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Local variations in sawlog- and sawn product quality

– sawing study of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) at a sawmill in central Sweden

Megumi Shimizu Nilsson

Examensarbete i skogshushållning, 15 hp
Skogsmästarprogrammet 2011:16
SLU-Skogsmästarskolan
Box 43
739 21 SKINNSKATTEBERG
Tel: 0222-349 50

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Megumi Shimizu Nilsson

Handledare: Lars Norman

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PREFACE AND ACKNOWLEDGEMENTS

This degree project was performed as a part of the requirements for a Bachelor of Science (BSc) degree in forest management at Swedish University of Agricultural Sciences (SLU).

The host company for the project is AB Karl Hedin (KH); a family owned saw mills- and trading group company with their headquarters located in and operations in central Sweden and Estonia.

The reason for being interested in this project is because of its diversity, containing the overall chain of supply. Various factors that can affect the production in forest, logistics as well as production at industries, makes it a complex chain of operations.

To be able to carry out the project successfully, it was necessary that each component of the work functioned properly, that is where I found myself quite powerless occasionally for not having enough practical experience and knowledge to make some of the required decisions. This study would definitely not have been completed without the kind support from each one of the individuals I met during the operation, and I would like to express my sincere gratitude to all of you, especially;

Germund Wahlbäck, previous marketing manager at KH for his inspiration and original idea behinde this project, to Fredrik Nilsson, MD for the saw mill division at KH and to Pär Granström, vice MD and marketing manager for the saw mill division at KH for their support to complete this project. Lars Eriksson, timber grading inspector at the regional timber measurement association (VMF Qbera), for helping me with control measurements of the timber quality and for sharing your experience and valuable knowledge about stem properties. Also thanks to my supervisors, Lars Norman and Daniel Gräns at SLU for their understanding and for encouraging my ideas, as well as their patience and support.

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Megumi Shimizu Nilsson

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1 ABSTRACT

Factors associated with raw materials are one of the most important keys to success among sawmill industries today. A common opinion is that the potential for further development for wooden industries lies in improved integration between different part of the so called « wood-flow chain ».

This project was carried out on request of a sawmills- and trading group company in central Sweden and Estonia as a part of the requirement for a Bachelor of Science degrees in forest management at Swedish University of Agricultural Sciences (SLU).

The aim of the project was to investigate how geographical and topographical variations in a particular saw mill's catchment area affect saw timber production of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*). The study area corresponds to the latitude ranges of approximately 59^{o} to 61^{o}N, the longitude from 14^{o} to 19^{o}E and altitude above sea level from 5 to 550 m.

A total of about 25 000 sawlogs was collected for the experiment during June 2010. Control measurements on sample logs, visual grading at the log sorting station and test sawing were performed.

The results revealed significant geographical variations within the catchments' area regarding timber quality of pine timber, however less obvious differences were found regarding spruce.

It was also found that there is a stronger correlation between quality of the raw materials and the yield of sawn products for pine, however weaker or no correlation for spruce, which could be explained by the raw materials' localization.

The results of this study will be used to help making decisions about future utilization of raw materials from the end user's point of view.

2 INTRODUCTION

Factors associated with raw materials are one of the most important keys to success among sawmill industries. Access to raw materials also becomes a primary issue when competition in the industry's catchment area increases as a result of today's increase in use of fiber. Good quality of the raw materials plays an important role in obtaining a stable production of high quality products. The vast majority of the manufacturing cost consists of raw materials, which forces producers to make careful and wise choices on how to utilize the raw materials.

Forest industries have made a great effort to optimize utilization of raw materials and production capacities, as well as the increasing the efficiency of production in order to secure their competitive position on both the domestic and foreign markets. A common opinion is that the potential for further development lies in improved integration between different parts of the so called « supply chain » or « wood-flow chain » (Carlsson & Rönnqvist, 2005).

According to Klinger et al. (1996), in an ideal « end-use oriented » system, each stand, each tree and each part of the stem should be given a destination in terms of the suitable end-product, the question follows however if it has been enough correlation between the stem properties and the end use. Using wood as an engineering material is a great challenge since a large variation can often be found within the material. Apparently it is an anisotropic material, meaning that the material's anatomical structure and strength properties in different directions have an influence on the processing as well as the end result (Grönlund, 1986).

During the last decades the effects of different wood and fiber properties of conifer wood on product quality and production efficiency in the wood-based industries has been studied, occasionally by studying environmental influences in general (Larson, 1963; Lindström, 1997; Morén & Perttu, 1994; Henderson & Petty, 1972), occasionally by focusing on geographical-and topographical factors (Ståhl, 1988; Prescher & ståhl, 1986; Ståhl et al., 1990; Persson & Ståhl, 1993; Persson et al., 1995; Tegelmark, 1999), and occasionally studying internal properties (Moberg, 1999). According to Arlinger et al. (2002) obtained knowledge about wood and fiber properties can be used to utilize the wooden raw materials in a more efficient way by;

- *Using the knowledge as a basis for pricing, that is, making it possible to give different priorities to different types of stands/species/regions based on predicted properties*
- *Supplying industries with a description of the wood that will be delivered from a certain site or within a certain time period, thus making it possible for the industry to adapt their process in advance according to the properties of the raw material*
- *Directing the wood from certain stands to certain industries thus supplying the individual industry with a more suitable raw material*

To capture the variation of wood and fiber properties in the industries' catchment areas, modelling for predicting properties has been developed and described by numerous authors in Sweden (Lundqvist, 2000; Wilhelmsson et al., 2002; Arlinger et al., 2002; 2009). Even if wood and fiber formation theories seem to vary using different research objectives and to have different views, those theories strongly argue the importance of environmental influence on wood formation. Some of them are introduced in this study as a literature review. The focus has been on the site localizations' influence on wood and fiber properties. It shall help understanding the theories behind and the present situation regarding practical use of this knowledge along the wood-supply-chain today.

2.1 Aim of the project

The aim of the project was to investigate;

- How geographical and topographical variations in a particular sawmills' catchment area affect sawn lumber production.
- Potential for sorting logs into two different quality classes according to market requirement on stem properties.

The result will be used to help making decisions about future utilization of raw materials from the end user's point of view, in this case Krylbo sawmill. The situation can be different from industry to industry, from region to region, from country to country, which limits the degree to which results are applicable to other cases.

2.2 Background

The project was carried out on request of Krylbo sawmill at AB Karl Hedin. The sawmill is located in Bergslagen in central Sweden. The Krylbo plant is a modern small-diameter (Ø 120 – 220 mm) sawmill that utilizes both spruce and pine at fixed lengths, so called « Krylbokubb », which means that the length of the log is fixed to 3.1 m (Anon., 2010).

Raw materials are supplied through Weda Skog AB, which is co-owned by Hedin-Bergqvist Company and Moelven Euro Timber A/S (Anon., 2010). The timber harvesting area stretches about 100-150 km in radius from the sawmill (see figure 2.1).

Figure 2.1. Map showing the Krylbo mill´s catchment area in central Sweden (Link A, AB Karl Hedin).

After harvesting with length and quality adjustments for certain industries in the forest, the sawlogs are delivered to the Krylbo mill. Logging and transportation is mostly carried out by contractors. After arriving at the mill the logs are sorted according to grading rules into two different classes, one sawable- and one non sawable class. There is an impartial round timber measurement system utilized by most forest industries in Sweden to ensure impartial grading and fair trade between sellers (forest owners) and buyers (forest industries) according to the Swedish sawlog grading instruction, VMR 1-07 (Link B, VMR). Further information about the instruction for Krylbo sawmill's case will be presented later in this report (see 4.3).

The information about the identity of a certain batch of logs is usually lost at the stage between the sorting plant and the sawmill. This stage could be looked upon as critical when issues about integrated wood-flow are discussed (Chiorescu & Grönlund, 2004).

The identity of the log is lost partly because log sorting plant has two separate main functions. One function is to measure log quality, diameter, length which forms the basis for grading and payment to the seller. In this stage, to be aware of the identity of the log batches is very important so that the seller receives the correct payment for the correct log batch.

The other function is to measure the variables necessary for sorting of the sawlogs to be suited for the production line. In Krylbo for instance, sawlogs are resorted by using a 3D scanner frame into different diameter ranges and into different stem parts (top & middle or bottom logs) in certain diameter ranges of certain species. In this stage, however, the identity from the forest log batches is no longer necessary as long as the logs are correctly sorted to be suitable for the mill production.

It is slightly above 200 000 m^3 sawn goods per year is produced at the Krylbo sawmill today (Link A, AB Karl Hedin). Investments into the modern sawing line in 2007, combined with a long experience of working on the necessary production flow, Krylbo sawmill has become one of the most efficient sawmills today. The raw materials consumption corresponds to just under six million sawlogs according to the budget 2010 (Link C, Veisto).

This positive development could be the result of the company's continuous quality improvements and management work. More than half of the main quality of sawn lumber is sent to the Japanese market which is known for its awareness of the value of high quality (Wahlbäck, pers. message, 2010). As the globalization of trade continues and competition becomes tougher, a higher quality standard of products is required even from domestic users in Sweden and other European users. Quality management work therefore continues within the group of AB Karl Hedin. To secure quality of the Krylbo sawn products, there is one specific person employed full time for the quality development and management.

This quality manager experiences that the origin of raw materials has a great influence on the finished-goods' quality. Requirements have been stated for better identification of the characteristics of logs before sawing, on the assumption that there are local variations in quality outcomes within the log catchment area (Wahlbäck, pers. message, 2010).

Further consideration is given on fair pricing of raw materials compared to outcomes on finished product. Today sawable logs are priced regardless of their quality.

3 MATERIALS AND METHODS

3.1 Experimental material

The majority of the experimental material has been collected by the group's own wood supply organization, Weda Skog AB. This is to keep better control over the harvesting area. The Krylbo mill's catchment area has been divided into three different regions, Region North, Region South and Region East.

- Region 1: North (North of *Limes norrlandicus*)
- Region 2: South (South of *Limes norrlandicus*)
- Region 3: East (Uppland county)

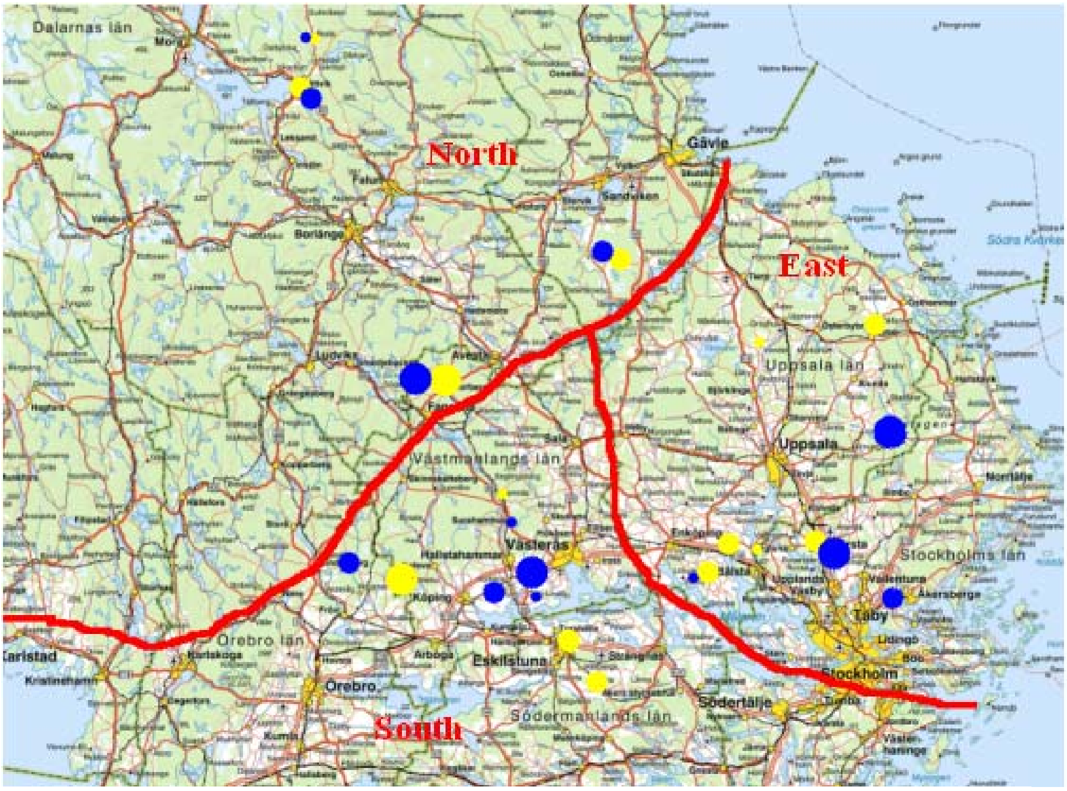


Figure 3.1. Map showing the division of the catchment area into three regions, North, South and East, and locations of harvesting sites for collecting the experimental materials. Yellow dots showing pine and Blue dots spruce. Sizes of the dots corresponding volume of the materials, aimed for this study.

3.2 Boundaries

A border between the North and South has been drawn along the biogeographical border called "*Limes norrlandicus*". This is the border between the South Boreal zone and the Nemoral zone in Sweden.

The East region is located on the east coast, north of Stockholm. In Edlund's study (2003) regarding the subject of sawlogs measurement on crooks, this region was identified based on common observations of defects such as crooks. The reason for the high frequency of crooks in this area according to Edlund (2003) could be due to the soil conditions in combination with heavy wind.

3.3 Preparation before the experiment

The Number of logs included in the sawing tests for each unit, sorted by region / species / quality / diameter range, has been aimed at a minimum of thirty, to obtain more reliable results.

The total amount of sawlogs to be included from each region was calculated backwards considering this minimum thirties and using general data from the operational production at Krylbo mill during the period from January to June 2010.

A total of about 25 000 sawlogs was collected for the experiment during June 2010. The storage time in the forest varies from batch to batch, but was limited to a minimum during the summer season to avoid insect infestation before logs were taken inside the log yard.

3.4 Control measurements

Sample materials, consisting of fifty sawlogs per region and species, were separately collected. Control measurements were performed visually by a grading inspector from the regional timber measurement association (VMF Qbera) according to measuring rules for pine and spruce sawlogs (Anon., 2007). Sample materials were randomly selected from each region, but strictly limited to the sawlogs from thinning operations to ensure a fair comparison.

3.5 Log sorting station

Visual grading by a professional grader from VMF Qbera was performed at the log sorting station in Krylbo. Experimental materials were classified as sawable or non sawable timber (reject / grade 9) and the cause for rejection was recorded to be reported to SDC (a national organization representing practically all timber registration and accounts in Sweden). The data needed for analysis of the possible differences in quality for the logs from the three different regions were obtained from VIOL (timber administrative reporting system) through SDC.

Certain top diameter ranges such as “Spruce 148” and “Spruce 173” and “Pine 147” and “Pine 170” were selected to produce a certain product (see 3.6) and resorted into two different (supperior and inferior) sawable classes before the sawing test. Grade 1 for spruce and grade 1, 2 and 3 for pine timber according to Swedish sawlog instruction indicates better quality. The inferior quality corresponds to grade 2 for spruce and grade 4 for pine timber.

3.6 Sawing test

Each unit was given a unique manufacturing number, to identify the origin of the experimental logs (table 3.1). It was followed by the test sawing for observation and comparison of the recovery from center cutting pieces of three and four ex log cutting. The product is called 24x110 mm Lamina (lamstock), aimed for the Japanese market.

Table 3.1. Production schedule for test sawing of the different units. « pk » stands for progressive kiln (for detailed explanation, see 4.6.).

Species	Diam	Grade	Region	Manufacturing No.	logs measured	Pcs after sawing	Kiln pkgs	Kiln
Spruce	S 148	grade 1	East	40387	1046	3138	4,8	pk 16
			North	40388	1411	4233	6,5	pk 16
			South	40389	804	2412	3,7	pk 16
Spruce	S 148	grade 2	East	40390	96	288	0,4	pk 16
			North	40391	46	138	0,2	pk 16
			South	40392	84	252	0,4	pk 16
Spruce	S 173	grade 1	East	40393	675	2700	4,2	pk 16
			North	40394	725	2900	4,5	pk 16
			South	40395	465	1860	2,9	pk 16
Spruce	S 173	grade 2	East	40396	42	168	0,3	pk 16
			North	40397	23	92	0,1	pk 16
			South	40398	42	168	0,3	pk 16
Pine	P 147	grade 1-3	East	40408	454	1362	2,1	pk 16
			South	40409	956	2868	4,4	pk 16
			North	40410	1157	3471	5,3	pk 16
Pine	P 147	grade 4	East	40411	60	180	0,3	pk 16
			South	40412	76	228	0,4	pk 16
			North	40413	45	135	0,2	pk 16
Pine	P 170	grade 1-3	East	40415	492	1968	3,0	pk 16
			South	40416	523	2092	3,2	pk 16
			North	40417	690	2760	4,2	pk 16
Pine	P 170	grade 4	East	40418	59	236	0,4	pk 16
			South	40419	28	112	0,2	pk 16
			North	40420	24	96	0,1	pk 16

3.7 Grading mill

After the kiln drying process the materials were cut and sorted into different qualities according to the Krylbo mill's standard. Pieces were graded into four different qualities by the automated grading scanner system applying the same grading criteria for each unit for fair comparison.

