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Analysis of relationship in the forest chain

– SÖDRA SKOG – MÖNSTERÅS SAW MILL – RETTENMEIER END USER

Johan J. Möller, Lennart Moberg
& Lars Wilhelmsson

EU-PROJECT LINESET – TECHNICAL NOTE TN 6.3.2

LINESET

Linking raw material characteristics with Industrial
Needs for Environmentally Sustainable and Efficient
Transformation processes QLRT-1999 - 01467

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This report presents results from the EU-financed project, QLRT – 1999 – 01467, LINESET – Linking raw material characteristics with Industrial Needs for Environmentally Sustainable and Efficient Transformation processes.

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1 Introduction

1.1 General

The basic aim of the LINESET project was to facilitate a secure and automated system for industrial use to enhance forest raw material utilisation and grant its origin. The basis for this, and the main technical objective, was to develop an industrial prototype system for automatic gathering of a detailed sawmill raw material database based on log and board individuals. The database consist of data from the forest, the log sorting station, the saw line, the automatic green sorting station for sawn timber, the handling of stacked wood and finally the automatic cross cut saw of the end manufacturer.

1.2 Project Phases

The LINESET-project can be divided into four phases. Work package six was the last of these four phases.

Phase 1
In phase 1 the needs and requirements of a traceability systems in the forestry wood chain (Wp 1.1, 1.2, 1.3) were described and a description of general guidelines for traceability systems depending on users needs, subsystems and detailed systems (Wp 1.4) were made.

Phase 2
Practical development of two systems for identification and control of the wood flow (Wp 2), designing and developing a database for establishing chains of information from forest to end user (Wp3).

Phase 3
Installation and functionality tests of two forestry information chains (Wp 5) were made. The tests were carried out with one forest chain from the Swedish forest to Södra Timbers Sawmill Mönsterås and to the German end-user Rettenmeier and the second chain was from the French forest to Escobois sawmill Castets in France.

Phase 4
The last phase was to analyse the relationships between stand description, data measured in the forest and actual properties measured at the industries of the forest raw material in the two test chains (Wp 6). And to develop simulation tools for analysing the wood flow in the whole conversion chain. The tools should be used to estimate the economic benefits of using advanced material wood flow developed in phase 2 (Wp 4, Wp 7).

1.3 Work package 6.32

In Wp 6.32 the relationship of data collected in the forest chain - Södra Forest – Mönsterås saw mill – Rettenmeier end user were compared and analyzed.

The quality of the logs/ boards depends on: where the tree has grown (latitude, altitude), how fast it has grown, age, competition with other trees, silvicultural treatment and the position of the log in the tree (Björklund & Moberg 2000, Moberg 1999, Wilhelmsson et al. 1999, 2001, Öyen 1999). In Wp 6.31 measured data of the boards at Mönsterås Sawmill have been compared with wood characteristics calculated by tree models and forest data collected by harvester and manually at Södra Skog.

Different needs for a traceability system, as described in the Wp 1.1 (Möller et al 2000), has also been tested by data collected in the Södra – Rettenmeier chain. The results from Wp 1.1 show that many of the needs for a traceability system are the same in the different countries and companies interviewed in the project.

Needs which are the same in all countries (see table 1) is automatic control (marking) of logs with special features, for example: quality, assortment, dimensions and wood from a special region. Other needs of interest for many companies are control of measurement accuracy, marking for identity and a system for traceability of timber from certified forests.

Table 1. Summary of needs of traceability systems for forest owners in the participant countries in the LINESET project. Each need found in the different countries is marked with a cross in the table.

Needs	France	Germany	Portugal	Spain	Sweden
Automatic control of quality/ assortment/ dimension and wood from special areas	X	X	X	X	X
System for development of new products/qualities		X			X
Automatic control of characteristics for log sorting and optimising	X		X		X
Traceability of timber from certified forest	X	X	X	X	X
Control of measurement accuracy	X	X	X	X	X
Date of cutting	X	X	X		X
Marking for identity	X	X	X	X	X
Automatic control of timber stock		X			X
Control of lead-time					X
System for marking of standing tree		X			

The synthesis table above was used as a list of demands for information needed when the data in the system were collected. The table was also used within Wp 6.32 to analyse if the prototype traceability system could full fill the needs found.

2 Objectives

The objectives in Work package 6.32 were to analyse the relationship of data collected in the forest chain – "Södra Skog" – "Mönsterås saw mill" – "Rettenmeier end user". The main aim was to analyse the possibilities to use tree models and harvester data for quality description of logs.

3. Materials and Methods

3.1 General

Within the project, data was collected in the chain from the stand to the end user. One of the main objectives was to test newly developed tree models for different features (knot size, basic density, heart wood). The idea was to compare calculated wood properties with measured wood properties.

The relationship between diameter and length measurement by harvester in the forest and diameter and length measurement at the sawmill was also studied. To make these analyses, we had to collect a lot of data from the harvester in connection to the crosscutting.

The study was made with logs from selected stands representing different age and site indices.

3.2 Material

3.2.1 Data collection in forest

For all marked logs a continuous measurements of diameter and length was collected and stored in the harvester computer. For each sampled tree, from which a log was selected and marked, data about the tree also was stored. Specially for the study, Timberjack modified the prd-file, created a pri-file and a stm-file according to the requested data. This provided automatic monitoring of stem data files by the harvester computer according to the forestry standard StanForD (Standard for Forestry Data and Communication).

In addition, tree data were collected manually from sample trees, sampled by the harvester.

General information collected for each stand
Identity of owner, stand identity, site index, GPS co-ordinates for the stand, altitude, latitude, stand-age, certificate code (FSC, PEFC etc.), average diameter, mixture of species, type of cutting,

Stand specific information collected by the harvester
Harvester/forest worker identity, name of apt-file, calibration date, date last reset, data saved, number of trees per species, log volume per assortment per price type, log volume per assortment m^{3}solid without bark, total volume

m^3solid without bark, number of bark parameters per tree species, bark parameters per tree species, volume type.

Tree specific information collected by the harvester
Species, type of tree (DBH/DBH average ratio), type of tree local (DBH/DBH average last 25 trees), tree age DBH, tree height, GPS co-ordinates for the tree, date/time of cutting.

Log specific information collected by the harvester
Tag number, dimensions (length cut by harvester, top diameter on bark, volume solid under bark, volume solid on bark, double bark thickness), assortment, log quality, start height in tree for the log, defects on logs (sweep, top break, rot, compression wood), time for cross-cutting.

Manually measured data collected for the manual sample trees
Age in but end, diameter first 10 growth rings, diameter first 20 growth rings, tag number of marked logs, length of the logs, total length of the tree, dbh and crown height. For 6 trees per tree species in each stand, 3 discs of about 5 cm thickness, were cut. For these discs an analysis of basic density, age, heart wood and late wood were made. The age in breast height and bark thickness of each log were also measured on these trees.

3.2.2 Stand description

The material from five stands harvested within the Swedish – German chain is described in table 2-3. The total volume harvested in the five stands was 10.528 m^3solid under bark (m^3s.u.b.) Four of the stands where dominated by Norway spruce while in the fifth stand (Dubberås2) the standing volume was almost evenly distributed between Scots pine and Norway spruce. The ages of the stands were around 90-100 years, the Scots pines were, on average, around 10 years older than the Norway spruces.

Table 2. Description of five stands cut in Småland in the south east of Sweden in the LINESET project. Norway spruce and Scots pine.

Stand	Site index	Altitude	Latitude	Volume pine	Volume spruce	Volume hardwood	Average volume /stem pine	Average volumel spruce
	(index)	(m)	63.3	(m^3s.u.b.)	(m^3s.u.b.)	(m^3s.u.b.)	(m^3s.u.b.)	(m^3s.u.b.)
Dubberås1	G26	175	63.3	43.32	351.47	0.66	0.666	0.1537
Dubberås2	T20	175	63.3	87.27	186.18	6.87	0.586	0.189
Hjortbäck021	G30 (26-32)	190	63.3	23.48	824.57	22.74	0.452	0.391
Flackemåla031	G27 (22-30)	190	63.3	93.82	577.95	9.94	0.745	0.436
Flackemåla32	G22-G34	190	63.3	763.69	2149.98	122.32	0.872	0.368

Table 3. Description of five stands cut in Småland in the south east of Sweden in the LINESET project. Norway spruce and Scots pine.

Stand	Stand age	Age pine	Age spruce	Crown height pine	Crown height spruce	Dbh pine	DBH spruce
	(year)	(year)	(year)	(m)	(m)	(cm)	(cm)
Dubberås 11	92.5	86.5	96.9	980.2	563.7	344.9	305.3
Dubberås 12	107.0	114.8	78.3	1103.0	326.0	290.6	165.1
Hjortbäck 21	97.2		97.2		614.5	247.8	220.4
Flackemåla 31	83.8	95.5	81.2	1325.0	569.0	373.2	254.2
Flackemåla 32	98.0	105.9	91.3	1257.1	649.0	337.65	211.3

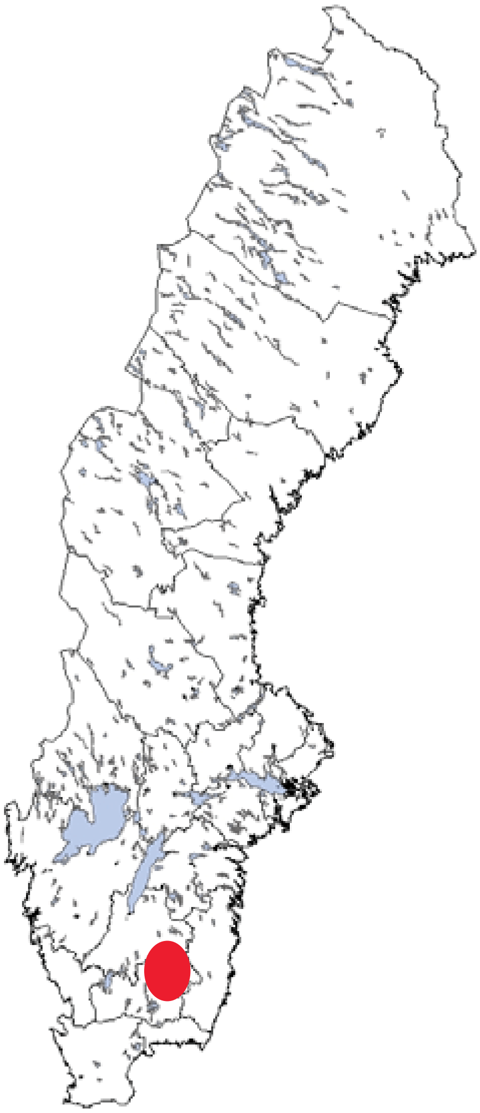
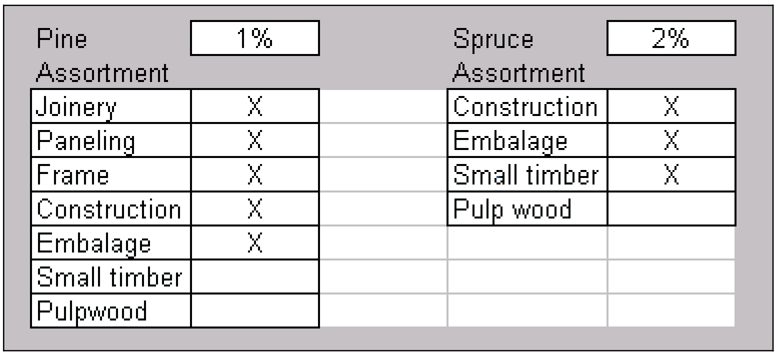


Figure 1. Map over Sweden with the area (black dot) where the 5 stands in the LINESET study were cut. Södra Skog (Upvidinge sbo, central Småland). The stands were situated approximately 75 km west of Mönsterås sawmill.

