# Assessment of external wood quality in planted Silver birch stands of different genetic origin in Tönnersjöheden Experimental Forest

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# Abstract

The main objective of the thesis was to find out how the wood quality differed among Silver birch provenances. The study was conducted in family, provenance and tree species experiments in SW Sweden. External features like stem straightness, spike knots, double leader, diameter, tree height, leaning and other defects were measured and analyzed. Significant differences were found between birch families and provenances for a number of measured parameters. In the family experiment, significant differences between families were found for the parameters straight trees and diameter while no significant differences were found for others measured parameters like spike knots, forking, leaning and tree height. The local provenance “Tönnersjöheden” had the best overall quality and growth in the provenance experiment while Kulbäcksliden provenance (North Sweden) had a low overall quality. In the tree species experiment, significant differences between provenances were only found for the frequency of straight and leaning trees. Asarum was suggested a good quality provenance with an overall high quality performance and a low percentage of leaning trees while Visingsö was judged a bad quality provenance with a high percentage of crooked stems and a many leaning trees.



*Keywords*: Silver Birch, Wood quality, Provenance, Double leader, Spike knots

# Abbreviations

| | |
|---|---|
| C | Crooked |
| CD | Co-dominant |
| DBH | Diameter at Breast Height, 1.3 m above ground |
| D | Dominant |
| DL | Double Leader |
| DO | Dominated |
| Exp | Experiment |
| L | Leaning |
| NBF | National Board of Forestry |
| NL | Not Leaning |
| S | Suppressed |
| Srt | Straight |
| SC | Slightly Crooked |
| SE | Standard Error |
| SL | Slightly Leaning |
| StdDev | Standard Deviation |
| ST | Suppressed Tree |
| SPN | Spike knot |
| QC | Quality Class |

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# 1 INTRODUCTION

## 1.1 General Overview

There are about 60 species of birches in the northern hemisphere. The most common species are *Betula pendula* and Betula *pubescens*. They occur in most parts of Europe except for the southernmost regions and in parts of Asia. The natural distribution of birch species is ranging from the Atlantic Ocean to eastern Siberia with wide natural occurrence on the Eurasian continent (Hulten & Fries, 1986). The proportion of birch out of the total volume of the growing stock varies between 11% and 16% in the Nordic countries and 17% and 18% in Baltic countries (Hynynen et al, 2010). Though the birch is wide spread in Europe, it is mostly abundant in the temperate and boreal forests of Northern Europe (Niemistö et al. 2008). It is commercially the most important broadleaved tree species in Northern Europe.

Birches are pioneer species, light demanding. They can grow in pure or mixed stand and have the ability to establish wherever there are bare soils (Telenius, 1999). Once established, they grow very rapidly in the first 20 years, but around 60 to 80 years most of the trees will decline. Rapid juvenile growth, self –pruning, the ability to grow on wide range of sites including infertile ones, reasonable high productivity, easy natural regeneration, soil improvement, easy to breed and highly estimated wood, are the main characteristics that explain the importance of the species.

Birch wood is almost white to pale in color, often with a wide range of finishing choices. It is easy to glue, polish, finish and impregnate (Dahlgren *et* al, *20*04). Due to straight grain properties it can be processed easily. The most common uses of birches are for pulpwood, plywood veneer, firewood and wood pellets for residential heating (Makinen et. al, 2003). Birch is an important choice for furniture making. Thermally modified birch is used to producing floor, deck etc. Birch is an important timber species in Scandinavia for manufacturing veneer and pulp (Viherä-Aarnio & Velling, 1999). Usually cradles for babies are made from birch wood. Moreover, birches have a spiritual significance in many religions. Due to its many uses the economic importance of birch might increase dramatically in future.

## 1.2 The Situation of Birch in Sweden

In Sweden two birch species are used in mechanical wood processing: Silver birch (*Betula pendula Roth*) and downy birch (*Betula pubescens Ehrh*). Birch is the third most commercially important tree species in Sweden (Stener & Jansson, 2005). It constitutes 12 % of the standing wood volume which amounts to a total standing volume of 420 million $m^3$ sk (Skogsdata, 2009) and is the most abundant broadleaved tree species in Sweden (National Board of forestry, 2010). There is a growing interest for birch trees in farm land afforestation in Sweden (Johansson, 1990). Mixed stands of birch and Norway spruce are increasing in Southern Sweden which is not only enhancing the economic importance but also adds ecological benefits (Felton et al, 2010).

In Sweden birch is mainly used for the production of chemical pulp due to high pulp quality, and only the small amount of bleaching chemicals are necessary. Besides for pulp and energy birch is at present often used for furniture and interiors in public settings. Due to the increasing use of birch, the commercial demand of birch in Sweden is high. During 2003, the import of broadleaved species (mainly birch) was around 4 million $m^3$ round wood in Sweden (Hynynen et al, 2010). Genetically improved seedling material and application of proper silvicultural techniques in growing forest stands should make it possible to produce sufficient amounts of high quality birch wood in the future (Stener & Jansson, 2005).

## 1.3 Low timber quality – a critical issue

The timber quality of birch is not considered be good in Southern Sweden. Birch stems are often crooked and hard to process (Kataikko, 1996). High timber quality is often important when making furniture and also when manufacturing plywood (Herajarvi, 2001). Defects on the tree trunk will increase the amount of waste wood. The quality timber production is important due to the big differences in prices between large sized timber and pulpwood, and also between veneers of different grades (Niemisto, 1995). Also, poor timber quality can increase the total sawmill costs. There has always been a demand of large size stems with good quality free from decay or defects (Luostarinen & Verkasalo, 2000). The average prices of birch logs is however often low since only the best logs can be used for end products with highly added value (Luostarinen & Verkasalo, 2000). The main traits defining timber quality are straightness, spike knots, double leader, DBH, height and branch diameter. Straightness is often of major importance when grading timber quality.

In recent years different quality improvement programs has been set up and practiced to improve the quality and production (Vihera-Aarnio & Velling, 1999). But the investigations and field research regarding the quality improvement concerning different genetic origin are few.  Thus it is important to study how birch quality differs among different provenances. This study is focused on stem quality among different provenance of birch planted in Southern Sweden.

### 1.4 Important properties for good quality birch timber

Basically, wood quality depends on the requirements on the end products. Thus quality is assessed in terms of market demand and need of the consumers. It is defined as suitability of a stem for proper processing or desired end use. One definition of quality is: "The physical and chemical characteristics showed by a tree or its parts that allow it to meet the property requirements for variety of end products" (MacDonald & Hubert, 2002). Different sectors of wood industry need different trees (Vihera-Aarnio & Velling, 2008). The pulp and paper industry requires proper wood chemical composition and suitable tracheid structure (Luostarinen & Verkasalo, 2000). Generally good external quality implies straight stems with few spike knots and small branch diameters (Stener, 1995). Many traits like double leader, taper, fiber dimension, leaning etc also affect the quality of sawn timber (Hallaksela & Niemistö, 1998). The following characters are decisive for timber quality:

- Straightness
- Occurrence of spike knots
- Occurrence of other defects
- Branch diameter
- Taper
- Fiber disturbances (e.g. compression wood caused by crookedness or leaning)

## 1.5 Silviculture and Breeding

### 1.5.1 Breeding

Breeding programs are focused on producing high growth and external stem quality traits like straightness, branch properties, spike knots etc (Danell & Werner, 1987). The principal aim of breeding is to improve the overall high volume production and better wood quality timber (Vihera-Aarnio, 1994). Breeding begins with selection of phonotypically superior trees called “plus trees”, found in naturally regenerated or planted forest stands. Then collected material is grown and crossed in seed orchards to produce seedling of genetically superior quality (Stener & Hedenberg, 2003). Based on breeding tests the best genotypes concerning straightness, spike knots and volume survival can be selected for mass propagation. Thus breeding makes it possible to transfer genetic traits in a large scale to practical forestry, so that successive generations will have better growth and quality and higher resistance to pests and diseases (Malcolm & Worrel, 2001). Tree breeding plays a vital role for the continuous supply of quality birch timber by continuously improving growth and quality features and it has been proven that stem quality and yield of birch have been improved significantly by breeding programs (Hagqvist & Hahl, 1998).

Due to many biological characteristic, birches are a more suitable for breeding than coniferous and considerable genetic gain has been obtained (Koski & Rousi, 2005). The first plus tree selection and breeding of birch in the Nordic countries was done in Sweden and Finland in 1940 (Johnsson, 1974). Significant development of the breeding program was later done in Finland (Koski & Rousi, 2005). Other European countries have also started breeding programmes in order to improve the quality and growth of birch timber (Stener & Jansson, 2005).

Different provenance trails and practical plantations have been established in Sweden. Provenance Ekebo 1, 2, 3 and 4, Visingsö, Asarum were produced by aimed at improving growth and quality in Southern Sweden. Ekebo 2 was a green-house seed orchard for Silver birch located at the forest research station Ekebo in Skåne, South Sweden. It was established in 1995 and included 9 selected Silver birch clones. Seeds from the Ekebo seed orchards are today the main recommendation for new Silver birch plantations in South Sweden. The Visingsö provenance consists of material from an abandoned Silver birch seed orchard located in Denmark. It was established with Swedish birch clones and intended to produce birch seeds for South Sweden. Likewise the provenance Asarum is material taken from a Silver birch seed orchard located in Blekinge, Southeastern Sweden. It was established in 1972 and included 19 birch clones from selected plus trees with origin from Skåne to Värmland. The seed orchard was intended to produce Silver birch seeds for South Sweden

### 1.5.2 Silviculture

Silviculture is the art and science of producing healthy fast growing forests with high quality. Quality can be improved by different silvicultural measures like spacing, appropriate regeneration methods, rotation lengths, pruning and selective thinning strategies (Cameron, 1996). Improper silvicultural practices and the use of low quality or poorly adapted plant material make it challenging to enhance the quality of birch timber in Sweden. There is no long tradition of birch management in Sweden and forest owners are not familiar with proper silvilcultural techniques (Ödlund, 2009).

At higher densities the individual stem growth of silver birch is slow due to that is a shade intolerant tree species (Hynynen & Niemisto, 2009). A proper thinning program is therefore important to produce the desired sawn timber. Pre commercial thinning is recommended in young stands with high densities (Makinen, 2002). Research on thinning regimes found that heavy thinning could produce large dimension logs with less stem defects (Cameron et al, 1995). Birch stems are usually free of living branches up to 5-7 m due to its self-pruning ability. Spacing experiments in Finland show that stands with high initial density had more straight stems, trees with thinner branches and high rate of natural pruning (Niemistö, 1995). Silviculture measures are helpful to create a desirable log size and other properties that meet the market demands.

## 1.6 Different external parameters to define wood quality

There are many external tree features which directly affect the quality of birch timber. The present study focuses mainly on straightness and occurrence of spike knots, which are factors crucial for timber quality (Agestam et al, 1998). Crookedness and spike knots decrease wood durability and strength, and increase the cost of processing, resulting in a lower the total value of the timber.

### 1.6.1 Straightness

Stem straightness influence the deviations of the grain angle and the formation of compression wood. These properties increase with increasing crookedness. Timber strength is reduced due to increase in grain angle and causes slow drying, distortions and warp (Donaldson &Turner, 2001). These features on wood causes failure on bending .Compression wood also decreases the quality of pulp, due to increased lignin content and shorter tracheids (Watson & Dadswell, 1957). Moreover crooked stems increase the cost of processing of logs.

### 1.6.2 Spike knots

Besides straightness, an important factor for the timber quality is the number and sizes of spike knots. Spike knots occurring up to 4 m seriously affect the quality of the bottom log. Spike knots reduce the strength as well as stability of wood, particularly when combined with ingrown bark. They also decrease the value of timber by making logs difficult to debark. Narrow branch angles typical for spike knots and thus affect the large proportion of the wood (Photo 4).

### 1.6.3 Leaning – Compression wood

If the tree centre departs from vertical line through the germination point it is referred to as leaning. The occurrence of leaning as well as cracking can be the result of high wind speed (Hynynen & Niemisto, 2009). Slightly leaning doesn’t create serious problem but heavier leaning causes problems on wood quality due to formation of compression wood, causing reduced strength and warp in the sawn material.

### 1.6.4 Forking - double leader

Forking on the stems decreases the timber quality. Forking in the lower part of stem causes of course more trouble than higher up. Forking reduces the merchantable wood. Forks also create high risk of crown or tree breakage by wind and snow (Mottonen, 2005).

## 1.7 Objectives of study

The objective of this study was to investigate the variation of stem quality among different birch provenances planted in Tönnersjöheden Experimental Forest in Southwest Sweden. External properties like straightness, spike knots, double leader etc. were measured and analyzed. The basic assumption was - there were no differentiation among families and provenances on the following parameters:

- Stem straightness within and among the provenances and families
- Stem defects like spike knots, double leader, leaning etc
- The overall timber quality
- Diameter distribution and tree height

## 2 MATERIALS AND METHODS

The material was collected in Silver birch stands in Tönnersjöheden Experimental Forest (lat 56° 42´ N, long 13° 06´ E, alt 60-140 m a. s. l.). All together nine stands with different provenances were measured (Table 1). Both long term experiments and practical plantations were used for the study. The stands were of different age. The stand area varied from 0.2 ha to 3.97 ha. In some stands all the trees were measured, whereas in other stands sample plots were selected. In some stands, the same provenance was planted where as in some stands different provenances were used. All stands were established by plantation during different time periods. In total 1577 trees were measured during the winter 2011.

In the experiment F1298, 20 different families (Annex 1) were planted on 60 plots, thus each family had 3 replicates. All families were known and included seedlings from half and full sibling crossings, from seed orchards and from stands approved for harvesting of seeds (Annex1). During the winter of 2006/2007 around 50 % of the trees were thinned. Thinning was done in 2000 and 2007 in tree species experiment T158 including 3 replicates of each species. Experiment T138 was thinned in 1980, 1985 and 1991 at the ages of 29, 35 and 41 years. This stand contained 4 provenances namely Tönnersjöheden (South Sweden), Tranås (South Sweden), Rankhyttan (Central Sweden) and Kulbäcksliden (North Sweden). There were altogether 16 plots in the experiment, i.e. 2-5 replicates of each provenance.