The results from the control measurements, the log sorting station and the test cutting are presented, analyzed, and discussed later in the thesis.

4 KRYLBO MILL'S WOOD-FLOW CHAIN

4.1 Geographical factors

The raw materials catchment area stretches for about 100-150 km in radius from the sawmill, corresponding to the latitude ranges of approximately 59^{o} to 61^{o}N, the longitude from 14^{o} to 19^{o}E and the altitude above sea level from 5 to 550 m, where the lower altitude starts at the east coastal area, around and north of Stockholm and gradually becomes higher northwestern wards after passing the Limes norrlandics (see the explanation below).

4.2 Climatic conditions

The conditions presented here is Limes norrlandicus, growing season and temperature sum.

4.2.1 Limes norrlandicus

Limes norrlandicus is a biogeographical border, which indicates the border between the South boreal climate zone and the Nemoral zone in Sweden. According to the Swedish geologist Lennart von Post it is « the most distinct and may be the most significant natural geographical border » in Sweden (Link D, SNA). This border runs across the centre of the Krylbo mill´s catchment area.

4.2.2 Length of Growing season

Growing season can be defined as the part of year with daily mean temperatures above +5 ^{o}C. Generally as you move further north to higher altitudes the growing season gets shorter, but it may vary locally as a result of the influence from for instance large lakes and the sea, which warms up slowly and gives a cooling effect in the spring time and vice versa in the autumn when it warms up the same area (Link E, SMHI). Within the Krylbo mill's catchment area the growing season is between 170-200 days (figure 4.1).

4.2.3 Temperature sum « Tsum »

Temperature sum (Tsum) could be defined as the daily mean temperature above +5 ^{o}C, summed during the growing season and it indicates how warm the growing season is (Link F, SLU). According to the map (see figure 4.1.) the Tsum ranges from 1100 to 1500 day degrees (dd) in the Krylbo mill's catchment area. The border between the Tsum 900-1100-1300 dd area (cool) and 1300-1500 dd area (favorable) stretches along « Limes norrlandicus ».

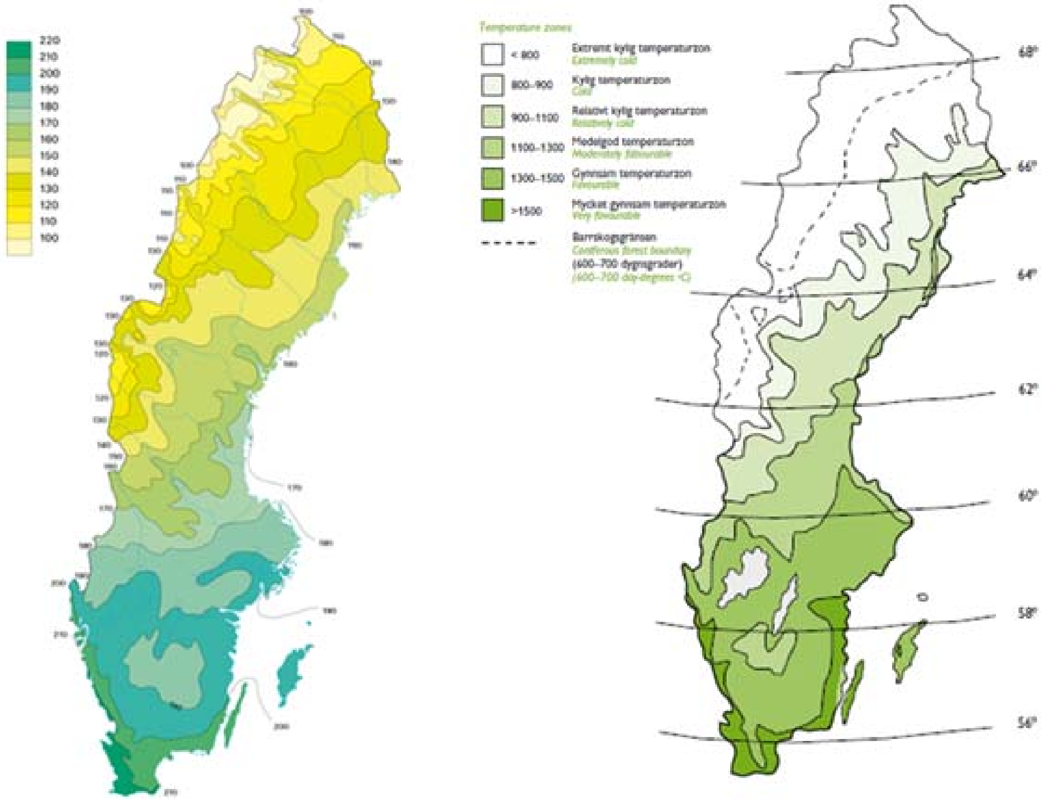


Figure 4.1. Map showing the length of the growing season in day(s) (left) and temperature sum in day degree(s) (right) in Sweden (Link E, SMHI; Link F, SLU).

4.3 Swedish sawlog instruction

The Swedish Forest Agency prescribes basic requirements on sawlogs of Norway spruce and Scots pine as sawlogs from a live stem section, cut by saw, free from insect damages and storage decay as well as free from coal, soot, stones, metal, and plastics.

Besides the basic requirements, sawlogs are classified into different grades according to Swedish sawlog instruction, called « VMR 1-07 » (Link B, VMR), by which knots properties, growth rings, straightness, top break, blue stain, forest rot, open scars and bark-encased scars are taken into account. The current instruction has been developed for a future automatic timber grading at the log sorting station. There are four grades for sawable pine timber and two grades for sawable spruce timbers (Link B, VMR).

One of the most important quality criteria that are judged visually by the measurer at the sorting station is straightness. It is measured in length with corresponding to the loss of saw yield, meaning length of the cylinder which does not fit into the actual log length due to crook. In principle logs shall be straight (up to 20 cm loss of yield allowed) to be graded as superior grade. For inferior sawlogs (grade 4 for pine and grade 2 for spruce) corresponding allowance is up to 120 cm loss of yield.

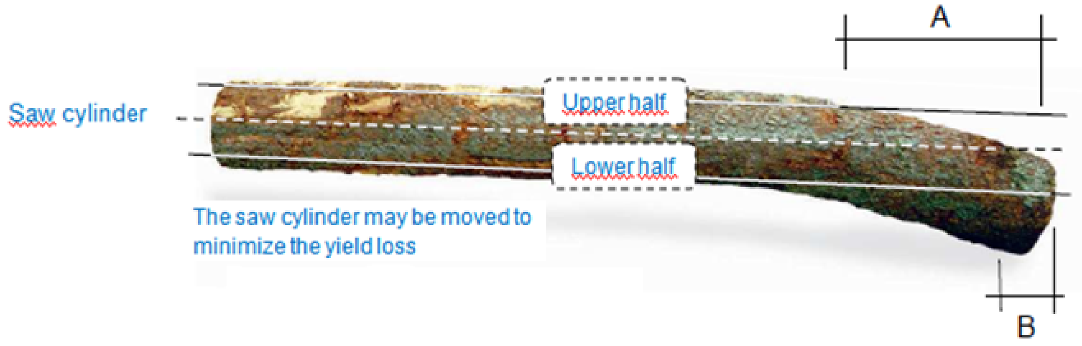


Figure 4.3. Determination of yield loss. A+B < 20 cm = Tolerance, 20 – 120 cm = the poorest grade and > 120 cm = reject (Anon., 2007).

All grading rules and statements are based on the minimum quality criteria that should be certifying the lumber quality. Any condition that will cause a reduction in the quality of the final products that might otherwise be cut out of a log is considered as a defect. Logs with this kind of defect would be classified as lower grade with a deduction of 1 cm in saw cylinder or rejected as non sawable logs depending on the condition of defects (for detailed instructions see appendix 9.1.).

In addition, there are written statements, called « B-circular », consisting of measurement criteria based on the general and specific agreement between particular partners. In case of Krylbo mill's raw materials, higher requirements on blue stain (not allowed) and straightness are applied due to its small diameter and fixed length of 3.1 m. The restriction for loss of the yield is maximum 30 cm (Link G, VMF qbera).

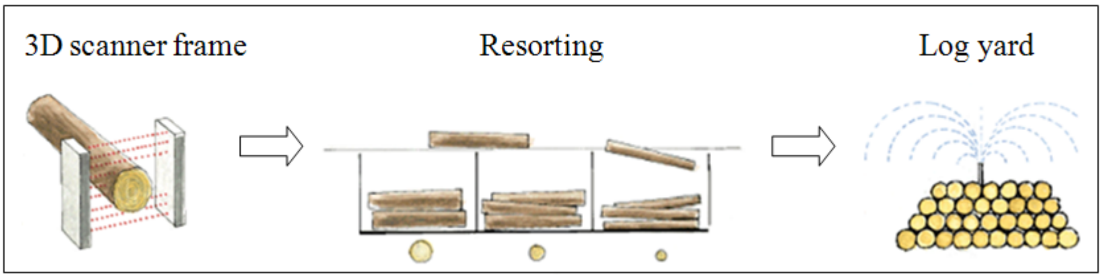


Figure 4.4. Timber sorting process for sawing production (Link H, NE).

4.4 Sawing line

After the « payment-basis-measurement » the logs go through a 3D scanner frame and are resorted into different diameter ranges and piled at the log yard (figure 4.4). Each pile corresponds to a different sawing pattern (figure 4.5) to achieve the maximum yield of volume and profit from each diameter range class to optimize the utilization of each log and minimize the waste (sold as byproducts i.e. sawdust and chip). A large sawmill survey in year 2000 showed that sawing yield in Swedish saw mills were on average about 47 percent of total log volume under bark (Link I, Träguiden).

The Krylbo mill has made investments in their circular sawing line to further optimize sawing. The sawing line consists of;

- *Log scanning and optimization*
- *Four side chipping and curve sawing*
- *Side board optimization and edging*
- *Double arbour rip sawing and optimized edging*

a) b)

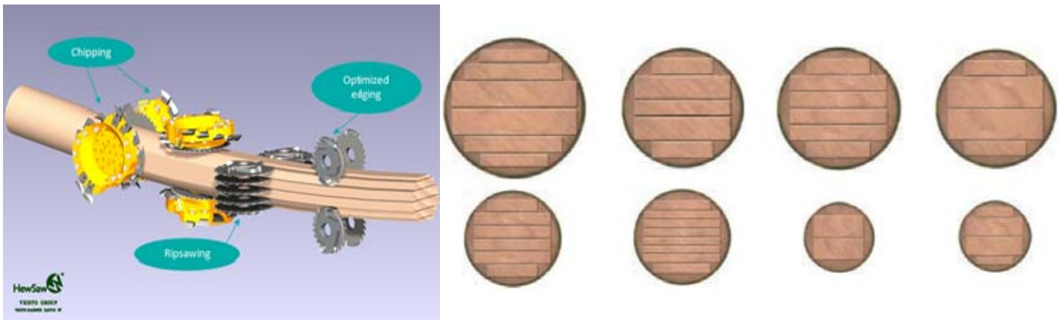


Figure 4.5. a) Hewsaw type R 200 PLUS installed at the Krylbo mill 2007 and b) some of the sawing pattern alternatives with the sawing line (Link J, Hewsaw).

4.6 Process of kiln drying

Nearly all lumber produced in Sweden is kiln dried at the sawmills before it reaches the market. The most common drying facilities are chamber kilns and progressive kilns. In a chamber kiln, which is also called a batch kiln, the climate is controlled for entire batches during the drying process. Those kilns are loaded and unloaded by forklift from one side. However in progressive kilns, the packages are dried during transportation through the different climate zones in a drying channel. The packages are placed on wagons and loaded at the kiln's intake end. An automatic feed system transports the wood through the kiln and out of the output end (Link K, Valutec).

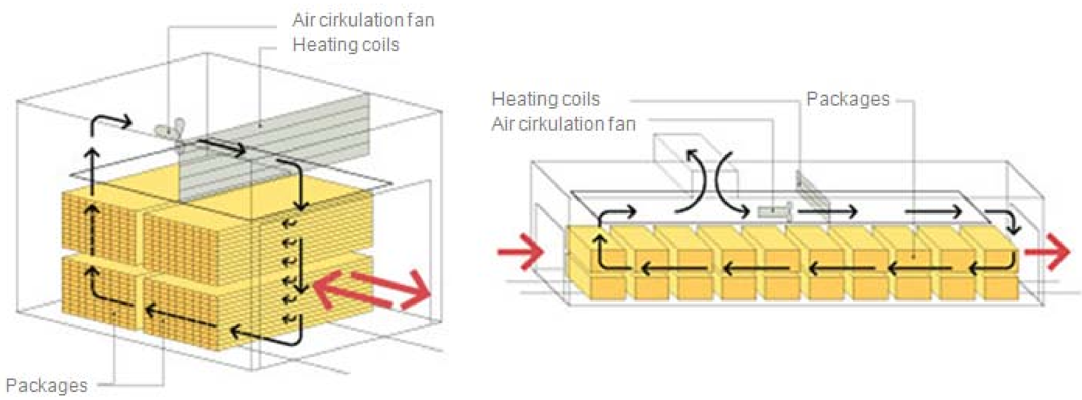


Figure 4.6. Illustration showing chamber kiln (left) and progressive kiln (right) (Link L, Träguiden).

The Krylbo mill is equipped with twelve chamber kilns and three progressive kilns, among which two of the latter kind are evaluated in 2008 in terms of their potential cover the production increase resulting from the new sawing line investment in 2007. All experimental materials (24x110) are dried in one of the progressive kilns.

Decisions about the drying process connected to for instance the moisture content (MC) for the final product, in this case lamstock for glulam-use aimed for the Japanese market, is one of the most important production steps to be able meet the market requirements and to achieve optimal results.

4.7 Grading mill

The batches that are kiln-dried to the desired MC are transported to the grading mill where pieces are cut (if necessary) and sorted into different qualities. Several grading rules are applied for the classification at different saw mill industries. In 1994 the Swedish domestic grading system, known as the « Green Book », was replaced by new edition, known as the « Blue Book » published by Nordic Timber, and it regulates sorting of sawn lumber in three Scandinavian countries, Sweden, Norway and Finland. In the year of 2000 European standard grading rules (SS-EN 1611-1) were introduced. These were partly based on the Nordic rules, but have a new classification system and new terminology. Approximate relations between different grading rules are presented in table 4.1.

Table 4.1. Approximate relations between different grading rules (Link M, AMA).

Grade		Highest Grade ⟷			Lowest
Green Book (1960)	4-sides grading	U/S (unsorted) I II III IV	V	VI	VII
Blue Book (1994)	4-sides grading	A A1 A2 A3 A4	B	C	D
SS-EN 1611-1 (2000)	4-sides grading	G4-0 G4-1	G4-2	G4-3	G4-4
	2-sides grading	G2-0 G2-1	G2-2	G2-3	G2-4

The grading mill in Krylbo is designed so that six different qualities could be produced all at once out of the same kind of dimension. Grading rules are in general based on the Nordic system, however the company has its own standards regarding grading systems and terminologies for each dimension and product, occasionally even for each customer.

The experimental product 24x110 mm is assorted into four different grades, A-, B-, C- and D-grade. The highest grade is sorted into three different lengths, main length (ML), second length (2L) and short length (SL). The highest yield of profit could expected from the A-ML (see figure 4.7).

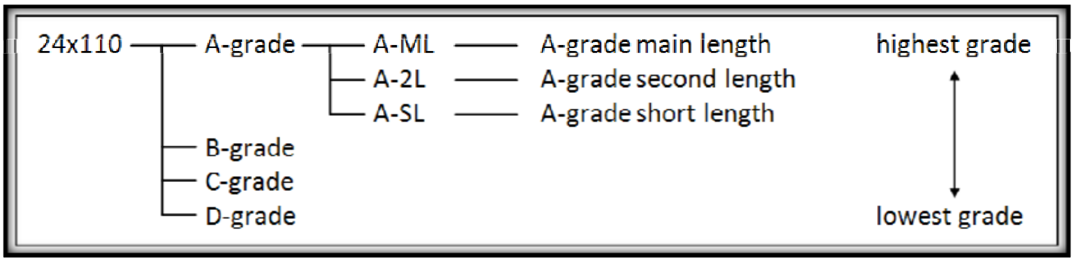


Figure 4.7. Sorting the experimental product 24x110 mm into six different grades.