3.2.3 Marking in forest

The harvester head was equipped with a transponder applicator for automatic marking with a transponder in the surface of the log top end. The software in the harvester was also adapted for the study. A function was developed to make it possible for the operator to indicate in the harvester computer which logs (assortment, dimension) should be marked by a transponder.

In the study, all spruce logs with top diameter 176-220 mm and length 435-549 cm (435, 465, 495 and 525 cm) were marked. These logs were used to saw the boards for Rettenmeier at Mönsterås sawmill (50*125 mm and 50*150 mm). An additional random sampling was made among trees that contained a log directed to Mönsterås sawmill (saw timber larger than 160 mm in top diameter, u.b.). For these randomly selected trees all logs with a top diameter above 160 mm were marked. The sampling frequency varied from 10% to 50% of the trees.



Pine 1%

Assortment	
Joinery	X
Paneling	X
Frame	X
Construction	X
Embalage	X
Small timber	
Pulpwood	

Spruce 2%

Assortment	
Construction	X
Embalage	X
Small timber	X
Pulp wood	

Figure 2. Example of a matrix in the harvester computer for selection of sample tree frequency and assortments to be marked by a transponder.

Figure 2 shows an example of the function in the harvester computer for random marking of trees. All logs that belong to the selected assortments were marked with a transponder for all selected trees. The example in figure 2 shows that 1% of the pine trees were selected and 2% of the spruce trees. In the pine trees all logs that belong to the marked assortments (Joinery, Panelling, Frame, Construction and Embalage) were marked. These were the assortments direct to Mönsterås sawmill. Small timber and pulpwood were not marked.

Table 4. Description of transponder logs cut in Småland in the south east of Sweden in the LINESET project. Norway spruce and Scots pine.

Stand	Manuel sample trees pine	Manuel sample trees spruce	Marked trees pine	Marked trees spruce	Transponders pine	Transponders spruce
	(no)	(no)	(no)	(no)	(no)	(no)
Dubberås11	17	19	53	343	115	721
Dubberås12	22	6	73	146	153	264
Hjortbäck 21	0	23	22	610	40	994
Flackemåla 31	2	9	46	548	122	737
Flackemåla 32	24	28	216	1962	604	2495
Total	65	85	410	3609	1034	5211

Table 4 shows the number of sample trees and logs selected for marking by the harvester. The column “Manual sample” present the trees where the manual control has been made. Number of transponders is the number of logs marked and number of marked trees is the number of different trees that the logs were cut from, in total 410 pines and 3609 spruces.

3.3 Methods

3.3.1 Data sources and factors analysed

The factors, which have been analysed in the wp 6.32, are presented in table 5. The measuring places where data have been collected are also shown in the table.

Table 5. Example of factors for studying in the forestry wood chain and links in the chain where data were collected in the LINESET project.

Place in wood chain		Factors analysed					
		Log length (cm)	Log diameter (mm)	Lead time (seconds)	Basic density (kg/m^{3}s.u.b.)	Heartwood (mm)	Knot size (mm)
Forest	Owner/ inventory				X (model)	X (model)	X (model)
	Harvester	X	X	X	X (model)	X (model)	X (model)
	Forwarder						
	Transport						
Sawmill	Log sorting station	X	X	X			
	Saw log intake	X	X	X			
	Green sorting	X					X
	Stacked package						
	Kiln dry						
	Dry sorter	X		X			
End User							
	Production line	X		X			
Manual analysis							
	Special measuring				X	X	

3.3.2 Analyses of measurements

Lead-time control

The time of cutting for each log was measured and collected in the harvester computer. Similar time measurements were carried out as: the time when the log passed through the timber sorting station, the saw log intake, the green sorting station, the dry sorter and finally the time when the boards were processed by the end user. These times were used for analysing the lead-time of the wood chain in the LINESET project. The time from cutting to end user has been split into 4 parts: cutting to timber sorting station, timber sorting station to sawing, sawing to dry sorting station and dry sorting station to end-use by Rettenmeier.

Diameter measurements

The diameter figures measured by the harvester in the forest (Timberjack 762 B harvester head), measured at the timber sorting station (Rema 9015 3D-scanner) and at the saw log intake (Rema 9015 3D-scanner) have been compared. The figures have been compared under bark. For the harvester and for the timber sorting station the logs were measured on bark and a reduction of the bark thickness was made, calculated by a bark function (VMR). At the saw log intake the diameter was measured directly under bark.

Length measurements

The length figures measured by the harvester in the forest (Timberjack 762 B harvester head), measured at the timber sorting station (Rema 9015 3D-scanner), at the saw log intake (Rema 9015 3D-scanner), at the green sorting station (Finscan measuring) and at the dry sorting (Rema measuring) have been compared. In the analysis the Finscan figures have been chosen as reference figures.

3.3.3 Wood properties

In this work package, a model predicting maximum knot size of individual logs (Moberg,1999) have been tested in comparison with knot size measurements by a Finscan equipment. Heartwood diameter, basic density and latewood content have been predicted by models for log cross-sections (Wilhelmsson et al. 2002) and validated by laboratory measurements on wood samples.

Measurements of knot quality and size

The knot quality of the Norway spruce boards for Rettenmeier have been determined according to Nordic Wood quality regulation for sawn wood (see table 6, Nordiskt Trä 1994). At the Mönsterås green sorting station the board quality was determined according to the knot diameter and type measured by the Finscan system. Other defects like vane, shake, twist, pitch pockets, mechanical damages, etc. were not taken into account.

Table 6. Maximum knot sizes accepted for quality A-D according to Nordic Wood, Norway spruce 50*125 mm and 50*150 mm.

Quality class	Maximum sound knot		Maximum dead knot		Maximum number per 1 meter	
	Board side	Edge	Board side	Edge	Board side	Edge
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
A 1-3	25	20	17	14	3	1
A 4	35	30	24	21	4	2
B	50	40	35	28	5	3
C	65	50	65	50	6	4
D	No limits	No limits	No limits	No limits	No limits	No limits

Predicting maximum knot size

For the logs which where cut for Rettenmeier (Norway spruce 176-220 mm top diameter under bark), the maximum internal knot size for each one-meter section has been calculated by using a prediction model developed by Moberg (1999). $KDmax = \mathrm{f}(Tsum, SI, AGE, DBH, Ht, CL, Hk)$ where the variable explanations are given in table 7 and the complete model design is given in the referred publication.

Table 7. Explanation of independent variables used in the function to predict maximum knot size diameter.

Symbol	Description
Intra tree variables	
Kdmax	knot diameter maximum at the sound/ loose knot boarder.
Hk	Height above the ground (m) for whorl k
Tree-leval variables	
CL	Crown length (Ht - Height to lowest live branch), average height per stand and species.
DBH	Diameter in breast height outside bark (measured 1,2 meter over bunch).
Ht	Total tree height, function of DBH per stand.
Stand-level variables	
Tsum	Temperature sum (above a temperature of 5 degrees C), calculated as a function of altitude and latitude (Morén & Perttu, 1994)
SI	Site Index (m). Heght of dominant trees at 100 years age (breast heght) (Hägglund, 1981)
Age	Average total age per stand and species.

Temperature sum and SI were determined for each stand before cutting. Age, CL and Ht were calculated from measured sample trees. DBH and Hk were measured by the harvester.

The measured (Finscan) average maximum knot size of the boards per one-meter section was defined as the sum of largest knot per each 1 meter length divided by number of knots per log. This measured variable was compared with predicted maximum knot sizes (KD_{max}) .

As defects detected by Finscan (e.g. spike knots) were not automatically separated from knot size measurements by the system, the biggest knot detected on each side of the boards were regarded as outliers and consequently excluded from the dataset when maximum knot sizes were determined.

Measurements of wood properties in disc wood samples

Discs (5 cm thick) were cut from log ends at three different heights in 6 sample trees per species from each of 5 stands dominated by spruce and each of 3 stands including pine. One disc was cut at the bottom of the second log, one at the bottom of the next or the second next log (depending on tree size) and one at the bottom of the top log of the tree (pulpwood). All discs were sent for laboratory measurements at the Department of Forest Products and Markets, SLU. The number and width of annual rings including earlywood/latewood demarcation was measured (in two directions along a cross-section line) by a WinDendro© image analysis followed by a manual demarcation (fresh wood) of the heartwood diameter, including heartwood reagent when necessary. Finally the fresh volume of each disc was measured, followed by a dry weight measurement to determine the basic density.

Predicted number of annual rings at cross-sections

The number of annual rings at height h (AGE_h) was predicted for each disc using equation (1) from Wilhelmsson (2001):

AGE_h=f(d_h, d_{bh}, AGE_{bh})

Predicted heartwood diameter

The heartwood diameter was predicted for each disc using heartwood functions developed by Wilhelmsson et al. (2002; S4 (Spruce) and P4, (Pine)).

Heartwood dia = f(d_h, AGE_h)

Table 8. Explanation of independent variables used in the heartwood functions to predict heartwood diameter.

Symbol	Description
Hearwood dia	Diameter for heartwood for a cross-section at height h in the tree
d_h	Diameter under bark (mm) at cross-section (heigth h)
AGE_h	Number of annual rings at cross-section (height h)

The predicted and measured heart wood diameters were compared.

Basic density

Discs including visible knots and/or considerable amounts of reaction wood, subjectively detected from disc surface images and objectively detected by comparisons of the two opposite measurements of latewood content (without taking density into account), were excluded from the analysis resulting in 43 pine discs (4 of 54 had indications of reaction wood and 8 of 54 had visible knots) and only 29 remaining spruce discs (28 of 81 had knots, and 37 of 81 had clear indications of a considerable amount of reaction wood).

Basic density, spruce = f(Tsum, d_h, *AGEh*)

Basic density, pine = f(DBH, AGEbh, Tsum, d_h, *AGEh*)

Table 9. Explanation of independent variables used in the function to predict basic density.

Symbol	Description
Intra tree variables	
Basic density	Basic density for a specific cross-section in the tree (kg/m3).
AGEh	Number of annual rings at the cross-section (height h).
Dh	Diameter under bark (mm) at heigth h.
Tree-leval variables	
DBH	Diameter in breast height outside bark (measured 1.2 meter above but end of but logp).
AGEbh	Age at DBH .
Stand-level variables	
Tsum	Temperature sum (above a temperature of 5 degrees C), calculated as a function of altitude and latitude (Morén & Perttu, 1994) including a correction of +100 day-degrees for local continental climate conditions.

