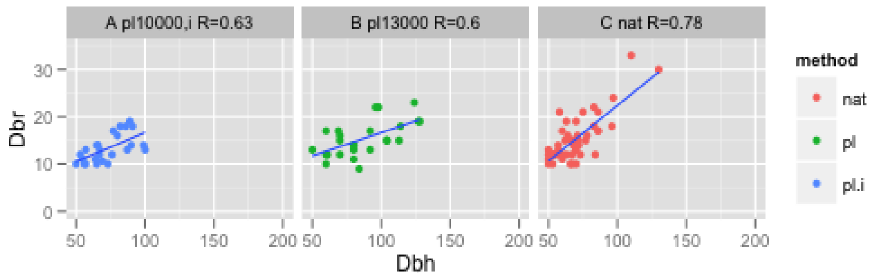


Figure 14. Diameter of the thickest branch related to the tree diameter.

3.2.2 The average diameter of the thickest branch

The differences between regeneration methods

In Linnebjörke and Värnamo the average branch diameter (Dbr) in planted stands on the clear cut and under shelter compared to the naturally regenerated plots was 122% and 114% respectively. It was not consistent in Potrzebowice where the mean branch diameter in naturally regenerated stands compared to the planted plots on the clear cut was 105%. The greatest average differences were found in Linnebjörke between treatments established on the clear cut and below the dense shelter (125%), (Fig. 15).

The effect of shelter

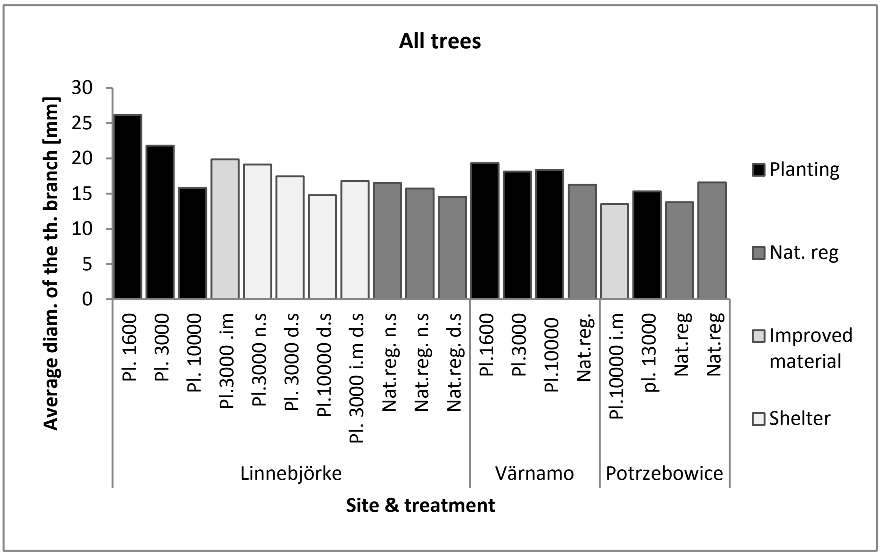
A clear influence of the overstory trees on the diameter of the thickest branch was observed. The planted plots under the dense shelter had on average 20% lower diameter of the thickest branch than the comparable plots established under normal shelter. Similarly between the naturally regenerated stands the difference was 11% favoring trees developing under close canopy of shelter trees, (Fig. 15).

The effect of spacing

The planting density had the most substantial influence on the diameter of branches in Linnebjörke, where the densest planted stand had 65% lower mean branch diameter compared to the most open planting. In Värnamo the same trend was observed, although the difference was much smaller, 5%. On the contrary in Potrzebowice in the plot planted in the highest density the mean diameter of the thickest branch was 13% higher compared to the stand planted in the lower density, (Fig. 15).

The effect of improved material

In Linnebjörke the stand established from improved planting material on the clear cut had on average 7% lower mean Dbr than the rest of the local material planted in equal density. Also the improved stand planted under the dense shelter had on average 27% lower Dbr compared to the local provenance planted in the same spacing on the clear cut. Correspondingly in Potrzebowice the Dbr was 27% lower in the improved stand compared to the not improved stand planted on the clear felled area, (Fig. 15).



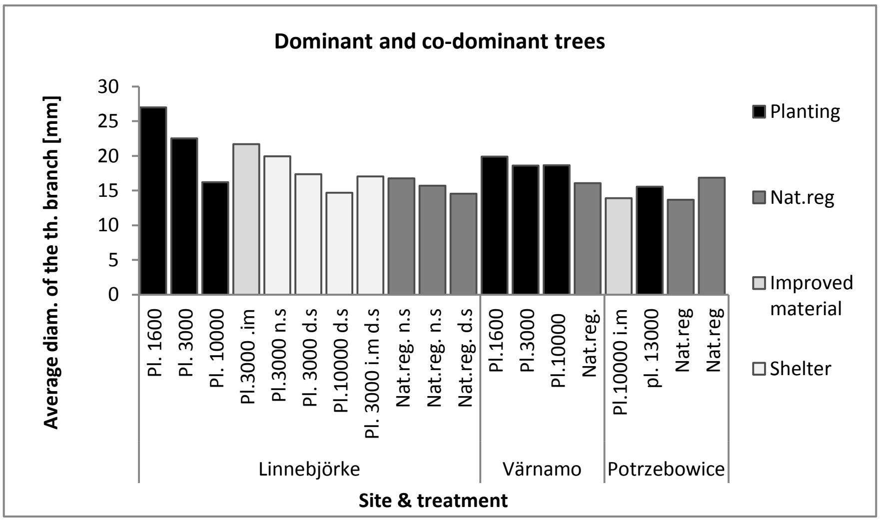


Figure 15. Average diameter of the thickest branch.
All trees (top), dominant and co-dominant trees (below).

3.2.3 Crookedness

Crookedness shown in *Figure 16* was assessed in all tree's classes.

The differences between regeneration methods

Both in Linnebjörke and Värnamo naturally regenerated stands had a lower relative frequency of crooked stems leading to rejection compared to the planted stands on the clear felled area. On average in Linnebjörke and Värnamo it was 8 and 4% lower, respectively. Contradictory in Potrzebowice planted plots had 4% lower frequency of substantially bended stems. In Linnebjörke on average 16% of trees were straight under the shelter compared to 0% on the clear cut, (Fig.16).

The effect of shelter

The frequency of very crooked and reject stems were 25% lower in stands planted under dense overstory compared to the normal shelter. Also among naturally regenerated stands 4% pines were rejected under normal shelter compared to 0% under the dense shelter, (Fig.16).

The effect of spacing

In Linnebjörke the differences of crookedness between trees planted at different densities on the clear cut were substantial. The occurrence of severely crooked stems was 40% higher in sparsest compared to densest spacing. Similar results were found in Värnamo, but the difference was much smaller and amounted to 4%. In Potrzebowice site none of the planted plots had substantially crooked stems, (Fig.16).