Each customer has a unique profile to be considered regarding quality requirements and thus grading rules. To meet the requirements without losing productivity, the Krylbo mill has installed an automated grading scanner system, the « WoodEye » scanner. The scanner uses color scanning technology to create a color image of all four sides of the board. WoodEye software then uses that information together with the warp- and MC-measurement systems to calculate and determine the proper grade and length for each board (Link N, WoodEye).

4.8 Quality requirements on sawn product 24x110 mm for the Japanese market

4.8.1 Materials' strength and stiffness

Glued laminated timber (glulam) for construction purpose requires strength and stiffness in the raw materials, so called « lamstock », in order to stabilize the quality and safety of the building. JAS (Japanese Agricultural Standard) ensures that those glulam products available in the Japanese market are living up to the standards including the strength requirements. During the decades, kiln dried lumbers and glulams have replaced non-dried green lumber for production of both laminated post and structural beams in Japan, especially after the introduction of the Housing Quality Assurance Act in 2002, where builders and suppliers are required to take full responsibility for structural defects in housing.

4.8.2 Straightness

The 24x110 mm lamstock is used for 5-ply glulam post manufacture. 24x110 mm is planed down to slightly over 21x105 mm to obtain a fine surface before pieces are glued and pressed. After the drying process it is planed to the finish dimension, 105 mm squire. The most undesired moment to detect defects on lamstock during the production from the end customer's point of view would be in this stage after the final planing process, since the production cost has already occured. One piece out of the five could cause the whole final product to be rejected due to for example crook since it cannot be planed away if the defects are too large.

Figure 4.8. 5-ply glulam post manufactured in different species (Link O, Sakurai).

4.8.3 Moisture content and size requirement

The correct moisture content (MC) is one of the important conditions to be met for size accuracy since this anatomical material shrink in different directions during the drying process. The goal with artificial drying is to lower the MC to the proper level quickly without causing splits and to the level where it can be stored or transported without damage. Besides, the wood's MC has a major impact on the material's strength and stiffness. Dry timber is both stronger and stiffer than wet timber. Swedish building standards for instance handles this by defining four different climate classes, each representing a specific MC-range depending on the environment where the material is going to be placed in (Link P, Svensktlimträ). Similar standard requirements on glulam has been set by JAS and the MC for lamstock is suppose to be 12 % (+/– 3 %) (Link Q, Jawic).

4.9 Knots property and pitch pocket

Clear grade (without knots) in the Japanese market has traditionally been appreciated and has been given the highest grade. It is used particularly for traditional Japanese rooms. Knots properties and pitch pockets on lumbers for glulam purpose are mainly restricted because of the strength and appearance purposes. For visual quality assurance intended for flat-gloss varnished surfaces, defects as e.g. knots holes, loose knots, pitch pockets shall be replaced by wood inserts or filler on exposed surface (Link Q, Jawic).

5 LITERATURE REVIEW

5.1 Environmental influences on wood properties

Environmental influences on wood formation of Norway spruce and Scots pine has been presented by Lindstöm (1997), where it is confirmed that variables related to crown development have strong effects on the variation of wood properties. Lindström found that all wood formation theories he studied strongly argue the importance of crown development as the fundamental regulator of wood formation. Consequently, any environmental factor such as climate, nutrient availability, and silviculture that influence crown development of a conifer will also influence the wood structure development.

Morén and Perttu (1994) studied climatic variables' influences on the establishment of new stand and made estimations of their mean yields in northern Sweden. Temperature and available soil or surface water were important for type of vegetation, however climate elements were expressed as « driving variables ». Temperature activates the growing season and is often the most limiting factor for forest growth and yield in Sweden. A formula for calculating temperature sum using geographical factors was presented in the study, and it is also used as one of the key variables for prediction of wood properties today.

Wood properties of coastal and interior provenances of Lodgepole pine (*Pinus contorta*) have been studied by Henderson and Petty (1972). It was observed that in the coastal provenance nominal density was about 20 % higher, incidence of compression wood was much higher, and tracheid length was about 20 % shorter than in the interior provenance. Correlation between shorter tracheid length and incidences of compression wood, poor stem form and tendency to basal bowing has been found in the same study.

Ståhl (1988) presented in a study that there is correlation between geographical factors and Scots pine wood basic density.

The trials behind this study were located in Sweden covering latitudes from 55 to 66^{o}N, and altitudes between 15 and 525 meters above sea level. Based on the presented model, basic density was negatively correlated with altitude. The same model shows that basic density was positively correlated with latitude and the positive effect reaches its maximum at about 60-61^{o}N and it decrease after reaching the maximum.

Closely studying the corresponding Krylbo mill´s catchment area in Ståhl's study, it shows that a 100 meter altitudinal increase decreased basic density by about 0.005-0.010 g/cm^3. The positive latitudinal effect up to 60-61^{o}N corresponds about 0.005 g/cm^3 increase per degree.

A model was developed for predicting the frequencies of trees with straight stems and stems without spike knots based on geographical variations, such as latitudinal and altitudinal factors, based on a series of spacing trials with Scots pine in Sweden (Prescher & Ståhl, 1986; Ståhl et al., 1990).

The first trials (Prescher & Ståhl, 1986) were located in South and Central Sweden between 55 and 60°N and 10 to 335 meters above sea level. The following trials (Ståhl et al., 1990) were situated north of 61°N and 15 to 525 meters above sea level.

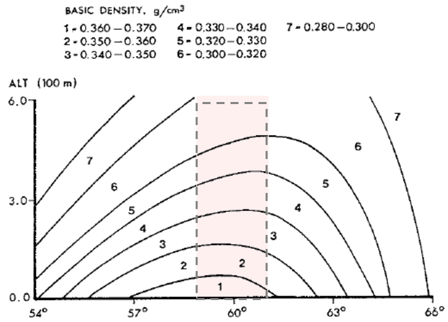


Figure 5.1. Model predicting locally basic density (Ståhl, 1988). = corresponding Krylbo´s catchment area.

According to the reports, besides branch diameter and basic density, the main factors affecting timber quality are stem straightness and the frequency of spike knots. As a result the measurements for both trials were concentrated on those defects. It is worth to point out that the study was focused on potential butt logs (up to 5 m high above ground) only as it is considered the most valuable part of the tree.

Based on the models briefly described above, the local variation had a major effect on the quality of Scots pine and it is possible to calculate the influence of latitude and altitude on the number of straight stems and the number of stems without spike knots. It was shown that there is a positive correlation between stem straightness and latitude as well as between the frequency of stems without spike knots and latitude. The positive latitudinal influence reaches its maximum at about 62°N. However correlation between the two defects and altitude (< 300 m.a.s.l.) is shown negative.

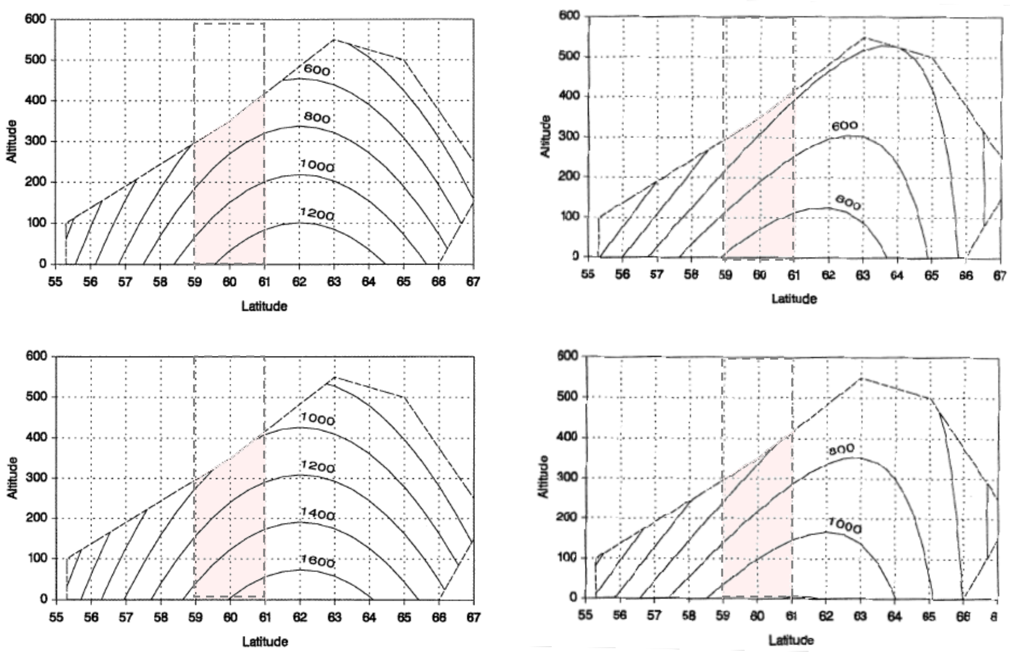


Figure 5.2. Model predicting locally the number of stems without spike knots (ha^{-1}) (to the left) and the number of straight stems (ha^{-1}) (to the right) at 2.0 m (A) and 1.25 m (B) spacing (Ståhl et al. 1990). = corresponding Krylbo mill´s catchment area.

Closely studying the results from the trials, areas corresponding to the Krylbo mill's catchment area show that one degree increase in latitude resulted in an increase in number of straight stems by about 100-150 ha^{-1}, and number of stems without spike knots by about 100-200 ha^{-1}. It was also found that a 100 meter altitudinal increase decreased the number of straight stems and stems without spike knots by about 150-200 ha^{-1}.

Prescher and Ståhl (1986) found one deviating trial where the poorer result was shown on the stem quality of trees situated on the west coast in the southern part of Sweden. The reason for the differing results was believed to be the site conditions (former abandoned farmland) and that the trial was exposed to strong western winds.

Persson and Ståhl (1993) continued the study using the same classifications regarding stem properties of Scots pine in northern Sweden, however supplemented with temperature sum and length of the growing season as additional predictors. In this study of Scots pine local provenances in different locations of northern Sweden (latitude between 60 and 68°N) has been compared. Based on the model, the estimated number of defect-free stems ha^{-1} was positively correlated with temperature sum, especially under 650 and over 1000 day degrees. In the interval between 650 and 1000 the correlation between number of defect-free stem and temperature sum was small. The number of defect-free stems ha^{-1} increased more constantly with increased length of growing seasons.

Additional studies of factors such as climate and soil and their effect on stem properties of naturally regenerated Scots pine in central Sweden has been performed by Tegelmark (1999), where branch property were also evaluated as quality features due to their importance for construction lumber as well as joinery. The evaluation was based on the potential butt logs (section between 0.5 and 4 m above ground) in naturally regenerated stands of Scots pine in the southern part of Sweden, latitudes between 56 and 61°N.

In contrast to other earlier studies it was not possible to construct a model that could predict values for all the included tree properties (stem straightness, spike knots, branch-numbers per whorl, branch size and branch angle) with acceptable accuracy based only on regional climate factors as predictors. However when this type of model was complemented with the site index, the degree of accuracy raised to an acceptable level. Classification in this study was therefore made with the so called ClSo model (Tegelmark, 1999), using the regional climate and soil factors in the stands as predictors.

Based on this model, it was again shown that local variation was an important factor when classifying sites in terms of their potential to produce Scots pine timber with desirable quality features. The prediction results with the ClSo model show that all tree properties had a maximum values in terms of good quality somewhere between latitudes 58 and 60°N, which covers quite a large part of the Krylbo mill's catchment area. The negative altitudinal influence was also shown for all studied properties with this model, especially over 200 meters above sea level.

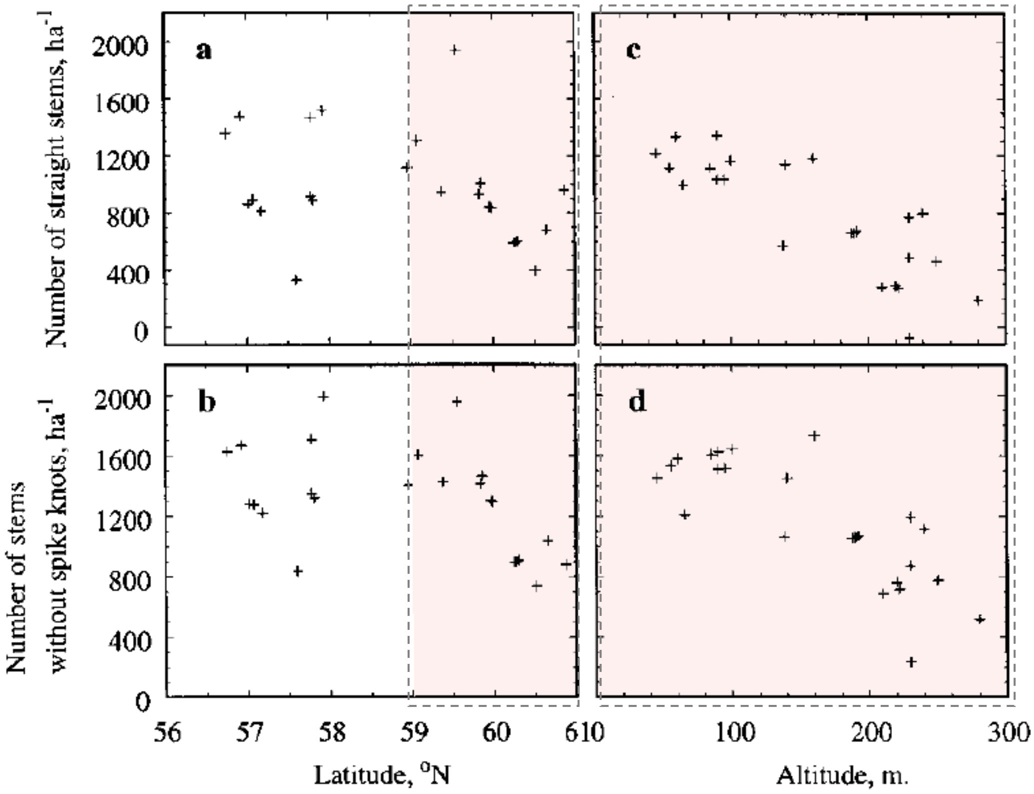


Figure 5.3. ClSo Model predicting the number of straight stems (ha^{-1}) (a & c) and the number of stems without spike knots (ha^{-1}) (b & d) locally (Tegelmark, 1999).
= corresponding Krylbo mill´s catchment area.

Additionally the number of straight stems and the number of stems without spike knots, especially the latter, were generally positively related to temperature sum and growing season. Especially high temperature sum during the entire growing season and during late spring and early summer (May-June) had a positive effect on the stem quality. High temperature during late summer and autumn (August-October), however, showed a negative influence. As for straight stems, the effect of temperature sum below 1300 degree days and growing season below 200 days (both 5°C) seemed to be small.

The study indicates that warm sites with a low frost frequency are suitable for producing high-quality timber in naturally regenerated stands of Scots pine. Another important factor is humidity, which has a tendency of decreasing eastwards in Sweden. The most important soil-related factor based on the model from this study is the site index, which could affect branch properties (Tegelmark, 1999).

The difficulty in predicting the effects of single factors was discussed in the previously mentioned study as for instance if favorable temperatures will tend to increase stand density, thereby improving quality properties and possibilities for stem selection. Branch size and number will tend to increase as well however. A key predictor affecting the number of stems of desired timber quality besides latitudinal and altitudinal factors was described as regional and local climate such as temperature sum and frost frequency and climatic conditions caused by the topography, closely-located water bodies (along sea shores and by large lakes) etc. The conclusion was that those factors should probably be given more weight than soil properties.

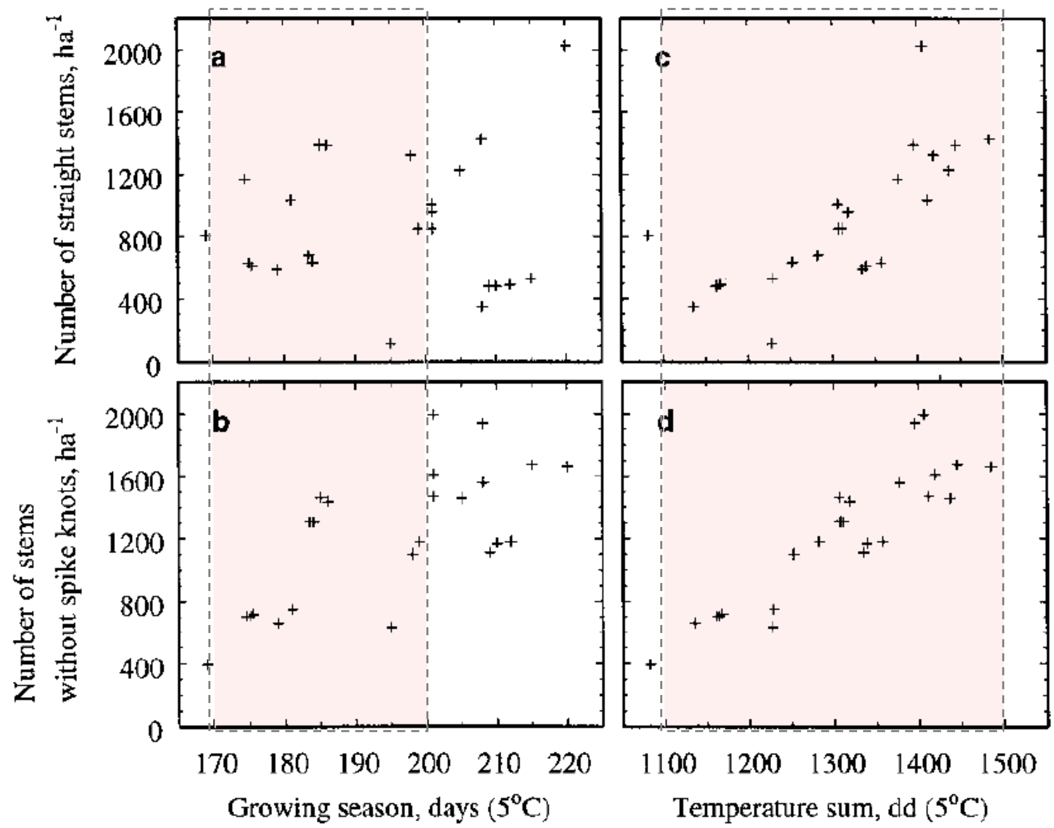


Figure 5.3. ClSo Model predicting climatically the number of straight stems (ha^{-1}) (a & c) and the number of stems without spike knots (ha^{-1}) (b & d) (Tegelmark 1999).
= corresponding Krylbo mill´s catchment area.