Latewood content

Average latewood content of a cross-section was predicted by models S2 (Spruce) and P2 (Pine) from Wilhelmsson et al. (2002). These models predict latewood according to the STFI "20-50" definition (Olsson et al. 1998), while all measurements in the present study were carried out with a WinDendro instrument using a 50%-greyscale threshold expected to result in correlated, but generally higher latewood values.

4. Results

4.1 Lead-time control

The results in figure 3 show the total time, from harvesting (Södra Skog) , to the end user (Rettenmeier).

In the study the average lead time from cutting to end-user was 88 days, with a variation from 66 to 218 days.

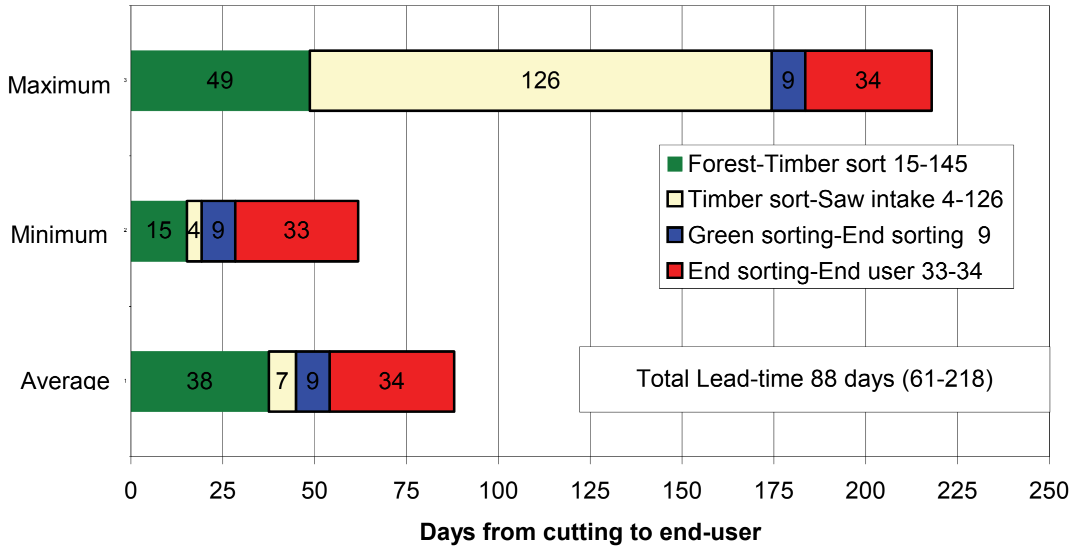


Figure 3. Lead-time from cutting at Södra Skog to end-user Rettenmeier via Mönsterås sawmill. Norway spruce top-diameter 176-220 mm u.b.

4.2 Measuring accuracy

4.2.1 Diameter

The results from comparisons of the diameter measurements (figure 4) showed that the average difference between harvester and timber sorting station was 0.1 mm and the standard deviation was 6.4 mm. Harvester diameter measurements of pine logs were on average 1.8 mm larger under bark and 5.9 mm larger over bark than the corresponding measurements at the timber sorting station. Similar comparisons (diameter from harvester vs.timber sorting station) of spruce logs were 0.25 mm smaller under bark and 1.4 mm larger over bark. The standard deviations for pine were 7.3 mm over bark and 7.9 mm under bark. The similar standard deviations for spruce were 5.4 mm over bark and 6.0 mm under bark.

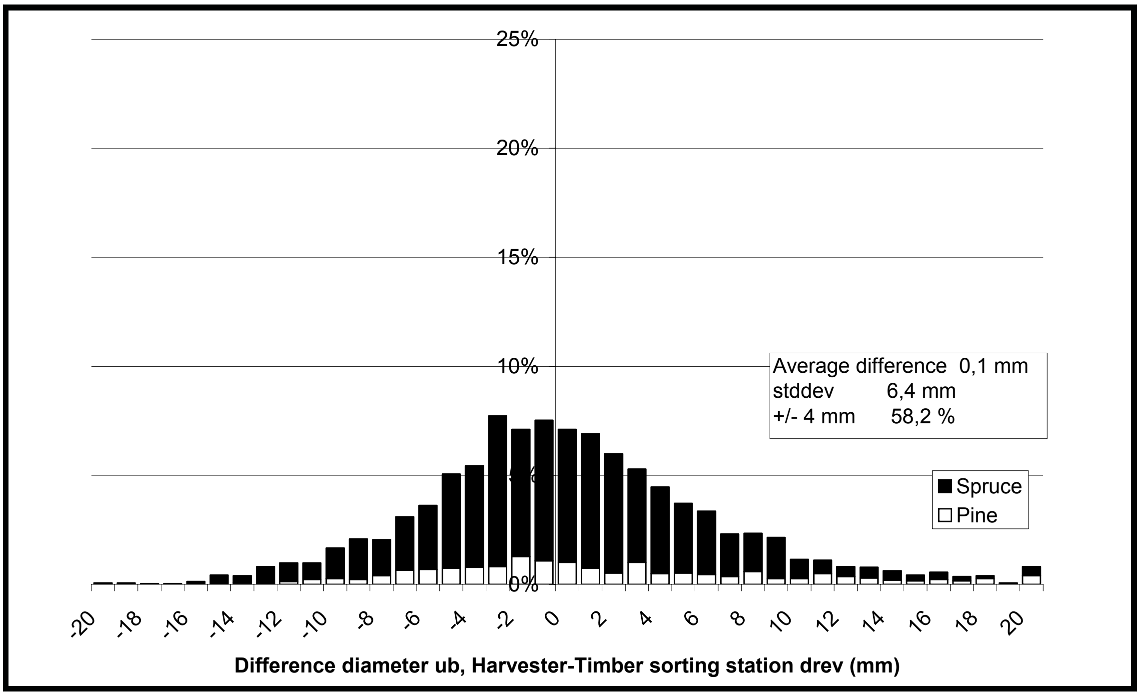


Figure 4. Diameter difference between harvester and timber sorting station under bark. Measured in forest by Timberjack 762B harvester head and at Mönsterås sawmill by Rema 9015-3D scanner. The total number of logs were 496 of Scots pine and 2572 of Norway spruce.

The average difference of the diameter under bark was -1.0 mm between timber sorting station and the saw log intake (see figure 5) and the stddev 5.1 mm.

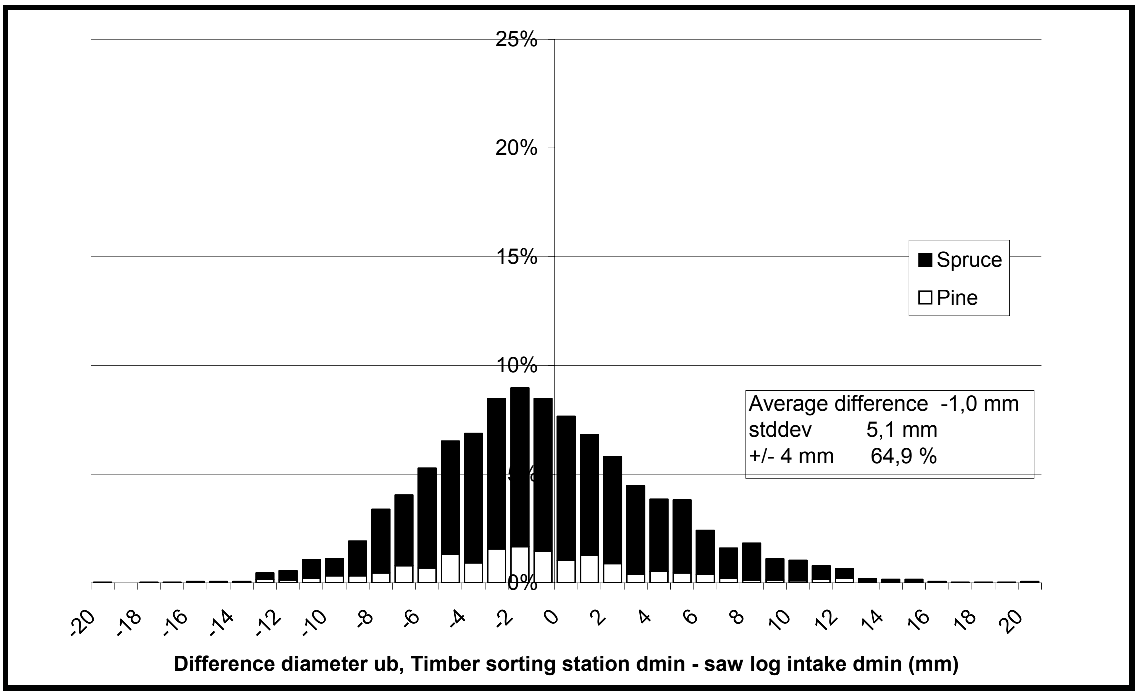


Figure 5. Diameter difference between timber sorting station and saw log intake under bark at Mönsterås sawmill. Measured at timber sorting station by Rema 9015-3D scanner over bark and at saw log intake under bark. The total number of logs were 496 of Scots pine and 2572 of Norway spruce.

4.2.2 Length

The results from comparisons of the length differences (figures 6-8) showed that the average difference between harvester and green sorting station was 0.6 cm and that the standard deviation was 4.2 cm. On average, the harvester length measurements for pine were 1.9 cm longer than the green sorting station and for spruce 0.65 cm longer.

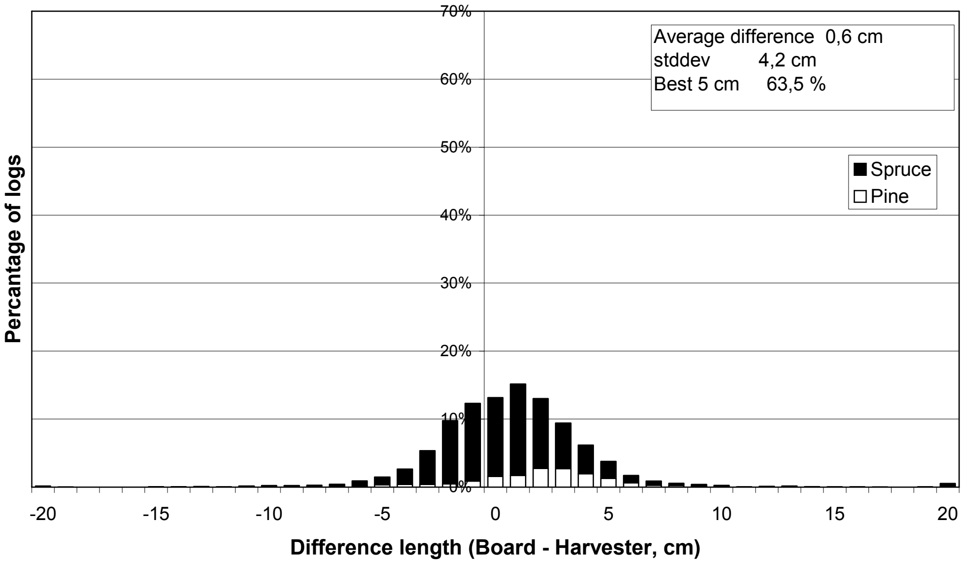


Figure 6. Length difference between harvester and green sorting station. Measured in forest by Timberjack 762B harvester head and at Mönsterås sawmill by Finscan. Total numbers: 306 boards of Scots pine and 2179 boards of Norway spruce.