Table1. Information on the study stands

| Stand | Area, ha | Age | Year of Planting | Origin | Measured trees (No) | Note |
|---|---|---|---|---|---|---|
| F1298 | 0.5 | 15 | 1998 | Sweden and Denmark (20 families) | 302 | Skog Forsk demo trial; 20 families, 3 blocks |
| T138 | 0.62 | 61 | 1953 | Sweden (4 provenances) | 383 | Provenance experiment; 4 provenances, 2-5 blocks |
| T158 | 0.3 | 28 | 1985 | Visingsö | 227 | Tree species experiment;3 blocks |
| T219 | 1 | 10 | 2003 | Ekebo 2 | 105 | Demo trial; 4-5 plots |
| T190 | 0.4 | 20 | 1993 | Asarum | 114 | Tree species experiment; 4 blocks |
| T154 | 0.2 | 30 | 1883 | Visingsö | 201 | Competition experiment with spruce and birch |
| T104 | 0.49 | 62 | 1951 | Visingsö | 40 | Growth & yield experiment |
| t72:4 | 1.06 | 26 | 1987 | Visingsö | 119 | Practical plantation |
| t11:3 | 3.97 | 5 | 2008 | Asarum | 86 | Practical plantation |

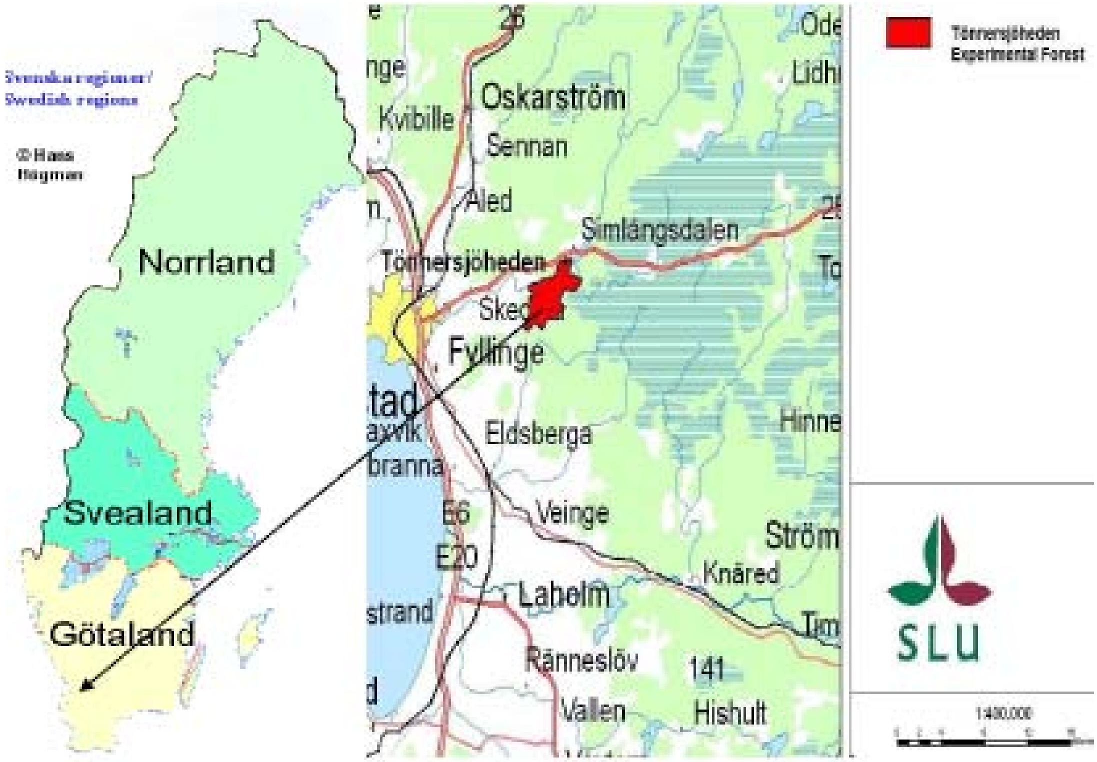



Figure 1. Location map of the study area in South region (Sweden)

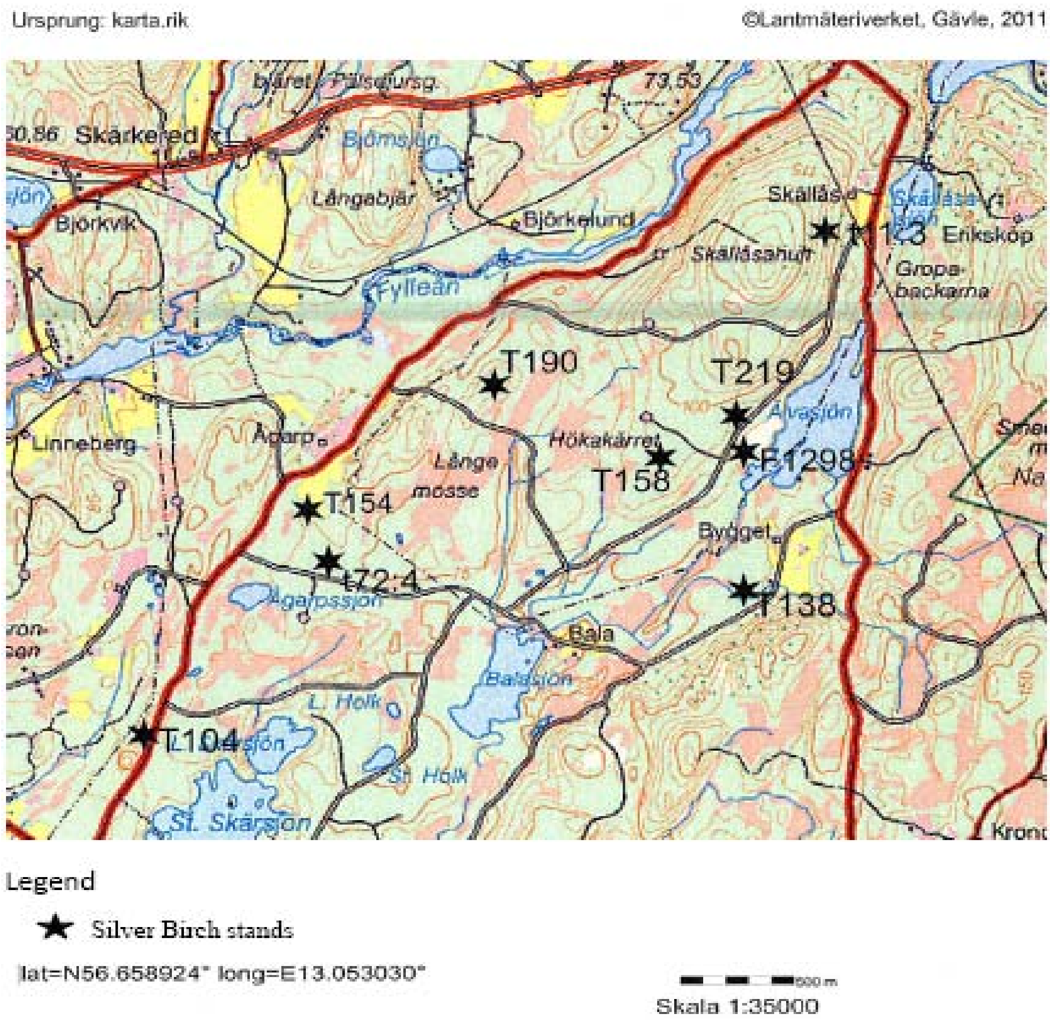



Figure 2. Location of the studied Silver birch stands of different genetic origins

## 2.1 Sampling and Measurements

All trees on the plots were measured in experiment F1298, T104, T138 and T154. In experiment T219, T190 as well as stands t72:4 and t11:3, temporary sample plots were established. In experiment T219, one of four available plots was selected for measuring. One this plot, 5 temporary circular plots was systematically placed, one in each corner and one in the centre. The radius of the circular plot was 5.64 m (100m2). All trees on the circular plots were measured. In total 11 temporary circular plots of the same radius as T219 were placed in the stand t72:4 distributed systematically over the area, In stand t11:3, 10 circular plots were distributed and the radius of the plots was 4m. In tree species experiment T190 every fifth tree in each row was measured.

## 2.2 Data Collection

General information regarding the stand age, year of planting, total area of stands, and provenances was taken from the Tönnersjöheden Experimental Forest database. Stem diameter, tree height, stem straightness, spike knots, double leader, leaning of tree and quality class were measured and judged for all observed trees. Parameters like the number of living branches and the diameter of the thickest branch could not be measured in all stands due to natural pruning. The total number of living branches and the diameter of thickest branch at the height between 1-2 m were recorded only in stand T219 and t11:3. The height of first living branch was above 4 m in the older stands T104, T138, T154, T190, T158 and t72:4 whereas in the younger stands T219 and t11:3 it was below 1 m.
Due to the low age and height in stand t11:3, the measurement instructions were slightly different than in the other stands.

The following data were collected on all stands:

a) Tree class: Dominant (D), Co-dominant (CD), Dominated (DO) and Suppressed (S).
   - Dominant – the tallest trees, most vigorous, straight bole, top and other side of crown were free.
   - Co-dominant – slightly shorter trees than dominant, vigorous, straight bole, crown were little restricted by side branches and top.
   - Dominated – tree characters between co-dominant and suppressed trees.
   - Suppressed – the smallest trees, not vigorous, not straight, the crown was dominated or suppressed by top and other sides.

b) Numbers of spike knots were counted in the stem sections 0-1 m, 1-4 m and above 4m. In stand t11:3, spike knots were counted at height classes between 0-0.5m, 0.5-1.5m and above 1.5m (Photo 4).

c) Stem straightness was measured in stem sections 0-1 m and 1-4 m expect for the stand t11:3 (where straightness was measured in stem sections 0-0.5 m and 0.5- 1.5m).Three classes were used in each section– straight (1), slightly crooked (2) and severely crooked (3) [Photo 1, 2 and 3]. It was measured with the help of 4 m long measuring stick and a thread placed straight to the eye and looked parallel to the stem (Photo 15).

Then crookedness was measured viewing how far the stem deviated from the vertical axis.

d) Diameter of the thickest branch was measured in the stem section between 1-2 m above ground.
e) The number of living branches was counted in the stem section between 1- 2 m above ground.
f) Height above the ground.
g) Diameter at 1.3 m.
h) Leaning of tree was classified as Not Leaning (NL), Slightly Leaning (SL) and Leaning (L) [Photo 5, 6 and 7]
i) Height above ground to the first living branch.
j) Total number of leading shots was counted if trees had double tops in the stem section between 1-4m and above 4m (Photo 8)

All measured trees were subjectively categorized into 4 quality classes according to their overall external appearances. i.e. class 1 = good quality, class 2 = moderately good, class 3 = slightly good and class 4 = bad quality (Photo 9, 10, 11 and 12). Class 1 included good candidates for future crop trees (very few spike knots and branches, good for timber, large diameter). Class 2 included possible candidates for crop trees (few spike knots, few branches – slightly more than class 1, large diameter). Class 3 included trees not acceptable as crop trees (more spike knots than quality class 2, more branches, and small diameter). Class 4 included bad quality trees (more spike knots and other defects, suppressed tree, small diameter, wolf tree)

The above listed variables b to j was not observed on suppressed tree.

### 2.3 Statistical Analysis

Microsoft Office Excel was used to gather and compile the data. Pivot tables were used for calculating frequency distributions of all the parameters. Figures and charts were also made in Excel and the program was used for analyzing and interpreting the gathered information.

Differences among means were tested by using one way analysis of variance and non parametric test (Kruskal Wallis test). The SAS statistical package was used. The one way analysis of variance was performed on the families experiment F1298 and provenance experiment T138.

# 3 RESULTS

## 3.1 Straightness

### 3.1.1 Families experiment F1298

The result of the ANOVA showed that the average number of straight trees differed significantly among families of experiment F1298 ($P < 0.05$) (Table 3). There was no significant difference found comparing slightly crooked and crooked trees. The maximum (94 %) and the minimum percentage (17 %) of straight trees were recorded on family 313 and 198 respectively (Table 2).

Table 2. Frequency of straight, slightly crooked and crooked trees among different families in experiment F1298. The figures in brackets show the individual replications.

| **Family** | **Straight (%)** | **Slightly Crooked (%)** | **Crooked (%)** |
|---|---|---|---|
| | **Mean** | **Mean** | **Mean** |
| 197 | 44 (25, 67, 40) | 49 (75, 33, 40) | 7 (0, 0, 20) |
| 198 | 17 (50, 0, 0) | 64 (50, 83, 60) | 19 (0, 17, 40) |
| 199 | 45 (34, 83, 17) | 44 (33, 17, 83) | 11 (33 ,0, 0) |
| 305 | 34 (60, 0, 43) | 65 (40, 100, 57) | 0 |
| 306 | 57 (50, 60, 60) | 43 (50, 40, 40) | 0 |
| 310 | 67 (80, 60, 60) | 33 (20, 40, 40) | 0 |
| 311 | 52(40, 67, 50)) | 41 (40, 33, 50) | 7 (20, 0, 0) |
| 313 | 94 (100, 83, 100) | 6 (0, 17, 0) | 0 |
| 314 | 60 (100, 20, 60) | 40 (0, 80, 40) | 0 |
| 319 | 67 (75, 75, 50) | 33 (25, 25, 50) | 0 |
| 321 | 70 (100, 60, 50) | 30 (0, 40, 50) | 0 |
| 350 | 71 (50, 80, 83) | 23 (33, 20, 17) | 6 (17, 0, 0) |
| 351 | 76 (80, 66, 83) | 24 (20, 34, 17) | 0 |
| 352 | 54 (83, 14, 66) | 46 (17, 86, 34) | 0 |
| 353 | 49 (75, 23, 50) | 47 (25, 67, 50) | 0 |
| 354 | 60 (100, 20, 60) | 40 (0, 80, 40) | 0 |
| 355 | 91 (100, 100, 75) | 8 (0, 0, 25) | 0 |
| 356 | 62 (50, 75, 60) | 38 (50, 25, 40) | 0 |
| 357 | 74 (67, 80, 75) | 26 (33, 20, 25) | 0 |
| 358 | 89 (67, 100, 100) | 11 (33, 0, 0) | 0 |

Table 3. One way ANOVA in family experiment F1298. Dependent variable: straight trees (class 1)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 19 | 20954.31 | 1102.85 | 1.98 | 0.034 |
| Error | 40 | 22262.66 | 556.56 | | |
| Corrected Total | 59 | 43216.98 | | | |

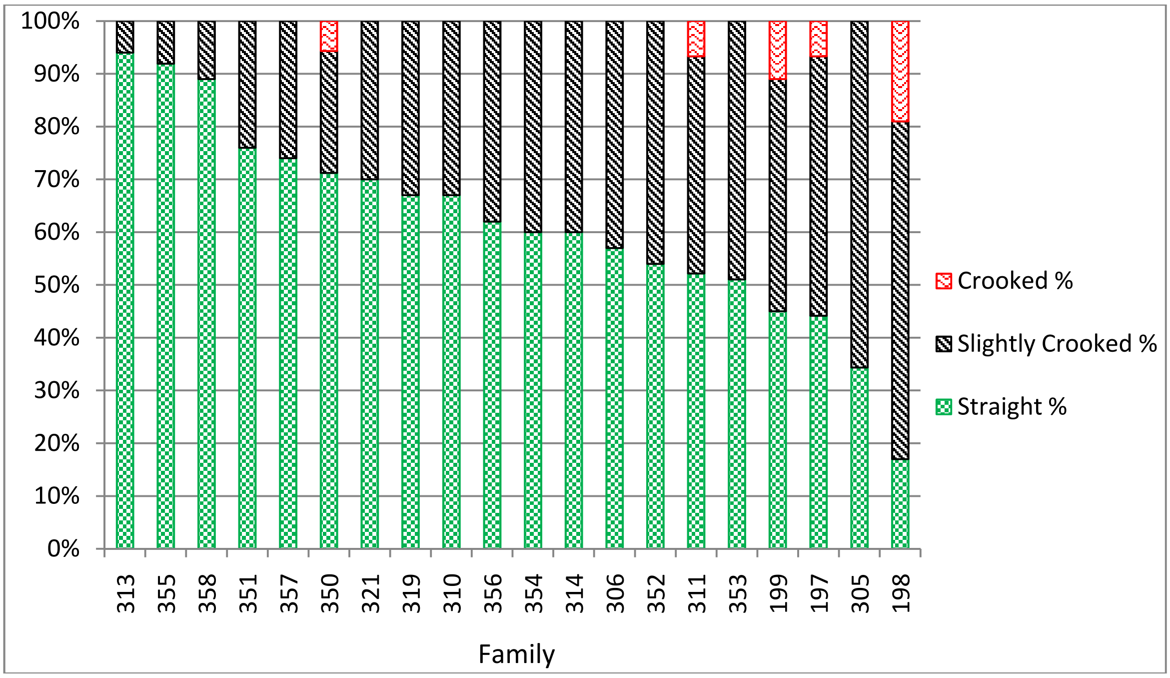


Figure 3. Frequency (%) of trees in straightness classes in family experiment F1298

### 3.1.2 Provenance experiment T138

The number of replication of treatments in the experiment was not equal and could influence the accuracy of the ANOVA significance test. The ANOVA table which is given in Table 5 shows significant differences among provenances on the frequency of crooked trees ($P < 0.05$). However, no significant differences were found comparing the percentage of straight and slightly crooked trees. Provenance Tranås had the smallest percentage of crooked trees (6%) and Rankhyttan the highest percentage (19%) (Table 4).