5.2 Internal properties

Norén and Persson (1997) confirmed in their study that it is difficult to predict board quality by inspecting the exterior of the logs, since there are internal defects as for instance stem crack, knot structure close to the pith and butt rots. Björklund and Moberg (1999) studied the variation between stems and stands in terms of internal knot properties (diameter, sound length, loose length, longitudinal angle and number of knots per whorl) of Scots pine in Sweden. The samples were collected from a broad range of latitudes, site indices, regeneration methods and thinning strategies to capture the variations. The mean values of knot properties were also measured within a stem section from 2.5 m to [site index/2-1 m], so called « constant-growth section » (Björklund, 1997), which was expected to be characterized by a more homogeneous knot structure as compared to other sections of the stem, and provide a basis for analysis of variation within and between stands.

Björklund and Moberg (1999) confirmed and presented three types of models for calculating knots' interior properties as type A: applicable in an inventory situation when growth ring data are collected, type B: applicable for knot property estimation based on site information and DBH distribution and type C: applicable in a harvesting situation when growth ring data from earlier inventories are available.

For individual tree measurements, variables such as growth-ring width close to pith and stem diameter at the height of the lowest dead branch were found to be highly significant and the modelling enabled calculations of the knots' interior properties such as knot diameter, sound-knot length, and loose-knot length.

Variations of those knot properties among different stands with geographical variations showed that northern localities had smaller knots and fewer knots per whorl, though the knot length showed no clear correlation with latitude. Site variables such as site index and temperature sum showed relatively strong positive correlations with knot diameter and number of knots per whorl, while correlations with knot length and knot angle were weaker. This study supports the expectation of longer loose-knot length at low temperature sum levels due to the longer self-pruning time.

Persson and Persson (1997) described the importance of wood density and called it the major wood property of concern for both lumber and pulpwood, since basic density is highly correlated with wood strength and pulp yield. Basic density is also a precondition for stem cracks to develop (Persson, 1994). This work was based on parts of a series of international provenance trials of Norway spruce established originally within the framework of the IUFRO (International Union of Forest Research).

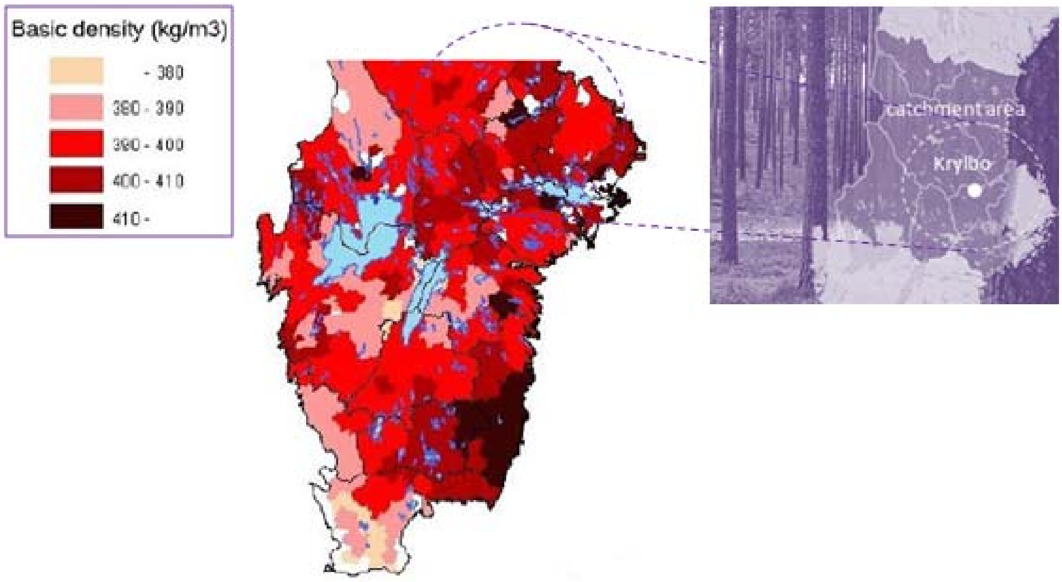


Figure 5.4. Visualization of variations in basic density levels of Picea abies pulp wood in southern Sweden by using data from the National Swedish Forest inventory database implemented in a GIS appreciation (Arlinger et al. 2002). = corresponding Krylbo mill´s catchment area.

It has been reported that the commercial value of the wood produced is influenced by stem form and the occurrence of defects. Persson and Persson (1992) showed that Norway spruce originally from eastern continent had lower incidences of spike knots and double stems.

5.3 Towards automatic timber quality grading

A modelling experiment has been carried out by Wilhelmsson et al. (2002) to predict the wood properties of Norway spruce and Scots pine for use in forest planning and in on-board bucking computers in harvesters. Investigated geographical range in this study was latitude between 56.6 and 65°80'N and altitudes were between 60 and 440 meters above sea level.

According to Wilhelmsson et al. (2002) breast height diameters, tree ages and climate conditions can be considered as "such explanatory variables as they are related to growth (and therefore to wood properties)". For their study samples were sliced into discs before measuring fiber dimensions, annual ring width as well as obtaining density profile by CT-scanning (computerized tomography scanning).

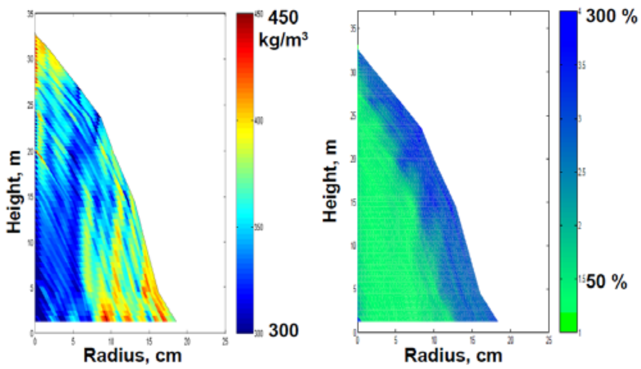
The model has been designed to provide general predictions of basic wood density, juvenile wood content, latewood content, heartwood content and bark thickness. Those properties are to be considered as relevant properties to analyze both pulp logs and sawlogs (Arlinger et al., 2002). The data needed for calculation was: tree age, location of the tree or stand (altitude and latitude), DBH, and diameters of log or position measured as height from ground of log and tree height.

The geographical information was used to understand the distribution of species in relation to latitude as well as in combination with altitude for calculation of temperature sum according to Morén and Perttu (1994). Calculated values have been corrected by – 50 for maritime and + 50 for local continental climate based on the demarcation map presented by Ångström in 1974 (Wilhelmsson et al., 2002).

Similar work on modelling has been done by collecting and scanning sample discs (see figure 5.5) for prediction of wood and fiber properties as a part of the project "Forest-pulp-paper" at STFI (the Swedish Pulp and Paper Research Institute). Close to 2000 samples were collected in cooperation between STFI, SkogForsk (the Forestry Research Institute of Sweden), Södra (the forest owners economic association in southern Sweden) and AssiDomän (currently Sveaskog, a state-owned forest company) for this project. Based on the data, models have been developed intended to be used for the development of model-based tools for optimized wood utilization (Lundqvist, 2001).

Figure 5.5. Sample discs from Norway spruce. (Lundqvist, 2001)

Lundqvist (2001) presented that there are, so called, "within-tree variations" in wood and fiber properties of trees obtained from different locations in Sweden. It was possible to use a model to predict wood and fiber properties based on the data collected from sample discs and visualize different properties with a procedure using computer tomography developed at STFI and LTU (Luleå University of Technology). Figure 5.6 shows that the heartwood and sapwood within an individual are easily distinguished by moisture content.



(A)Basic wood density (B) Wood moisture content

Figure 5.6. Property maps showing the within-tree variations in basic wood density (A) and wood moisture content (B), determined using a method based on computer tomography (Lundqvist, 2001).

Modelling by several researchers other than the above mentioned studies has made it possible to generate stem files and to calculate average wood and fiber properties for different assortments of sawlogs and pulpwood.

Arlinger et al. (2002) presented practical tools and methods for the calculation of these wood properties. The case study was presented as a concrete example of how the models can be used in a real life situation in southern Sweden. It describes the whole analysis in four steps and the data and tools listed below are required.

Steps:
1. *Generation of stand data*
2. *Bucking simulation*
3. *Calculation of properties for each log*
4. *Calculation of mean values for different assortments of logs*

Bucking simulation software applications are commonly used in Sweden today and the measurements needed for this analysis can be collected from cut-to-length harvesters. For bucking simulation the information files listed below are required.

- *APT-file; a bucking instruction file, containing important information as for e.g. price matrix, which instructs the bucking computer about the value or priority of a log with certain dimensions, lengths and a certain quality.*
- *STM-file; stand information file, containing detailed stand information as taper, height, quality, defects, and bark thickness.*

With the earlier mentioned predictive model by Wilhelmsson (2002), calculations of value for each log and mean values for individual trees with identical dimension/age/growth location would be possible. Using these analysis methods and tools enables the prediction of wood and fiber properties at a regional level (see figure 5.4) (Arlingar et al., 2002).

5.4 Property calculation program

There is a wood property calculation program for Norway spruce and Scots pine developed by Arlinger, J. at Skogforsk which can be downloaded from internet (Barth, pers. message, 2010-12-03; Link R, Skogforsk). The program is called « property calculation » and the calculated result refers to expected arithmetic mean value for an individual log/stem with the same specified input data.
According to the instruction the variation between individual trees/logs is often significant, especially for properties such as density and late wood proportion (largely due to genetics and growth environment). The theories behind the calculations are partly based on work published by Wilhelmsson et al. (2002) which was presented earlier in this chapter.

The materials used for developing the models were sampled within the following approximate intervals; Altitude 0-400 m.a.s.l., Latitude 56-66^{o}N, Longitude 15-22^{o}E, Age 20-180 years, DBH 125-380 mm and Tree height 5-33 m.

As figure 5.8 a-c shows, density is negatively related with both latitude and altitude, but positively related with Temperature sum for Norway spruce timber supposing input data is properly collected.

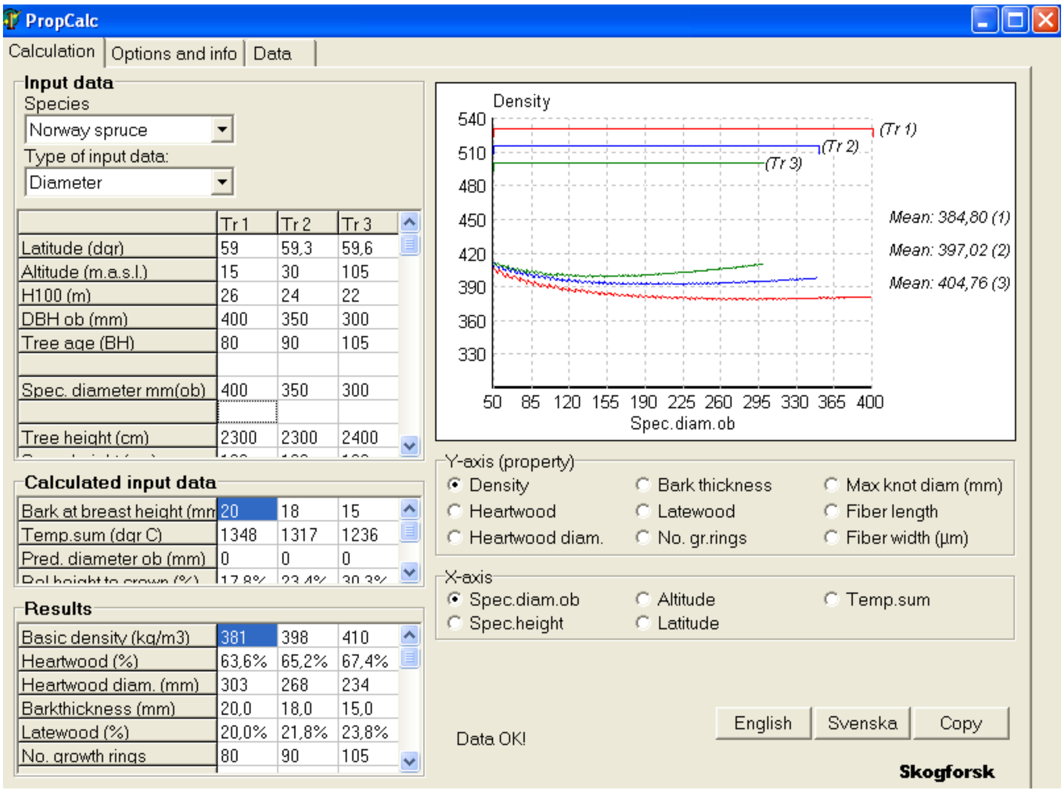


Figure 5.7. Program for calculating wood properties (Link R, Skogforsk). Simulated result from three different locations, Tr 1) 59°0'N 15 m.a.s.l., Tr 2) 59°3'N 30 m.a.s.l. and Tr 3) 59°6'N 105 m.a.s.l.

a) b) c)

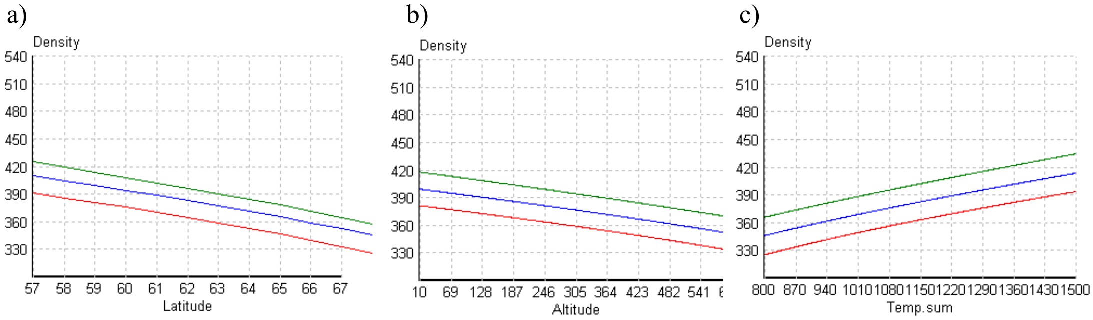


Figure 5.8. Diagrams showing the correlation between basic density and a) latitude b) altitude c) temperature sum calculated by the program (Link R, Skogforsk).

The current focus on the wood-flow chain resulted in the creation of a relatively new system with automatic determination of sawlog quality using the measurements from cut-to-length harvesters and wood property models. The measurements are saved for a production report as so called PRI-files (production individual file), consisting each of log length, diameter, species, and quality (Arlinger et al., 2009). Defects registered are butt rots, crooks and compression wood leading to forced manual cross-cutting, and deviation from the price matrix.

Comparisons have been made between calculated wood property values and the value obtained by grading by impartial staff at sawmills for both Norway spruce and Scots pine. The standard deviations from this study as well as the earlier study from 2004-2005 (Möller et al., 2005) were relatively small, about 2-3 percent for both species. Basic density was the main quality factor for spruce while knot size had the most effect on pine.

These ongoing technical developments in combination with the utilization of collected variables from harvested sites and results from earlier modelling and projects for prediction of wood and fiber properties encourage the development of the current wood-flow chain system in Sweden.

6 RESULTS

The results presented in this chapter are from the control measurements, the timber sorting station study and the sawing study.