63.5 % of the harvested logs were within the "best 5". This is a distribution that describes the percentage of logs within +/- 2 cm from the average length. For the timber sorting station 98.8% of the logs were within the "best 5" and for the saw log intake 99.6% of the logs were within the "best 5".

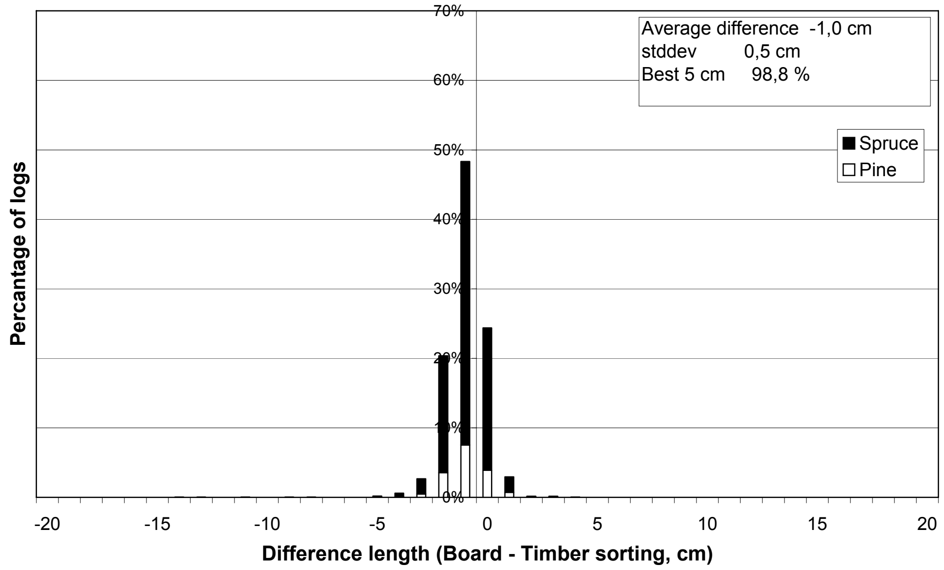


Figure 7. Length difference between timber sorting station and green sorting station at Mönsterås sawmill. Measured at timber sorting station by Rema 9015 3D-scanner and at green sorting station by Finscan. Total numbers: 306 boards of Scots pine and 2179 boards of Norway spruce.

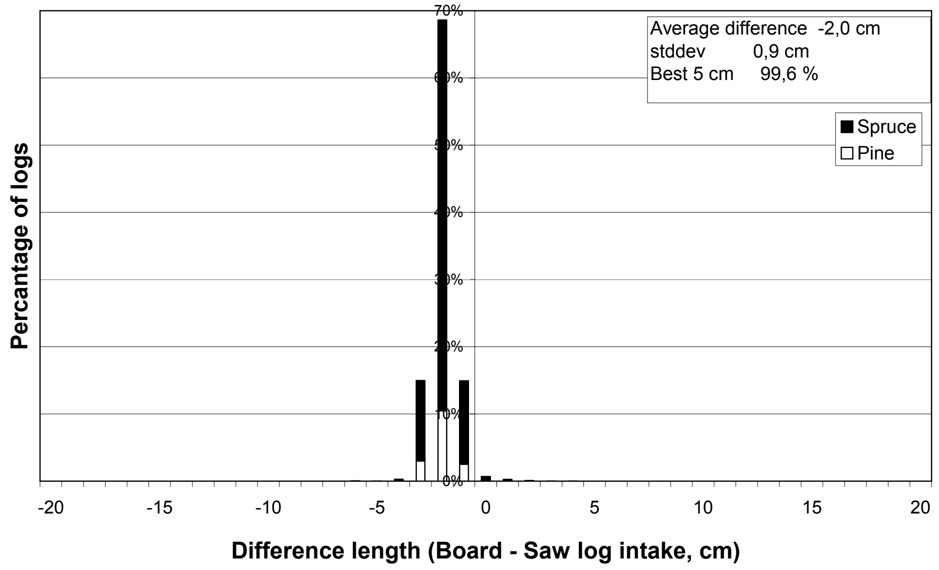


Figure 8. Length difference between saw log intake and green sorting station at Mönsterås sawmill. Measured at saw log intake by Rema 9015 3D-scanner and at green sorting station by Finscan. Total numbers: 306 boards of Scots pine and 2179 boards of Norway spruce.

4.3 Wood properties

4.3.1 Maximum knot size

The average predicted knot size was 26.4 m while the average knot size measured by Finscan at Mönsterås sawmill was 25.8 mm. The stddev for the models value was 4.7 mm and for the measuring 5.0 mm. Stand 11 had the largest measured knots, it also had the largest predicted knot size using the models. The stand which had the smallest knots, stand 32, also had the smallest predicted size (see figure 9).

Table 10. Maximum knot diameter measured by Finscan at Mönsterås sawmill. Sawn wood dimension 50*150 mm and 50*125 mm and maximum knot diameter predicted with models. Norway spruce logs 176-210 mm u.b. in top. Average of maximum knot diameter per each 1 meter of each log.

Stand	Mean Finscan	StdDev Finscan	Max Finscan	Min Finscan	Average Model	StdDev Model	Max Model	Min Model	Number of logs
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(number)
Dubberås11	27.8	5.7	43.4	18.2	28.3	6.0	41.0	18.7	68
Dubberås12	27.4	4.3	41.8	18.4	26.4	5.9	39.4	19.9	44
Hjortbäck 21	26.1	4.9	40.4	14.6	26.8	4.8	40.8	19.7	270
Flackemåla 31	27.2	5.2	46.8	13.6	26.8	4.6	38.8	19.0	224
Flackemåla 32	25.1	4.7	43.8	14.0	26.0	4.4	41.6	18.2	782
Total	25.8	5.0	46.8	13.6	26.4	4.7	41.6	18.2	1388

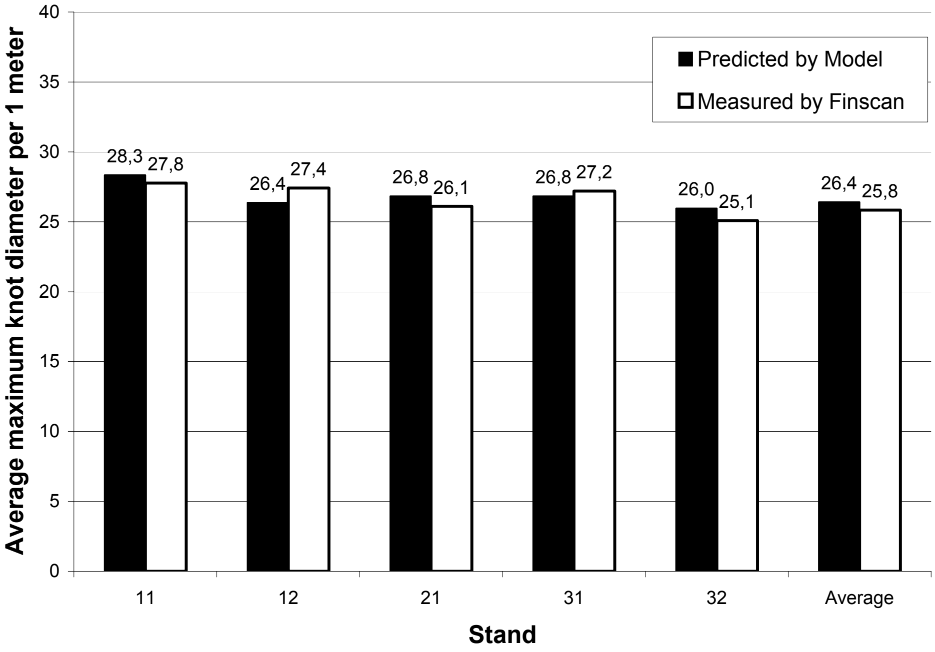


Figure 9. Average maximum knot diameter per log. Predicted and measured on the boards by Finscan at Mönsterås Sawmill. Average value per stand. Norway spruce log diameter 176-220 mm u.b. in top.

Figure 10 shows the correlation for maximum knot diameter between prediction and control measuring for spruce logs in class 176-200 mm in top-diameter. The result shows that the average value is similar for logs from small trees (DBH >350 mm). For logs from bigger trees (top logs) the model's knot size diameters are much bigger.

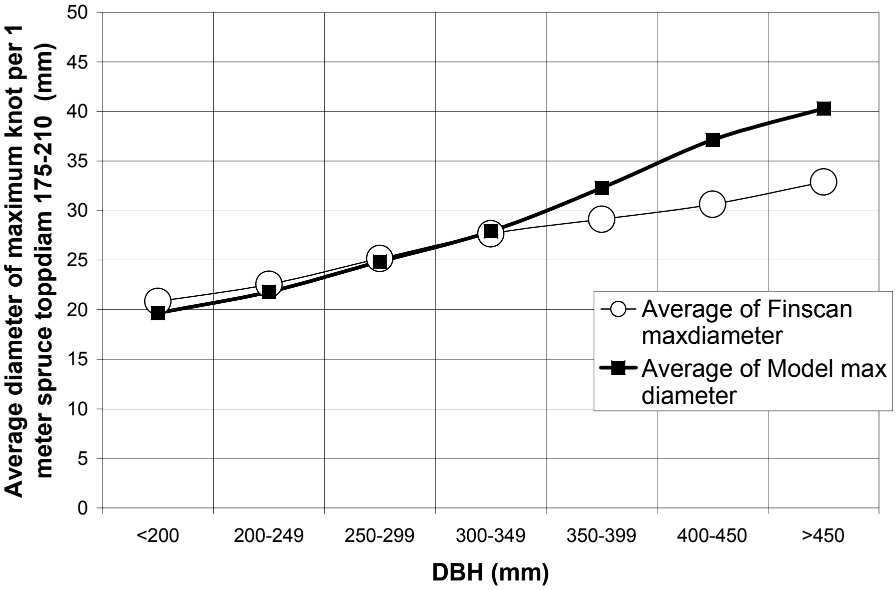


Figure 10. Correlation of predicted average maximum knot diameter per log and measured on the boards by Finscan at Mönsterås Sawmill. Average value per breast height diameter classes of the trees. Norway spruce log diameter 176-220 mm u.b. in top.

The average knot sizes for all spruce logs with top-diameter 176-220 are illustrated in figure 11. The figure shows a large spread between model and measured value. The R^2 -value indicates the proportion of variation that can be explained by the model. The R^2 value for spruce varied between 0.3-0.5 for the different stands and the average was 0.37.