Table 4. Frequency of straight, slightly crooked and crooked trees among different provenances in exp T138

| **Provenance** | **Straight %** | | | **Slightly Crooked %** | | | **Crooked %** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **SE** | **StDev** | **Mean** | **SE** | **StDev** | **Mean** | **SE** | **StDev** |
| Kulbäcksliden | 20 | 2 | 2,82 | 62 | 2,5 | 3,54 | 18 | 4,5 | 6,37 |
| Rankhyttan | 27 | 4,73 | 10,56 | 54 | 3,01 | 6,72 | 19 | 3,48 | 7,78 |
| Tranås | 35 | 3,77 | 7,54 | 60 | 4,17 | 8,34 | 6 | 1,03 | 2,06 |
| Tönnersjöheden | 25 | 3,73 | 8,33 | 65 | 1,69 | 3,77 | 10 | 3,07 | 6,87 |

Table 5. One way ANOVA in provenance experiment T138. Dependent variable: crooked trees (class 3)

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
|---|---|---|---|---|---|
| Model | 3 | 489,70 | 163,23 | 4,05 | 0,033 |
| Error | 12 | 484,05 | 40,33 | | |
| Corrected Total | 15 | 973,75 | | | |

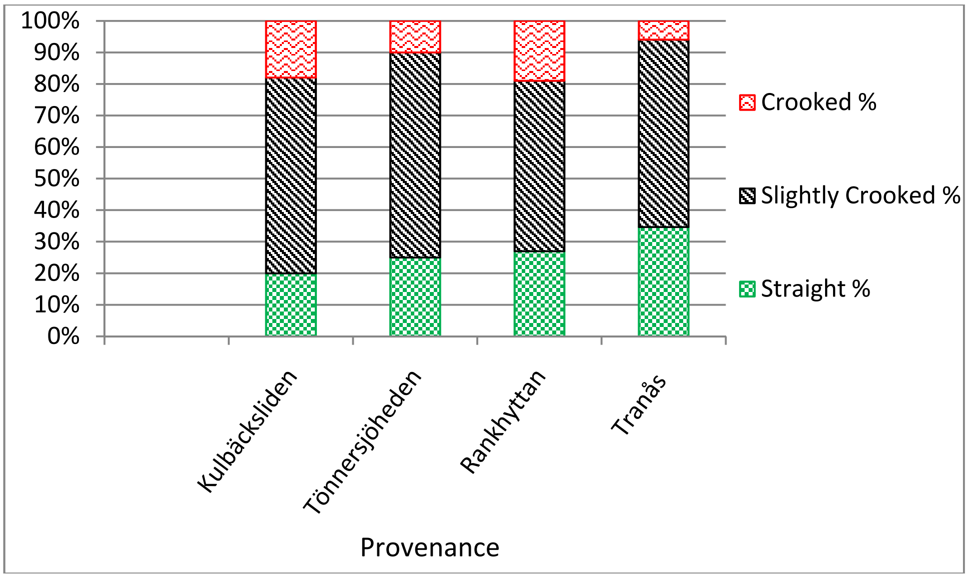



Figure 4. Frequency (%) of trees in straightness classes in provenance experiment T138

### 3.1.3 The tree species experiment

The frequencies of straight and crooked trees were significantly different in the tree species experiment (Table7). The mean percent of straight trees (Table 6) were highest in Ekebo2 (60 %) and lowest in Visingö (17%). The highest frequency of crooked trees was found in Visingsö (22%).

Table 6. Frequency of straight, slightly crooked and crooked trees among different provenances in the tree species experiment

| **Provenance** | **Straight %** | | | **Slightly Crooked %** | | | **Crooked %** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **SE** | **StDev** | **Mean** | **SE** | **StDev** | **Mean** | **SE** | **StDev** |
| Visingsö | 17 | 3 | 11 | 58 | 4 | 12 | 22 | 4 | 13 |
| Asarum | 56 | 4 | 9 | 43 | 4 | 10 | 2 | 1 | 2 |
| Ekebo2 | 60 | | | 39 | | | 1 | | |

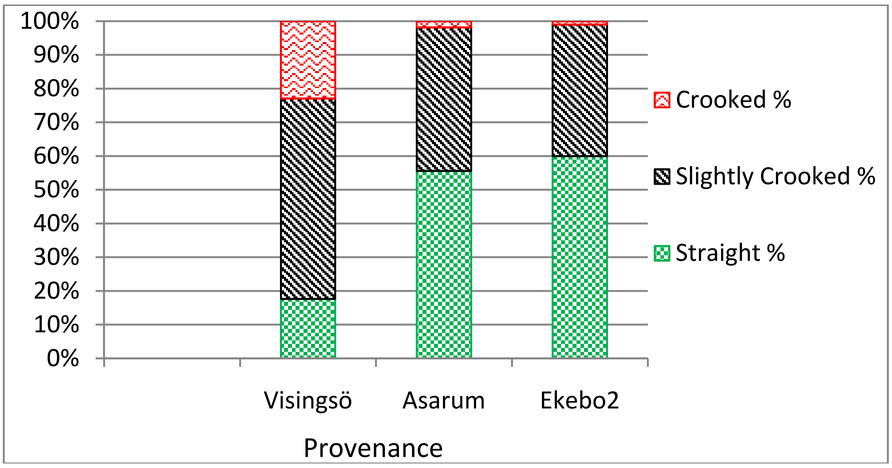



Figure 5. Frequency (%) of trees in straightness classes on tree species experiment

Table 7. Kruskal-Wallis Test on data from the tree species experiment. Dependent variable: frequency of straight trees (class 1) and crooked trees (class 3)

| **Wilcoxon Scores (Rank Sums) for Variable Straight & Crooked % Classified by Variable Provenance** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Provenance** | **N** | **Sum of Scores** | **Expected Under HO** | **Std Dev Under HO** | **Mean Score** | **Sum of Scores** | **Expected Under HO** | **Std Dev Under Ho** | **Mean Score** |
| Visingsö | 9 | 45 | 72 | 8.47 | 5 | 99 | 72 | 8.439 | 11 |
| Asarum | 5 | 61 | 40 | 8.15 | 12.2 | 18 | 40 | 8.121 | 3.6 |
| Ekebo 2 | 1 | 14 | 8 | 4.31 | 14 | 3 | 8 | 4.297 | 3 |
| Average scores were used for ties. | | | | | | Average scores were used for ties. | | | |
| **Kruskal-Wallis Test (Variable Straight %)** | | | | | | **Kruskal-Wallis Test (V. Crooked %)** | | | |
| Chi-Square | | | | | 10.27 | Chi-Square | | | 10.24 |
| DF | | | | | 2 | DF | | | 2 |
| Pr > Chi-Square | | | | | **0.006** | Pr > Chi-Square | | | **0.006** |

## 3.2 Spike knots

### 3.2.1 Families experiment F1298

No significant differences among the families in experiment F1298 were found concerning the average number of spike knots per tree and the percentage of trees without spike. The maximum (52 %) of trees without spike knots were recorded on family 351 (Table 8). The minimum (0%) percentage of trees without spike knots was on family 311 and 319.

Table 8. Average number of observed spike knots and percentage of trees without spike knots in the family experiment F1298. The figures in brackets show the individual replications.

| Family | Spike knots | % of trees without Spike knots |
|---|---|---|
| | Mean | Mean |
| 197 | 2,4 (4, 1.33, 2 ) | 7 ( 0, 0, 20 ) |
| 198 | 2,3 (1.6, 2,7, 2,8) | 12 ( 20, 17 , 0 ) |
| 199 | 3.6 (3.6, 3, 3.5 ) | 16 ( 0, 16, 33 ) |
| 305 | 2.4 ( 2, 3, 2.3 ) | 13 ( 0, 25, 14 ) |
| 306 | 1.8 ( 1, 1.4, 3 ) | 8 ( 25, 0, 0 ) |
| 310 | 2.1 ( 3.4, 1.2, 1.8) | 13 ( 0, 40, 0 ) |
| 311 | 2.9 ( 3..5, 2.8, 2.5 ) | 0 |
| 313 | 1.1 ( 2, 1, 0.5 ) | 33 ( 0, 50, 50 ) |
| 314 | 1.1 ( 1, 1.4, 1 ) | 13 (20, 0, 20 ) |
| 319 | 3.8 ( 2.5, 3.5, 5.5 ) | 0 |
| 321 | 1 ( 0.2, 1.2, 1.7 ) | 33 ( 80, 20, 0 ) |
| 350 | 1.8 ( 1.2, 1.8, 2.5 ) | 30 (33, 40, 17 ) |
| 351 | 0.7 ( 1, 1, 0.2 ) | 52 ( 40, 33, 83 ) |
| 352 | 1.5 ( 1.5, 1.6, 1.3 ) | 16 (0, 14, 33 ) |
| 353 | 1.7 ( 1.5, 2, 1.5 ) | 16 ( 0, 33, 17 ) |
| 354 | 1.6 ( 1.3, 1.7, 1.8 ) | 11 ( 33, 0, 0 ) |
| 355 | 1.8 ( 1.6, 1.6, 2.3 ) | 20 ( 20, 40, 0 ) |
| 356 | 1.5 ( 1.3, 1.7, 1.4 ) | 8 ( 25, 0, 0 ) |
| 357 | 3.2 ( 5,2, 3, 1.5 ) | 17 ( 0, 50, 0 ) |
| 358 | 1.9 ( 3.7, 1, 1 ) | 25 ( 0, 25, 50 ) |

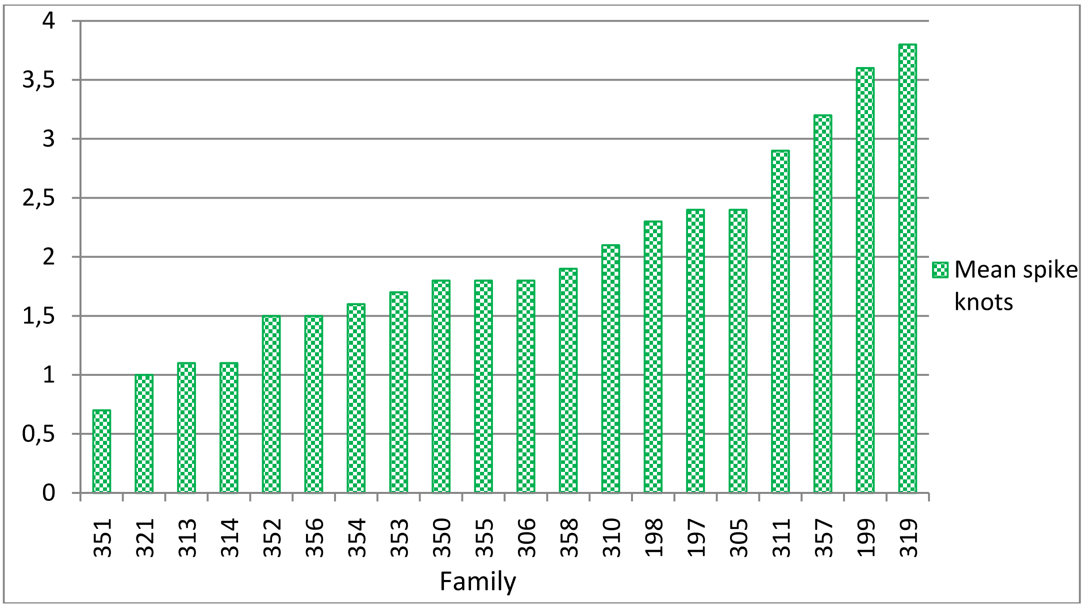



Figure 6. Average number of spike knots among families in experiment F1298

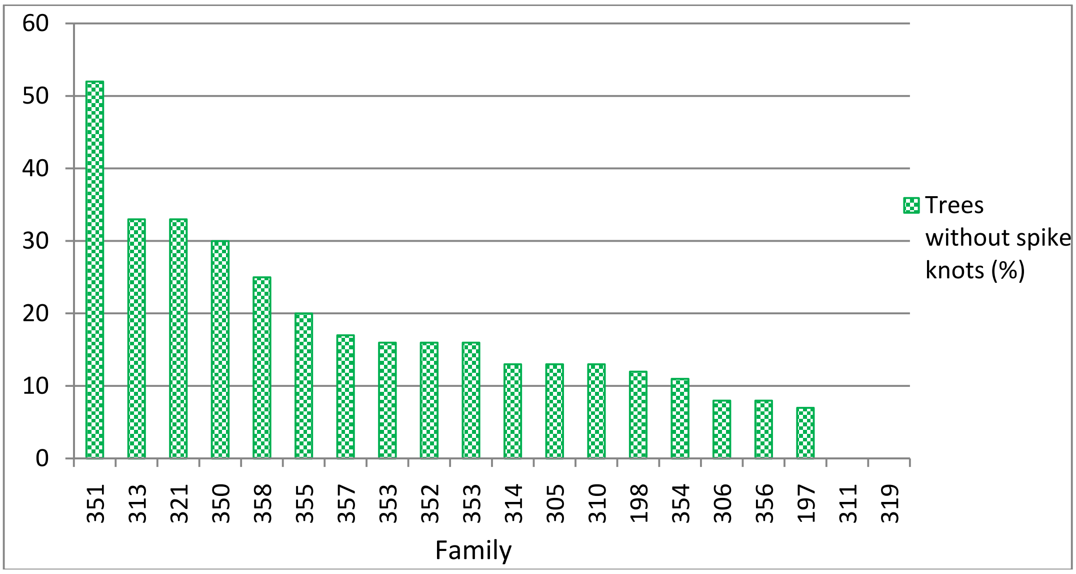



Figure 7. Frequency (%) of trees without spike knots among families in experiment F1298

### 3.2.2 Provenance experiment T138

Statistically significant differences (P < .01) were found for the average number of spike knots and percentage of trees without spike knots among the provenance in experiment T138 (Table 10 & 11). Provenance Tönnersjöheden and Kulbäcksliden had the maximum (89%) and minimum (45%) percentage of trees without spike knots respectively (Table 9).

Table 9. Average number and frequency of trees without spike knots in provenance experiment T138

| Provenance | No of spike knots | | | % of Trees without Spike knots | | |
|---|---|---|---|---|---|---|
| | Mean | SE | St Dev | Mean | SE | StDev |
| Kulbäcksliden | 1 | 0,3 | 0,42 | 45 | 18,6 | 26,4 |
| Rankhyttan | 0,7 | 0,15 | 0,35 | 51 | 8,63 | 19,29 |
| Tranås | 0,5 | 0,09 | 0,19 | 73 | 5,96 | 11,93 |
| Tönnersjöheden | 0,2 | 0,06 | 0,15 | 89 | 4,11 | 9,19 |

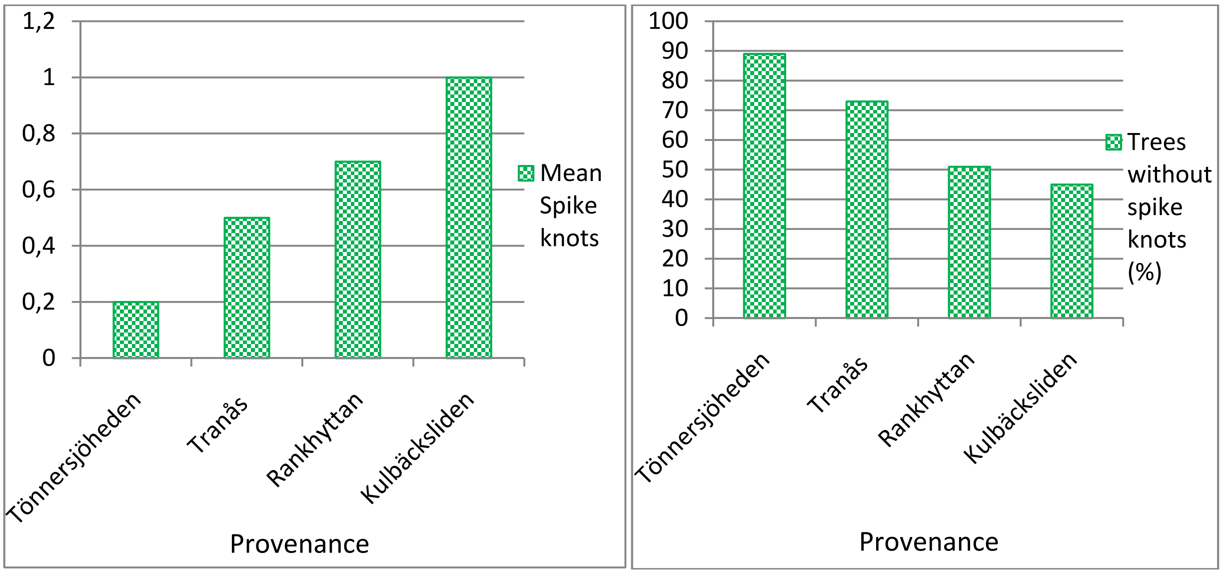



Figure 8. Average number of spike knots (left panel) and percentage of trees without spike knots (right panel) in provenance experiment T138

Table 10. One way ANOVA on data from provenance experiment T138. Dependent variable: mean number of spike knots

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 3 | 2,18 | 0,72 | 9,88 | 0,001 |
| Error | 12 | 0,88 | 0,07 | | |
| Corrected Total | 15 | 3,06 | | | |