The effect of improved material

In Linnebjörke and Potrzebowice the improved stands planted on the clear cut had much better stem straightness compared to the rest of the planted local provenances. On average in Linnebjörke 8% of reject crooked pines were recorded in 3000i planted on the clear felled area compared to 14% in the rest of the planted stands. In 10.000 planted in Potrzebowice 28% of pines were straight compared to 0% in 13.000 planted, (Fig.16).

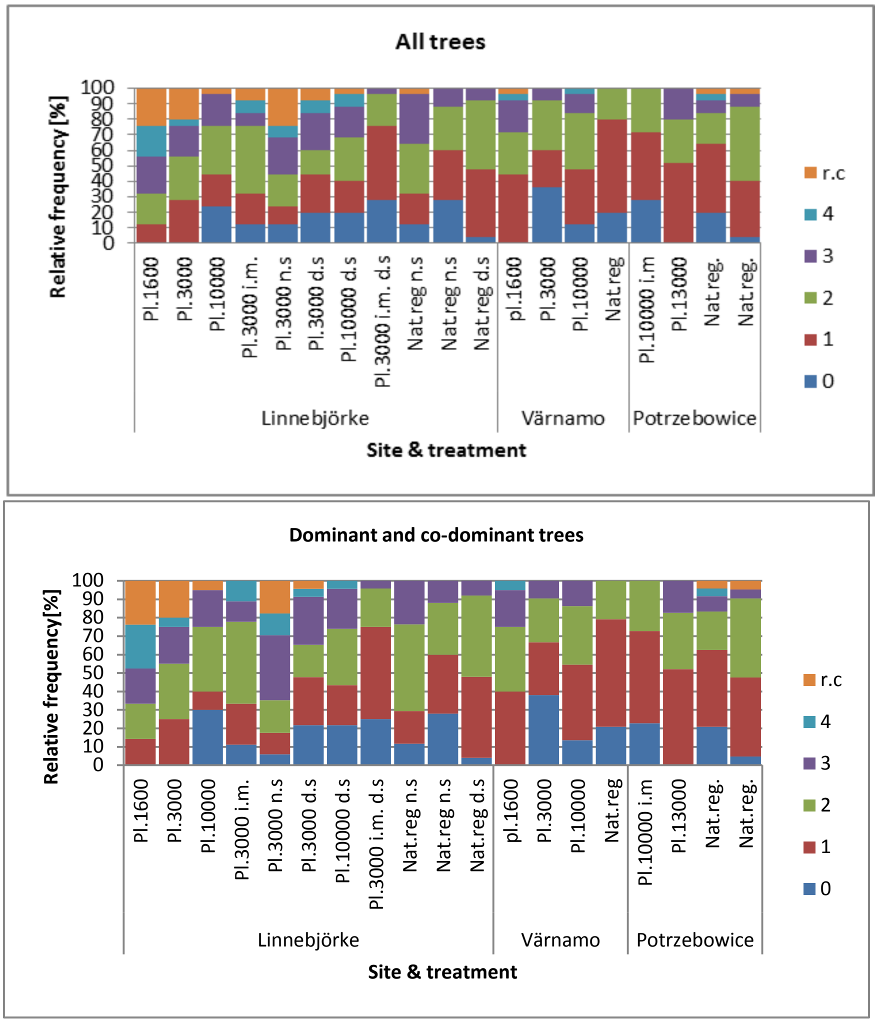


Figure 16. Crookedness frequency.
All trees (top), dominant and co-dominant trees (below).
Straight, relative deviation < 1; Slightly crooked 1-2; Crooked 3; Very crooked 4;Reject crooked (r.c) represents substantial crooks, relative deviation > 4. (Agestam et al. 1998).

3.2.4 Spike knots

The differences between regeneration methods

On average in Linnebjörke 25% of planted trees on the clear cut had spike knots compared to 40% in naturally regenerated stands. On the contrary in Värnamo mean results were 43% for planted and 40% for naturally regenerated plots, whereas in Potrzebowice it was 36% in planted and 36% in naturally regenerated stands, (Fig.17).

The effect of shelter

Not decisive differences were noticed between stands planted under dense and normal shelter. However among naturally regenerated plots in Linnebjörke the stand under the dense canopy had on average 6% lower frequency of spike knots compared to those growing under the normal shelter, (Fig.17).

The effect of spacing

Both in Linnebjörke and Värnamo the lowest average frequency of spike knots was found in 1600 planted (24%) compared to (40%) in 10.000 planted. Contradictory in Potrzebowice much less spike knots were recorded in the closest planting (24%) compared to (48%) in sparsest planted stand, (Fig.17).

The effect of improved material

On average in Linnebjörke 16% of the improved trees had spike knots, while the comparable material established in the same way had 28% spike knots. It was not consistent to the results in Potrzebowice, since the proportion amounted 48 to 24% favoring not improved stand, (Fig.17).

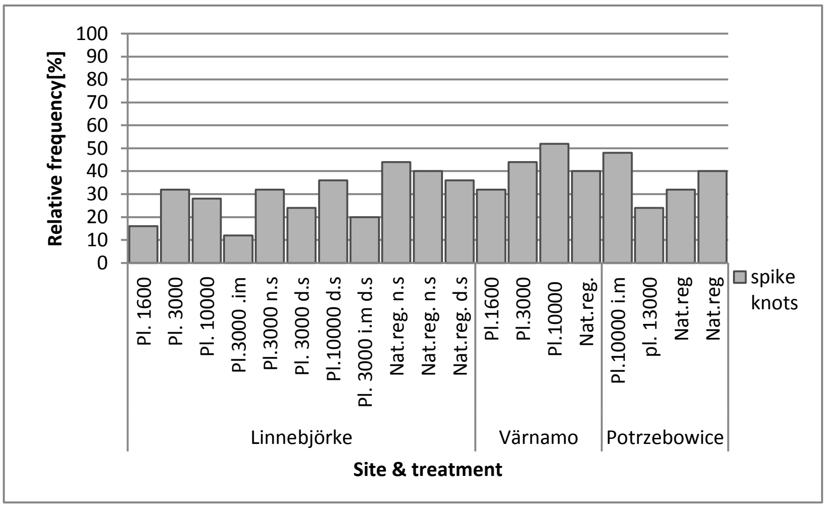


Figure 17. Spike knots frequency.

3.2.5 Judged overall quality

The differences between regeneration methods

In Linnebjörke planted stands on the clear felled area had considerably lower external quality than the naturally regenerated plots. On average 36% of the planted pines had worst quality compared to 8% in the naturally regenerated stands. Similarly in Potrzebowice the mean result for the naturally regenerated stands was 6% and in planted stands 12%. Contradictory, in Värnamo on average 20% trees had the worst quality in the naturally regenerated plot compared to 17% in planted stands. Comparing planted plots in Linnebjörke on the clear cut to those growing under dense and normal shelter the mean difference of worst class amounted to 19%, favoring sheltered stands, (Fig.18).