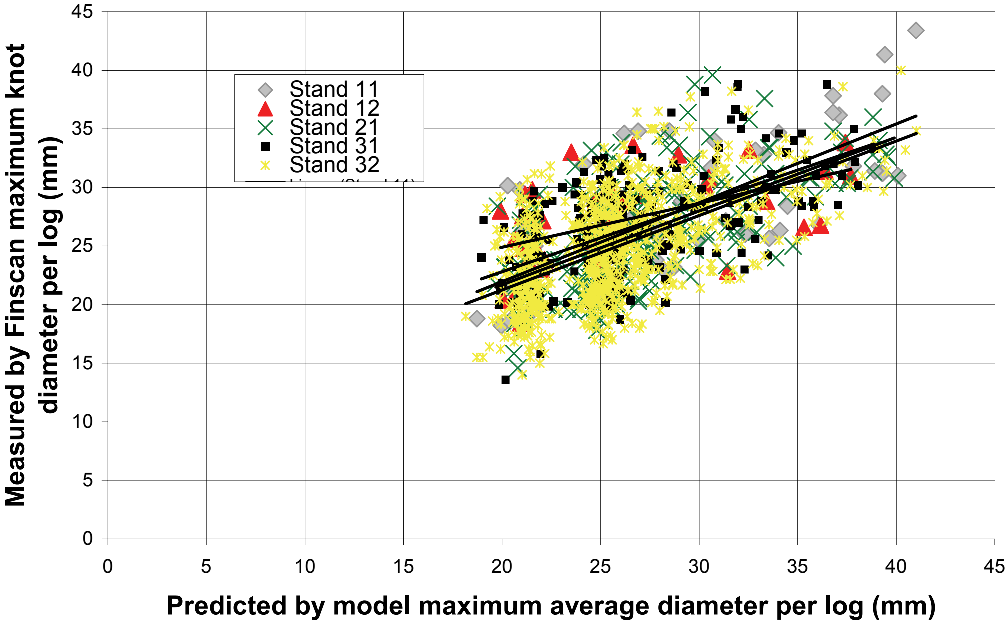


Figure 11. Correlation of predicted average maximum knot diameter per log and measured on the boards by Finscan at Mönsterås Sawmill. Norway spruce log diameter 176-220 mm u.b. in top.

The general relationship between measured and predicted knot size does not vary between the stands (table 11). The result of the predictive models are, in other words, quite similar in all stands.

4.3.2 Knot quality according to Nordic wood

The quality distribution, according to Nordic Wood, of logs from different tree classes is shown in figure 12. The results show that the proportion of quality A logs was highest in small trees (79%, DBH<200 mm) and smallest in large trees (4%, DBH>450 mm).

The results also shows that the stand with the smallest predicted knot diameter (stand 32) gave the highest share of quality A (46%) (see figure 9 and 13). Stands 11 and 12 gave the lowest share of quality A. Stand 11 was the stand with the highest predicted knot diameter. Stand 12 was a stand with spruce that has grown under pine as a second generation. The stand had relatively few stems per hectare.

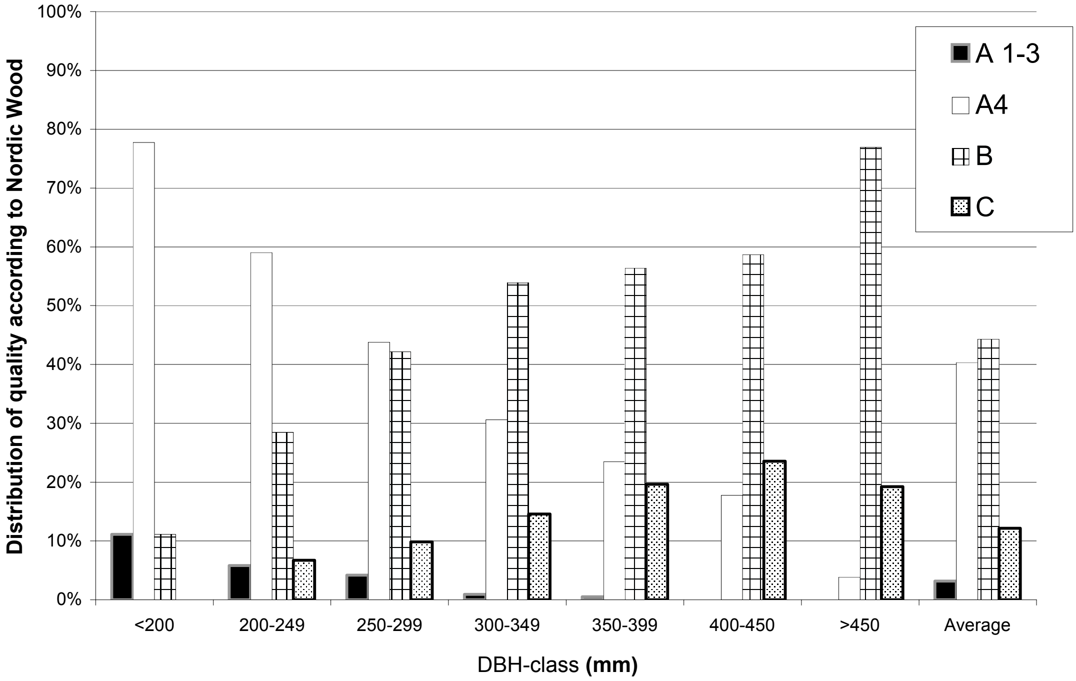


Figure 12. Distribution of Nordic wood knot quality of the boards from tree classes with different diameter in breast height. Spruce log with top diameter 176-220 mm u.b.

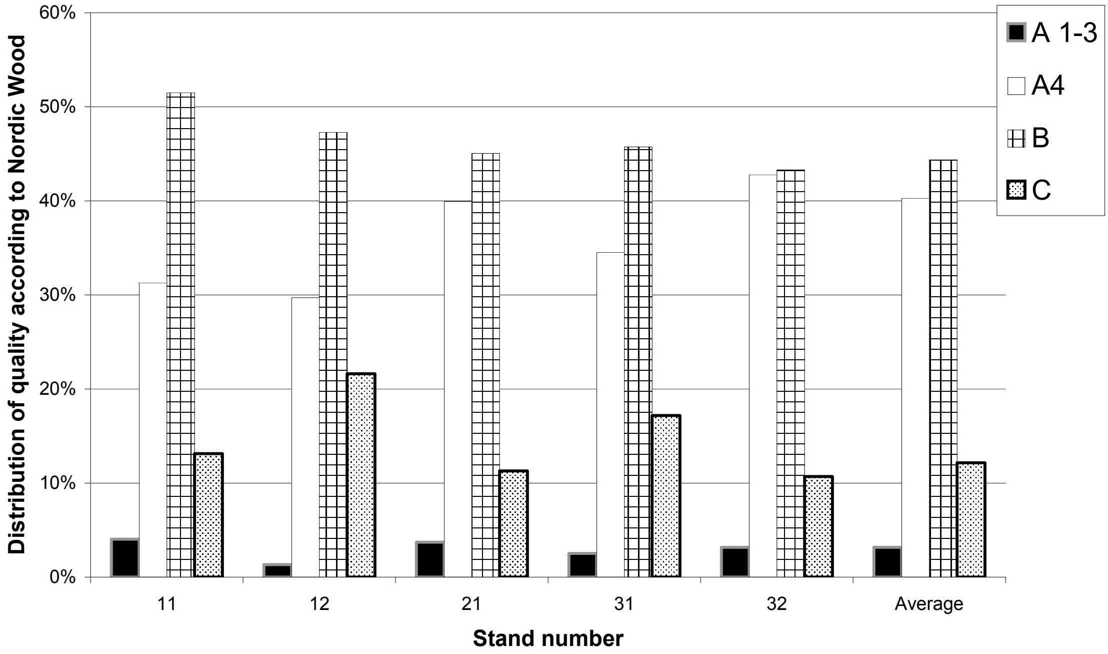


Figure 13. Distribution of Nordic wood knot quality of the boards from different stands. Spruce log with top diameter 176-220 mm u.b..

4.3.4 Number of annual rings

When tree ages was based on stand averages of breast height (one per stand and species) the prediction error was 10.4 rings, + 5 rings bias for pine and 12.6, + 6 rings bias for spruce. The corresponding figures when individual tree age was used as a basis for predictions were 6.3, + 7 rings for pine and 7.5, + 5 rings bias for spruce. (See discussion).

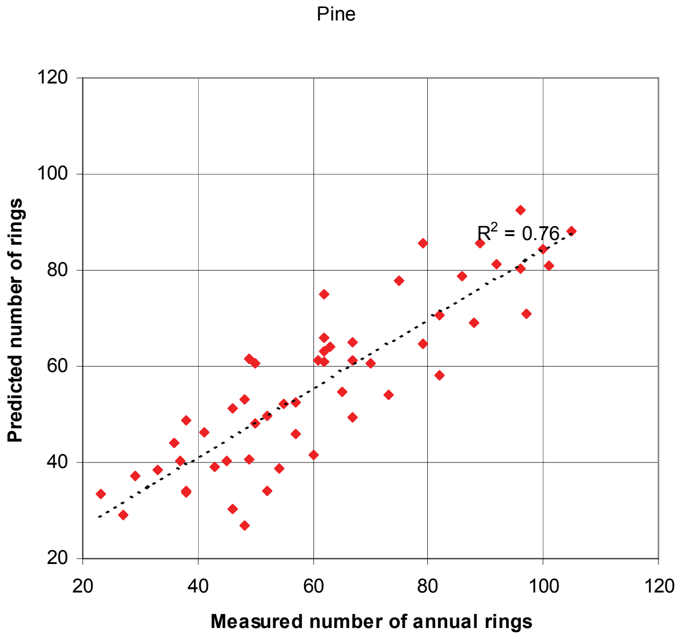


Figure 14. Predicted versus measured number of annual rings (n.o.r) in Scots pine sample discs. Observe that predictions of the number of rings in cross-sections are all based on one average tree age per stand and equation (1) from Wilhelmsson (2001).

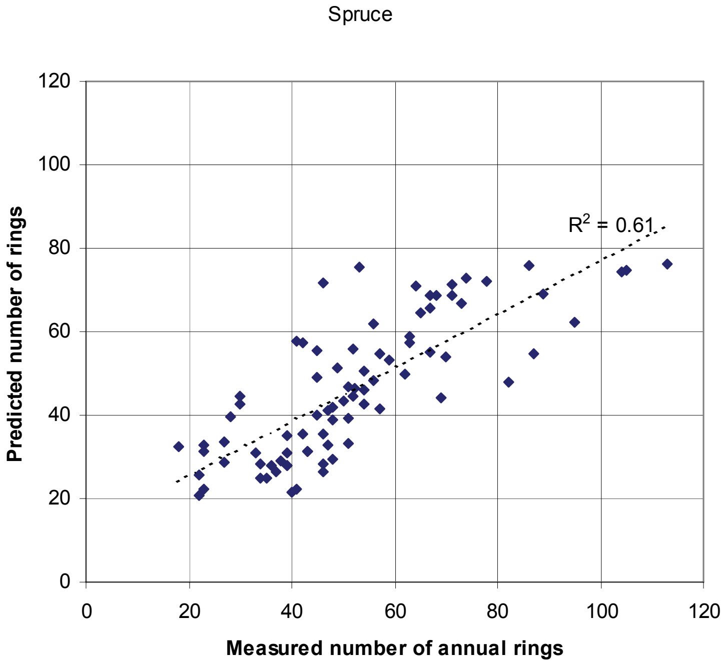


Figure 15. Predicted versus measured number of annual rings (n.o.r) in Norway spruce sample discs. Observe that predictions of the number of rings in cross-sections are all based on one average tree age per stand and equation (1) from Wilhelmsson (2001).