Table 11. One way ANOVA on data from provenance experiment T138. Dependent variable: frequency of trees without spike knots

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 3 | 4692 | 1564 | 6,37 | 0,008 |
| Error | 12 | 2948,56 | 245,71 | | |
| Corrected T | 15 | 7640,57 | | | |

### 3.2.3 The tree species experiments

No significant differences were found for the average spike knots frequency and percentage of trees without spike knots among provenance in the tree species experiments. However, provenance Visingsö and Ekebo2 had maximum (14.3 %) and minimum (2.3%) percentage of trees without spike knots respectively (Table 12)

Table12. Frequency of average number of spike knots and percentage of trees without spike knots in tree species experiment

| **Provenance** | **No. of spike knots** | | | **% of trees without Spike knots** | | |
|---|---|---|---|---|---|---|
| | **Mean** | **SE** | **StDev** | **Mean** | **SE** | **StDev** |
| Visingsö | 1,9 | 0,27 | 0,81 | 14,3 | 4,07 | 12,21 |
| Asarum | 2,5 | 0,4 | 0,91 | 2,9 | 1,34 | 3 |
| Ekebo 2 | 2,2 | | | 2,3 | | |

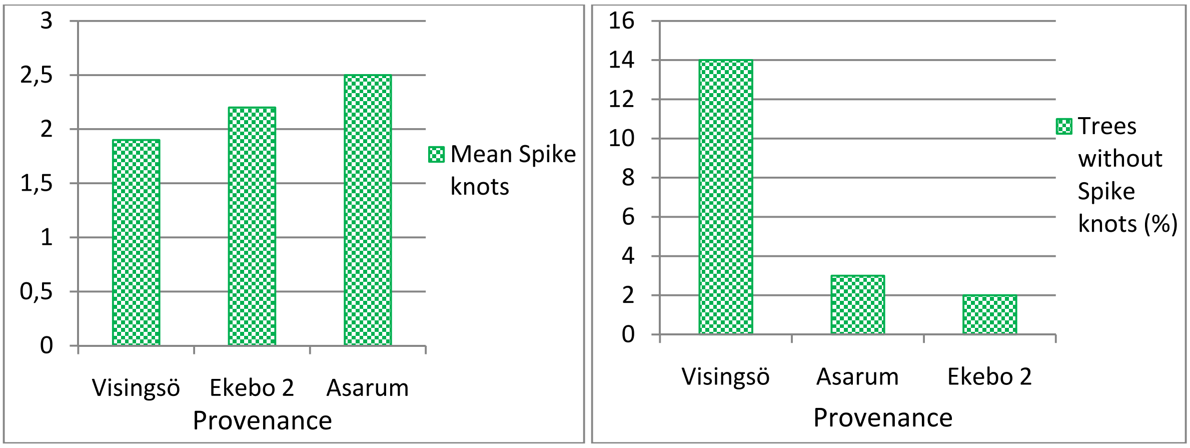



Figure 9. Average number of spike knots (left panel) and percentage of trees without spike knots (right panel) in the tree species experiment

## 3.3 Leaning trees

### 3.3.1 Families experiment F1298

There were no significant differences found comparing the frequency of non leaning, slightly leaning and leaning trees among families in family experiment F1298. The maximum (92 %) and the minimum percentage (37 %) of not leaning trees were recorded for family 356 and 198 respectively (Table 13). The highest percentages of leaning trees (31 %) were recorded for family 198.

Table13. Frequency of leaning, slightly leaning and not leaning trees in family experiment F1298. The figures in brackets show the individual replications.

| Family | NL trees (%) | SL trees (%) | L trees (%) |
|---|---|---|---|
| | Mean | Mean | Mean |
| 197 | 78 (75, 100, 60 ) | 22 ( 25, 0, 40) | 0 |
| 198 | 37 (40, 50, 20 ) | 32 (60, 17, 20) | 31 ( 0, 33, 60 ) |
| 199 | 56 (33, 67, 66 ) | 44 ( 66, 33, 33) | 0 |
| 305 | 45 (80, 25, 29) | 44 ( 0, 75, 57) | 11 ( 20, 14 , 0 ) |
| 306 | 72 ( 75, 60, 80 ) | 28 ( 25, 40, 20) | 0 |
| 310 | 87 ( 100, 80, 80) | 13 (0, 20, 20) | 0 |
| 311 | 64 ( 100, 83, 50) | 36 ( 40, 17, 50 ) | 0 |
| 313 | 83 (75, 100, 75) | 17 ( 25, 0, 25) | 0 |
| 314 | 80 ( 100, 60, 80 ) | 20 ( 0, 40, 20 ) | 0 |
| 319 | 83 ( 75, 75, 100 ) | 17 (25, 25, 0) | 0 |
| 321 | 78 (100, 100, 33) | 22 ( 0, 0, 67 ) | 0 |
| 350 | 77 (67, 80, 83) | 23 (33, 20, 17) | 0 |
| 351 | 83 ( 100,100, 50 ) | 16 ( 0, 0, 50 ) | 0 |
| 352 | 79 ( 50, 87, 100 ) | 21 ( 50, 14, 0) | 0 |
| 353 | 75 ( 75 , 100, 50 ) | 25 ( 25, 0, 50 ) | 0 |
| 354 | 77 (100, 50 , 80 ) | 23 ( 0, 50, 20 ) | 0 |
| 355 | 50 ( 50, 60, 40 ) | 43 ( 60, 20, 50 ) | 7 ( 0, 20, 0 ) |
| 356 | 92 ( 100, 75, 100 ) | 8 ( 0, 25, 0 ) | 0 |
| 357 | 77 ( 50, 80, 100) | 23 ( 0, 20, 50 ) | 0 |
| 358 | 50 ( 50, 50, 50 ) | 50 ( 50, 50, 50 ) | 0 |

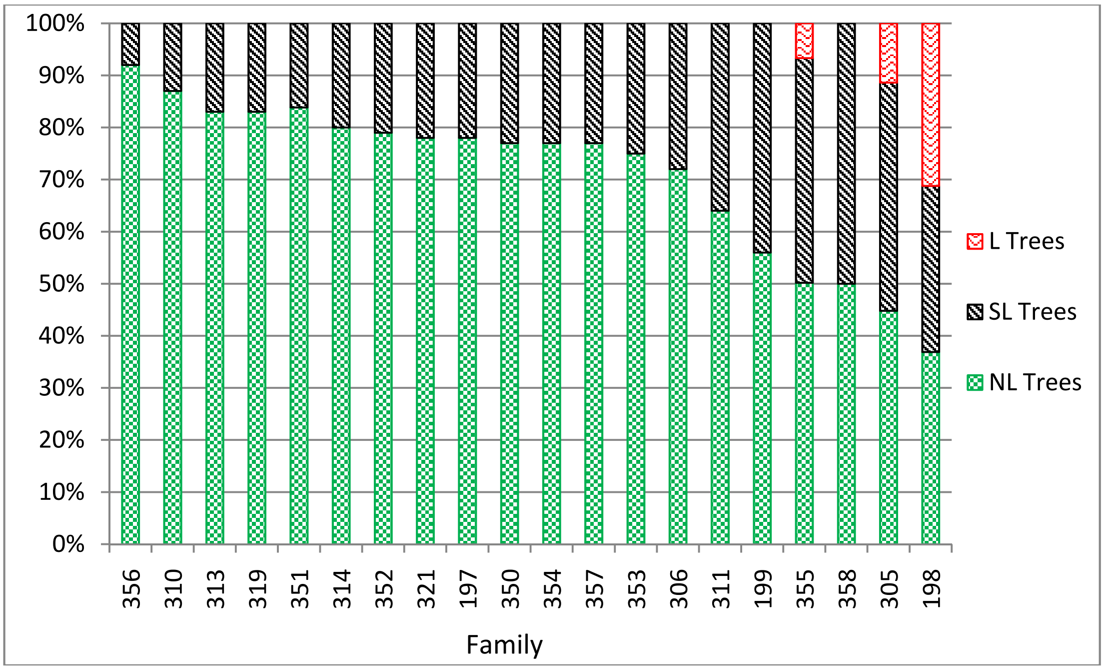



Figure 10. Frequency (%) of trees in leaning classes in family experiment F1298

### 3.3.2 Provenance experiment T138

The average percentage of leaning trees varied considerably among provenance. Statistically significant differences were found for mean values of NL and SL trees (P < 0, 01) in experiment T138 (Table 15 & 16). Provenance Kulbäcksliden had the maximum frequency of leaning trees (12%) whereas Tranås had minimum frequency (2%) among the studied provenances (Table 14). The lowest average percentage of not leaning trees (43%) was found for provenance Kulbäcksliden.

Table 14. Frequency of leaning, slightly leaning and not leaning trees in provenance experiment T138

| **Provenance** | **NL trees (%)** | | | **SL trees ( % )** | | | **L ( % )** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **SE** | **StDev** | **Mean** | **SE** | **StDev** | **Mean** | **SE** | **StDev** |
| Kulbäcksliden | 43 | 7,5 | 10,61 | 46 | 4,5 | 6,36 | 12 | 12 | 17 |
| Rankhyttan | 67 | 2 | 4,47 | 30 | 1,81 | 4,04 | 3 | 2,09 | 4,67 |
| Tranås | 67 | 2,56 | 5,12 | 31 | 1,49 | 2,99 | 2 | 1,15 | 2,31 |
| Tönnersjöheden | 54 | 3,87 | 8,64 | 38 | 1,78 | 3,97 | 7 | 3,4 | 7,6 |

Table 15. One way ANOVA on data from provenance experiment T138. Dependent variable: frequency of not leaning trees (NL)

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
|---|---|---|---|---|---|
| Model | 3 | 1207.7 | 402.6 | 8.47 | 0.003 |
| Error | 12 | 570.1 | 47.5 | | |
| Corrected Total | 15 | 1777.6 | | | |

Table 16. One way ANOVA on data from provenance experiment T138. Dependent variable: slightly leaning trees (SL)

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
|---|---|---|---|---|---|
| Model | 3 | 479.35 | 159.78 | 9.8 | 0.002 |
| Error | 12 | 195.65 | 16.3 | | |
| Corrected Total | 15 | 675 | | | |

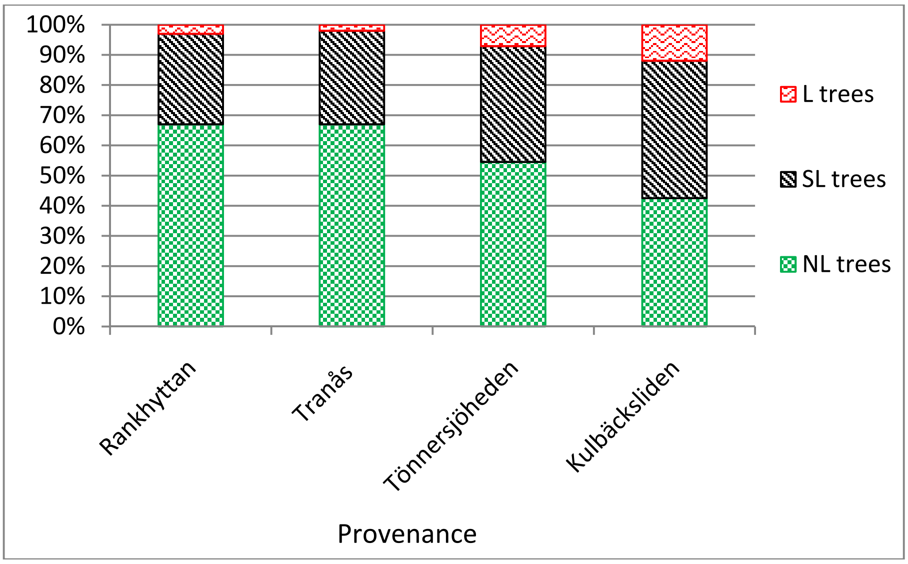


Figure 11. Frequency (%) of birch trees in leaning classes in provenance exp T138

### 3.3.3 The tree species experiment

Statistically significant differences among provenance were found for variables NL and L trees in the tree species experiments (Table 18). However, there were no significant differences for SL trees. The maximum percentage of leaning trees (17%) were found in provenance Visingsö and the minimum percentage of leaning tree (6%) were found in Ekebo2 provenance (Table 17). The highest proportion of not leaning trees was judged in Asarum (58%).

Table 17. Frequency of leaning, slightly leaning and not leaning trees in the tree species experiment

| Provenance | **NL trees (%)** | | | **SL trees ( % )** | | | **L ( % )** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **SE** | **StDev** | **Mean** | **SE** | **StDev** | **Mean** | **SE** | **StDev** |
| Visingsö | 34 | 3,91 | 11,73 | 49 | 3,45 | 10,36 | 17 | 2,09 | 6,26 |
| Asarum | 58 | 7,05 | 15,76 | 35 | 5,81 | 12,99 | 7 | 3,31 | 7,4 |
| Ekebo 2 | 48 | | | 46 | | | 6 | | |

Table 18. Kruskal-Wallis Test on data in the tree species experiment. Dependent variables: frequency of not leaning trees (NL) and Leaning trees (L)

| Wilcoxon Scores (Rank Sums) for Variable NL and L trees (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Classified by Variable Provenance | | | | | | | | | |
| Provenance | N | Sum of Scores | Expected Under H0 | Std Dev Under H0 | Mean Score | Sum of Scores | Expected Under H0 | Std Dev Under H0 | Mean Score |
| Visingsö | 9 | 51 | 72 | 8,48 | 5,66 | 93,5 | 72 | 8,46 | 10,38 |
| Asarum | 5 | 59 | 40 | 8,16 | 11,8 | 21,5 | 40 | 8,14 | 4,3 |
| Ekebo 2 | 1 | 10 | 8 | 4,32 | 10 | 5 | 8 | 4,31 | 5 |
| Average scores were used for ties. | | | | | | Average scores were used for ties. | | | |
| **Kruskal-Wallis Test ( NL trees )** | | | | | | **Kruskal-Wallis Test (L Trees )** | | | |
| Chi-Square | | | | 6,26 | | Chi-Square | | 6,47 | |
| DF | | | | 2 | | DF | | 2 | |
| Pr > Chi-Square | | | | 0,04 | | Pr > Chi-Square | | 0,04 | |

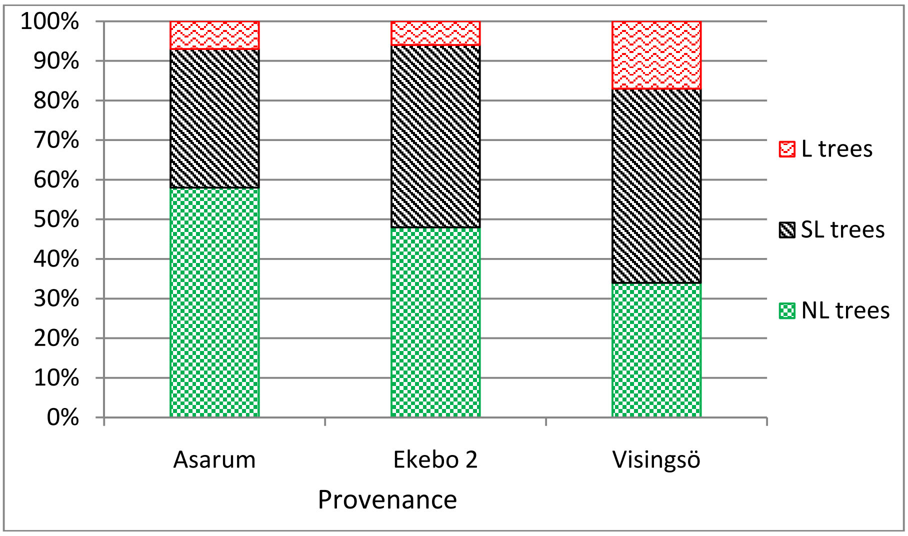



Figure 12. Frequency (%) of birch trees in leaning classes in the tree species experiment

## 3.4 Forking

### 3.4.1 Families experiment F1298

There was no significant difference found comparing the frequency of forking among families in experiment F1298. The maximum (56 %) and the minimum percentage (6 %) of double top were recorded on family 352 and 358 respectively (Table 19). The highest occurrence of double top (17%) between 1-4m stem sections was in Family 319.