The effect of shelter

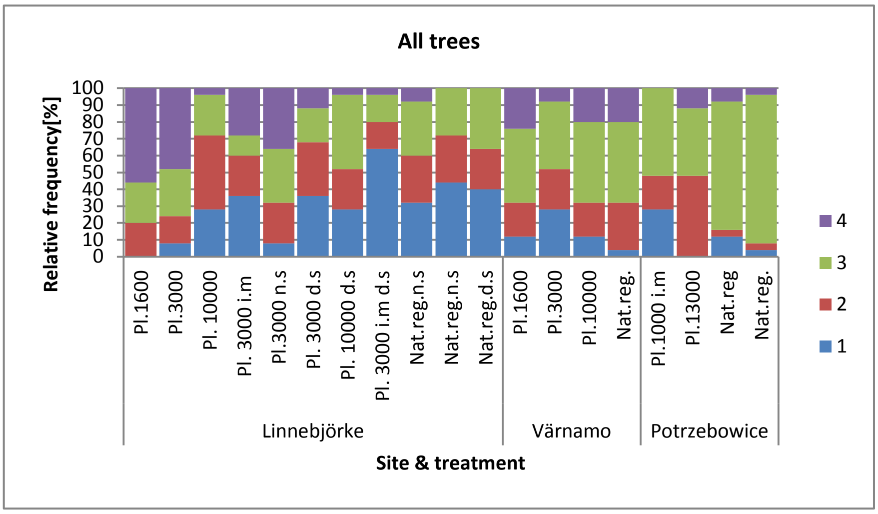
Shelter had substantial influence on the quality of pines. 3000 planted under dense canopy of overstory trees, represented much better quality than below normal shelter. The frequency of best and good quality pines was 68% under the dense shelter to 32% under the normal shelter. The differences between the naturally regenerated plots under overstory in Linnebjörke were not decisive, (Fig.18).

The effect of spacing

In Linnebjörke trees planted in the closest spacing had considerably greater frequency of stems in the two best classes. On average it was 72% compared to 15% in the lowest planting densities. However, this trend was not observed in Värnamo where 3000 planted had 20% bigger share of trees in the two classes compared to 10.000 planted. Similarly in Potrzebowice 28% of trees developing in the sparsest stand had the best quality compared to 0% in 13.000 planted, (Fig.18).

The effect of improved material

In Linnebjörke stands originated from best planting material had substantially better frequency of best and good quality trees then the rest of the planted local provenance. For 3000 improved planted material on the clear cut and below the dense shelter the difference was 36 and 56% respectively compared to the same not improved material. In Potrzebowice 10.000 improved planted had 28% trees in best quality compared to 0% in 13.000 planted, (Fig.18).



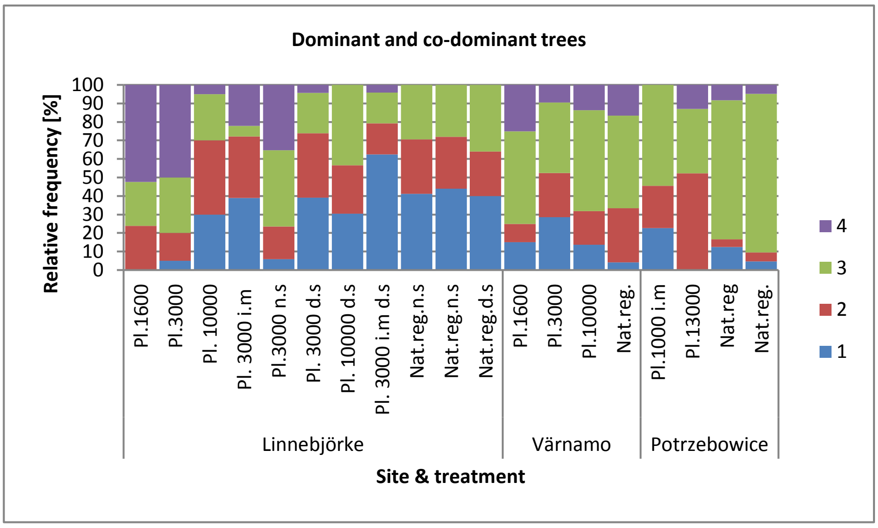


Figure 18. Quality distribution.
All trees (top), dominant and co-dominant trees (below).
The quality is represented in the following classes: 1-The best; 2-Good;3-Bad;4-The worst. (Agestam et al. 1998).

3.2.6 Damages

The damages were related mainly to stripping and fraying by ungulates. Despite that there were visible traits of moose existence on the studied area both in Linnebjörke and Värnamo, measured pines were not browsed. Contradictory, on Polish sites especially naturally regenerated plots were substantially browsed. 44 and 32 % of measured trees were browsed at breast height of the trees, (Fig. 19).

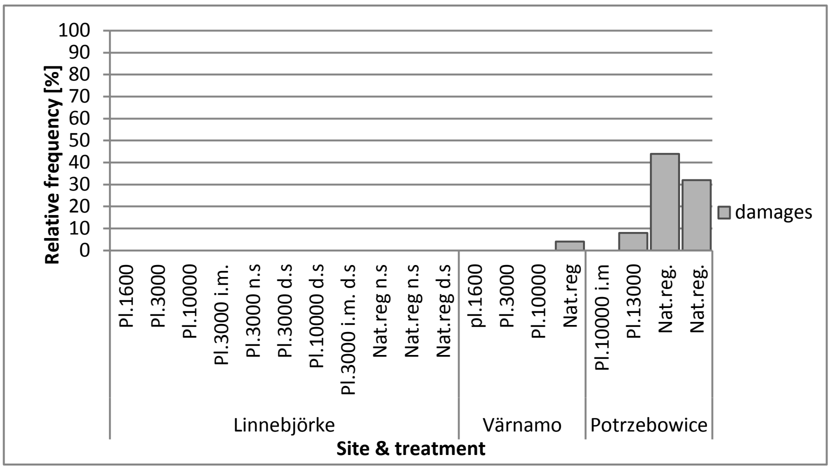


*Figure 19.*Relative frequency of observed damages.