4.3.5 Heartwood, basic density and latewood content

The results from predicting heartwood, basic density and latewood by diameter and predicted or measured number of annual rings are compared to measured (or assessed) property values in table 11-12. Observe that the determinations of heartwood and latewood in this study are different from the methods used for development of the models used for predictions. The basic density values of spruce were severely affected by reaction wood and also to a considerable extent by knots. (Se discussion).

Table 11. Predicted property values of Scots pine disc samples, based on measured diameter and predicted (alt 1.)and measured (alt 2.) number of annual rings versus measured (assessed) values.

Scots Pine	**Heartwood Diameter (mm)**		**Basic density (kg/ m^3)**		**Latewood Content (%)**	
Measured averages	101		406.7		32.6	
Standard deviation	52		26.4		3.3	
Min – max values	17- 259		355-470		25.7-41.8	
Number of rings	Pred	Meas	Pred	Meas	Pred	Meas
Predicted average	108	110	407.6	408.9	24.1[1]	24.4[1]
Bias	-7	-9	+0.9	-2.2	8.5 (0)	8.2 (0).
Predicted vs. measured values, regression R^2	0.88	0.93	0.52	0.53	0.42	0.57
RMSE (bias excluded)	18	14	18.6	18.3	2.6	1.6

1) Predicted ”STFI 20 -50%” *RMSE=Root Mean Square Error*

Table 12. Validation of predicted property values of Norway spruce disc samples, based on measured diameter and predicted (Pred.) measured (alt 2.) number of annual rings versus measured (assessed) values.

Norway spruce	**Heartwood Diameter (mm)**		**Basic density (kg/ m³)**		**Latewood Content (%)**	
Measured averages	125		415.7		33.0	
Standard deviation	67		27.8		3.3	
Min – max values	9- 307		376-481		23.9-39.0	
Number of rings	Pred	Meas	Pred	Meas	Pred	Meas
Predicted average	137	141	398.0	407.2	22.4^1	23.4^1
Bias	-12	-16	-17.7	-8.5	10.6 (0)	9.6 (0)
Predicted vs. measured values, regression R²	0.89	0.91	0.25	0.19	0.26	0.50
RMSE (bias excluded)	22	20	24.5	25.5	2.9	1.6

1)” Predicted “STFI 20 50&”” *RMSE=Root Mean Square Error*

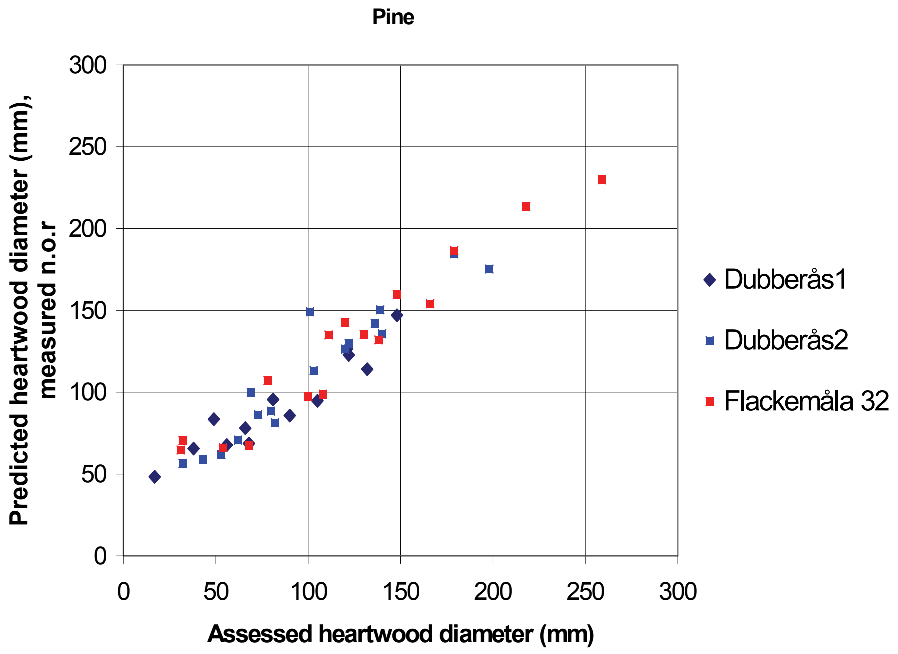


Figure 16. Heartwood diameter of Scots pine sample discs presented by single stands. Predicted values (Model P4, Wilhelmsson et al. 2002) were based on disc diameter and measured number of annual rings (n.o.r) vs. assessed disc values. Log top diameters from 120 to 400 mm u.b. R²-values (predicted vs. assessed) varies from 0.88 to 0.95 between the stands.

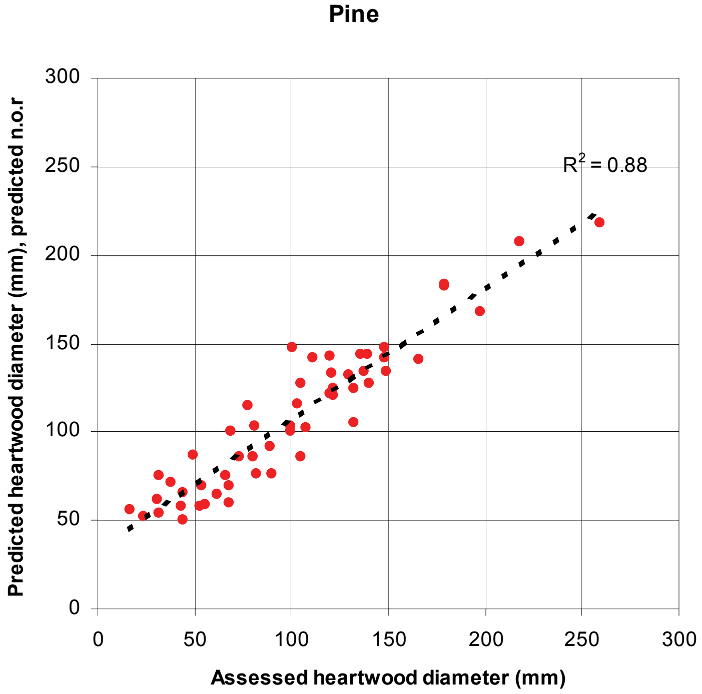


Figure 17. Predicted vs assessed heartwood diameter of Scots pine sample discs (n=54). Predicted values (Model P4, Wilhelmsson et al. 2002) were based on disc diameter and predicted number of annual rings (n.o.r. Annual ring numbers predicted by single stand averages for breast height and model 1 (Wilhelmsson, 2001). Log top diameters from 120 to 400 mm u.b.

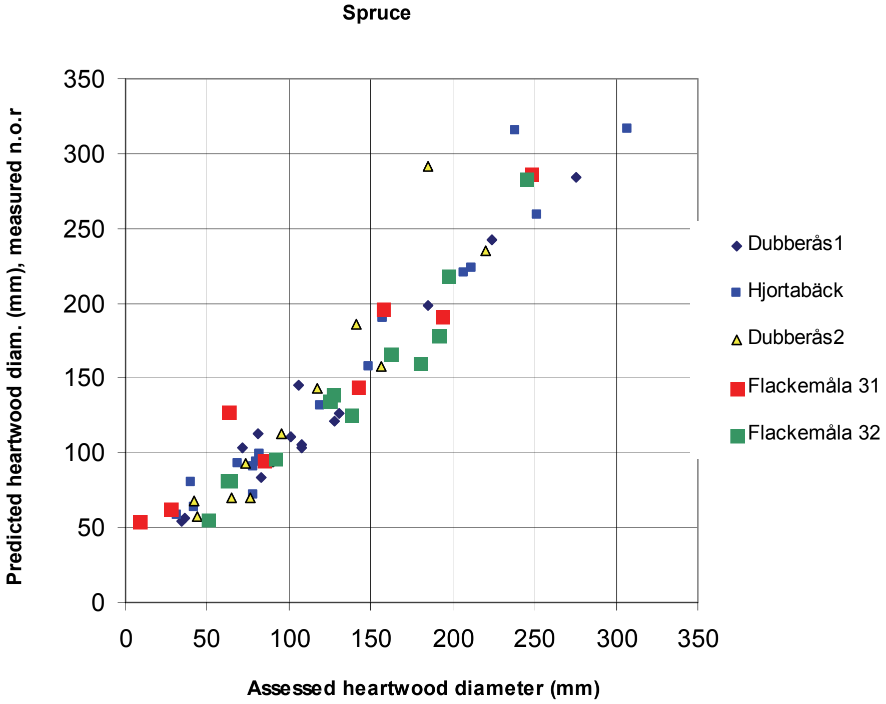


Figure 18. Predicted vs. assessed heartwood diameter of Norway spruce sample discs presented by single stands. Predicted values based on disc diameter (Model S4, Wilhelmsson et al. 2002) and measured number of annual rings (n.o.r). Log top diameters from 120 to 400 mm.