6.1 Control measurements

The control measurement's section consists of the following three different regional comparisons; non-sawable (reject) logs included, sawable logs only and cause for quality reduction to the lower grade. Detailed results from the control measurements are presented later in the report (see appendix 9.2).

6.1.1 Comparison North/ South/East catchment areas including non-sawable timber in all diameter range

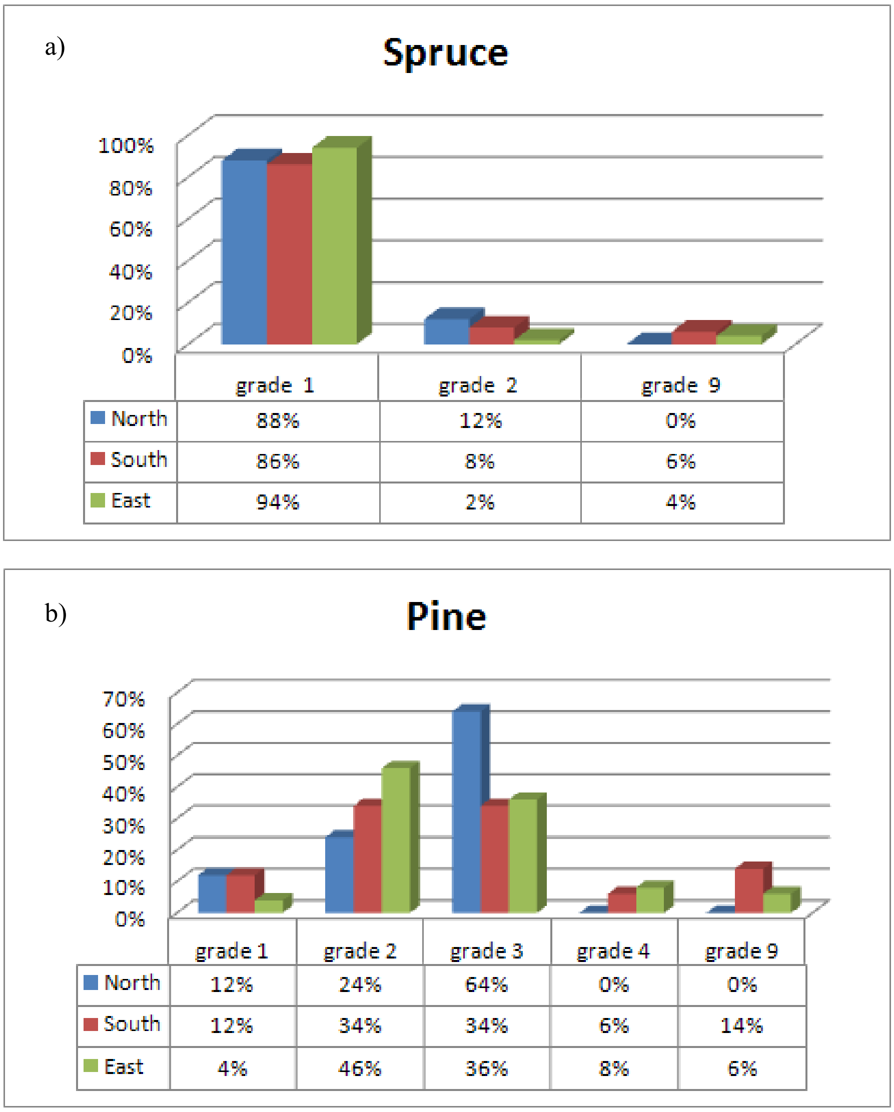


Figure 6.1. Figure showing the result from control measurements for a) spruce and b) pine.

The variation among Norway spruce and Scots pine samples from three different regions has been summarized in figure 6.1 a+b. The largest proportion of higher grade (grade 1) for spruce, 94 % was observed in the Eastern region and the lowest proportion, 86 % was observed in the Southern region. The Northern region had 0 % reject (grade 9). The volume was graded as lower sawable grade (grade 2).

The results from Scots pine show that the Northern and Southern regions received the equal amount of grade 1, 12 %. As for the Northern region, however, the largest share was observed for grade 3 with 64 %, and no observations were made for the lower grades 4 and 9. For the Southern region on the other hand the largest proportion of grade 9, 14 % was observed. As for the Eastern region, approximately half the amount of logs was observed in grade 2. The share of grade 1 was the least for the Eastern region with only 4 %.

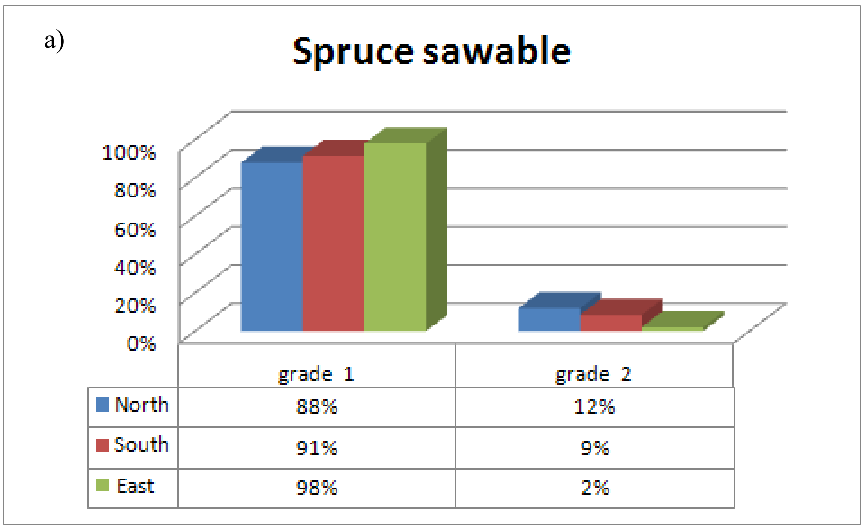
The cause for the rejection (grade 9) of the Spruce and Pine sawlogs was almost entirely due to crooked stems, except one pine log from the Southern region which was not delimbed properly.

6.1.2 Comparisons between the catchment areas in terms of obtained sawtimber in all diameter classes

The sawtimber was divided into two different quality classes. The lowest grade for sawable timbers, grade 2 for spruce, and grade 4 for pine, was sorted separately to study how the yield affected by sawing the lower-graded timber.

The variation in the Norway spruce sawable timber samples over the three different regions is presented in figure 6.2 to the left. It shows that the Eastern region had the largest share of grade 1, 98 %. The lowest share of better grade was observed in the Northern region with 88 %.

As for the Scots pine sawable timbers, the results show a slight difference compared to Spruce. All the volume from the Northern region was assorted as grade 1-3, meaning 0 % in grade 4. The smallest share of grade 1-3 observed was 91 % in the Eastern region (see figure 6.2). This was the same region as the best performance on spruce timber was found.



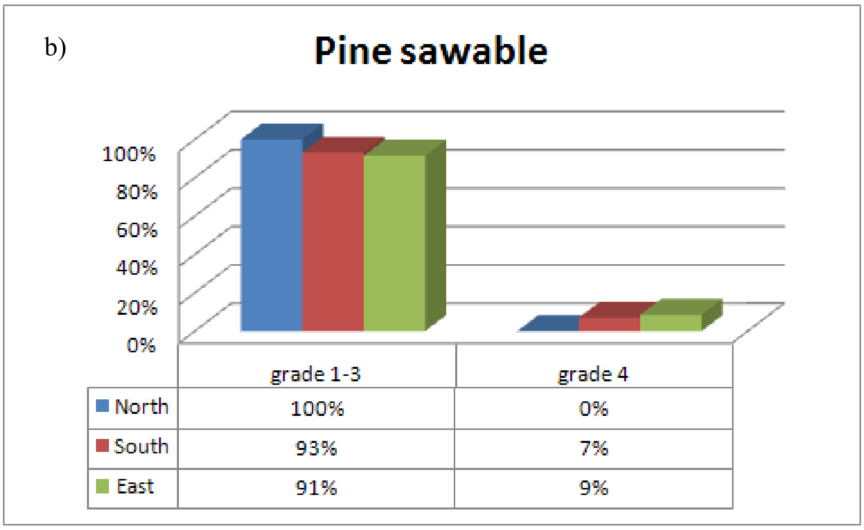


Figure 6.2. The result from dividing sawable timbers into superior and inferior timber qualities per region for a) spruce and b) pine.

6.1.3 Comparison of the cause for quality reduction between regions

The cause for quality reduction for all control batches are presented below in table 6.1. The reasons varied, however with a relatively heavy concentration on crook, especially in the South. The general impression of the timber from the Eastern region was that it appeared to contain relatively larger fresh knots, particularly in the pine material. Remarkably on 18 % (9 out of 50 logs) of the pine timbers from the Northern region was graded as sawable, but with reduction on the saw cylinder with 1 cm due to open stem scars. This was presumably caused by the earlier thinning operations (Eriksson, pers. message, 2010-06-28) (see appendix 9.2 for detailed information).

Table 6.1. Table showing cause for quality reduction by region.

Quality Reduction Cause	Spruce			Pine		
	North	South	East	North	South	East
grade 2 (spruce) or 4 (pine) pcs	6	4	1	0	3	4
knots						50%
growth rings		25%				
forest rot	33%	25%				
straightness	17%	25%			67%	25%
top break	17%		100%		33%	25%
blue stain						
spike holes + splits fr felling/cross-cutting						
(for spruce even)						
open scar	17%	25%				
bark-encased scar	17%					

6.2 Timber sorting plant

The following results are based on visual grading by a timber grader from the regional timber measurement association (VMF Qbera) at the timber sorting plant.

Slightly over 25 000 logs were collected for the experiment. Grading results from the timber sorting plant contains three different factors; sawable and non-sawable (reject), cause for the rejection and sawable logs only.

6.2.1 Comparison between North/South/East catchment areas in terms of sawable/non-sawable timber in all diameter classes

Table 6.2. Table showing the grading result from the log sorting plant.

species	region	on-grade		reject					
		pcs	$m^3$to ub	pcs	share	$m^3$to ub	share	mean	stdv
spruce	North	5401	364,49	56	1,03%	3,98	1,08%	1,29%	1,10%
	South	3419	229,55	57	1,64%	3,91	1,67%	2,37%	1,30%
	East	4389	300,78	81	1,81%	5,61	1,83%	2,26%	1,41%
	tot	13209		194	1,45%				
pine	North	5287	376,45	74	1,38%	5,6	1,47%	1,49%	1,14%
	South	3767	265,04	85	2,21%	5,82	2,15%	2,19%	1,55%
	East	2343	161,39	222	8,65%	15,89	8,96%	9,98%	6,80%
	tot	11397		381	3,23%				
tot		**24606**		**575**	2,28%				

It shows quite stable results regarding spruce timber. Rejected share was the highest in the Eastern region with 1.81 %. The lowest share was observed in the Northern region with 1.03 %. The total rejected share for spruce from these experimental materials was 1.45 %.

As for pine timber the results varied somewhat from the lowest 1.38 % in the North to the highest 8.65 % in the East. The total rejected share for pine was 3.23 %.

Total rejected share for both species from all three regions was calculated to 2.28 % for the experimental material.

When comparing the results with the average percentage for reject share for Krylbo reported during January – May 2010, it was slightly better with 1.44 % for spruce and 2.04 % for pine, 1.64 % in total.

6.2.2 Comparing the cause of rejection over different regions

Table 6.3. Table showing cause for the rejection and its share for each region.

Reject Cause	Spruce			Pine		
	North	South	East	North	South	East
species/assort fault				1%	1%	
crook	50%	84%	73%	96%	95%	97%
forest rot	36%	9%	22%			
diameter fault			1%			
length fault						
quality fault (e.g. knots)					2%	
processing fault (e.g. buttress, spike knot)	12%	7%	3%	2%	2%	3%
metal etc	2%		1%			1%
storage decay						

As table 6.3 shows, it has been a heavy concentration on crooked timber as a cause for the rejection among all three regions and on both species, but particularly on pine logs since over 95 % of the rejects were due to crooked stems. The second largest cause for rejection for spruce timber was forest rot. The share of each rejection was calculated based on the volume.

6.2.3 Comparisons between North/South/East catchment areas for sawable timber in two different dimension ranges

In contrast to the control measurements, the experimental materials are here limited to two diameter ranges, S 148 and S 173 for spruce and P 147 and P 170 for pine. The results show the average of those two ranges per species.

As the figure 6.3 shows the largest share of grade 1 for spruce was observed with 97 % in the Northern region. The other two regions displayed quite similar results, with 91-92 % in the better grade. See results from the control on the right for comparison.

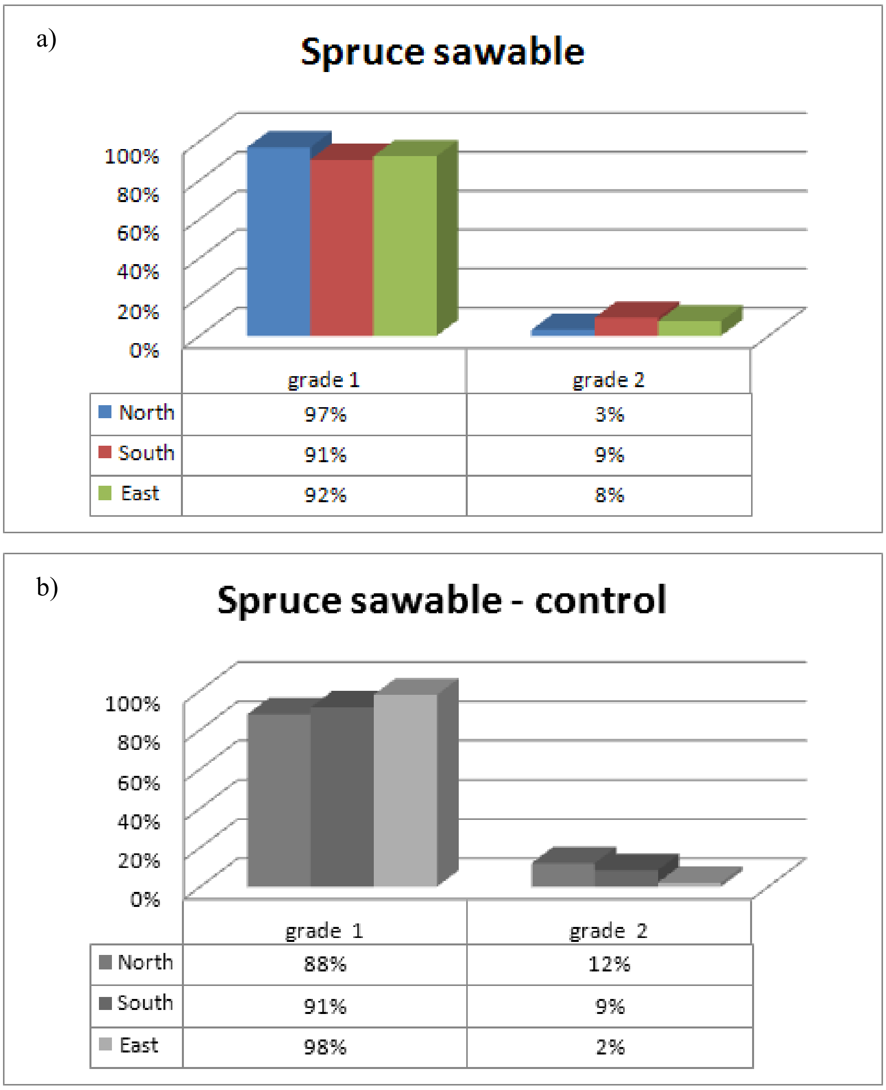
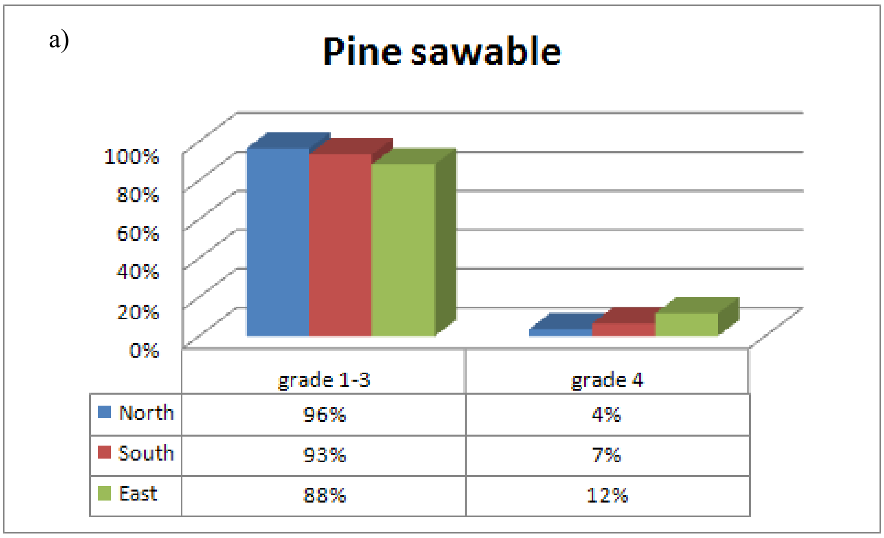


Figure 6.3. a) The results from dividing sawable spruce timbers in two diameter classes, S 148 and S 173, superior and inferior timber qualities presented by region. See results from the control b) for comparison.