4 Discussion

4.1 Effects on stand development

There was a considerable difference in height, diameter, volume and mean annual increment (MAI) development between regeneration methods. Planted stands had on average greater mean heights (34%), diameters (39%), compared to naturally regenerated ones. The corresponding result for the mean annual increment was on average (242%) higher compared to the naturally regenerated stands, (Table 2.,Fig. 9-11). These findings can be supported by Huuskonen et al. (2008), Agestam et al.(1998), Ekö&Agestam (1994), Ackzell (1993). The results might be explained by a better nutritional condition of planted seedlings coming from nursery and heavier competition between young pines and shelter trees. Also in the naturally regenerated plots the soil scarification is usually done during first establishment, whereas in the planted plots every establishment is preceded by scarification. Furthermore, the process of natural regeneration will results in an uneven spatial distribution of seedlings, creating patches with gaps. It takes some time to close the gaps, which cause slower growth compared to the even planted stands. The longer shelter period the longer it will take until the gaps will be closed, (Valkonen, 2000), (Agestam et al., 1998), (Ekö&Agestam,1994). Finally, the mineralization process might be faster and the abundance of nutrients, water higher in planted stands on the clear cut site, compared to the conditions on naturally regenerated and sheltered sites, (Bèland et al., 2000) and (Agestam et al., 1998).

Effects of shelter

The effect of different shelter periods on planted and naturally regenerated stands was studied in Linnebjörke where the pines grew under the two different shelter densities and the two shelter period lengths. The results show that especially volume, height and diameter were lower under the shelter compared to the corresponding planted plots on the clear felled area, (Fig 9-11.). This idea has been explored by Ekö&Agestam (1994) who suggest that the volume in the 25 years old planted pine site might be five times higher compared to under a shelter. However, the loss in volume yield was 20% considering the whole rotation. The estimate included the growth of the overstory. (Ekö&Agestam,1994). However it must be born in mind that in this study the shelter period was very long and lasted over 30 years, the overstory was subjected to two thinnings and the shelter was removed completely when the mean height of the new generation had reached 6 meters. A common practice in natural regeneration is that the shelter period is much shorter and that the new generation is released when it is established at a height of about 0,5 to 1 m. This procedure has been estimated to cause a loss of 5-10% volume yield considering the whole rotation.

Jakobsson (2005) found that the production under the overstory decreased over a whole rotation by 2-4%, with 10 retained pines per ha. Valkonen et al. (2002) concluded that the potential yield was 9-17% lower under 30 retained pines per hectare.

Effect of spacing

In Värnamo and Potrzebowice the planting density influenced volume and MAI development, (Fig 11.Table 2.). The plots planted in the lowest spacing had the highest mean height, total volume per ha and MAI. These results are consistent with other investigations conducted by Liziniewicz et al. (2012), Malinauskas (1999), Agestam et al. (1998). However the effect of spacing on the mean height, volume and mean annual increment was not consistent in Linnebjörke, (Fig 9,11. Table 2.). On average the differences in mean height, volume and MAI between the most open (1600/ha) and closest (10.000/ha) planted stands were not decisive. The stand established in the densest spacing has been subjected to the pre-commercial thinning one year before the current inventory, thus affecting comparison with the other spacings. The PCT was carried out only in the 10.000 spacing because the aim was to favor the candidates within dominant and co-dominant tree classes. In order to produce high quality timber the stand had to be pre-commercially thinned, otherwise the possibility for selection in the first thinning had been heavily restricted.

Furthermore, Ruha&Varmola (1997) found that higher stand density after PCT decreased its mean height. Ulvcrona et al. (2007) and Huuskonen et al. (2006) stated that light pre-commercial thinning decreases the diameter increment. According to the above mentioned findings one can say that the total production of the pre-commercially thinned stand might be lower. This statement agrees well with Varmola&Salminen (2004) who found that the intensity of PCT and timing affected stand volume.

The planting density did not influence the mean height of the planted stands in Linnebjörke. These results seems to be unexpected but are supported by studies conducted by Cochran&Dahms (1998) and Johnstone (2005) which did not confirm that spacing had an impact on the mean height of Lodgepole pine, however the investigated planting densities in these studies were much lower compared to this study. Malinauskas (2003) found that up to 4,444 planted Scots pines per ha the mean tree height increased, while over 6,667 planted trees per ha it started to decrease.

According to numerous investigations Liziniewicz et al. (2012), Husskonen et al. (2008), Malinauskas (2003), Malinauskas (1999) and Agestam et al. (1998) the mean diameter decreases with higher planting densities. However in Potrzebowice and Värnamo the closest spacing had the greatest average diameters, (Fig 10). A possible explanation for this results might be that in Potrzebowice the densest (13.000/ha) planted stand is 4 years older than another planted plot (10.000/ha).

In Linnebjörke a light PCT has as said been carried out in the 10.000 planted plot, causing an unexpected slight decrease of the mean diameter compared to the other planted stands, (Fig.10). This result contradicts with the studies done by Pettersson (1993) who found that after PCT dbh distribution increased. On the other hand, Ulvcrona et al. (2007) and Huuskonen et al. (2006) found that a late or light PCT compared to a heavy and early one decreased dbh of trees in the first commercial thinning. Furthermore more opened stands will give a faster diameter increment, (Ruha et al.,1997).

In Värnamo the densest planted stand had on average 12% greater mean diameter compared to the sparest planted one, (Fig 10.). This result might be attributed to difference in site quality but on the other hand this is not reflected in top height. Another possible explanation could be that the average diameter depended quite much from some trees with big dbh, which was not present in other plots.

Effects of genetic origin

In Linnebjörke height and volume performance was on average 5 and 4% respectively greater compared to the not improved plots planted on the clear cut, (Fig 9,11). However these findings were not consistent with the results from Potrzebowice where the plot originated from best planting material had 16 % lower mean height and 45% lower volume than the not improved. The difference in volume between the studied stands in Potrzebowice could be compensated by using the general growth model. Because the improved stand is 4 years younger, (Table 2.) it might influence the volume, height and diameter development of the trees. According to the general growth model it might be assumed that the stand volume could be 15% lower in the improved plot if it would be in the same age as the not improved one, (Fig. 9,11). It has to be highlighted that the improved plot was 4 years younger. The superiority in terms of volume and height growth of improved planting material compared to not improved planting stock agrees well with the investigations conducted by Andersson et al. (2007), Jansson (2007), Andersson et al. (2003), Matziris (2000), Dhakal et al. (1996).

Also site quality should be considered, as stated by Matziris (2000) who studied growth of Aleppo pine and Dhakal et al. (1996) who investigated the development of Slash pine. The gains in volume increment from improved planting stock seemed to be more expressed on more fertile sites.

4.2 Effect on timber quality

Diameter of the thickest branch

The diameter of branches in the lower part of the stem is one of the most important features, since it is highly correlated with the strength and quality of the timber, (Fahlvik et al., 2005), (Agestam et al.,1998), (Ekö&Agestam, 1994).

On average the mean branch diameter was 20% lower in the naturally regenerated plots compared to the planted plots, (Fig.15). This finding agrees well with investigations conducted by Andrzejczyk&Żybura (2012), Agestam et al. (1998), Ekö&Agestam (1994). The pines planted in the most open spacing had in general bigger diameter of the branches than those planted in higher densities, however it was not consistent for the Potrzebowice site. As stated in many studies the higher planting density the lower diameter of branches, Liziniewicz et al. (2012), Gort et al. (2010), Malinauskas (2003), Malinauskas (1999), Agestam et al. (1998). Furthermore, the branch diameter might be influenced by site quality. As concluded by Malinauskas (1999) a thinner branch has been reported on less fertile sites planted in closer spacing. Lämsä et al. (1990) found that branches die off more rapidly on fertile sites.