Table19. Frequency of forking in different stem sections in families experiment F1298.

| Family | One top (%) | | | Double top > 4m (%) | | | Double top 1-4m (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SE | StDev | Mean | SE | StDev | Mean | SE | StDev |
| 197 | 48 | 7 | 13 | 44 | 12 | 21 | 8 | 8 | 14 |
| 198 | 73 | 13 | 23 | 26 | 13 | 23 | 0 | 0 | 0 |
| 199 | 67 | 16 | 28 | 27 | 14 | 25 | 6 | 5 | 9 |
| 305 | 84 | 8 | 14 | 16 | 8 | 15 | 0 | 0 | 0 |
| 306 | 75 | 25 | 43 | 25 | 25 | 43 | 0 | 0 | 0 |
| 310 | 53 | 29 | 50 | 40 | 30 | 52 | 7 | 6 | 11 |
| 311 | 93 | 6 | 11 | 7 | 6 | 12 | 0 | 0 | 0 |
| 313 | 83 | 16 | 28 | 16 | 16 | 29 | 0 | 0 | 0 |
| 314 | 87 | 13 | 23 | 13 | 13 | 23 | 0 | 0 | 0 |
| 319 | 42 | 8 | 14 | 42 | 8 | 14 | 17 | 16 | 28 |
| 321 | 70 | 10 | 17 | 30 | 10 | 17 | 0 | 0 | 0 |
| 350 | 81 | 11 | 20 | 19 | 11 | 20 | 0 | 0 | 0 |
| 351 | 83 | 9 | 16 | 17 | 9 | 17 | 0 | 0 | 0 |
| 352 | 39 | 19 | 33 | 56 | 22 | 38 | 5 | 4 | 8 |
| 353 | 72 | 14 | 25 | 28 | 14 | 25 | 0 | 0 | 0 |
| 354 | 60 | 14 | 24 | 34 | 8 | 15 | 6 | 5 | 9 |
| 355 | 92 | 8 | 14 | 8 | 8 | 14 | 0 | 0 | 0 |
| 356 | 60 | 10 | 17 | 40 | 10 | 17 | 0 | 0 | 0 |
| 357 | 77 | 14 | 25 | 23 | 14 | 25 | 0 | 0 | 0 |
| 358 | 94 | 5 | 9 | 6 | 5 | 10 | 0 | 0 | 0 |

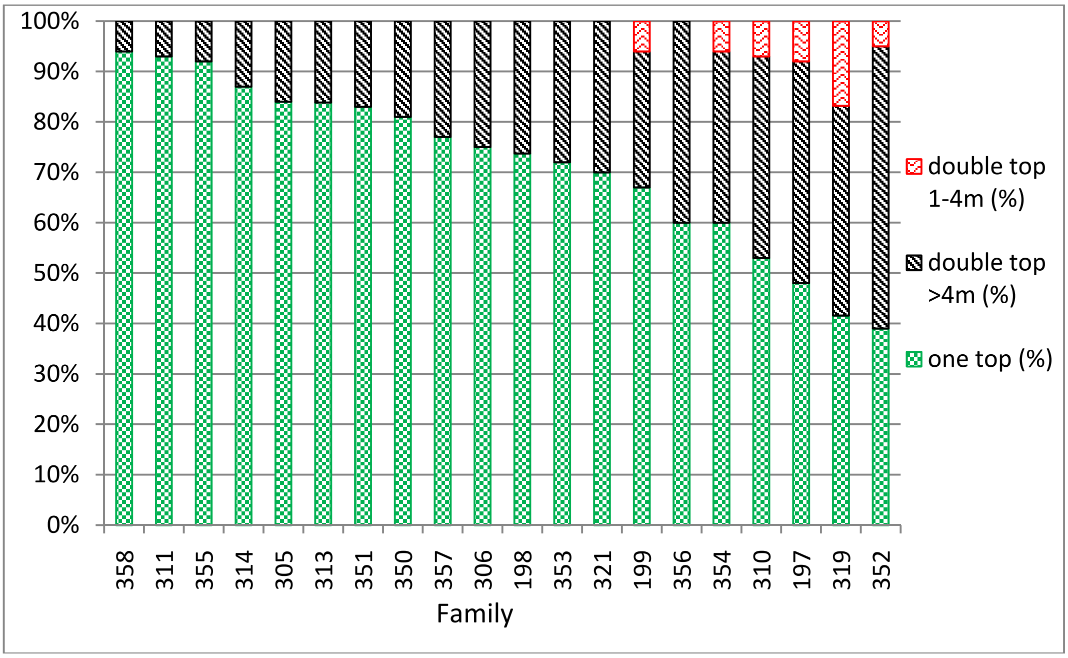



Figure13. Frequency (%) of forking in different stem sections in family experiment F1298

### 3.4.2 Provenance experiment T138

Frequency of forking for different stem sections in the provenance trial varied considerably (Table 20), and statistically significant differences among the provenance were found for one top and double top above 4 m (Table 21 & 22). However, no significant difference found comparing the frequency of double top between 1-4m stem sections in experiment T138. The maximum (80 %) and the minimum percentage (61 %) of double top were recorded for provenance Tranås and Tönnersjöheden respectively (Table 20).

Table 20. Frequency of forking in different stem sections in provenance experiment T138

| Provenance | One top (%) | | | Double top > 4m (%) | | | Double top 1-4m (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SE | StDev | Mean | SE | StDev | Mean | SE | StDev |
| Kulbäcksliden | 21 | 2 | 2 | 79 | 2 | 2 | 0 | 0 | 0 |
| Rankhyttan | 22 | 4 | 9 | 78 | 4 | 9 | 0 | 0 | 0 |
| Tranås | 20 | 2 | 4 | 80 | 2 | 4 | 0 | 0 | 0 |
| Tönnersjöheden | 38 | 4 | 10 | 61 | 4 | 10 | 0 | 0 | 0 |

Table 21. One way ANOVA on data from provenance experiment T138. Dependent variable: frequency of one top

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 3 | 1043.25 | 347.75 | 5.01 | 0.017 |
| Error | 12 | 832.75 | 69.39 | | |
| Corrected Total | 15 | 1876 | | | |

Table 22. One way ANOVA on data from provenance experiment T138. Dependent variable: frequency of double top > 4m

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 3 | 1043.25 | 347.80 | 5.01 | 0.01 |
| Error | 12 | 832.75 | 69.41 | | |
| Corrected Total | 15 | 1876 | | | |

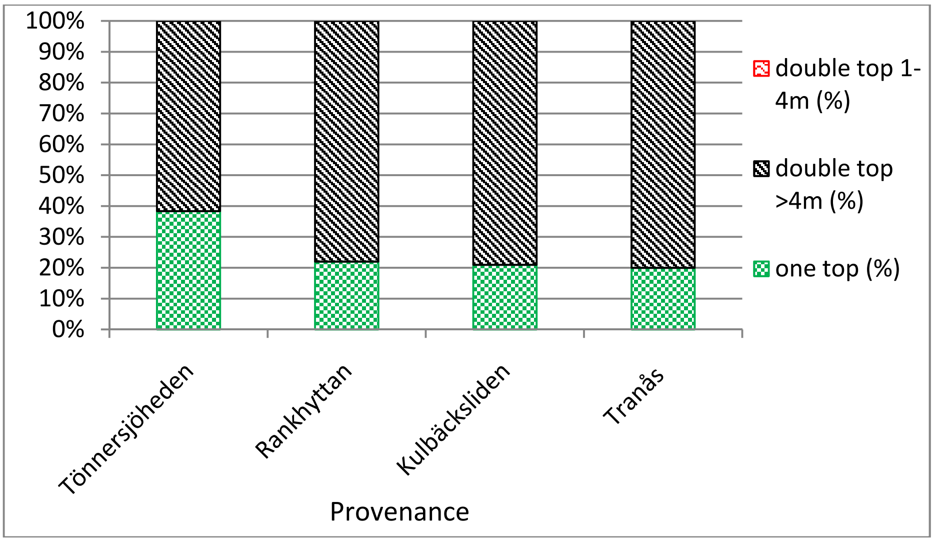


Figure 14. Frequency (%) of forking in different tree sections in provenance experiment T138

### 3.4.3 The tree species experiment

There was no significant difference comparing the frequency of double leader among provenances in the tree species experiment. The maximum (25 %) and the minimum percentage (16%) of double tops were recorded for provenance Visingsö and Asarum respectively (Table 23). The highest proportions of single top (82%) were recorded also in Asarum provenance.

Table 23. Frequency of forking in different stem sections in the tree species experiment

| Provenance | One top (%) | | | Double top > 4m (%) | | | Double top 1-4m (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SE | StDev | Mean | SE | StDev | Mean | SE | StDev |
| Visingsö | 74 | 4 | 12 | 25 | 4 | 12 | 0 | 0 | 0 |
| Asarum | 82 | 3 | 7 | 16 | 3 | 7 | 1 | 0.6 | 1 |
| Ekebo 2 | 72 | 0 | 0 | 20 | 0 | 0 | 8 | 0 | 0 |

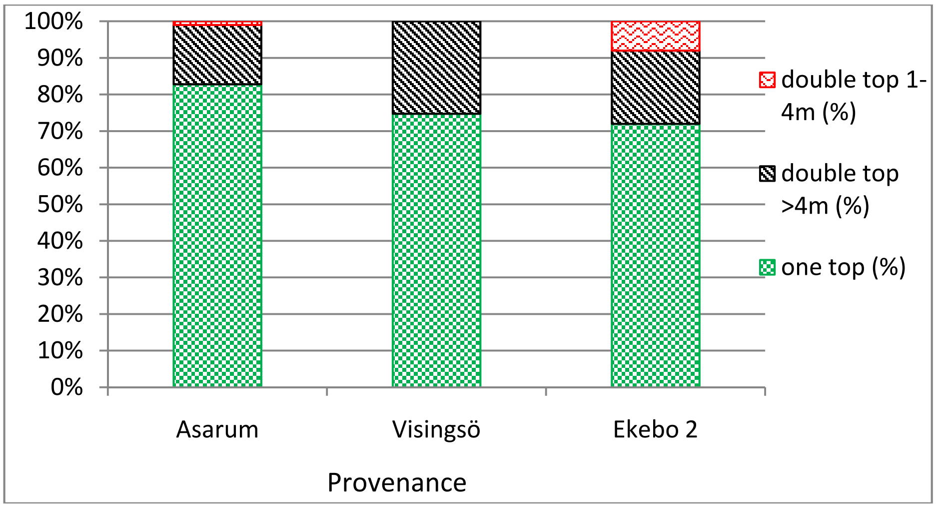


Figure15. Frequency (%) of forking in different tree sections in the tree species experiment

## 3.5 Quality Class

### 3.5.1 Families experiment F1298

Statistically significant differences ($P < .001$) among families in experiment F1298 were only found for quality class 3 (Table 25). However, significant differences were not found for other quality classes. The maximum (44%) percentages of trees in quality class 1 (good quality) were recorded for family 313, while no trees were recorded in quality class 1 for family 305 (Table 24). The highest proportion of trees (56%) in quality class 3 (slightly good) was recorded in family 198 (Table 24).

Table 24. Frequency (%) of birch trees in quality classes on family experiment F1298. The figures in brackets show the individual replications.

| **Family** | **Class 1 (Good quality)** | **Class 2 (Moderately Good)** | **Class 3 (Slightly Good)** | **Class 4 (Bad quality)** |
|---|---|---|---|---|
| 197 | 15 (25, 0, 20 ) | 70 ( 50, 100, 60) | 15 ( 25, 0, 20 ) | 0 |
| 198 | 7 ( 20, 0, 0 ) | 31 ( 40, 33 , 20) | 56 ( 40, 67, 60 ) | 7 ( 0, 0, 20 ) |
| 199 | 28 (33, 17, 33 ) | 61 ( 67, 67, 50) | 11 ( 0, 16, 17) | 0 |
| 305 | 0 ( 0, 0 , 0 ) | 100 ( 100, 100, 100 ) | 0 | 0 |
| 306 | 15 ( 25, 20, 0 ) | 85 ( 75, 80, 100 ) | 0 | 0 |
| 310 | 20 ( 40, 20, 0) | 67 ( 60, 40, 100 ) | 20 ( 0, 60, 0 ) | 0 |
| 311 | 33 (40, 33, 25) | 67 ( 60, 67, 75 ) | 0 | 0 |
| 313 | 44 ( 75, 33, 25 ) | 50 ( 25, 50, 75 ) | 6 ( 0, 17, 0 ) | 0 |
| 314 | 33 (40, 60, 0 ) | 67 ( 60, 40, 100 ) | 0 | 0 |
| 319 | 8 ( 25, 0, 0 ) | 58 ( 50, 75, 50) | 33 (25, 25, 50 ) | 0 |
| 321 | 31 ( 40, 20, 33) | 63 ( 60, 80, 50 ) | 6 ( 0, 0, 17 ) | 0 |
| 350 | 18 ( 17, 20, 17 ) | 76 ( 67, 80,83 ) | 6 ( 16, 0, 0 ) | 0 |
| 351 | 23 ( 20, 33, 17 ) | 77 ( 80, 67, 83 ) | 0 | 0 |
| 352 | 23 ( 20, 16, 33 ) | 77 ( 80, 84, 67 ) | 0 | 0 |
| 353 | 17 ( 0, 33, 17 ) | 66 ( 100, 33, 67 ) | 16 ( 0, 33, 16 ) | 0 |
| 354 | 22 ( 33, 33, 0 ) | 71 ( 67, 67, 80 ) | 7 ( 0, 0, 20 ) | 0 |
| 355 | 35 ( 60, 20, 25 ) | 58 ( 40, 80, 55 ) | 7 ( 0, 0, 20 ) | 0 |
| 356 | 17 ( 0, 50, 0 ) | 77 ( 100, 50, 80 ) | 7 ( 0, 20, 0 ) | 0 |
| 357 | 37(67, 20, 25 ) | 56 ( 33, 60, 75 ) | 7 (0, 20, 0 ) | 0 |
| 358 | 25 ( 17, 25, 33 ) | 50 ( 33, 50, 67 ) | 25 ( 50, 25, 0 ) | 0 |

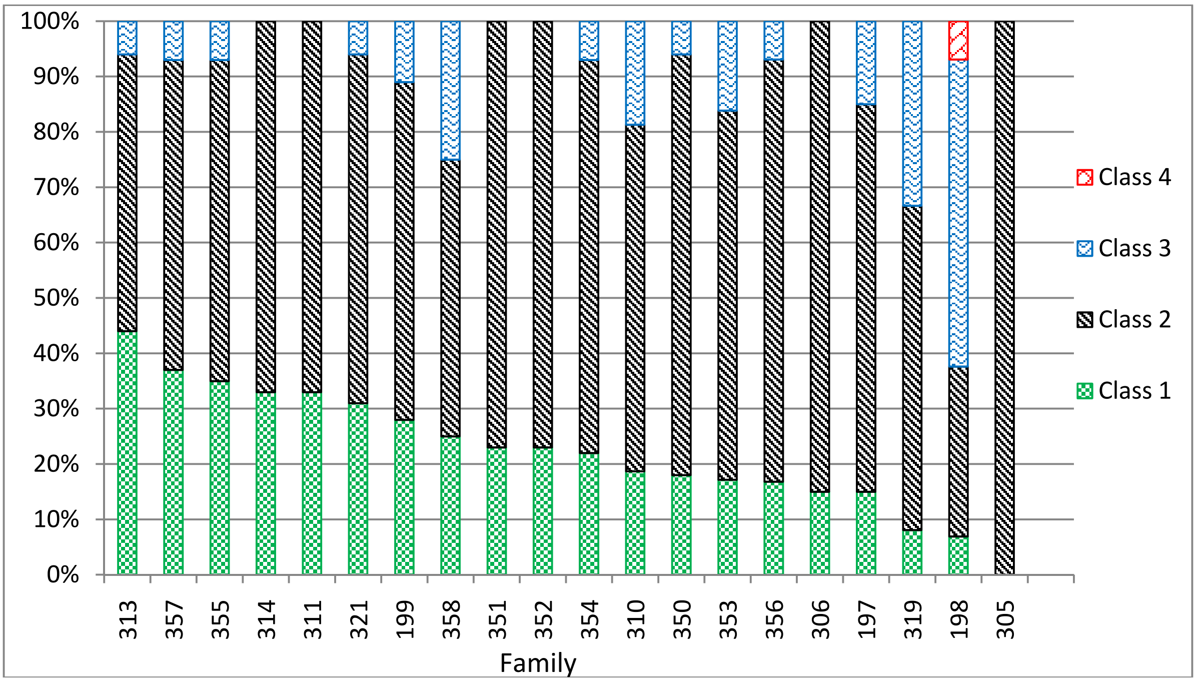


Figure 16. Frequency (%) of birch trees in quality classes in family experiment F1298

Table 25. One way ANOVA on data from family experiment F1298. Dependent variable: frequency of quality class 3

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 19 | 11116,31 | 585,06 | 3,27 | 0,0008 |
| Error | 40 | 7158,66 | 178,96 | | |
| Corrected Total | 59 | 18274,98 | | | |

### 3.5.2 Provenance experiment T138

There were no significant differences among the provenance in experiment T138 in overall quality classes. Provenance Tönnersjöheden and Kulbäcksliden had the maximum (18%) and the minimum (4%) percentage of trees in quality class 1 respectively (Table 26).