The largest share of grade 1-3 for pine was observed with 96 % in the North, followed with 93 % by the South and finally with 88 % by the East (see figure 6.4 below), in the same order as in the control measurement.



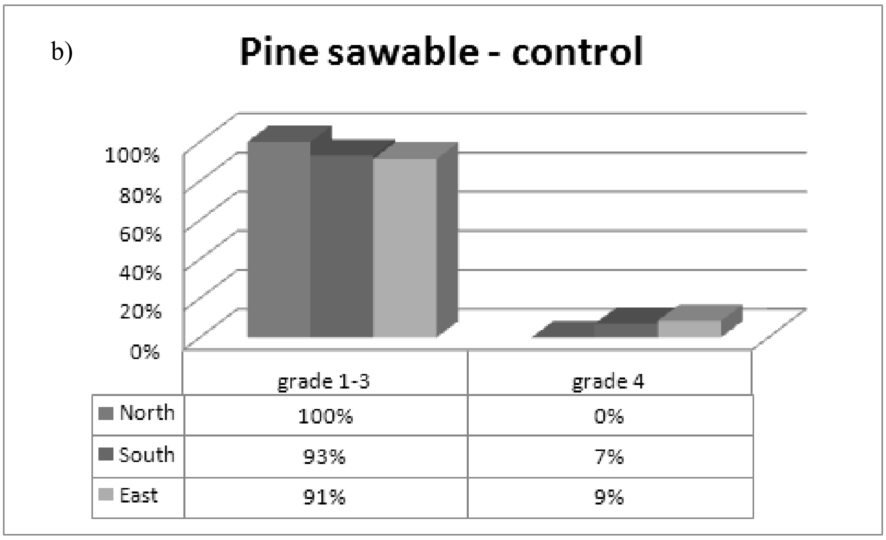


Figure 6.4. a) The result from dividing sawable pine timbers in two diameter classes, P 147 and S 170, superior and inferior timber qualities presented by region. See results from the control b) for comparison.

6.3 Grading mill - comparison of sawn timber

The results are based on the quality estimates obtained from Woodeye-data. It is presented in relation to two important issues.

- *Comparison between North/South/East regions*
- *Comparison between the better and the poorer timber quality*

The comparison between the three regions is based on yield per species and cause for quality reduction. The comparison between two different timber qualities consists of yield per species and region. As a final comparison, profitability of sawn timber from each species and region is calculated.

No consideration has been made regarding possible defects caused by mould or blue stain in the following results.

6.3.1 Comparison between the catchment areas in terms of obtained yield from sawn lumber 24x110 mm

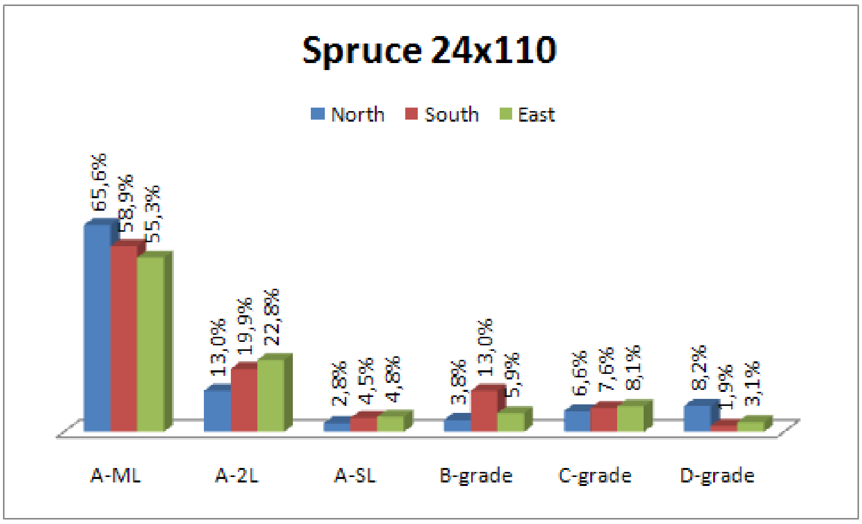


Figure 6.5. Comparison between different regions for spruce lumber 24x110 mm.

As figure 6.5 shows the Northern region had the largest share of A-grade Main Length (A-ML). On the other hand, it had also the largest share of D-grade among the three regions. All three lengths of A-grade together provide the least share with about 81 % in the North.

The other regions, South and East, received a fairly equal amount of A-grade as a total (all lengths), however the outcome when it comes to length recovery differs remarkably, with about 59 % of A-ML and about 20 % of A-2L from the South while about 55 % of A-ML and 23 % of A-2L from the East.

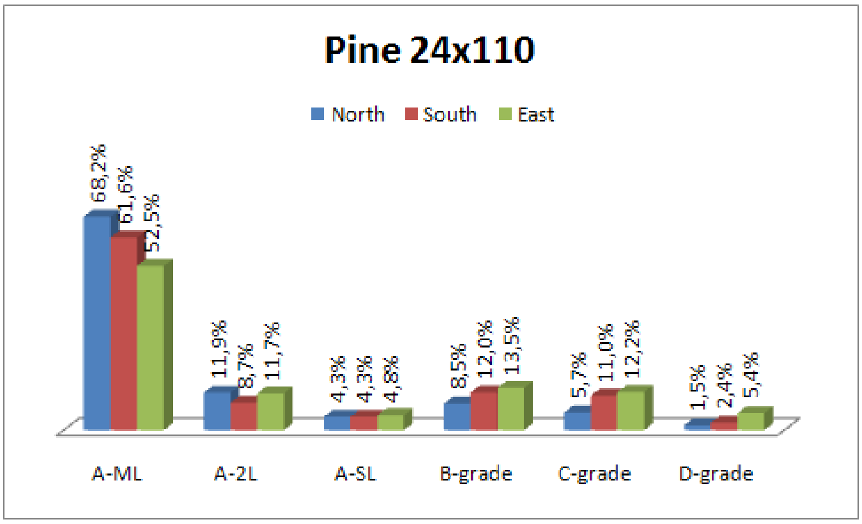


Figure 6.6. Comparison between different regions for pine product 24x110 mm.

As for the pine 24x110 mm dimension (see figure 6.6) it was observed as having the largest share of A-grade as a total (all lengths) with about 84 % in the Northern region. Corresponding numbers in the South and East were 75 % and 69 % respectively.

Results regarding A-grade Main Length (A-ML) which provides the highest recovery was observed in the same order, the largest share with about 68 % in the North, with about 62 % in the South and with about 53 % in the East.

The Northern and Eastern regions had approximately the same amount of A-grade Second Length (A-2L), about 12 %. The Southern region had the least share of A-2L, about 9 %. Variation in A-grade Short Length (A-SL) between three regions was insignificant, within 0.5 %.

6.3.2 Comparison North/South/East cause for the quality reduction

The cause for the quality reduction is presented with five different criterions, which are considered as important facts deciding lumber quality, especially for structural purposes. The remaining types of defects as for instance moisture contents, mould, knots etc. are included in the category "others". No remarkable differences between different lots are found from the results for moisture content, at the maximum 0.07 % for both spruce and pine.

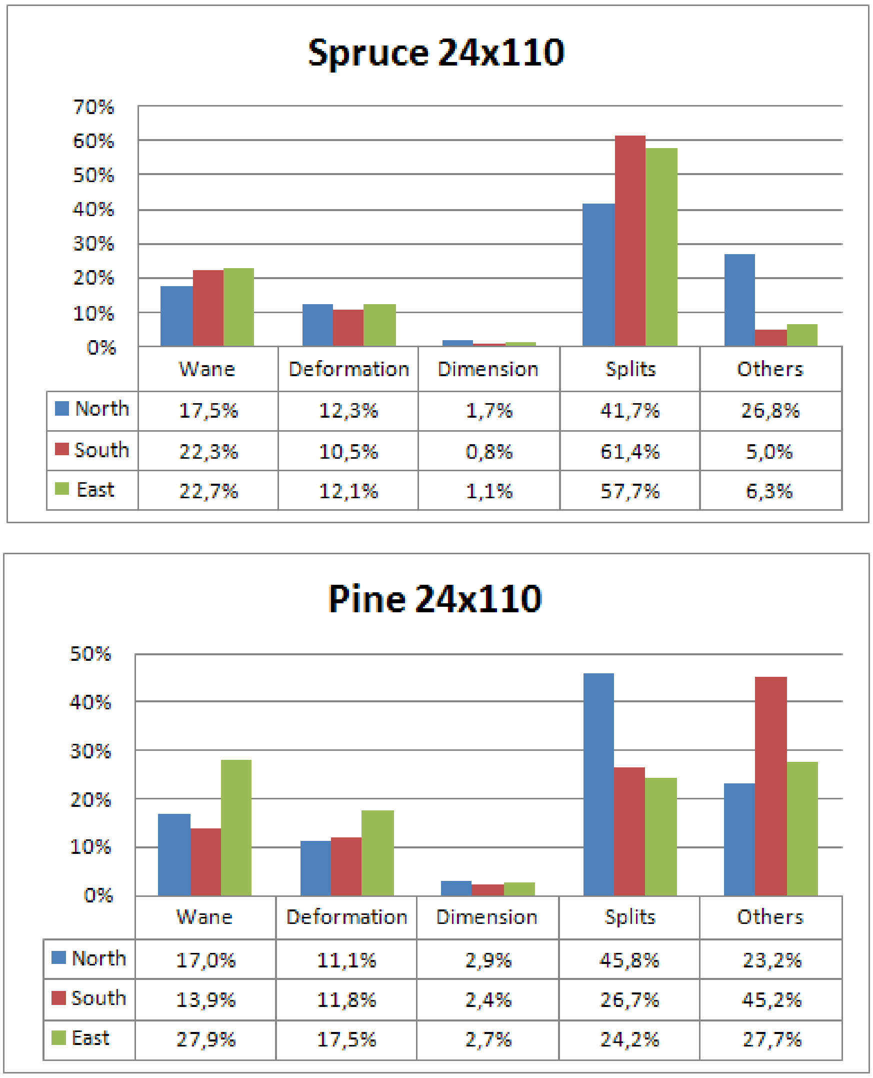


Figure 6.7. Diagram showing the causes for quality reduction and its share per region.

As for the spruce, the most serious cause for quality reduction was splits in all three regions. The South and the East show more or less identical results. With splits representing about 60 % of the quality reduction cause. The second biggest issue for the same regions was wane with over 20 % and the third deformation as twist, crook and bow with about 10 %. The Northern region was registered with a notably large share of other defects, in this case mould.

As for the pine, however, the splits still represent the major issue in the North, while in the Eastern region, wane was the biggest issue and for the South, “other defects”.

6.3.3 Comparison between recovery levels with two different log qualities

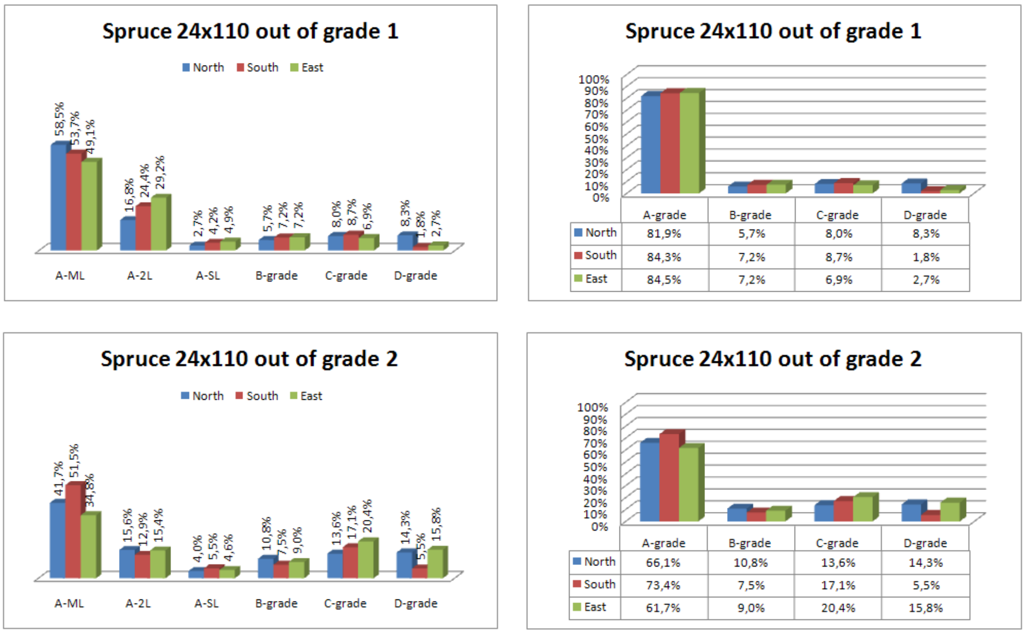


Figure 6.8. Diagrams showing comparison between recovery performances on sawn lumber produced with grade 1 versus 2 spruce timbers.

The results show there is a major difference between recovery performances among the two different log grades in all three regions. Differences are registered at the most as about 17 % in the Northern region for A-ML grade. Clearly the logs in the poorer quality conditions decrease the recovery levels.

Table 6.4. Differences between recovery percentages, grade 1 vs. 2.

	A-ML	A-2L	A-SL	B-grade	C-grade	D-grade
North	16,8%	1,2%	-1,4%	-5,0%	-5,6%	-6,0%
South	2,2%	11,5%	-1,3%	-0,3%	-8,5%	-3,6%
East	14,2%	13,9%	0,3%	-1,7%	-13,6%	-13,0%

	A-grade	B-grade	C-grade	D-grade
North	15,9%	-5,0%	-5,6%	-6,0%
South	11,0%	-0,3%	-8,5%	-3,6%
East	22,9%	-1,7%	-13,6%	-13,0%

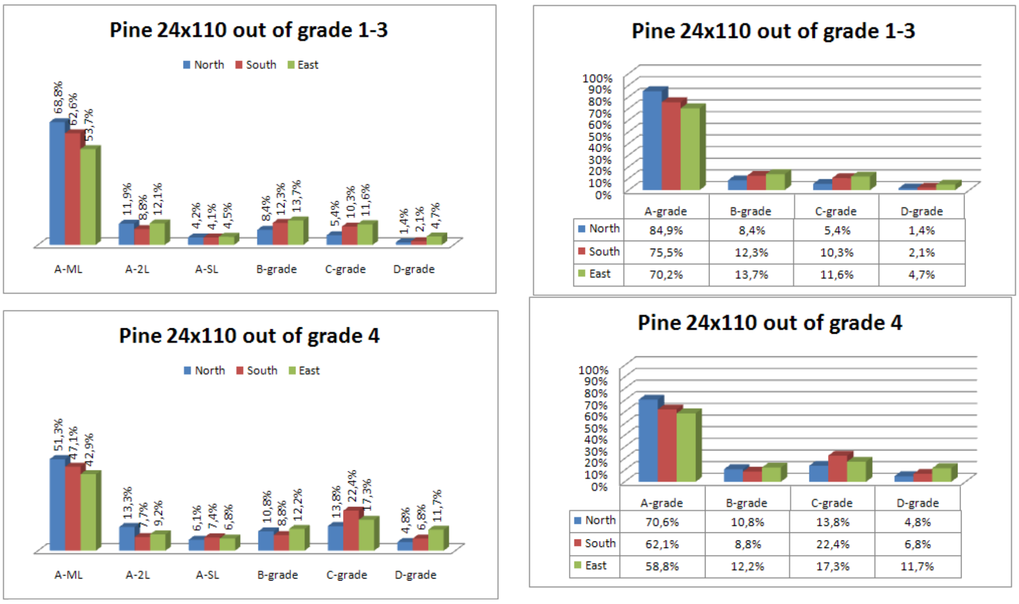


Figure 6.9. Diagrams showing comparison between recovery performances of sawn lumber produced with grade 1-3 versus 4 for pine timbers.

Again the results show a remarkable difference between recovery performances from two different log grades. Differences for A-grade were more than 10 % in the North and the East. The largest difference was shown again in the Northern region with about 18 % difference in A-ML grade. Most of the share that disappeared from the A-grade was found in the C-grade category.

Table 6.5. Differences between recovery percentages, grade 1-3 vs. 4.

	A-ML	A-2L	A-SL	B-grade	C-grade	D-grade
North	17,6%	-1,4%	-1,9%	-2,4%	-8,4%	-3,4%
South	15,5%	1,2%	-3,3%	3,5%	-12,1%	-4,8%
East	10,8%	2,9%	-2,3%	1,5%	-5,7%	-7,1%

	A-grade	B-grade	C-grade	D-grade
North	14,3%	-2,4%	-8,4%	-3,4%
South	13,4%	3,5%	-12,1%	-4,8%
East	11,4%	1,5%	-5,7%	-7,1%

6.3.4 Comparison in terms of profitability (contribution margin)

Profitability was calculated using the identical log prices, production cost, sawing patterns per assortment, as well as the identical price for the same product and byproduct for fair comparison.