The most decisive influence on the relationship between the diameter at breast height and branch diameter was attributed to the regeneration method and to the effect of the shelter. On average the planted stands had stronger linear relationship between the studied variables than the naturally regenerated stands. However, it was not consistent for the Potrzebowice site, (Fig. 12-14). This finding corresponds well to the investigations conducted by Fahlvik et al. (2005), Agestam et al. (1998), Ekö&Agestam (1994). The dbh was correlated with branch diameter, (Fahlvik et al.,2005), (Agestam et al.,1998), (Petersson,1998). In general the slope of the regression line was steeper for the planted stands than for the naturally regenerated ones, (Agestam et al., 1998).

In Linnebjörke, in the naturally regenerated stands, the shelter period influenced the branch size growth in relation to the dbh. There was a weak correlation between the studied variables under the dense shelter contrasting with significant correlation under the normal shelter, (Fig. 12). This result might be explained by the higher heterogeneity and slower growth of the naturally regenerated pine stand under the dense shelter compared to the stands developing below the normal shelter, (Ekö&Agestam, 1994). Thanks to the lower correlation more trees with high quality timber might be selected in dominant and co-dominant classes during pre-commercial thinning. In the planted stands the correlation is stronger, thus pines with big diameters would have big branches.

In the Potrzebowice site a higher average branch diameter was found in 13.000 planted than in 10.000 planted, (Fig.15). It might be explained by the difference in growth intensity, related to the site index. This corresponds well with Fahlvik et al. (2005) who found that up to 4000 planted per ha the branch diameter has a very low genetic heritability, therefore depends mainly on growth intensity. In general dbr at the same dbh was 17% lower in the younger stand than on the comparable planted plot. Also the effect of breeding might be considered.

Stem straightness

Crookedness is an important parameter influencing the characteristics and yield of sawn timber. Agestam et al. (1998), Warensjö&Rune (2004), Warensjö (2003) concluded that severe bends in the bottom log contains compression wood, which causes deformations and warp in sawn goods. The trees with compression wood in bottom logs have more lignin content than normal logs. As a result timber from such trees often breaks easily, (Krzysik, 1978).

The most distinct differences in crookedness were noticed between spacing and regeneration methods, (Fig.16). Both Swedish sites had less crooked stems in stands planted at highest density, but it must be born in mind that the 10.000 planted in Linnebjörke, as mentioned before, was pre commercially thinned in 2011. Furthermore the occurrence of severely crooked stems was lower in the naturally regenerated stands. However these findings were not consistent with the Polish site, (Fig.16). The effect of planting density on the crookedness has been investigated in numerous studies, showing that with higher planting density and decrease in soil fertility the relative frequency of substantially bended stems decrease, (Huuskonen et al., 2008), (Malinauskas, 2003), (Malinauskas, 1999), (Agestam et al., 1998). According to Huuskonen et al. (2008), Agestam et al. (1998) and Ekö&Agestam (1994) the regeneration method by itself seems to have an influence on stem crookedness. The reason could be that planted seedlings might have deformations in root system, also the selection possibilities are smaller in planted stands compared to the naturally regenerated ones, (Agestam et al., 1998). Another explanation is that as well the development of the root system could not corresponds with stem growth, (Nichols&Alm,1983).

The differences in terms of crookedness for Potrzebowice compared to Linnebjörke and Värnamo might be attributed to planting density, stand history and breeding. The spacing of the planted stands was much higher on the Polish site (10.000 and 13.000 per ha) compared to the Swedish planted plots. Studies conducted by Malinauskas (2003) and Malinauskas (1999) show that Scots pines planted in closer spacing have lower frequency of severely crooked stems.

Also the higher frequency of crooked stems in one of the two naturally regenerated stands in Potrzebowice might be influenced by unfavorable site conditions, related mainly to the water table, which could hampered the regeneration process. As a consequence, the heterogeneity of the stand is high resulting in two generations of the trees (14 and 25 years old respectively). Finally the better quality of the planted stands might be caused by breeding, as investigated by Ståhl et al. (1990) and Ståhl&Prescher (1986) straightness of pine stems was dependent on provenance of planting material and spacing density.

Spike knots

The occurrence of spike knots regarding the regeneration method was different only in Värnamo. It was not consistent with Linnebjörke and Potrzebowice, (Fig. 17). The result from Värnamo agrees with the studies conducted by Agestam et al. (1998) who discovered lower spike knots frequency in the naturally regenerated stands. The possible reasons might be greater selection opportunities and better frost protection of naturally regenerated sheltered stands.

The spacing seems to have an influence on spike knots frequency only in Potrzebowice where the densest planted stand (13.000/ha) had less spike knots, (Fig. 19). Ståhl et al.(1990) reported that spacing did not influence spike knot frequency before the first commercial thinning, however in this study the investigated stands were planted at a much lower spacing.

Comparing the 10.000 planted stands in Linnebjörke and the 10.000 planted in Värnamo one can assume that lower frequency of spike knots recorded in the stand in Linnebjörke was thanks to the PCT, (Fig. 17). It might be supported by the studies of Ulvcrona et al. (2007) and Ruha&Varmola (1997) who concluded that pre-commercially thinned stands had better stem quality compared to the not thinned stands.

Except for Värnamo the stands with tallest trees had fewer spike knots, (Fig. 17). This result might be supported by Ståhl et al. (1990) who found that tall trees had less spike knots and crooks. According to Tegelmark (1999), Ståhl et al. (1990) and Ståhl&Prescher (1986) the possible factors influencing spike knots occurrence could be related to the provenance transfer and climate conditions. They found that Scots pines to be not well adapted to the local climate conditions, such as the length of the growing season, frost frequency and temperature sum are prone to the damages of the leading bud. As a consequence a height reduction and spike knot occurred. Therefore the Scots pine provenances from Northern regions planted in the South in lower spacing had less spike knots and had more straight stems, (Ståhl&Prescher, 1986).

Browsing damages

Despite the fencing around the studied Swedish stands browsing was observed, however the pine stems were not damaged. In Potrzebowice no fencing were made and serious damages were observed, (Fig.19). According to Puchniarski (2008) Scots pine trees can recover from wounds on their stems but still the quality of the timber would be deteriorated. The damaged timber could decay in the outer parts of the stems, Krzysik (1978). The possible explanation for the differences among the sites could be that in Linnebjörke and Värnamo the Scots pines have grown enough to not be damaged by the animals, while in Potrzebowice the trees had optimal height for ungulates an thus were often frayed or stripped.