Table 26. Frequency of trees in quality classes on provenance experiment T138

| Provenance | Class1 | | | Class 2 | | | Class 3 | | | Class 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Frequency (%) | SE | StDev | Frequency (% | SE | StDev | Frequency (%) | SE | StDev | Frequency (%) | SE | StDev |
| Kulbäcksliden | 4 | 4.5 | 6.3 | 68 | 3.5 | 4.9 | 28 | 8 | 11.3 | 0 | 0 | 0 |
| Rankhyttan | 12 | 4.8 | 10.8 | 62 | 4 | 9 | 18 | 5 | 11.2 | 8 | 5.4 | 12 |
| Tranås | 17 | 3.7 | 7.4 | 68 | 7 | 14.6 | 14 | 4 | 8.1 | 1 | 1.2 | 2.5 |
| Tönnersjöheden | 18 | 1.7 | 3.9 | 71 | 2 | 6 | 10 | 3.5 | 8 | 0 | 0 | 0 |

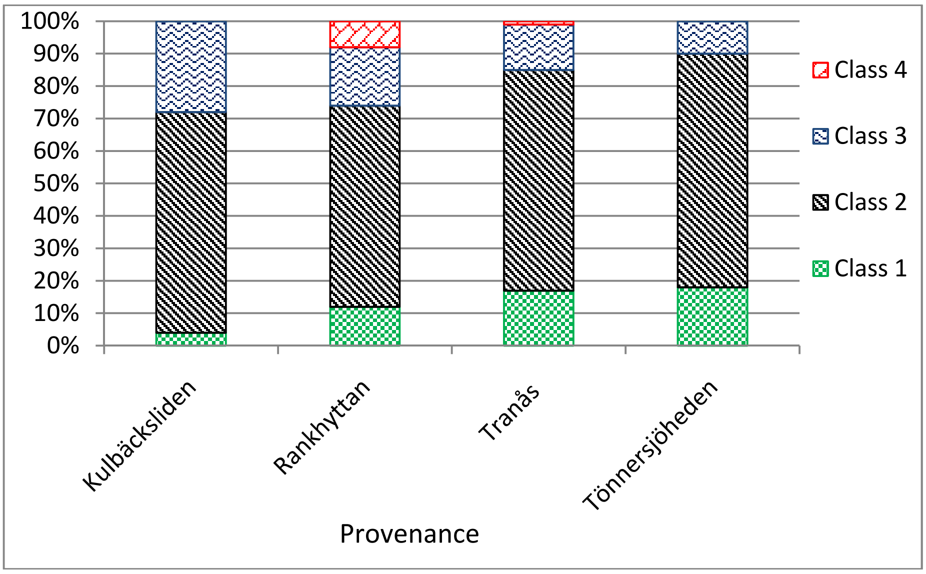



Figure 17. Frequency (%) of trees in quality class in provenance experiment T138

### 3.5.3 The tree species experiment

There were no significant differences among provenance in the tree species experiment concerning overall quality classes. Provenance Visingsö and Ekebo2 had the maximum (1.3 %) and minimum (1%) percentage of trees in quality class 4 (bad quality) respectively (Table 27). Provenance Asarum had the maximum percentage of trees in quality class 1.The highest percentages of trees in quality class 2 (moderately good) were recorded in Ekebo 2.

Table 27. Frequency of trees in quality classes among provenance of tree species experiment

| **Provenance** | **Class1** | | | **Class 2** | | | **Class 3** | | | **Class 4** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Frequency (%)** | **SE** | **StDev** | **Frequency (%)** | **SE** | **StDev** | **Frequency (%)** | **SE** | **StDev** | **Frequency (%)** | **SE** | **StDev** |
| Visingsö | 7 | 2,93 | 8,81 | 59 | 3,9 | 11,71 | 32 | 5,82 | 17,47 | 1,3 | 0,89 | 2,69 |
| Asarum | 17 | 2,75 | 6,16 | 69 | 4,17 | 9,34 | 12 | 2,44 | 5,44 | 0,8 | 0,8 | 1,78 |
| Ekebo 2 | 6 | | | 73 | | | 20 | | | 1 | | |

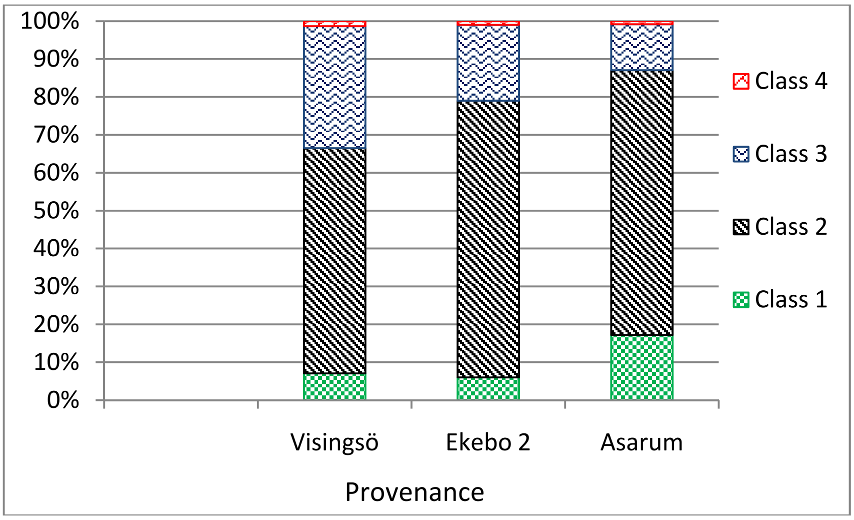



Figure 18. Frequency (%) of trees in quality classes in tree species experiment

## 3.6 DBH, Height and Volume per Stem

### 3.6.1 Families experiment F1298

Significant differences were found ($P < 0.01$) for average DBH and volume per stem among families in the family experiment F1298 (Table 29 & 30). Differences in the height among families were not significant. Average DBH and volume per stem was highest in Family 357 and lowest in family 197 (Table 28).

Table 28. Average DBH, Height and Volume/Stem among families in experiment F1298

| Family | DBH (cm) | | | Height (m) | | | Volume/stem (m3) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SE | St Dev | Mean | SE | St Dev | Mean | SE | St Dev |
| 197 | 7,9 | 0,3 | 0,52 | 10 | 0,32 | 0,56 | 0,027 | 0,002 | 0,004 |
| 198 | 9,4 | .03 | 0,05 | 11,5 | 0,26 | 0,45 | 0,043 | 0,002 | 0,004 |
| 199 | 10,6 | 1,09 | 1,9 | 11,6 | 0,35 | 0,6 | 0,053 | 0,01 | 0,01 |
| 305 | 10,7 | 0,72 | 1,24 | 12,2 | 0,54 | 0,94 | 0,056 | 0,01 | 0,01 |
| 306 | 10,3 | 0,64 | 1,12 | 11,7 | 0,44 | 0,76 | 0,049 | 0,007 | 0,01 |
| 310 | 8,9 | 0,81 | 1,4 | 10,8 | 0,38 | 0,66 | 0,037 | 0,005 | 0,009 |
| 311 | 10,8 | 0,31 | 0,55 | 11,4 | 0,23 | 0,4 | 0,052 | 0,003 | 0,006 |
| 313 | 10,3 | 0,2 | 0,35 | 11,9 | 0,1 | 0,17 | 0,049 | 0,008 | 0,001 |
| 314 | 9,4 | 0,68 | 1,19 | 11,7 | 0,38 | 0,66 | 0,042 | 0,007 | 0,012 |
| 319 | 11,5 | 0,45 | 0,78 | 11,3 | 0,54 | 0,94 | 0,057 | 0,006 | 0,011 |
| 321 | 10,2 | 0,12 | 0,2 | 11,9 | 0,59 | 1,02 | 0,049 | 0,004 | 0,007 |
| 350 | 10,1 | 0,46 | 0,8 | 11,7 | 0,52 | 0,9 | 0,048 | 0,005 | 0,008 |
| 351 | 9,9 | 0,39 | 0,68 | 11,9 | 0,31 | 0,55 | 0,047 | 0,003 | 0,006 |
| 352 | 9,7 | 0,4 | 0,7 | 11,3 | 0,66 | 1,15 | 0,042 | 0,006 | 0,01 |
| 353 | 10,5 | 0,56 | 0,98 | 11,9 | 0,39 | 0,68 | 0,052 | 0,007 | 0,011 |
| 354 | 9 | 0,86 | 1,5 | 11,2 | 0,78 | 1,35 | 0,038 | 0,008 | 0,014 |
| 355 | 10,2 | 0,29 | 0,51 | 11,2 | 0,28 | 0,49 | 0,047 | 0,003 | 0,055 |
| 356 | 8,3 | 0,63 | 1,09 | 10,4 | 0,43 | 0,75 | 0,030 | 0,004 | 0,088 |
| 357 | 11,7 | 0,33 | 0,58 | 12,1 | 0,7 | 1,21 | 0,065 | 0,006 | 0,011 |
| 358 | 9,8 | 0,38 | 0,66 | 11,2 | 0,17 | 0,3 | 0,043 | 0,001 | 0,033 |

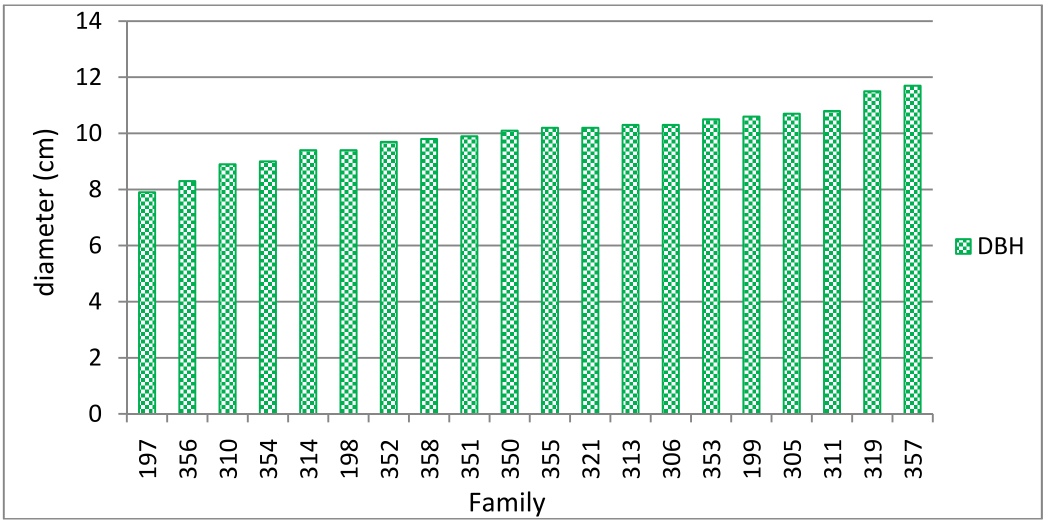


Figure 19. Average DBH among the families in experiment F1298

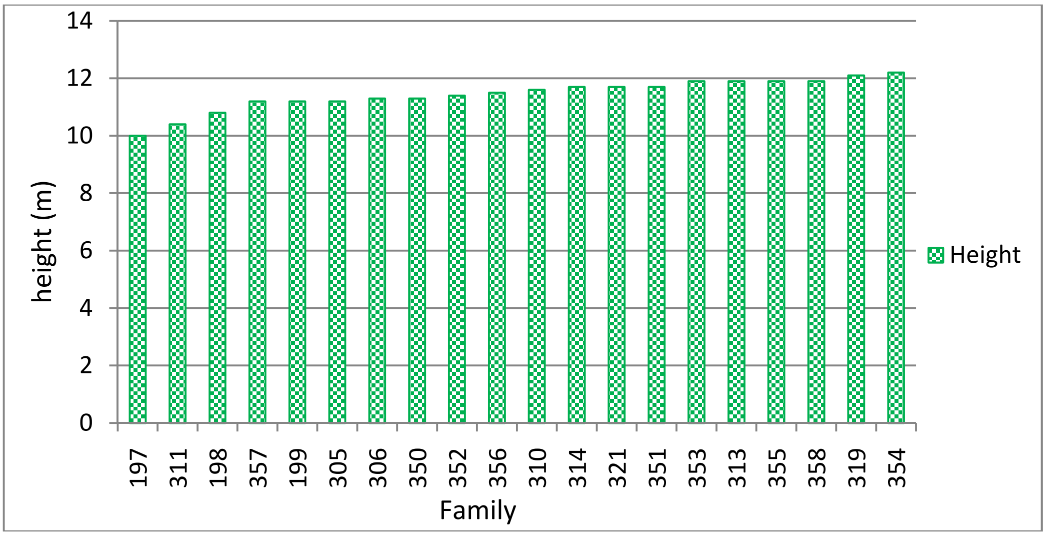


Figure 20. Average Height among the families in experiment F1298

Table 29. One way ANOVA on family experiment F1298. Dependent variable: average DBH

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
|---|---|---|---|---|---|
| Model | 19 | 53,19 | 2,79 | 3,06 | 0,01 |
| Error | 40 | 36,56 | 0,91 | | |
| Corrected Total | 59 | 89,75 | | | |

Table 30. One way ANOVA on family experiment F1298. Dependent variable: average volume per stem

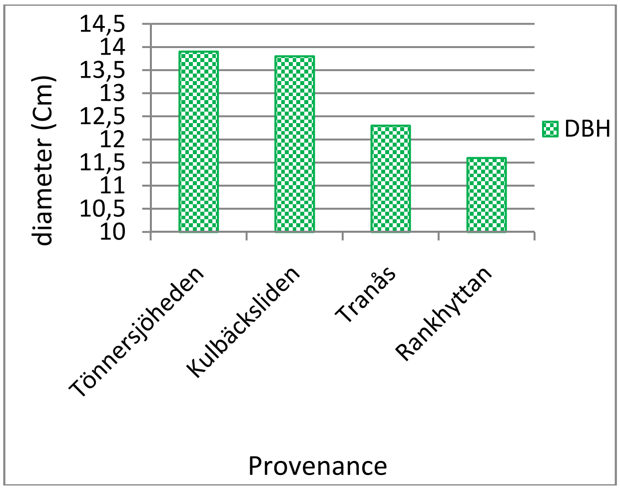
| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
|---|---|---|---|---|---|
| Model | 19 | 0,0046 | 0,00024 | 2,36 | 0,01 |
| Error | 40 | 0,0041 | 0,0001 | | |
| Corrected Total | 59 | 0,0087 | | | |

### 3.6.2 Provenance experiment T138

The average tree size in the provenance trial varied considerably (Table 31), and statistically significant differences among the provenance were found for DBH, Height and Volume per stem (Table 32, 33 & 34). Provenance Tönnersjöheden had higher DBH, height and volume per stem among the provenances. The lowest mean diameter, height and volume per stem were recorded in Rankhyttan.