Considering two different species, the most profitable sawing was observed in the South for spruce timber and in the North for pine timber. The lowest profitability was found in the North for spruce and in the East for pine.

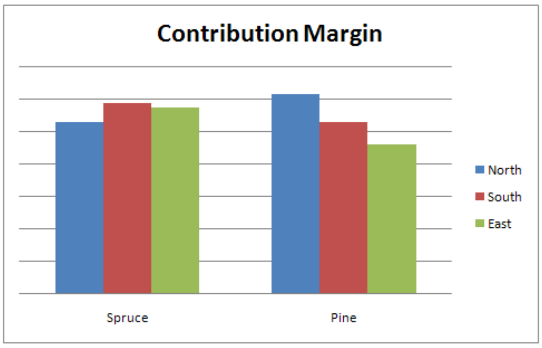


Figure 6.10. Diagram showing the differences on profitability among three regions per species.

The highest profitability for spruce timber was found with southern spruce in S 173 diameter range graded as grade 1. The lowest was found with eastern spruce in S 148 diameter range graded as grade 2. Remarkably the highest had three times higher contribution margin (CM) per m^3 sawn goods compared to the lowest.

For the pine timber the highest CM was found with northern pine in the P 170 diameter range graded as grade 1-3. The lowest was found with eastern pine in the P 147 diameter range graded as lower grade timber. The highest received twice high profitability compared to the lowest.

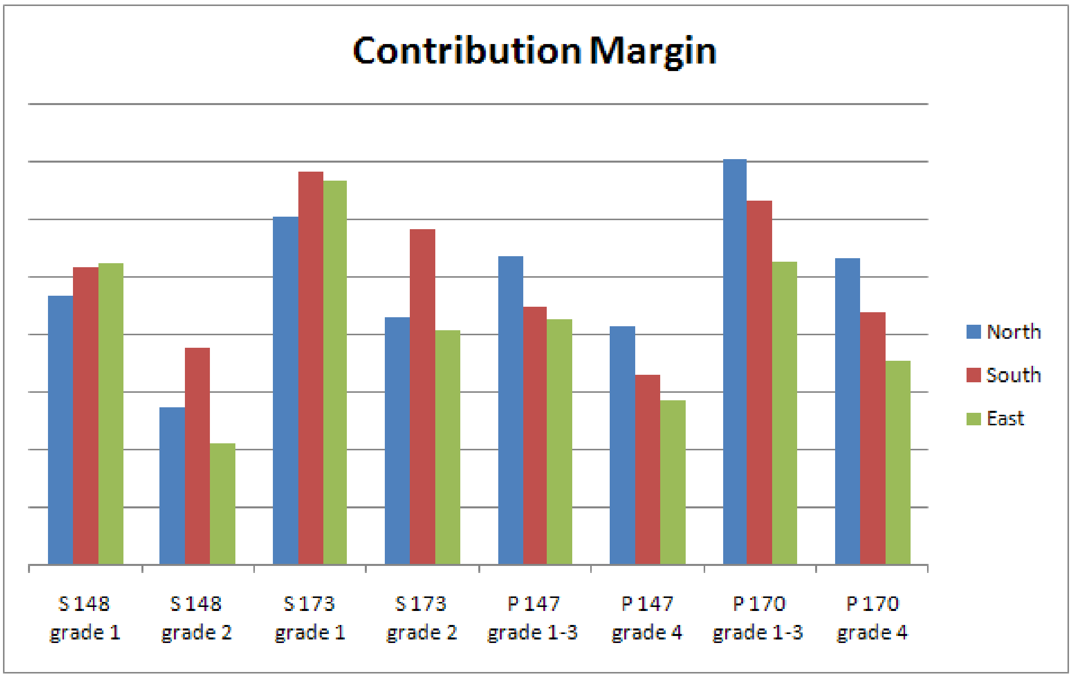


Figure 6.11. Diagram showing the results on contribution margin 2 (SEK per m^3 sawn goods) for different regions, timber quality and dimension ranges, where S stands for spruce and P stands for Pine.

As figure 6.11 shows grade 1 spruce timber displays quite a similar CM level over regions, especially those from the South and the East. However there is a remarkable difference in grade 2 spruce timbers, where the Southern region shows 40-80 % better profitability compared to the other two regions.

As for pine timber, the Northern region shows the highest CM in all categories, followed by the South and finally the East. It is noteworthy that P 147 grade 4 from the Northern region is showing the same profitability level as P 147 grade 1-3 for the South and the East. The similar tendency has been seen in P 170 grade 4 from the North, which was as profitable as grade 1-3 from the East.

7 DISCUSSION AND CONCLUSIONS

7.1 For fair log pricing

According to the « stem bank » provided by VMF Qbera, quality distributions on sawlog spruce and pine timbers differs between different areas as it shows in table 7.1 (Möller & Moberg, 2007).

Table 7.1. Table showing the timber quality distributions for corresponding areas for the Krylbo mill's catchment area. Area 1 corresponding the North region and Area 2 corresponding the South + East regions (see figure 7.1).

Spruce	grade 1 (%)	grade 2 (%)	grade 9 (%)
area 1	88,8	9,3	1,9
area 2	83,4	14,3	2,3

Pine	grade 1 (%)	grade 2 (%)	grade 3 (%)	grade 4 (%)	grade 9 (%)
area 1	22,2	10,5	54,7	10,6	2,0
area 2	14,8	9,1	58,5	16,0	1,6

Comparing with the experimental results, the Northern region follows the VMF Qbera's distribution patterns quite well except that the frequency of rejected timber was much lower (0 %) in the control measurements for both species.

Log pricing is determined by its quality and assortment. A larger share of grade 1 timber increases the raw material cost. No rejected timber has the same kind of effect but often larger effect due to the wider price difference between sawable and non-sawable timber. The better quality timbers with higher material costs are expected to give both industries and their end-customers a better profitability.

Figure 7.1. Map showing regional divisions within VMF Qbera's area (Möller & Moberg,, 2007).

The results show that there is a correlation between quality distributions of raw materials and recovery distributions on sawn products. Both species have shown clear differences between recovery performances from two different log grades. The spruce grade 1 timber gave about 11-23 % higher recovery result on A-grade sawn product. The pine grade 1-3 timber gave about 11-14 % better recovery result on A-grade total (all lengths) compared with grade 2 and grade 4 timbers in inferior quality.

An obvious effect was observed for the contribution margins (CM). Using lower grade logs meant about 20-48 % CM reduction for spruce and about 24-33 % CM reduction for pine for the saw mill according to the test sawing results (figure 7.2).

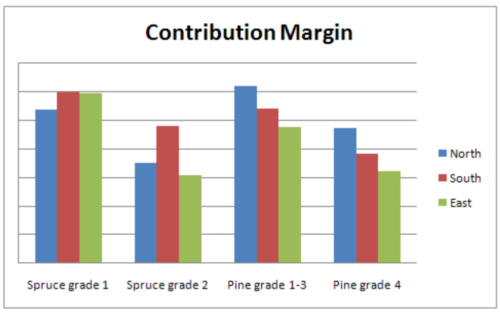


Figure 7.2. Diagram showing the CM by cutting better log grade versus poorer log grade per region.

Under the condition that sawable logs are priced regardless of their quality today in

Krylbo, these results puts today's fair pricing on raw materials in question. It is apparent that the lower-quality-logs are overvalued and the better-quality-logs are undervalued.

7.2 Regional variations

The investigation of the regional variations within the catchment revealed significant variations among the three regions regarding timber quality of pine timber. However less obvious differences were found regarding spruce (see appendix 9.3 for the significance analysis).

The experimental results also show that there is a stronger correlation between quality of the raw materials and the yield of sawn products for pine, however weaker or no correlation for spruce, which could be explained by the raw materials' localization.

As for the pine timber, the Northern region delivered the best results on timber quality and on finished products' recovery. It was followed by the Southern region and finally the Eastern region. The main issue with the Eastern region was due to deformations in the raw materials, especially crook. It was registered as a major cause for the quality reduction from log sorting station to grading mill, which confirms the earlier studies by Henderson and Petty (1972). The results from the timber sorting station show over 200 logs (out of approx. 2 500) from the Eastern region have been rejected due to the stem crookedness. The logs with smaller defects (e.g. < 30 cm loss of the yield) are possibly still causing the poorer recovery on the finished products. The difference between outcome of A-grade 24x110 mm from the North and the East was whole 15.5 %, decreasing the CM by over 25 %. When comparing the North with the South there was a 9.8 % difference in A-grade recovery performance, which decreased the CM by about 14 %. The poorer quality pine timer from the North had the same profitability level compared to the better quality pine timber from the South and the East. The regional variations of timber quality and finished products' recovery put today's fair pricing on pine timber in question.

In contrast with pine timber, the result from control measurements of spruce timber was observed in the opposite order, 1) East, 2) South and 3) North. However the results from the timber sorting station (sawable vs. non-sawable timber) was observed in the same order as pine, 1) North, 2) South and 3) East. Unexpectedly the profitability was found in a new order, 1) South, 2) East and 3) North, meaning the Southern logs were underestimated and gave a better profitability than expected, while logs from the other two regions were relatively overevalued and gave a poorer CM.

The main cause behind the quality reduction of spruce A-ML-grade was observed to be registered splits. According to Persson (1994) low basic density is a precondition for stem cracks to develop. The visualization of variations in basic density levels of spruce by using the wood property prediction model by Arlinger et al. (2002) (figure 5.4) shows that the southern area has the highest density levels comparing with the other two regions. Considering the CM performance from the southern region, it indicates that collecting spruce timber from the South seems to be the best alternative for the Krylbo mill. The problem with splits on the other hand might be a seasonable issue during the summer, since the main cause for the quality reduction through January-May 2010 was reported as wane (Fernvik, pers. message, 2010-07-12).

7.3 Possible weaknesses of this study

Transportation costs have not been taken in consideration for calculation of the yield for this experiment. It is possible to make further investigations on the average timber transportation cost for each region for better understanding of the regional variations. The result can also be used to make decisions about the threshold for "how far you could go to fetch the better timber quality".

There is a risk that an error was made during resorting of experimental materials according to the report from the log sorting station. One grapple (about 75 logs) in diameter class Pine 147 from the East was mixed-up with Pine 170 East, which could have played a crucial role for recovery performance of the Eastern region for pine timber and it actually shows on the recovery performance report that the Eastern region had a large share of wane problems as quality reduction cause for pine though the most important consequence should have been found on the side boards. The recovery performance might be descended from the other factors since the same region received over 200 logs that were rejected due to crook.

7.4 Conclusions

Following conclusions are reached by this study (see appendix 9.3 for significant analysis).

- *There is a correlation between quality distributions on raw materials and recovery distributions on sawn products. At least 20 % (at the most 48 %) of CM reduction has been caused by producing with raw materials of inferior quality. The result should be taken in consideration for possible future pricing based on timber quality and in that case the increases in sorting cost should be also analyzed and included in the calculation.*
- *There is a significant variation in pine timber quality between different regions within the Krylbo mill's catchment area. A correlation between quality distributions of raw materials and recovery distributions of sawn products was found for pine timbers. The result encourages the reconsideration of putting priority on a certain catchment area or stretching thresholds for transport distances towards the direction of the area with better profitability.*
- *There is a weaker or not significant variation in spruce timber quality between different regions within the Krylbo mill's catchment area. No correlation between quality distributions of raw materials and recovery distributions of sawn products was found for spruce timbers. It is not necessary to put any priority on any certain area for spruce timber as long as the raw materials collected in a similar way and under the assumption that market requirements remain the same.*

7.5 Future quality determination

Log quality is determined visually at the Krylbo mill's log sorting station today. It requires good skills and competence to determine « internal defects » while inspecting the exterior of the logs. During the last decade the development of an automatic log quality determination procedure has been in focus both in the forest and at the industries.

The automation is a great challenge since not only seasonal factors and geographical factors needs to be included but various variables affecting this living material's properties needs consideration. At the same time the requirement from end-customers' changes as the market constantly moves in different directions and the customer oriented marketing seems to be the necessary choice to keep a position in the market.

The continuous improvement of the customer adaptive system in the forest seems necessary for further development in the future. Modern cut-to-length harvesters have a system function, called « adaptive stem prognosis ». This function enables the system to successively learn for instance mean taper of the stand and adapt bucking within the site. It would be ideal if bucking adaptation could adjust directly to the current requirements from the customers' side and adjust the volume and time as well as quality while the same machine is learning its local conditions within the site.

Communication and cooperation as well as accuracy of the reported information from harvesting site seems to be the key to make fast and good decisions as well as to make a proper production and transport plan from forest to industries.

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9 APPENDIX

9.1 Measuring rules for pine and spruce sawlogs VMR 1-07

These rules apply to pine (*Pinus silvestris*) and spruce (*Picea abies*) roundwood intended for sawing.

Basic requirements for measurement of pine and spruce sawlogs

Basic requirements according to the Swedish Forest Agency (SKSFS 1999)

A sawlog must:
- Have been cut from a live stem section and crosscut with a saw.
- Be free from insect damages and storage decay (applies to the wood).
- Be free from coal, soot, stones, metal and plastics (applies to wood and bark)

Additional requirements recommended by the Timber Measurement Council (VMR)

A sawlog must:
- Not have buttresses higher than or equal to 15,0 cm.
- Not contain gravel in neither wood nor bark.
- Not contain more than 5 % forest rot on the end surface (buttresses not included) Forest rot caused by *Phellinus pini* is not allowed.
- Fulfil the length and diameter requirements set by the trading parties.
- Be satisfactorily straight (a maximum of 120 cm loss of saw yield where both log
- halves must fulfil the length requirement).
- Not have open scars, indents caused by feed rolls, splits from felling or crosscutting or other stem damages (except for flutes) that affect more than 20 % of the diameter of the scaling cylinder.
- Not have shakes or splits originating from the growing tree. Heart shakes are allowed.
- Not have spike knots larger than 120 mm.
- Be satisfactorily delimbed or delimbed according to agreement.

Scaling of volume

A delivery of sawlogs that is to be graded into more than **one** grade must be measured log by log. The scaling of volume can be based on top measurement, top and butt end measurement or by measurement of sections. Sampling methods are allowed.

Grading

A log’s grade is based on its properties on the whole mantle surface and on both end surfaces. If the log´s position on the ground or on the conveyor can be regarded as random, it is sufficient to regard only the exposed part when grading. According to agreement between buyer and seller, grades may be merged or excluded. If all grades are merged the grade is set to 0.

Pine grades

	Grade			
	1	2	3	4
Log type	Butt log	Not butt log	All log types	All log types
Knots, whole mantle surface	Max 20 mm, all knot types. Max 5 knots	Sound knots max 120 mm. Other knots max 60 mm.	Sound knots max 120 mm. Other knots max 60 mm	Spike knot max 120 mm. Other knots unlimited.
Knot within 15 dm from butt end		A minimum of two distinct whorls or one sound knot		
Knot swelling	Max 5			
Growth rings 2-8 cm from pith	Minimum 20		Minimum 12	
Straightness	Max. 20 cm loss of saw yield			Max. 120 cm loss of saw yield
Indication of top rupture	Not allowed			Allowed
Blue stain	Not allowed			Allowed
Forest rot	Not allowed			Max 5 % of end surface

Tolerance:

- Knot, knot swelling, flutes and scars within 20,0 cm from log end (applies also to causes for reject). Tolerance may be applied only for one log end.
- Scars, including holes after pulled-out branches, shorter than 7,0 cm.

Definitions:

- For grade 1 sound knots are taken into account if their diameter ≥ 15 mm, other knots if they are ≥ 9 mm.
- For grade 2 sound knots are taken into account regardless of their diameter.
- A distinct whorl comprises at least two knots ≥ 15 mm.
- Indents caused by feed rolls, splitting, other stem damages and scars from pulled-out branches are regarded as open scars.
- Growth rings are counted in the radial direction which gives the least number of rings.
- Scaling cylinder: a straight cylinder based on a cross-callipered top end diameter minus 15 mm. If the measurement unit is cm, the scaling cylinder is based on the top end diameter minus 1 cm.
- Loss of saw yield: length of the scaling cylinder which does not fit into the actual log due to crook.

Deduction of diameter (pine)

If a log has scars or flutes that affect the scaling cylinder it's diameter is deducted by 1 cm unless these defects are within 20 cm of one log end (tolerance).