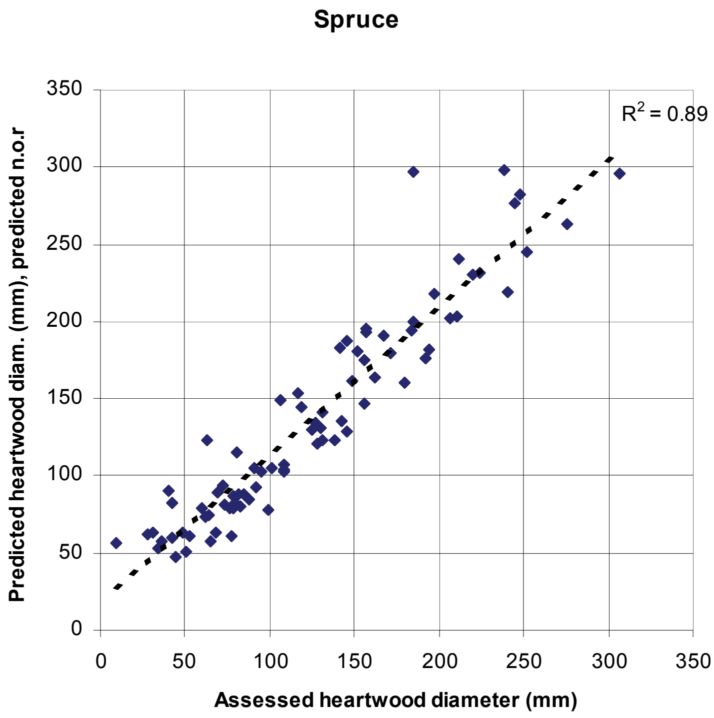


Figure 19. Predicted vs. assessed heartwood diameter of Norway spruce sample discs. Predicted values (Model S4, Wilhelmsson et al. 2002) based on disc diameter and predicted number of annual rings (n.o.r). Log top diameters from 120 to 400 mm

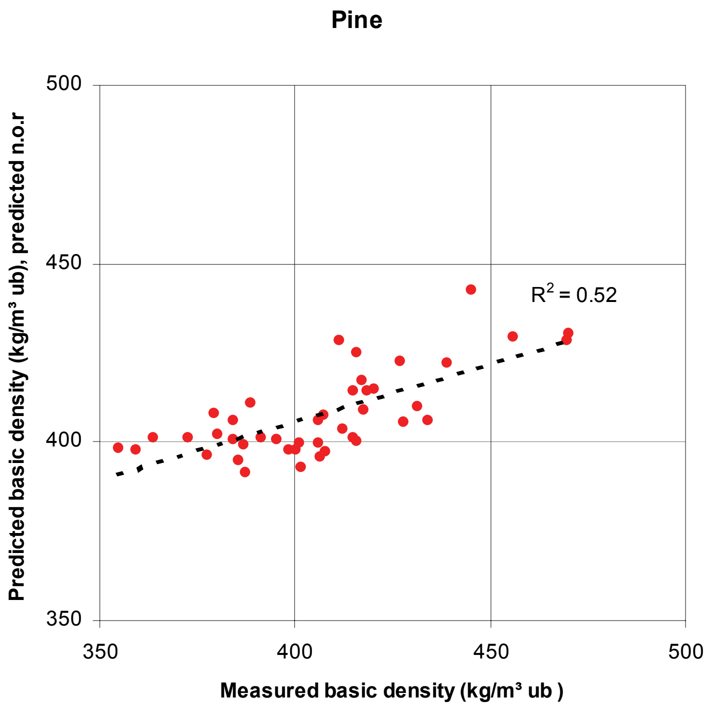


Figure 20. Predicted vs. measured basic density of Scots pine sample discs. Predicted values (Model P1, Wilhelmsson et al. 2002) based on disc diameter and predicted number of annual rings (n.o.r). Log diameters from 120 to 400 mm u.b.

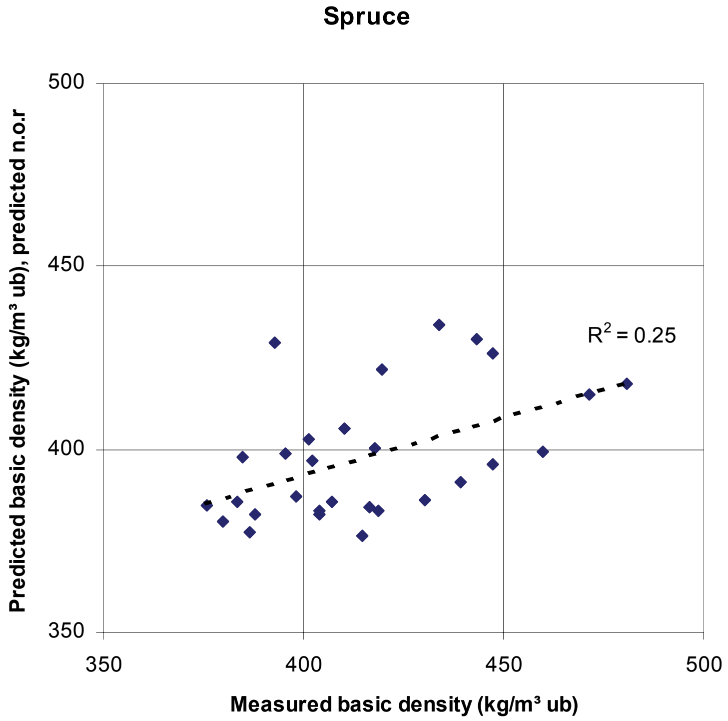


Figure 21. Predicted vs. measured basic density of Norway spruce discs. Predicted values (Model S1, Wilhelmsson et al. 2002) based on disc diameter and predicted number of annual rings (n.o.r). Log diameters from 120 to 400 mm u.b.

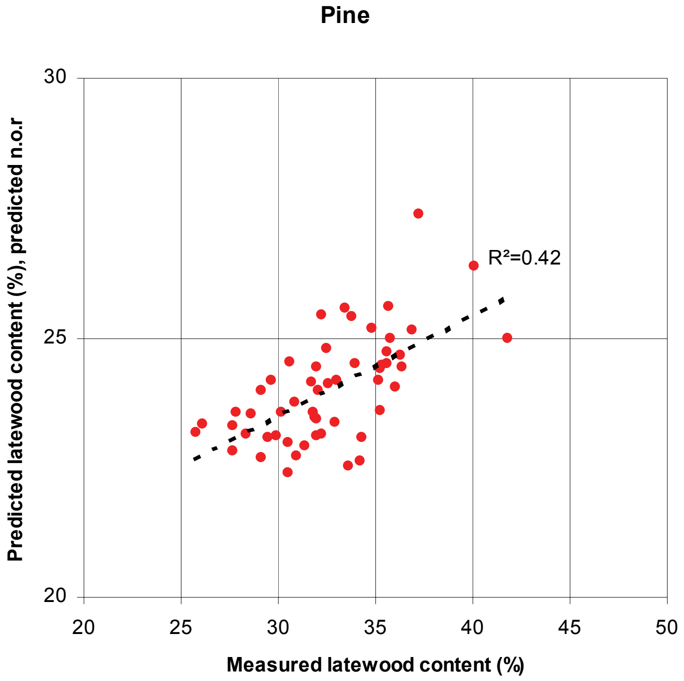


Figure 22. Predicted vs. measured latewood content of Scots pine sample discs (n=50). Predicted values (latewood according to STFI “20-50%”) based on diameter (Model P4, Wilhelmsson et al. 2002) and predicted number of *annual rings (n.o.r). Measured latewood content by WinDendro “50%”. Log top diameters from 120 to 400 mm u.b.*

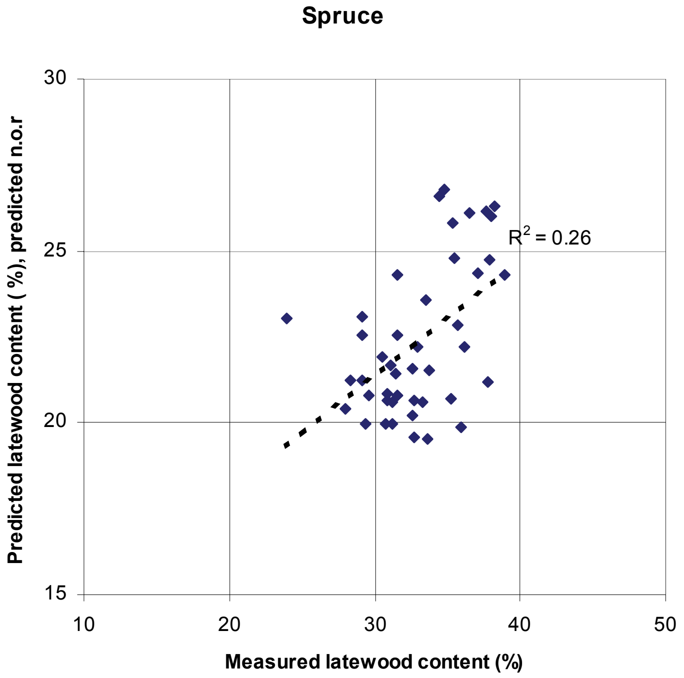


Fig 23. Predicted vs. measured latewood content of Norway spruce sample discs (n=50). Predicted values (latewood according to STFI "20-50%") based on diameter (Model P4, Wilhelmsson et al. 2002) and predicted number of annual rings (n.o.r). Measured latewood content by WinDendro "50%". Log top diameters from 120 to 400 mm u.b.

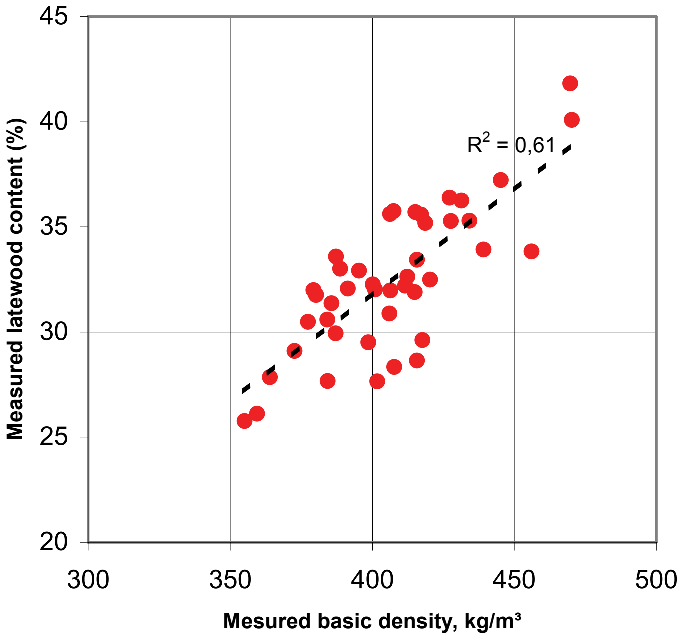


Fig 24. Measured latewood content vs. measured basic density of Scots pine sample discs (n=43). Log top diameters from 120 to 400 mm u.b.

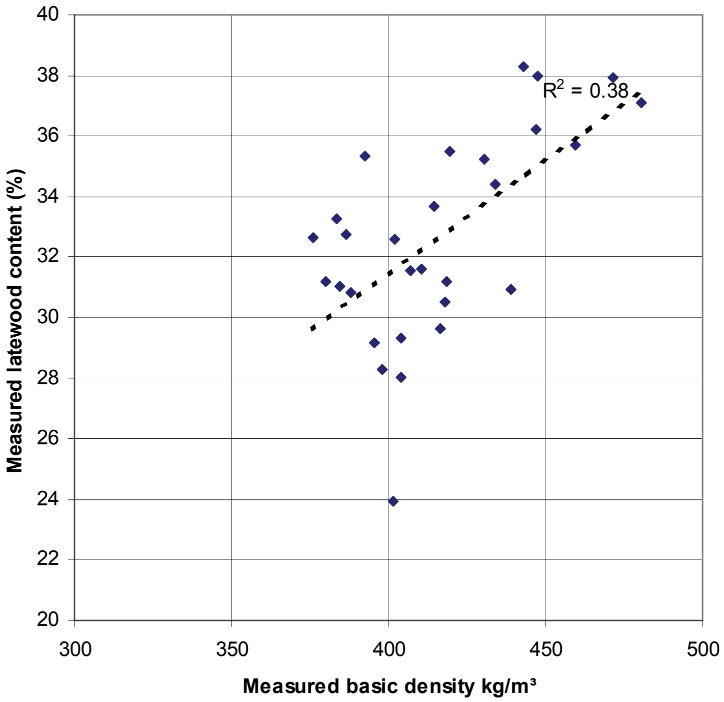


Fig 25. Measured latewood content vs. measured basic density of Norway spruce sample discs (n=29). Log top diameters from 120 to 400 mm u.b.