Quality assessment

The overall impact of the measured quality traits was defined as timber quality.

On average in Linnebjörke and Potrzebowice naturally regenerated Scots pine stands had better judged overall quality, (Fig.18). However the quality of trees in the naturally regenerated stands in Potrzebowice could be better if the pines stems would not have been damaged by the ungulates. Several investigations have been carried out showing that naturally regenerated Scots pines have superior stem quality compared to planted trees, (Huuskonen et al., 2008), (Agestam et al., 1998), (Ekö&Agestam, 1994).

In Värnamo naturally regenerated trees had lower overall quality than the planted ones, (Fig.18). A possible explanation might be related to the result of natural regeneration in Värnamo which was not as successful as on the other sites. As a consequence the density of judged trees was considerably lower compared to those in Linnebjörke and Potrzebowice, which might explain the result.

Shelter period

The length of the shelter period and the density had a distinct influence on the planted stands. The considerably better quality of pines planted under the dense shelter than under normal shelter might be explained by the slower growth of the trees under a close overstory. It might be assumed that stem quality could be favored by the slower growth. As a result of the slower growth the straightness of tree stems could be better and might be reflected in the overall quality, (Fig.18), (Andrzejczyk&Żybura, 2012), (Agestam et al., 1998), (Ekö&Agestam, 1994).

Spacing

In Linnebjörke the overall judged quality was noticeably higher in the densest planted stands, (Fig.18). This finding corresponds well to the studies conducted by Malinauskas (2003), Agestam et al. (1998), Persson et al. (1995). However it must again be highlighted that the closest planted stand (10.000/ha) in Linnebjörke was subjected to the PCT in 2011. As concluded by Huuskonen et al. (2008), Ulvcrona et al. (2007) and Ruha&Varmola (1997) average stem form was improved after pre-commercial thinning.

Contradictory in Väranmo quality of tree stems was somehow better in the 3000 spacing compared to 10.000 spacing, (Fig.18). This result might be attributed to the stem straightness. 20% higher frequency of straight and slightly crooked stems was recorded in 3000 spacing compared to 10.000 spacing. Furthermore less spike knots were observed (8%) in the more open stand compared to the densest one. Worth mentioning is that none of the stands in Värnamo were not pre-commercially thinned. Consequently it might be expected that the quality of stems is lower in the closest planted stand because its density is too high. Since there is still quite high number of potential candidates with good stem quality, the stand structure might be improved by pre-commercial thinning.

In Potrzebowice the effect of genetic origin of planted material could influence the quality of pine logs, (Fig.18). Much greater frequency of straight stems was recorded in the improved stand compared to the not improved one. This idea agrees well to the investigations done by Andersson et al. (2003), Ståhl et al. (1990), Ståhl&Prescher (1986). Furthermore the site quality might influence the stem form. As concluded by Tegelmark (1999), Malinauskas (1999) on less fertile sites the frequency of stem crooks was smaller.

5 Conclusions from the study

- Naturally regenerated Scots pine stands will have superior overall quality compared to planted stands on the clear cut.

- Especially the frequency of severely crooked stems and average diameter of the thickest branch will be lower in the naturally regenerated stands.

- In the current growing stage the planted pines develop considerably faster. As a result the mean annual increment in planted stands was on average (242%) higher compared to the naturally regenerated stands.

- On average the linear correlation coefficient between branch diameter and diameter at breast height was lower in the naturally regenerated stands. Therefore the naturally regenerated pine stands will have higher selection possibilities compared to the planted ones.

- Pines planted in 1600 density per ha will have great dbh growth but the quality and straightness of stems will be seriously deteriorated.

- One can consider planting under the shelter as a method to improve stem quality. Also unsuccessfully naturally regenerated gaps could be closed by planting.

- Breeding could increase the quality and growth of Scots pines. Especially planted improved stands under the dense shelter might have superior quality compared to the local provenance established on the clear cut.

5.1 General remarks

- In order to produce high quality timber in the naturally regenerated Scots pine stands, the stems of future crop trees should be protected from ungulates until the stand will reach 20-25 years, (Puchniarski, 2008).
- From an economical perspective a high number of seed trees (100-200 per ha) can assure long timber supply of high quality saw logs, because in naturally regenerated sheltered stands the rotation cycles of the overstory and understory overlaps, (Ståhl&Karlmats, 1995) and (Hyytiäinen et al., 2006).

- In general natural regeneration is cheaper, gives higher selection possibilities and keeps the soil in good condition, (Puchniarski, 2008). However when the regeneration is abundant the stand would require more frequent pre-commercial thinning, compared to the planted stands. Furthermore, the result of the natural regeneration is uncertain, characterized by uneven spatial distribution and dependent mainly on the site and climatic conditions. (Béland et al., 2000), (Agestam et al., 1998).

- Scots pines growing under the shelter seems to be able to survive under the competition from the overstory. The shelter hampers the growth of pines thus decreasing the total yield over the whole rotation. A stand growing under the long shelter period requires to be opened up when the understory will reach (0,5-1 m) in height, in order to give a light to the seedlings. On the other hand the younger generation is well protected from frosts, (Andrzejczyk&Żybura, 2012), (Agestam et al.,1998), (Ekö&Agestam, 1994).

- Logging operations are more complex and require more labor in the sheltered stands. Moreover the overstory might be damaged by storms, which is more serious for the dense shelter. More opened sheltered stands have higher stability thanks to the extended root system and stem shape of the shelter trees. Felling down the overstory could damage the understory. Finally, extraction of the logs might damage roots of the remaining trees, causing infection by the root rot *Heterobasidion annosum*. (Valkonen, 2000).

- The planting in 1600 density per ha may require less thinning operations and might give superior yield up to the first commercial thinning. Furthermore the dbh increment is higher in more open planted stands, giving a possibility to shorter the rotation length.

- In order to produce high quality timber, selection of candidates of the future stand has to be done. Especially in the close planted stands (10.000/ha, 13.000/ha) as well in the naturally regenerated, PCT should be carried out. Neglecting of PCT could result in high number of wolf tress, consequently the stand quality might be deteriorated.

This study was done on previously uninvestigated sites both in Sweden and in Poland and the conclusions stated by Agestam et al. (1998) and Andrzejczyk&Żybura (2012) were confirmed. However the different site index might influence the results.

Further research should be done to confirm the conclusions stated in the Thesis. To study the effect of the shelter period length on the stand characteristics and timber quality all the measured sites should be sheltered. Furthermore to make good comparisons, studied stands within investigated site, should be in the same age. Also to draw conclusions about the influence of planting density on the mentioned traits, all the planted stands should not be pre-commercially thinned. In order to investigate the differences in quality and growth between planting and natural regeneration, all studied stands should be fenced and have the same site index. Still there is a need for a long term research about the effects of regeneration methods for Scots pine quality.