Table 31. Average DBH, Height and Volume/Stem among provenances in experiment T138

| Provenance | DBH (cm) | | | Height (m) | | | Volume/stem (m3) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SE | StDev | Mean | SE | StDev | Mean | SE | StDev |
| Kulbäcksliden | 13,8 | 0,95 | 1,35 | 13,1 | 1,15 | 1,6 | 0,09 | 0,01 | 0,02 |
| Rankhyttan | 11,6 | 0,33 | 0,74 | 12,2 | 0,41 | 0,91 | 0,06 | 0,005 | 0,01 |
| Tranås | 12,3 | 0,35 | 0,71 | 13,4 | 0,14 | 0,29 | 0,07 | 0,004 | 0,008 |
| Tönnersjöheden | 13,9 | 0,37 | 0,84 | 13,8 | 0,24 | 0,55 | 0,1 | 0,005 | 0,01 |



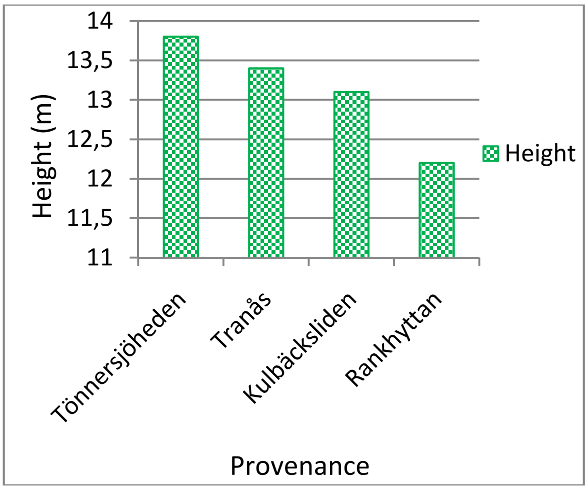




Figure 21. Average DBH (left panel) and Height (right panel) among provenances in experiment T138

Table 32. One way ANOVA on provenance experiment T138. Dependent variable: average DBH

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 3 | 17.60 | 5.86 | 8.36 | 0.002 |
| Error | 12 | 8.42 | 0.70 | | |
| Corrected Total | 15 | 26.02 | | | |

Table 33. One way ANOVA on data in family experiment F1298. Dependent variable: average height

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 3 | 7.17 | 2.39 | 3.81 | 0.03 |
| Error | 12 | 7.54 | 0.62 | | |
| Corrected Total | 15 | 14.71 | | | |

Table 34. One way ANOVA on family experiment F1298. Dependent variable: average volume per stem

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
|---|---|---|---|---|---|
| Model | 3 | 0.0035 | 0.0011 | 6.57 | 0.007 |
| Error | 12 | 0.0021 | 0.00017 | | |
| Corrected Total | 15 | 0.0056 | | | |

### 3.6.3 The tree species experiment

There was age differentiation among provenances in tree species experiment (Table 1). Hence, comparison among provenances in tree species experiment was not done concerning growth parameters. The age of birch of origin Ekebo2 was smaller compared to the two others provenances Asarum and Visingsö.

Table 35. Average DBH, Height and Volume/Stem among provenances in tree species experiment

| Provenance | **DBH (cm)** | | | **Height (m)** | | | **Volume/Stem (m3)** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **SE** | **St Dev** | **Mean** | **SE** | **St Dev** | **Mean** | **SE** | **St Dev** |
| Visingsö | 10 | 1,02 | 3,08 | 13 | 0,81 | 2,43 | 0,054 | 0,01 | 0,039 |
| Asarum | 9 | 1,95 | 4,36 | 11 | 2,18 | 4,89 | 0,048 | 0,01 | 0,03 |
| Ekebo 2 | 8 | | | 9 | | | 0,02 | | |

## 3.7 Tree Class

### 3.7.1 Families experiment F1298

There were no significant differences in the average percentage of tree classes among families on experiment F1298. Family 305 and 356 had maximum (59%) and minimum (20%) percentage of trees in dominant class among families respectively (Table 36).

Table 36. Frequency of birch trees in tree classes among families in exp F1298.

| Family | Dominant(%) | Co-dominant(%) | Dominated(%) | Supressed(%) |
|---|---|---|---|---|
| 197 | 22 | 36 | 27 | 14 |
| 198 | 34 | 23 | 33 | 10 |
| 199 | 38 | 39 | 22 | 0 |
| 305 | 59 | 31 | 9 | 0 |
| 306 | 58 | 35 | 6 | 0 |
| 310 | 26 | 40 | 33 | 0 |
| 311 | 40 | 47 | 12 | 0 |
| 313 | 41 | 36 | 22 | 0 |
| 314 | 40 | 33 | 26 | 0 |
| 319 | 38 | 38 | 16 | 7 |
| 321 | 24 | 69 | 6 | 0 |
| 350 | 34 | 61 | 0 | 5 |
| 351 | 35 | 46 | 18 | 0 |
| 352 | 48 | 37 | 14 | 0 |
| 353 | 52 | 41 | 5 | 0 |
| 354 | 33 | 39 | 22 | 5 |
| 355 | 28 | 58 | 13 | 0 |
| 356 | 20 | 56 | 12 | 11 |
| 357 | 57 | 26 | 11 | 5 |
| 358 | 25 | 41 | 33 | 0 |

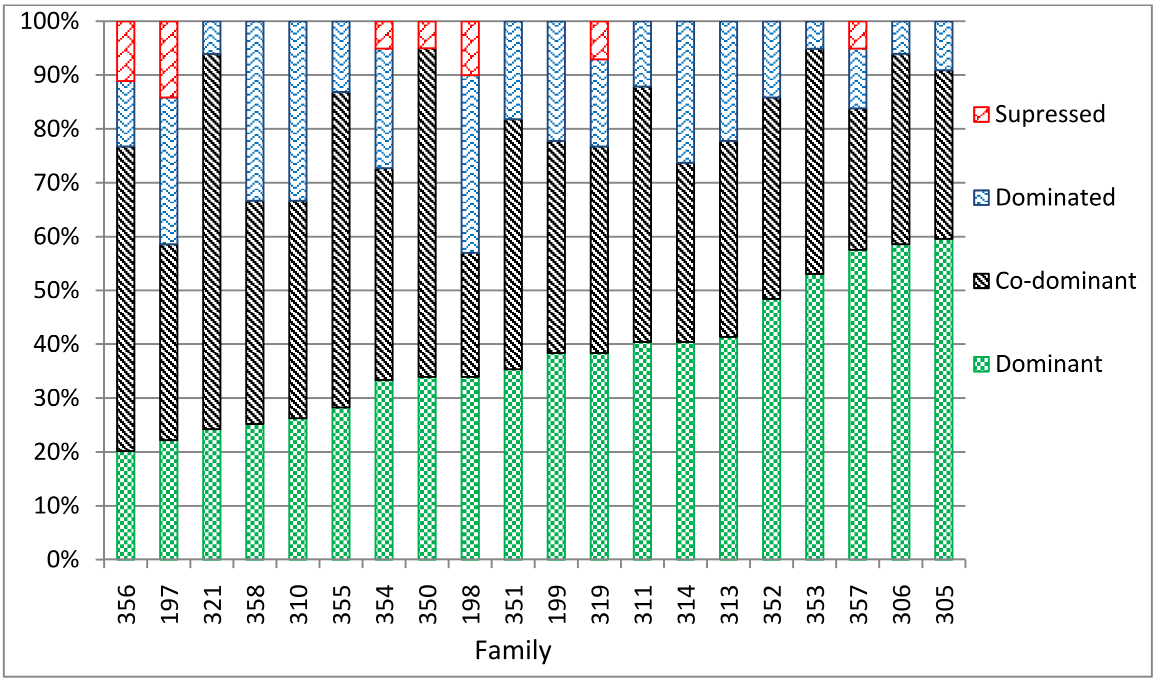



Figure 22. Frequency (%) of birch trees in different tree classes in family experiment F1298

Table 37. Distribution of quality classes in different tree classes in families experiment

| Tree Class | Quality Class (%) | | | |
|---|---|---|---|---|
| | Class 1 | Class 2 | Class 3 | Class 4 |
| Dominant | 33 | 62 | 5 | 0 |
| Co-dominant | 19 | 73 | 7 | 1 |
| Dominated | 6 | 61 | 33 | 0 |

### 3.7.2 Provenance experiment T138

The average percentage of tree classes varied considerably, and statistically significant differences among provenance were found for mean values of dominant trees (P < 0, 01) in experiment T138 ( Table 39).However, differences in the frequency of trees in the co-dominant, dominated and supressed classes were not significant. Provenance Tönnersjöheden had the maximum dominant trees (62%) whereas Tranås had minimum dominant trees (40%) among others provenance (Table 38)

Table 38. Frequency of trees in tree classes on provenance experiment T138

| Provenance | Dominant(%) | Co-dominant(%) | Dominated(%) | Supressed(%) |
|---|---|---|---|---|
| Kulbäcksliden | 53 | 39 | 3 | 6 |
| Rankhyttan | 43 | 35 | 13 | 8 |
| Tranås | 40 | 35 | 16 | 7 |
| Tönnersjöheden | 62 | 29 | 5 | 3 |

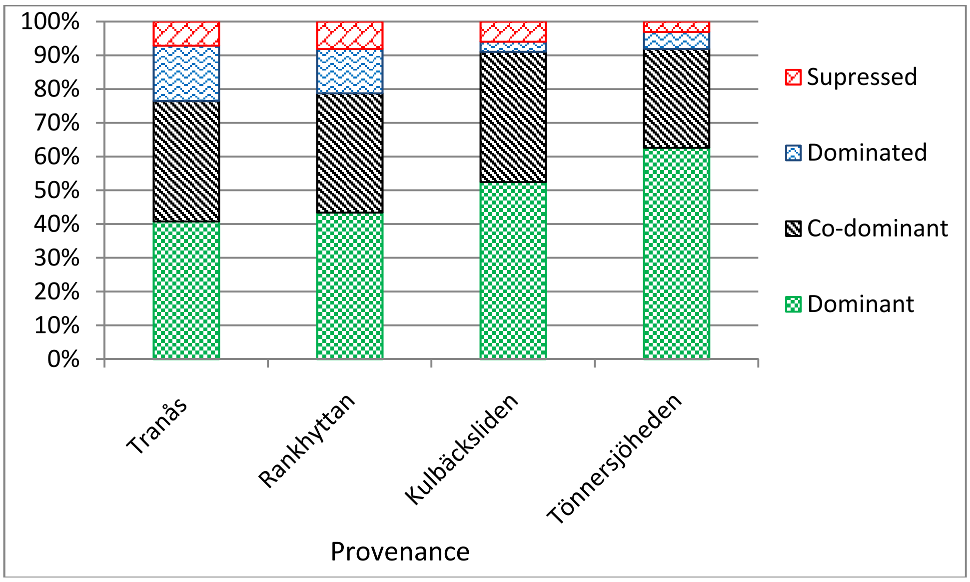



Figure 23. Frequency (%) of birch trees in tree classes in provenance experiment T138

Table 39. One way ANOVA on provenance experiment T138. Dependent variable: dominant tree

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
|---|---|---|---|---|---|
| Model | 3 | 1290.7 | 430.25 | 5.77 | 0.01 |
| Error | 12 | 895 | 74.5 | | |
| Corrected Total | 15 | 2185.7 | | | |

Table 40. Distribution of quality classes in different tree classes in provenance experiment

| Tree Class | Quality Class (%) | | | |
|---|---|---|---|---|
| | Class 1 | Class 2 | Class 3 | Class 4 |
| Dominant | 22 | 73 | 5 | 0 |
| Co-dominant | 8 | 73 | 17 | 2 |
| Dominated | 8 | 26 | 55 | 11 |

### 3.7.3 The tree species experiment

There were no significant differences in the frequency of tree classes among provenance in the tree species experiment. Provenance Asarum and Visingsö had maximum (40%) and minimum (29%) percentage of trees in the dominant class respectively (Table 41). The highest proportion of trees in the supressed class was found in Visingsö (32 %).

Table 41. Frequency of birch tree on tree classes in the tree species experiment

| **Provenance** | **Dominant(%)** | **Co-dominant(%)** | **Dominated(%)** | **Supressed (%)** |
|---|---|---|---|---|
| Visingsö | 29 | 21 | 16 | 32 |
| Asarum | 40 | 43 | 13 | 3 |
| Ekebo 2 | 33 | 43 | 20 | 4 |

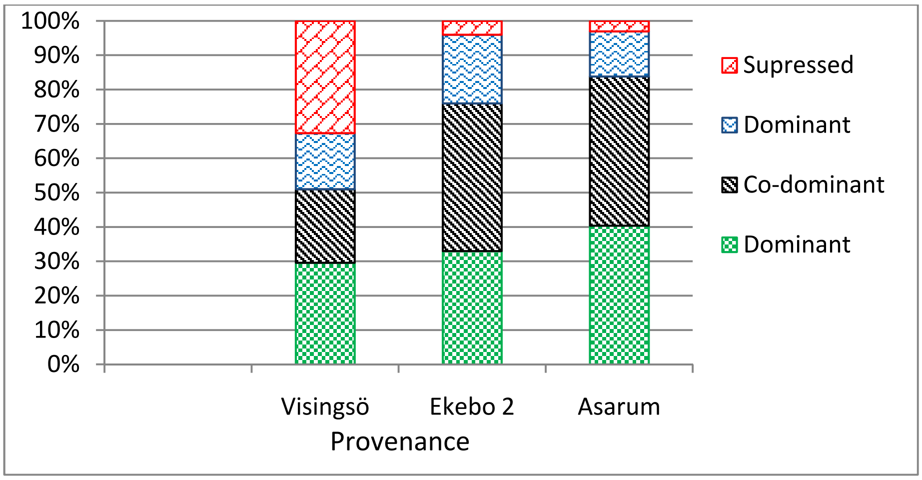



Figure 24. Frequency (%) of trees in tree classes on tree species experiment

Table 42. Distribution of quality classes in different tree classes in the tree species experiment

| Tree Class | Quality Class (%) | | | |
|---|---|---|---|---|
| | Class 1 | Class 2 | Class 3 | Class 4 |
| Dominant | 13 | 73 | 13 | 1 |
| Co-dominant | 12 | 66 | 21 | 1 |
| Dominated | 7 | 48 | 41 | 4 |

# 4 DISCUSSION

The quality of birch is often considered poor in South Sweden regarding stem straightness, spike knots, double leader and growth. The ways of improving the quality is breeding and changed silvicultural practices.  This study analyzed the difference in stem quality among Silver birches of different genetic origin planted in South Sweden. The study was divided into three sections according to the experimental setting and ages of the provenance. Although branch diameter was an important parameter to describe the stem quality, it couldn't be measured due to self natural pruning of the stems.

## 4.1 The family experiment F1298

The difference on the frequency of straight trees among families was high. The average percentage of straight trees varied between 94 % in the family 313 and 17 % in the family 198. The frequency of straight trees in the family experiment was much higher than in the provenance and tree species experiments. Niemisto (1996) studied planted Silver birch in Finland and showed that the frequency of crooked stems were 60 % on abandoned agricultural land and 44 % in forest land. In the present study, the frequency of crooked stems were quite low (6 %) compared to the Niemisto study for some good quality families. However, some families which were judged poorer than other had a higher frequency of crooked stems (83 %) compared to Niemisto (1996).

Many trees in the family experiment had generally a high frequency of spike knots. In family 351, 52 % of the trees were free from spike knots while in family 319 and 311all trees had spike knots.  The result suggested that the differences in spike knots frequency were higher among families. The family experiment had a higher frequency of trees with spike knots than the provenance and tree species experiments.

In most of the families there were no leaning trees. Differences were found for slightly leaning trees where the percentage of trees in this category varied between families 356 with 8 % slightly leaning trees and family 358 with 50 % SL trees.

The frequency of single top trees was high compared to double top trees among the families and varied between 94% in family 358 to 39 % in family 352. Most of the double tops were recorded in the section above 4m. Furthermore, high differences between families were observed for the frequency of double tops above 4m, family 358 had only 6% trees with double tops and family 352 had 56 %.

Comparing the overall quality, family 313 had the highest percentage of trees in quality class 1 (good quality) and 2 (moderately good). Family 305 had no trees in the quality class 1 but all trees of this family were in class 2. Family 198 had the highest proportion of trees in quality class 3 (slightly good) and it was also the only family with trees in quality class 4 (bad quality). The result of all parameters suggested that there existed a quality difference among the families. Some families with a high frequency of straight trees had the potential of producing high quality timber in the future, while others with more crooked stems were judged as bad timber quality.

### 4.2 The provenance experiment T138

The average percentage of crooked trees varied between 19 % in the provenance Rankhyttan (Central Sweden) to 6 % in the Tranås (South Sweden) provenance. The provenance Kulbäcksliden (North Sweden) had only 20 % straight trees which was lower than all the other provenances. There were no differences among provenances on the frequency of trees in the slightly crooked category. The provenances from Central and North Sweden had more crooked stems in compared to the southern provenances. Although the percentages of crooked stems were similar in the North and Central provenances, the frequency of straight trees were higher in Central provenance .Compared to the family experiment, the frequency of crooked trees was higher in the provenance experiment. Niemisto (1996) reported a higher frequency of crooked trees than this provenance experiment if we combine slightly crooked and crooked trees together.