Spruce grades

	Grade	
	1	2
Knots, whole mantle surface	Max 60 mm regardless of knot type	Spike knot max 120 cm. Other knots unlimited.
Growth rings	Min 12	
Straightness	Max 20 cm loss of saw yield	Max 120 cm loss of saw yield
Indication of top rupture	Not allowed	Allowed
Blue stain	Not allowed	Allowed
Open scar	Scar which affects the scaling cylinder is not allowed	Depth of scar max 20 % of scaling cylinder diameter.
Bark-encased scar	Length max 2 x top end diameter	Allowed
Forest rot	Not allowed	Max 5 % of log end surface

Tolerance:

- Knot, knot swelling, flutes and scars within 20,0 cm from log end (applies also to causes for reject). Tolerance may be applied only for one log end.
- Scars, including holes after pulled-out branches, shorter than 7,0 cm.

Definitions:

- For grade 1 sound knots are taken into account if their diameter ≥ 15 mm, other knots if they are ≥ 9 mm.
- For grade 2 sound knots are taken into account regardless of their diameter.
- A distinct whorl comprises at least two knots ≥ 15 mm.
- Indents caused by feed rolls, splitting, other stem damages and scars from pulled-out branches are regarded as open scars.
- Growth rings are counted in the radial direction which gives the least number of rings.
- Scaling cylinder: a straight cylinder based on a cross-callipered top end diameter minus 15 mm. If the measurement unit is cm, the scaling cylinder is based on the top end diameter minus 1 cm.
- Loss of saw yield: length of the scaling cylinder which does not fit into the actual log due to crook.

Logging damages

Logging damages are splits in log ends originating from felling or cross-cutting, and spike holes caused by the feed rolls of the harvester. Logging damages are classified by delivery.

Splits from felling and cross-cutting

If a delivery at visual examination exhibits splits in more than 1 % of the logs the delivery is classified as damaged.

To be taken into account the split, as observed in the end surface, must be 1) tangential 2) affect the scaling cylinder and 3) reach the mantle surface.

Spike holes

A log is considered to be damaged if spike holes caused by the feed rolls have penetrated deeper than 6 mm (the truncated value which means that 6.0 – 6.9 mm are registered as 6 mm) into the wood. The depth is measured from the mantle surface under bark and the damage includes broken or torn fibres. The delivery is classified as damaged if more than 5 % of the logs have spike holes.

Logging damage classification chart

	No spike holes	Spike holes
No splits from felling or cross-cutting	1	2
Splits from felling or cross-cutting	3	4

Scaling and grading requirements

Sawlogs that are collectively measured in stacks must fulfil the same basic requirements as sawlogs measured log by log. Additional requirements are:

- Forest rot, black wood and aniline coloured wood is not permitted
- Blue stain is not permitted
- Max 1 % bow height for logs cut to standard length
- No diameter deductions for pine

Scaling of volume

The volume is determined by measuring the dimensions of the stack in conjunction with estimation of the wood volume percentage.

Determination of the share of reject logs

The share of reject logs may be estimated from the visible sides of the stack. The logs that are exposed are to be regarded as a sample from which the occurrence of reject logs is determined.

When the occurrence of reject logs is difficult to determine or if the occurrence is approaching the permitted level, the stack must be spread out and examined more carefully.

9.2 Detailed results control measurement

Reg.	North		Species	Spruce
log No.	**grade**	**quality reduction cause**		**comments**
1	1			
2	2	forest rot < 5 %		
3	1			strong fibre twist
4	1			
5	1			
6	1			
7	1			
8	1			
9	1			
10	1			
11	1			
12	1			
13	1			
14	1			
15	1			
16	1			
17	1			
18	1			
19	1			
20	1			bigger knot, within toleration Ø≈50mm
21	1			
22	1			
23	2	crook < 20 cm		tolerance 1 cm reduction saw cylinder
24	1			open scar < twice top diam
25	1			
26	1			
27	1			flutes on spruce => seldom defect => OK
28	2	spike knot + top break		
29	1			
30	1			
31	1			
32	1			
33	1			
34	1			
35	1			
36	1			
37	1			
38	1			
39	1			
40	2	bark-encased scar bigger than twice top diam		
41	2	forest rot < 5 %		not going up 15 cm from mantle surface
42	1			
43	1			
44	1			
45	1			
46	1			
47	1			
48	1			
49	1			
50	2	open scar		tolerance defect < 7 cm (apart fr natural open scar e.g. woodpecker hole or saw mark)

Reg.	South		species	Spruce		

log No.	grade	quality reduction cause	comments
1	1		
2	1		
3	1		
4	9	crook > 30 cm yield loss	
5	1		
6	1		
7	1		
8	2	20 cm < crook < 30 cm yield loss, growth rings > 12 rings within 2-8 cm fr pith	
9	1		
10	1		
11	1		
12	1		
13	1		
14	1		
15	1		
16	1		
17	1		
18	9	crook > 30 cm yield loss	
19	1		
20	1		
21	1		
22	1		
23	1		
24	1		
25	1		
26	1		
27	1		
28	1		
29	1		
30	1		
31	1		
32	1		
33	1		
34	1		
35	1		
36	1		
37	9	crook > 30 cm yield loss	
38	1		
39	1		
40	1		
41	1		
42	1		
43	1		
44	1		
45	1		
46	1		
47	2	open scar within saw cylinder	
48	1		
49	2	forest rot	
50	2	20 cm < crook < 30 cm yield loss	

Reg.	East	Species	Spruce
log No.	**grade**	**quality reduction cause**	**comments**
1	1		
2	1		
3	1		
4	1		
5	1		
6	1		
7	1		
8	1		
9	1		bark-encased scar > twice top diam
10	1		
11	1		
12	1		
13	1		
14	1		
15	1		
16	9	crook > 30 cm yield loss	
17	1		
18	9	crook > 30 cm yield loss	
19	2	top break	
20	1		
21	1		
22	1		
23	1		compression wood/swerve crook OK due to relatively large butt end
24	1		
25	1		
26	1		
27	1		
28	1		
29	1		
30	1		
31	1		
32	1		open scar not affect saw cylinder
33	1		
34	1		
35	1		
36	1		
37	1		
38	1		
39	1		
40	1		
41	1		
42	1		
43	1		
44	1		
45	1		
46	1		
47	1		
48	1		
49	1		
50	1		

Reg.	North		Species	Pine
log No.	grade	quality reduction cause	comments	
1	1			
2	3	with 1 cm saw cylinder reduction due to open scar	stem damage by earlier operation	
3	2			
4	3			
5	3	with 1 cm saw cylinder reduction due to open scar	stem damage by earlier operation	
6	3			
7	3			
8	3			
9	3			
10	3			
11	2			
12	2			
13	3	with 1 cm saw cylinder reduction due to open scar	stem damage by earlier operation	
14	3			
15	3	with 1 cm saw cylinder reduction due to open scar	stem damage by earlier operation	
16	1			
17	3	with 1 cm saw cylinder reduction due to open scar	stem damage by earlier operation	
18	2			
19	2			
20	2			
21	3			
22	3			
23	3			
24	3			
25	2			
26	3			
27	2			
28	3			
29	3			
30	3	with 1 cm saw cylinder reduction due to open scar	stem damage by earlier operation	
31	3	with 1 cm saw cylinder reduction due to open scar	stem damage by earlier operation	
32	3			
33	3			
34	3			
35	1			
36	1			
37	1			
38	2			
39	3			
40	2	with 1 cm saw cylinder reduction due to open scar	stem damage by earlier operation	
41	3			
42	3	with 1 cm saw cylinder reduction due to open scar	stem damage by earlier operation	
43	3			
44	3			
45	2			
46	3			
47	3			
48	2			
49	3			
50	1			

Reg.	South	Species	Pine
log No.	**grade**	**quality reduction cause**	**comments**
1	4	top break	
2	9	crook > 30 cm yield loss	
3	2		
4	3		
5	4	w/ 1 cm saw cylinder reduction due to delimbing damage	
6	2		
7	1		
8	2		
9	3		
10	2		
11	2		
12	2		fungi damage OK due to live stem > half of log length and diam
13	3		crook < 20 cm yield loss
14	2		
15	4	20 cm < crook < 30 cm yield loss	
16	1		
17	2		
18	9	crook > 30 cm yield loss	
19	3		
20	2		
21	9	not satisfactorily delimbed (branch stump > 30 mm diam ub and 40 mm high)	
22	3		
23	9	crook > 30 cm yield loss	
24	3		
25	3		
26	3		
27	2		
28	3		
29	3	with 1 cm saw cylinder reduction due to open scar	
30	2		
31	3		
32	1		
33	9	crook > 30 cm yield loss	
34	3	with 1 cm saw cylinder reduction due to open scar	
35	2		
36	3		
37	1		
38	9	crook > 30 cm yield loss	
39	3		
40	2		
41	1		
42	1		
43	3		
44	9	crook > 30 cm yield loss	
45	2		
46	3		
47	2		
48	2		
49	2		
50	3		

Reg.	East		Species	Pine
log No.	grade	quality reduction cause	comments	
1	2		top log with min. two distinct knot whorls	
2	2		top log with min. two distinct knot whorls	
3	3			
4	2			
5	1	with 1 cm saw cylinder reduction due to open scar	splits along growth rings accepted due to not going through full circle	
6	3			
7	2		top log, sound knot within 1,5 m fr butt end	
8	2			
9	9	krök > 30 cm utbytesförlust		
10	2		top log, sound knot within 1,5 m fr butt end	
11	1			
12	2	with 1 cm saw cylinder reduction due to open scar		
13	2	with 1 cm saw cylinder reduction due to open scar		
14	3			
15	2		top log, sound knot within 1,5 m fr butt end	
16	3			
17	2	with 1 cm saw cylinder reduction due to open scar		
18	3			
19	4	with 1 cm saw cylinder reduction due to open scar		
20	2			
21	3			
22	2			
23	3			
24	2			
25	3			
26	3			
27	3			
28	3			
29	2			
30	2			
31	3			
32	2			
33	3			
34	4	encased knot / other than sound knot > 60 mm (grade 4 = knot size unlimited)		
35	3			
36	3		butt log, knot > 20 mm	
37	3	with 1 cm saw cylinder reduction due to open scar		
38	3			
39	4	top break		
40	2			
41	2			
42	2			
43	4	encased knot / other than sound knot > 60 mm (grade 4 = knot size unlimited)		
44	2			
45	9	crook > 30 cm yield loss		
46	2			
47	3			
48	2			
49	9	crook > 30 cm yield loss		
50	2			

9.3 Significant analysis

To find out if there is a significant differences between timber quality in the North/South/East, following hypothesizes are proposed and tested.

Form: $z = \frac{P_1 - P_2 - (\pi_1 - \pi_2)}{\sqrt{P(1-P)\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$ where $P = \frac{n_1 P_1 + n_2 P_2}{n_1 + n_2}$

9.3.1 Spruce

$P_N = \frac{56}{5457} = 0.0103$ $5457 \times \frac{56}{5457} = 56$ $5457 \times (1 - \frac{56}{5457}) = 5401$

$P_S = \frac{57}{3476} = 0.0164$ $3476 \times \frac{57}{3476} = 57$ $3476 \times (1 - \frac{57}{3476}) = 3419$

$P_E = \frac{81}{4470} = 0.0181$ $4470 \times \frac{81}{4470} = 81$ $4470 \times (1 - \frac{81}{4470}) = 4389$

North vs. South

H_0: There is no significant difference between northern and southern timber qualities. ($\pi_N = \pi_S$)
H_1: There is significant difference between northern and southern timber qualities. ($\pi_N \neq \pi_S$)

Suppose $\pi_N = \pi_S \rightarrow \pi_N - \pi_S = 0$

$$z = \frac{0.0164 - 0.0103 - (0)}{\sqrt{0.0126736259(1 - 0.0126736259)\left(\frac{1}{3476} + \frac{1}{5457}\right)}} \approx 2.51285378$$

$$P = \frac{3476 \times 0.0164 + 5457 \times 0.0103}{3476 + 5457} \approx 0.0126736259$$

5 %, z ≈ 1.96 H_0 rejected
1 %, z ≈ 2.58 H_0 accepted

With 95 % accuracy there is significant difference between northern and southern timber qualities (*-significance).

South vs. East

H_0: There is no significant difference between southern and eastern timber qualities. ($\pi_S = \pi_E$)
H_1: There is significant difference between northern and southern timber qualities. ($\pi_S \neq \pi_E$)

Suppose $\pi_S = \pi_E \rightarrow \pi_S - \pi_E = 0$

$$z = \frac{0.0181 - 0.0164 - (0)}{\sqrt{0.0173563302(1 - 0.0173563302)\left(\frac{1}{4470} + \frac{1}{3476}\right)}} \approx 0.5756271952$$

$$P = \frac{4470 \times 0.0181 + 3476 \times 0.0164}{4470 + 3476} \approx 0.0173563302$$

5 %, $z \approx 1.96$ H_0 accepted

There is no statistical difference between southern and eastern timber qualities (no-significance).

East vs. North

H_0: There is no significant difference between eastern and northern timber qualities. ($\pi_E = \pi_N$)
H_1: There is significant difference between northern and southern timber qualities. ($\pi_E \neq \pi_N$)

Suppose $\pi_E = \pi_N \rightarrow \pi_E - \pi_N = 0$

$$z = \frac{0.0181 - 0.0103 - (0)}{\sqrt{0.0138122393(1 - 0.0138122393)\left(\frac{1}{4470} + \frac{1}{5457}\right)}} \approx 3{,}315325549$$

$$P = \frac{4470 \times 0.0181 + 5457 \times 0.0103}{4470 + 5457} \approx 0.0138122393$$

5 %, $z \approx 1.96$ H_0 rejected
1 %, $z \approx 2.58$ H_0 rejected
0,1 % $z \approx 3.29$ H_0 rejected

With 99.9 % accuracy there is significant difference between eastern and northern timber qualities (***-significance).

9.3.2 Pine

$P_N = \frac{74}{5361} = 0.0138$ $5361 \times \frac{74}{5361} = 74$ $5361 \times (1 - \frac{74}{5361}) = 5287$

$P_S = \frac{85}{3852} = 0.0221$ $3767 \times \frac{85}{3852} = 85$ $3767 \times (1 - \frac{85}{3852}) = 3767$

$P_E = \frac{222}{2565} = 0.0865$ $2565 \times \frac{222}{2565} = 222$ $2565 \times (1 - \frac{222}{2565}) = 2343$

North vs. South

H_0: There is no significant difference between northern and southern timber qualities. ($\pi_N = \pi_S$)
H_1: There is significant difference between northern and southern timber qualities. ($\pi_N \neq \pi_S$)

Suppose $\pi_N = \pi_S \rightarrow \pi_N - \pi_S = 0$

$$z = \frac{0.0221 - 0.0138 - (0)}{\sqrt{0.0172702703(1 - 0.0172702703)\left(\frac{1}{3852} + \frac{1}{5361}\right)}} \approx 3.016317024$$

$$P = \frac{3852 \times 0.0221 + 5361 \times 0.0138}{3852 + 5361} \approx 0.0172702703$$

5 %, z ≈ 1.96 H_0 rejected
1 %, z ≈ 2.58 H_0 rejected
0,1 % z ≈ 3.29 H_0 accepted

With 99 % accuracy there is significant difference between northern and southern timber qualities (**-significance).

South vs. East

H_0: There is no significant difference between southern and eastern timber qualities. ($\pi_S = \pi_E$)
H_1: There is significant difference between northern and southern timber qualities. ($\pi_S \neq \pi_E$)

Suppose $\pi_S = \pi_E \rightarrow \pi_S - \pi_E = 0$

$$z = \frac{0.0865 - 0.0221 - (0)}{\sqrt{0.0478419355(1 - 0.0478419355)\left(\frac{1}{2565} + \frac{1}{3852}\right)}} \approx 11.83989296$$

$$P = \frac{4470 \times 0.0181 + 3476 \times 0.0164}{4470 + 3476} \approx 0.0478419355$$

5 %, z ≈ 1.96 H_0 rejected
1 %, z ≈ 2.58 H_0 rejected
0,1 % z ≈ 3.29 H_0 rejected

With 99.9 % accuracy there is significant difference between southern and eastern timber qualities (***-significance).

East vs. North

H_0: There is no significant difference between eastern and northern timber qualities. ($\pi_E = \pi_N$)
H_1: There is significant difference between northern and southern timber qualities. ($\pi_E \neq \pi_N$)

Suppose $\pi_E = \pi_N \rightarrow \pi_E - \pi_N = 0$

$$z = \frac{0.0865 - 0.0138 - (0)}{\sqrt{0.0373270628(1 - 0.0373270628)\left(\frac{1}{2565} + \frac{1}{5361}\right)}} \approx 15.97433084$$

$$P = \frac{2565 \times 0.0865 + 5361 \times 0.0138}{2565 + 5361} \approx 0.0373270628$$

5 %, z ≈ 1.96 H_0 rejected

1 %, z ≈ 2.58 H_0 rejected
0,1 % z ≈ 3.29 H_0 rejected

With 99.9 % accuracy there is significant difference between eastern and northern timber qualities (***-significance).