6 References

Ackzell, L.,1993. A comparison of planting, sowing and natural regeneration for *Pinus sylvestris*(L.) in boreal Sweden. *Forest Ecology and Management* 61, 229-245.

Agestam, E., Ekö P.M. and Johansson, U.,1998. Timber quality and volume growth in naturally regenerated and planted Scots pine stands in S.W. Sweden. *Studia Forestalia Suecica* 204, 17pp.

Andersson, B., Elfving, B., Ericsson, T., Persson, T. and Gregorsson, B., 2003. Performance of improved Pinus sylvestris in northern Sweden. *Scandinavian Journal of Forest Research* 18, 199-206.

Andersson, B., Elfving, B., Persson, T., Ericsson, T. and Kroon, J., 2007. Charecteristics and development of improved Pinus sylvestris in northern Sweden. *Canadian Journal of Forest Research* 37, 84-92.

Andrzejczyk ,H. and , Żybura, T., 2012. Sosna zwyczajna Odnawianie naturalne i alternatywne metody hodowli. *PWRiL*, 278pp.(Available only in Polish.) Title translation: The natural regeneration and alternative methods of Scots pine silviculture.

Bèland, M., Agestam, E.,Ekö, P.M.,Gemmel, P. and Nilsson, U., 2000. Scarification and seedfall affects natural regeneration of Scots pine under two shelterwood densities and a clear- cut in southern Sweden. *Scandinavian Journal of Forest Research* 15, 247-255.

BULiGL, 2012 Biuro Urządzania Lasu i Geodezji Leśnej, oddział Poznań. Maszynopis. Wg stanu na 22.06.2012. Opis Taksacyjny dla Nadleśnictwa Potrzebowice, obręb Drawsko i obręb Potrzebowice. *SILP*. (Available only in Polish.) Title translation: Forest Management Plan for the Potrzebowice State Forest District.

Brandel, G., 1990. Volymfunktioner för enskilda träd. Tall, gran och björk. SLU, *Inst f skogsproduktion*, Garpenberg Rapport 26, 72 s. Available: http://www.skogforsk.se/KunskapDirekt/Alla-Verktyg/Volymberakning/Volymfunktioner/ date: 2013.04.16

Cochran, P.H. and Dhams, W.G., 1998. *Lodgepole pine development after early spacing in the Blue Mountains of Oregon*. Report No. 503. United States Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Dhakal, L.P., White, T.L and, Hodge, G.R, 1996. *Realized genetic gains from Slash pine tree improvement*. Silvae Genetica 45, 4.United States Department of Forestry, Institute of Food and Agriculture Sciences, University of Florida.

Ekö, P.M. and , Agestam E., 1994. A comparison of naturally regenerated and planted Scots pine (*Pinus sylvestris* L.) on fertile sites in southern Sweden. *Forest and Landscape Research* 1, 111-126.

Fahlvik , N., Ekö, P.M. and, Pettersson, N.,2005. Influence of precommercial thinning grade on branch diameter and crown ratio in *Pinus sylvestris* in southern Sweden. *Scandinavian Journal of Forest Research* 20, 243-251.

Gort, J., Zubizarreta-Gerendiain, A., Peltola, H., Kilpeläinen, A., Pulkkinen, P., Jaatinen, R., Kellomäki, S., 2010. Differences in branch characteristics of Scots pine (*Pinus sylvestris* L.) genetic entries grown at different spacing. *Annals of Forest Science* 67, 705:1-8.

Hägglund, B., 1974. Site index curves for Scots pine in Sweden. Skogskolan, inst. för skogsproduktion. *Report No*. 31, 54pp. (In Swedish with English summary.)

Huuskonen, S., Hynynen, J., Ojansuu, R., 2008. Stand characteristics and external quality of young Scots pine stands in Finland. *Silva Fennica* 42, 397-412.

Huuskonen, S., Hynynen, J.,2006. Timing and intensity of precommercial thinning and their effects on the first commercial thinning in Scots pine stands. *Silva Fennica* 40, 645-662.

Hyytiäinen, K., Ilomäki, S., Mäkelä A., Kinnunen, K., 2006. Economic analysis of stand establishment for Scots pine. *Canadian Journal of Forest Research* 36, 1179-1189.

Jakobsson, R. 2005. Growth of retained Scots pines and their influence on the new stand. *Swedish University of Agricultural Sciences, Silvestria* 34, 7-33.

Jansson, G., 2007. Gains from selecting Pinus sylvestris in southern Sweden for volume per hectare. *Scandinavian Journal of Forest Research* 22, 185-192.

Johnstone W.D., 2005. The effects of juvenile spacing on 7 year-old Lodgepole pine in Central British Columbia. British Columbia Ministry of Forests, Research Branch, Kalamalka Research Station, Vernon, BC, Canada. *Western Journal of Applied Forestry* 20, 160-166.

Karlsson,C., 2000. Effects of release cutting and soil scarification on natural regeneration in *Pinus sylvestris* shelterwoods. *Silvestria* 137, 7-35.

Krzysik, F., 1978. Nauka o drewnie. *PWN*, 653 pp. (Available only in Polish.) Title translation: Wood science.

Lämsä, P., Kellomäki, S.,Väisänen, H., 1990. Branchiness of young Scots pine as related to stand structure and site fertility. *Folia Forestalia* 746, 22pp.(In Finnish.)

Liziniewicz M., Ekö P.M., Agestam, E., 2012. Effect of spacing on 23-year-old Lodgepole pine (*Pinus contorta Dougl. var. latifolia*) in southern Sweden. *Scandinavian Journal of Forest Research* 27, 361-371.

Malinauskas, A., 1999. The influence of the initial density and site conditions on Scots pine growth and wood quality. *Baltic Forestry* 2, 8-19 .

Malinauskas, A., 2003. Influence of initial density and planting design on the quality of butt logs in Scots pine (*Pinus sylvestris* L.) plantations. *Baltic Forestry* 9, 10-15.

Map data© 2012 GIS Innovatsis. *Google Maps*. Available: https://maps.google.com/ date: 2012.11.19

Matziris, D.I., 2000. Genetic variation and realized genetic gain from Aleppo pine tree improvement. *Silvae Genetica* 49, 5-10.

Nichols, T.J. and Alm, A.A.,1983. Root development of container-reared, nursery-grown, and naturally regenerated pine seedlings. *Canadian Journal of Forest Research* 13, 239-245.

Pape, R., 1999. Effects of thinning on wood properties of Norway spruce on highly productive sites. *Silvestria* 88, 7-30.

Persson, B., Persson, A., Ståhl, E.G., Karlmats, U., 1995. Wood quality of *Pinus sylvestris* progenies at various spacings. *Forest Ecology and Management* 76, 127-138.

Petersson, H., 1998. Prediction of branch variables related to timber quality in *Pinus sylvestris*. *Scandinavian Journal of Forest Research* 13, 21-30.