The mean spike knots frequency was low in the provenance experiment. The percentage of trees without spike knots was higher in provenance experiment than in the family and tree species experiments. In the Tönnersjöheden (South Sweden) provenance, 89 % of trees had no spike knots compared to 45 % in the Kulbäcksliden provenance.

The percentage of leaning trees varied between 2 % in the Tranås provenance and 12 % in Kulbäcksliden provenance. Differences were also found in not leaning trees where Kulbäcksliden had only 43% where as Tranås and Rankhyttan had 67%.

There were no double tops observed in stem section between 1-4m in all provenances. However, slight differences were observed in the frequency of single top trees, which varied from 38% in the Tönnersjöheden provenance to 20% in the Tranås provenance.

Small differences among provenances were observed in the best quality classes (1 and 2) and the Tönnersjöheden provenance had 18 % of the trees in class 1 while Kulbäcksliden had 4 %. Higher differences were found in quality class 3 among provenances where the Kulbäcksliden provenance had the highest frequency. The provenance Rankhyttan had the highest frequency of trees in quality class 4. The growth and yield data showed differences among provenances. The provenance Rankhyttan had a lower diameter than the provenance Tönnersjöheden while the differences for mean height were small. Thus, the results suggested there were differences among provenances on the observed parameters. The local provenance Tönnersjöheden had a higher frequency of straight trees along with few spike knots. Kulbäcksliden was judged as a bad quality provenance with less straight stems and more defects.

### 4.3 The tree species experiments

The tree species experiments were not systematically replicated and also the stand age varied among them. Consequently, the growth result was not comparable. Differences on quality parameters were observed in the tree species experiments. The average percentage of straight trees varied between 60 % in the provenance Ekebo2 and 17 % in the Visingsö provenance. Furthermore, Visingsö had higher frequency of crooked stems than the others provenances. The difference between Ekebo2 and Asarum was small; Ekebo 2 had a slightly higher frequency of straight trees than Asarum. The frequency of straight trees was higher in this experiment than the provenance experiment mainly for the Ekebo 2 provenance, but it was lower than in the family experiment. The mean straightness in the tree species experiments was quite similar to the results reported by Niemisto (1996) for the Asarum provenance, however a slightly higher frequency of straight trees found for Ekebo 2. However, for the Visingsö provenance a higher frequency of crooked stems was observed compared to Niemisto (1996).

The provenances Asarum and Ekebo 2 had a high frequency of spike knots. The percentage of trees without spike knots was low in both provenances. The provenance Visingsö had more trees without spike knots and also less average spike knots per stem in comparison to both the other provenances. A big difference on the frequency of leaning trees were observed among Visingsö (17 %), Ekebo2 (6 %) and Asarum (7 %). The highest frequencies of not leaning trees (58%) were recorded for the Asarum provenance. There were only small differences on the frequency of forking trees among the provenances.

The highest proportions of trees in the quality class 2 were observed in Ekebo2, while the proportion of trees in quality class 1 was higher in the Asarum provenance. Visingsö had a high frequency of trees in quality class 3, while the proportion of trees in the quality class 4 was similar among the provenances. The percentage of trees in quality class 3 and 4 was lower in Asarum compared to other two provenances. The results of all the parameters suggested that there existed a quality difference among the three provenances. The provenance Asarum had an overall good potential for higher timber quality with few stem defects, while Visingsö had a bad timber quality with many crooked stems.

# 5 CONCLUSIONS

In the family experiment, significant differences between families were found for the parameters straight trees and diameter. Differences between families were also observed in the overall quality analysis for class 3 and for the volume per stem. No significant differences were found for others measured parameters like spike knots, forking, leaning and tree height. The results suggested that some families like 313 had a higher proportion of good quality trees with a higher percentage of straight trees and few spike knots. While others families like 198 had a bad quality with low percentage of straight trees and many spike knots. The frequency of straight trees was higher in the family experiment compared to the provenance and the tree species experiments.

In the provenance experiment, differences were found for more of the observed parameters as compared to the family and tree species experiments. Significant differences were found for the frequency of crooked trees, spike knots, leaning trees and forking trees as well as for diameter and tree height. Differences between provenances were also observed for volume per stem. No significant differences were found for quality class. The local provenance Tönnersjöheden had an overall better quality performance than the others provenances with a higher percentage of straight trees and few defects like leaning, spike knots and forking. The provenance from North (Kulbäcksliden) and Central (Rankhyttan) Sweden had a bad quality performance with higher frequency of crooked trees and spike knots. The frequency of spike knots was generally lower in the provenance experiment than in the family and tree species experiments.

Significant differences between provenances were only found for the frequency of straight and leaning trees in the tree species experiments. Asarum was suggested as a good quality provenance with an overall high quality provenance and a low percentage of leaning trees. Visingsö was judged as a bad quality provenance with a high percentage of crooked stems and many leaning trees. The frequency of straight trees was lower in the tree species experiment in comparison to the family and provenance experiments.

# 6 REFERENCES


Agestam, E., Ekö, P.M. & Johansson, U. 1998. Timber quality and volume growth in naturally regenerated and planted Scots pine stands in S.W. Sweden. Stud. For. Suec. 204, 17 pp

Cameron, A.D. 1996. Managing birch woodlands for the production of quality timber. Forestry 69: 357-371.

Cameron, A.D., Dunham, R.A & Petty, J.A. 1995. The effects of heavy thinning on stem quality and timber properties of silver birch. Forestry 68*:* 275-*285*.

Dahlgren, T., Wistrand, S. & Wiström, M. 2004: Nordiska träd och träslag. Byggförlaget, ISBN 91-973626-2-X (In Swedish)

Danell, Ö. & Werner, M. 1989. Förädlingsplan för björk. Årsbok . Uppsala: Föreningen Skogsträdsföradling, Institutet for Skogsförbättring. (In Swedish with English summary.)

Donaldson, L.A., & Turner, J.C.P. 2001. The influence of compression wood and micro fibril angle on the occurrence of distortion in window frames made from radiata pine (*Pinus radiata*). Holz Roh- Werkstoff 59: 163–168

Ekö, P.M., Johansson, U., Petersson, N., Bergqvist, J., Elfving, B. & Frisk, J. 2008. Current growth differences of Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) and birch (*Betula pendula* and *Betula pubescens*) in different regions in Sweden. Scandinavian Journal of Forest Research. 23(4): 307-318

Felton, A., Lindbladh, M., Brunet, J. & Fritz, O. 2010. Replacing coniferous monocultures with mixed-species production stands: An assessment of the potential benefits for forest biodiversity in northern Europe.Forest Ecology and Management 260(6): 939-947

Hagqvist, R. & Hahl, J. 1998. Genetic gain provided by seed orchards of silver birch in Southern and Central Finland. Rep. Found. For. Tree Breed.13:1-32. (In Finnish with English summary).

Hallaksela, A-M. & Niemistö, P. 1998. Stem discoloration of planted silver birch. Scand. J. For: Res. 13:189-176

Herajarvi, H. 2001. Technical properties of mature birch (*Betula pendula* and *B.* pubescens) for saw milling in Finland. Silva Fennica 35(4): 469–485.

Hulten, E. & Fries, M. 1986. Atlas of North European vascular plants north of the Tropic of Cancer I. Koeltz Scientific Books, Königstein. 498p.

Hynynen, J. & Niemisto, P. 2009. Silviculture of Silver Birch in Finland. General Forestry Journal: The Forest. 64(13): 709:711.

Hynynen, J., Niemistö, P., Viherä-Aarnio, A., Brunner, A., Hein, S. & Velling, P. 2010. Silviculture of Birch (*Betula pendula Roth and Betula pubescens Ehrh*.) in Northern Europe. Forestry 83(1): 103-119.

Johnsson, H. 1974. Genetic characteristics of *Betula verrucosa*. and *Betula pubescens*. Annales Forestales. Anali za Šumarstvo. 6: 91-133.

Johansson, T. 1990. Afforestation of arable land. Sver. Skogsvårdsförb. Tidskr. 4:28-35 (In Swedish; with English summary)

Kataikko, M.-S. 1996. Huonekaluvalmistajien tarpeet sahaamisen lähtökohtana. Taitemia 5. Kuopion Käsi- ja Taideteollisuusakatemia. 126 p. + app. 41 p. (In Finnish)

Koski V. & Rousi. M. 2005. A review of the promises and constraints of breeding silver birch (Betula pendula Roth) in Finland. *Forestry* .78: 187-198.

Luostarinen, K. & Verkasalo, E. 2000. Birch as sawn timber and in mechanical further processing in Finland. A literature study. Silva Fennica Monographs 1. 40p.

MacDonald, E. & Hubert, J. 2002. A review of the effects of silviculture on timber quality of Sitka spruce. Forestry. Vol 75. No.2: 107-138

Makinen, H. 2002. Effect of stand density on the branch development of silver birch (Betula pendula Roth) in central Finland. Trees – Structures and Function 16: 346-353.

Makinen, H., Ojansuu R. & Niemisto P. 2003. Predicting external branch characteristics of planted silver birch (Betula pendula Roth.) on the basis of routine stand and tree measurements. Forest Science 49: 301-317.

Malcolm, D.C. & Worrel, R. 2001. Potential for the improvement of silver birch (*Betula Pendula Roth*) in Scotland. Forestry 74: 439.453.

Mottonen, V. 2005. Variation of color and selected physical and mechanical properties related to artificial drying of sawn silver birch (*Betula pendula* Roth) timber from plantations. University of Joensuu, Faculty of Forestry. ISBN: 951-651-114-7. Dissertationes Forestales 13. 43 p.

National Board of Forestry, 2010. Statistical yearbook of Forestry 2003. Jönköping: National Board of Forestry.

Niemistö, P. 1995. Influence of initial spacing and row-to-row distance on the crown and branch properties and taper of silver birch (*Betula pendula*). Scandinavian Journal of Forest Research 10: 235–244.

Niemisto, P. 1996. Yield and quality of planted silver birch (Betula pendula) in Finland - preliminary review. Norwegian Journal of Agricultural Sciences(Suppl. 24): 51-59

Niemistö, P., Viherä-Aarnio, A., Velling, P., Heräjärvi, H. & Verkasalo, E. 2008. Koivun kasvatus ja käyttö [Management and utilization of birch]. Metsäkustannus, Helsinki. 254 p ( In Finnish with English Summary)

Ödlund, L. 2009. Varför sågas så lite björk i Sverige? : Why isn't more birch wood being sawn in Sweden?" Examensarbete på magisternivå nr: TD 123/2009 Växjö, Avdelningen för Skog och Träteknik. (In Swedish)

Skogsdata, 2009. Sveriges officiella statistik. SLU. Fakulteten för skogsvetenskap. ISSN 0280-0543; Available at: www-riksskogstaxeringen.slu.se (In Swedish) (Cited on: 2011-05-25)

Stener, L-G. 1995. Comparison of silver birch of Finnish and Swedish origin in a trial in southern Sweden. Jamforelse mellan bjork av finskt och svenskt ursprung i ett forsok i sodra Sverige. Redogorelse -SkogForsk. 1995, No. 1, 17 pp (In Swedish)

Stener, L.-G. & Hedenberg, Ö. 2003. Genetic parameters of wood, fiber, stem quality and growth traits in a clone test with *Betula pendula*. Scand. J. For. Res. 18: 103-110.

Stener, L-G & Jansson, G. 2005. Improvement of *Betula pendula* by clonal and progeny testing of phenotypically selected trees. Scand. J. For. Res. 20: 292-303

Telenius, B.F. 1999. Stand growth of deciduous pioneer tree species on fertile agricultural land in southern Sweden. Biomass and Bioenerg. 16, 13 – 23

Viherä-Aarnio, A. 1994. Genetic variation and breeding strategy of birch in Finland. Norwegian J. Agric. Sci. Suppl.:19-26

Vihera-Aarnio, A. & Velling, P. 1999. Growth and stem quality of mature birches in a combined species and progeny trial. Silva Fennica. 33:225-234.

Vihera-Aarnio, A. & Velling P. 2008. Seed transfers of silver birch (*Betula pendula*) from the Baltic to Finland - effect on growth and stem quality. Silva Fennica. 42(5):735-751.

Watson, A.J. & Dadswell, H.E. 1957. Paper making properties of compression wood from Pinus radiata. Appita 11: 56–7

# ANNEXES

## Annex 1: Information on families in the experiment F1298

| Code | Family | Father | Mother | Remarks |
|---|---|---|---|---|
| 197 | Börshult, E-Län | | | Stand selected for seed harvest, Börshult, E-Län |
| 198 | Dansk Nödebo | | | Danish Nödebo, seed orchard |
| 199 | Svensk Visingsö | | | SwedishVisingsö, seed orchard |
| 305 | S21H9630002 | S213BJ795 | S21K883007 | Full sibling crossing. Ekebo1, Ekebo2 |
| 306 | S21H9630003 | S213BJ798 | S21K883007 | Full sibling crossing. Ekebo1, Ekebo2 |
| 310 | S21H9630007 | S21K883059 | S21K883060 | Full sibling crossing. Ekebo1, Ekebo2 |
| 311 | S21H9630008 | S213BJ794 | S21K883060 | Full sibling crossing. Ekebo1, Ekebo2 |
| 313 | S21H9630010 | S213BJ794 | S21K883075 | Full sibling crossing. Ekebo1, Ekebo2 |
| 314 | S21H9630011 | S213BJ805 | S21K883075 | Full sibling crossing. Ekebo1, Ekebo2 |
| 319 | S21H9630016 | S21K883044 | S21K883126 | Full sibling crossing. Ekebo1, Ekebo2 |
| 321 | S21H9630018 | S213BJ798 | S21K883126 | Full sibling crossing. Ekebo1, Ekebo2 |
| 350 | S21X9530001 | | S213BJ794 | Half sibling crossing. Ekebo1 |
| 351 | S21X9530003 | | S213BJ798 | Half sibling crossing. Ekebo2 |
| 352 | S21X9530004 | | S213BJ805 | Half sibling crossing. Ekebo2 |
| 353 | S21X9530008 | | S21K883007 | Half sibling crossing. Ekebo2 |
| 354 | S21X9530009 | | S21K883059 | Half sibling crossing. Ekebo2 |
| 355 | S21X9530010 | | S21K883060 | Half sibling crossing. Ekebo2 |
| 356 | S21X9530011 | | S21K883075 | Half sibling crossing. Ekebo2 |
| 357 | S21X9530013 | | S21K883113 | Half sibling crossing. Ekebo2 |
| 358 | S21X9530014 | | S21K883126 | Half sibling crossing. Ekebo2 |

## Annex 2: List of photos showing different quality traits

Photo 1. Straight tree (1)

Photo 2. Slightly Crooked tree(2)

Photo 3: Crooked tree(3)

Photo 4. Spike knots at the middle section of the stem

Photo 5. Not Leaning tree(NL)

Photo 6. Slightly Leaning tree(SL)

Photo 7. Leaning tree(L)

Photo 8. Forking at the middle section of the stem


Photo 9: Quality class 1

Photo 10. Quality Class 2

Photo 11. Quality Class 3

Photo 12. Quality Class 4


Photo 13: Suppressed tree (S)


Photo 14. Measured trees in the tree species experiment

Photo 15. The author measuring the straightness of a stem with the help of a rope and a measuring stick

Photo 16. The author measuring DBH in the family experiment F1298

Photo 17. The author checking the straightness at the bottom section of a stem

**Annex 3: Quality Assessment Data Record Sheet**

Data collector: ……………………… Date: …………………..

Stand Age: ……………. Stand origin: ……………….. Stand Location: ………………….

| Tree No. | Sample Plot No | Tree Class (D,CD,DO,S) | DBH , cm | Straightness | | Spike knots | | | Diameter of the thickest branch |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 0-1m | 1-4m | 0-1m | 1-4m | > 4m | |
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**Annex 4: Quality Assessment Data Record Sheet contd.**

| Tree No. | Number of living branches (1 – 2 m) | Tree height, m | Height of first living branch, m | Leaning of tree (NL,SL, L) | Quality Class | Double Leader | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 1-4m | > 4m | |
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