5 Discussion

5.1 Lead-time

The lead times measured in the LINESET-project are not normal lead-times because in the project logs were collected for a longer period than normal before sawing. The results just show the possibilities to use a traceability system like the prototype system tested for lead-time control.

5.2 Dimension

Diameter

The results from comparing harvester measurements and measuring at the sawmill give a standard deviation for spruce of 5.5-6 mm and for pine of 7-8 mm. These figures are the same as have been found earlier (Möller 2000). The spread depends on differences in measurements techniques, bark thickness, bark damages and oval shaped logs.

One interesting result is that for measuring on bark, the difference between the harvester and the timber sorting station is 1.4 mm larger diameter for the harvester for spruce and 5.9 mm for pine. Under bark, the harvester value is

0.25 mm smaller for spruce and 1.8 mm bigger for pine. The conclusion of this is that the measurement frame at the sawmill measures the log diameter under bark in many cases. The operator at the industry tells the measuring system that the log has no bark and thus corrects this problem. 15% of the spruce logs were indicated to be without bark and 9% for pine logs. For pine the thin bark function has been used for 80% of the logs, to be compared to the harvester that used the middle bark function for all logs.

Length
The results show that the length measuring at the saw log intake gives very good correlation with the length from the Finscan system. The length measuring at the timber sorting station are a little bit less accurate but still satisfactory.

The length measuring in the forest shows quite poor results and compared to other similar test these results are also poor. The tracebility system with transponders could be a very useful tool for monitoring the measuring precision of different machines to achieve better calibration, measuring and faster development of the measuring techniques.

5.3 Knot size

The coefficient of determination (R^2) of maximum knot size was 0.37 for the Rettenmeier logs and the standard deviation of the residuals was 4.0 mm. When Moberg (2001) developed the model the prediction of maximum knot got an R^2 of 0.61. In Moberg´s test the actual age, height and crown height of each tree were used. In this study, the average age and crown height per stand and a function describing the height according to the trees DBH were used. This probably decreases the coefficient of determination.

Another reason for the lower R^2 value could be that a small number of stands from a limited geographic area were included in the study, were as in Moberg´s (2001) original study a large number of stands from all over Sweden were included. The models were better at explaining the variation among stands than within stands.

Measurement errors in Finscan data probably explain at least 0.1 of the difference in results for this study. The model calculates the biggest size of each knot and this part of the knot will not always be at the surface of the boards. The knot of the boards would expected to be smaller in the top part of the trees where the branches are still alive, and the knots will reach maximum size at the surface of the log (outside of the boards). This also affected the coefficient of determination degrees for the study.

For logs from large trees, the model results in larger knot diameter size than measured by Finscan (see figure 10). One explanation is probably that the larger knots predicted by the model is outside of the board and not measured.

In general, the prediction and the measured size are on the same value; in total the difference was just 0.6 mm. Also, the correlation between knot size and tree classes (see figure 10), and between average predicted knot size and measured knot size shows very good correspondence. This means that it should be possible to use the models to describe a stand or an assortment.

5.4 Knot quality

The quality distribution, according to Nordic Wood, of logs from different tree classes is shown in figures 12-13. The results show that the proportion of quality A is highest when the log comes from small trees (79%, DBH<200 mm) and smallest from big trees (4%, DBH>450 mm). This result was expected because the trees are of similar age. This means that the small trees have grown slower compared to the big trees, which indirectly means smaller knots. The model describes this type of difference between different parts of trees and different types of trees.

These results are very promising and indicate that knot models will probably be possible to use for cross-cutting decisions in the harvesters.

5.5 Number of annual rings

The predictions of the number of annual rings in cross-sections (sample discs) were based on breast height averages at the stand level. As a consequence all within stand deviations will enlarge the prediction error of the number of rings in cross-sections. One way to reduce this effect is to use a function were the relative diameter of trees are used to predict the differences in breast height age. No such covariance analysis was carried out in this investigation. According to earlier studies such a calculation would probably reduce the prediction error of the number of annual rings with about 25- 50% of the differences in prediction errors between breast height ages based on stand averages and individual tree breast height ages.

The prediction errors were well in correspondence with figures given by Wilhelmsson (2001), but the bias was larger than expected. All reasons for this are not known, but some possible errors in breast height ages have been detected. Another reason may be a very quick height growth at early stand age. Further analyses are needed.

5.6 Heartwood

The heartwood diameter models (P4, S4 Wilhelmsson et al , 2002) were based on water content demarcation (tomography) of heartwood/sapwood of discs. In the present investigation a visual, or reagent supported, demarcation was used to assess heartwood content. According to earlier comparisons of these different demarcations a slightly negative bias (assessed-predicted values) would be expected. This expectation was verified by the results for both species.

R^2-values and prediction errors (expressed as RMSE) were close to expectations when compared to the prediction errors presented by Wilhelmsson et al. (2002). Prediction errors for heartwood diameter based on predicted number of annual rings in comparison with measured number of rings increased 4 mm for pine and 2 mm for spruce.

5.7 Basic density

The basic density predictions were in line with expectations for pine but relatively poor for spruce when compared with the prediction errors Wilhelmsson et al. (2002). This was true for both prediction alternatives.

There are several possible explanations for the poor spruce predictions. Two of them are however quite obvious: 1. Reaction wood was detected as very common in discs and a large number were excluded for this reason. It is still quite possible that moderate amounts of reaction wood affect the remaining discs 2. Many discs included detected knots, there may however still be parts of knots and smaller diameter knots not detected in the discs considered as knot-free. 3. The growth pattern of the trees in some of the sample stands was so different from an average situation that it had a considerable effect on the density. 4. Genetic differences between trees are reported by e.g. Hannrup (1999); Hannrup et al. (2001) . As the validation was carried out for a small number of trees this may have affected the results to some extent. 5. Other environmental and physiological effects that may result in other relationships between annual rings width and density. 6. Errors at the laboratory can not be totally excluded. Howeveer pine and spruce were handled at the same time, with the same routines and the pine results were OK according to expectations. Furthermore the laboratory routines have followed well adapted standards and the operator was both experienced and skilled. Finally the correlation between latewood content and basic density is in line with earlier results (Wilhelmsson et al. 2002). The conclusion is that laboratory errors is a most unlikely explanation.

At spruce the predicted number of ring alternative (tab 11-12) resulted in a slightly higher R^2-value than the measured number of rings. The main reason for this unexpected result was the fact that the annual ring width was almost uncorrelated with the basic density. When testing the spruce density model on each stand separately (all discs except the ones with large knots were included, however still to few independent discs to provide certain results) the R^2-values (Predicted vs. measured) was below 0.1. in three out of five stands.

When all discs were included in the validation of all stands together the models explained only 7% of the spruce basic density variation, while pine basic density variation was explained by 52%.

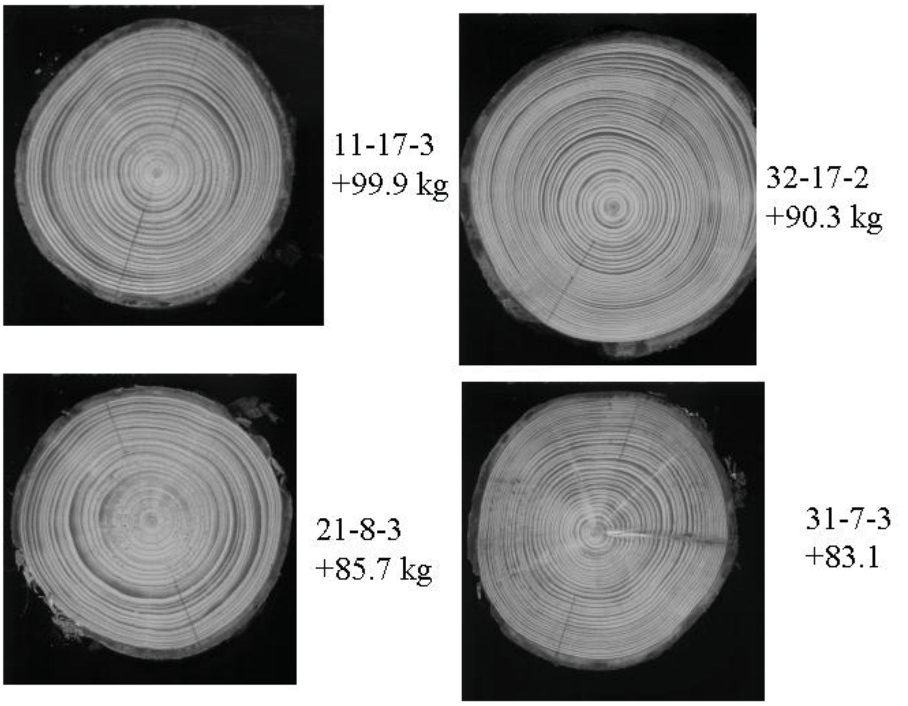


Fig 26. Examples of spruce discs with large amount of reaction wood

5.8 Latewood content

As already has been described the latewood content was measured with another instrument and image analysis than was used at the development of the models. This resulted in a large difference in latewood content levels (tab 11-12), but R^2-values (predicted vs. measured) well in correspondence with Wilhelmsson et al. for pine but considerably poorer than expected for spruce. The explanations are about the same as for basic density, above.

5.9 Use of traceability system

The data colleced during the LINESET project show that a traceability systemis a powerful tool for development and control of the process. Many interesting analyses, that can not be done during normal production today, will, with such a system, be possible to do on-line.

For most of the needs found in Wp 1 (Möller et. al. 2000) a low marking sample will be enough, but the cost are still too high. The transponder or other marking device, needs to be cheaper than today.

6. Conclusions

The results from these studies together with earlier studies show some interesting conclusion to point out:

- To use a measurement frame like Rema 9015 3D scanner for control of measurement accuracy of the harvester gives similar result as a manual control (Sondell, et al 2002).
- The knot size model looks very promising to use for quality descriptions of a stand or assortment.
- The knot size model also looks very promising to use for cross-cutting decisions for different assortment, or to use for choosing different stands for different products.
- Heartwood models shows that they can be used for cross-cutting decision and sorting in the forest. For practical use the model has to be adapted with average stand age and calculated tree age and tree height. This will probably decrease the correlation figures.
- Basic density models, together with models predicting properties of the final product will probably be a useful tool for addressing wood to different assortments and pricing assortments and stands. These models can also be used in new algorithms adapted to automatic merchandising by harvesters.
- A traceability system in connection with data from harvester, timber sorting station and sawmill equipment, like Finscan, is a very effective tool for development of models and algorithms for use in the forest and for control of generated data.

7. Literature

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