Pettersson, N.,1993. The effect of density after precommercial thinning on volume and structure in *Pinus Sylvestris* and *Picea Abies* stands. *Scandinavian Journal of Forest Research* 8, 528-539.

Puchalski, T.,2000. Rębnie w gospodarstwie leśnym. *PWRiL*, 288 pp.(Available only in Polish.) Title translation: The cutting systems used in forest management.

Puchniarski,T., 2008. Sosna zwyczajna Hodowla i ochrona. *PWRiL*, 256pp.(Available only in Polish.) Title translation: The silviculture and protection of Scots pine.

Ruha, T., Varmola, M.,1997. Precommercial thinning in naturally regenerated Scots pine stands in northern Finland. *Silva Fennica* 31, 401-415.

Ståhl, E.G. and Karlmats, U., 1995. Yield, wood properties, and timber harvest at establishment of seed-tree and shelterwood regeneration systems. *Studia Forestalia Suecica* 197, 3-15.

Ståhl, E.G. and Prescher, F., 1986. The effect of provenance and spacing on stem straightness and number of stems with spike knots of Scots pine in south and central Sweden. *Studia Forestalia Suecica* 172, 3-12.

Ståhl, E.G., Persson, B., Prescher, F., 1990. Effect of provenance and spacing on stem straightness and number of stems with spike knots in *Pinus sylvestris* L.-northern Sweden and countrywide models. *Studia Forestalia Suecica* 184, 3-16.

Tegelmark, D.O.,1999. Prediction of stem properties based on climate and soil factors in naturally regenerated *Pinus sylvestris* stands. *Scandinavian Journal of Forest Research* 14, 131-142.

Ulvcrona Ahnlund, K., Claesson, S., Sahlén, K., Lundmark, T., 2007. The effects of timing of pre-comercial thinning and stand density on stem form and branch characteristics of *Pinus sylvestris* . *Forestry* 80, 324-335.

Valkonen, S., 2000. Effect of retained Scots pine trees on regeneration, growth, form, and yield of forest stands. *Finnish Forest Research Institute*,122-145.

Valkonen, S, Ruuska, J., Siipiletho, J.,2002. Effect of retained trees on the development of young Scots pine stands in southern Finland. *Forest Ecology and Management* 166, 227-243.

Varmola, M., Salminen, H., 2004. Timing and intensity of precommercial thinning in *Pinus sylvestris* stands. *Scandinavian Journal of Forest Research* 19, 142-151.

Warensjö, M., 2003. Compression wood in Scots pine and Norway spruce- distribution in relation to external geometry and the impact on dimensional stability in sawn wood. *Silvestria* 298, 7-36.

Warensjö, M.,Rune,G., 2004. Stem straightness and compression wood in a 22 year-old stand of container- grown Scots pine trees. *Silva Fennica* 38, 143-153.

Zasady hodowli lasu, 2003. *Ośrodek Rozwojowo-Wdrożeniowy LP Bedoń*, 159 pp.(Available only in Polish.) Title translation: The guidelines to forest silviculture.

7 Photo appendix

Photo 1.3000 i Planted under dense shelter, example of pines with straight stems.

Photo 2.Spike knots.

Photo 3.Natural regeneration under sparse shelter in Linnebjörke.

*Photo 4.*Natural regeneration under dense shelter in Linnebjörke

*Photo 5.*Natural regeneration in Värnamo.

*Photo 6.*1600 planted , examples of reject crooked stems.

Photo 7.13.000 planted in Potrzebowice.

Photo 8. 10.000 i planted in Potrzebowice.

Photo 9. Natural regeneration in Potrzebowice, older generation (25 years old), (Plot G)

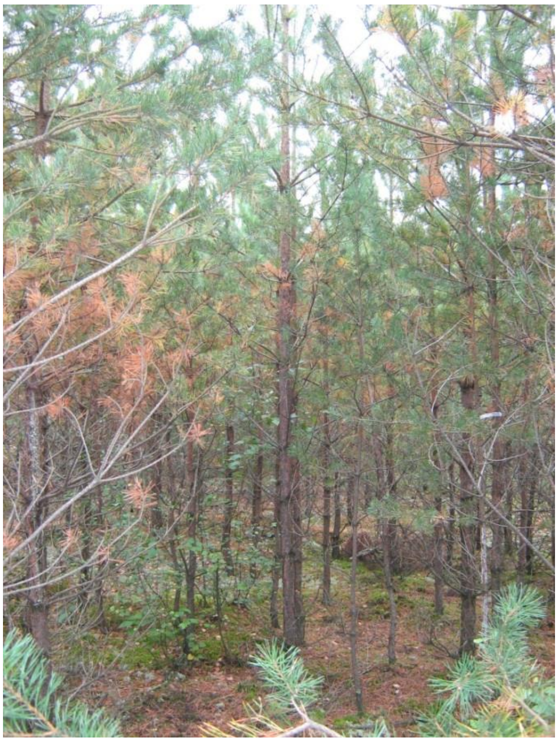


Photo 10. Natural regeneration in Potrzebowice, younger generation (14 years old). (Plot G)

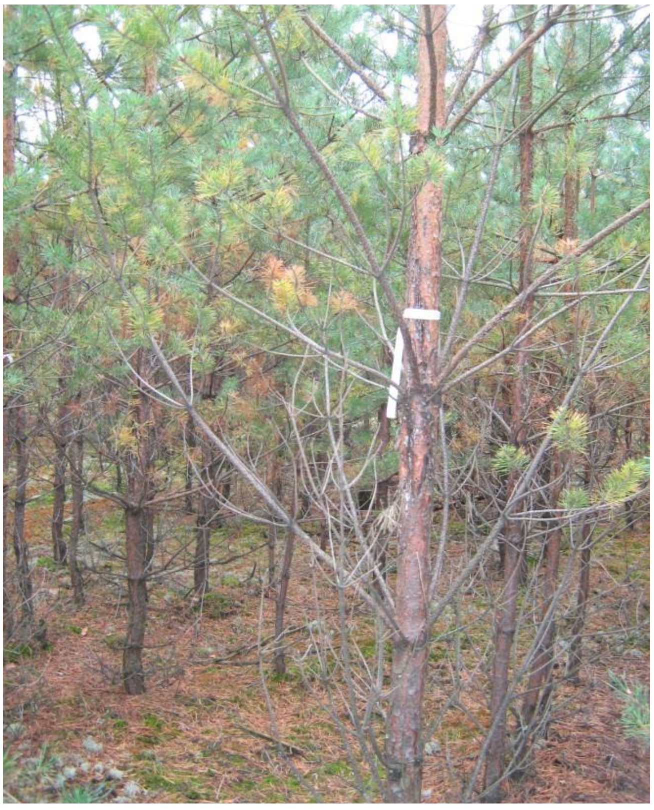


Photo 11.Natural regeneration in Potrzebowice (Plot B).

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