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SPRUCE AND PINE ON DRAINED PEATLANDS — WOOD QUALITY AND SUITABILITY FOR THE SAWMILL INDUSTRY

Juha Rikala

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Opponent:

Professor Torbjörn Elowson
Department of Forest Products and Markets
Swedish University of Agricultural Sciences
SE-750 07 Uppsala, Sweden

Reviewers:

Professor Matti Kärkkäinen
Sepetlahdentie 7 A 21
FIN-02230 Espoo, Finland

Professor Mats Nylinder
Department of Forest Products and Markets
Swedish University of Agricultural Sciences
SE-750 07 Uppsala, Sweden

Supervisor:

Professor Marketta Sipi
Department of Forest Resource Management
FIN-00014 University of Helsinki, Finland

Revision of English:

Carol Pelli
Language Center
FIN-00014 University of Helsinki, Finland

Cover:

Upper left: Mature spruces on Herb-rich type, Jaakkoinsuo, Municipality of Vilppula
Upper right: Mature pines on *Vaccinium vitis-idaea* type, Ruotsinkylä, Municipality of Tuusula
Lower left: A felled spruce stem cut into logs. Sample discs were taken for wood property studies.
Lower right: Sawn pieces on conveyor, Pori College of Forestry, Municipality of Kullaa

(Photos: Juha Rikala)

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ABSTRACT

Drained peatlands are a characteristic specific to Finnish forestry. Almost 5 million hectares of peatlands have been drained for wood production, which is exceptional even on a global scale. According to the National Forest Inventories, forest drainage seems to be a major factor in the increased volume growth observed in Finnish forests. To date, only a few studies have focused on the qualitative properties of peatland trees, and thus, knowledge has been insufficient to evaluate the suitability of the wood for various end-uses. This is, however, an essential component in assessing the overall profitability of drainage investments.

This study aimed at clarifying the most important external and internal quality properties of Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) timber trees growing on drained peatlands. The suitability of raw wood material for sawn timber and its processed products were examined, as were the differences in quality properties between tree stands on drained peatland and mineral soil. The primary hypothesis was that growing conditions typical of peatlands affect the phenotype of trees, and hence, the properties of wood and sawn timber.

Study material was collected from two site types of Norway spruce (Herb-rich type, *Vaccinium myrtillus* type) and two site types of Scots pine (*Vaccinium vitis-idaea* type, Dwarf-shrub type) in southern Finland. Five sample plots were chosen to represent each site type (total of 20 plots). Part of all counted trees (measured for diameter at breast height) was graded as standing trees. These trees were measured for tree height, diameter at a height of 6 m, height of the living crown, and dead branch height. From each stand, 10 trees were felled for further experiments. The stems were cut into saw logs and the logs were graded according to external quality properties. Merchantable tree tops were cut into 2-m bolts to a minimum diameter of 7 cm. Sample discs were taken from each cut to examine the following wood properties: annual ring width and latewood proportion, heartwood proportion, basic density, and proportion of compression wood. Logs were measured by a logscanner, barked using a barking machine and sawn by blade settings commonly used in the Finnish sawmill industry.

Sawn timber was graded before and after drying according to Nordic Timber grading rules. Centre yield was also graded according to the stress grading rules of NS-INSTA 142 and T-grading. Special attention was paid to features affecting quality. Sawn timber was dried to a 20% final moisture content in a warm air kiln at a temperature suitable for size and quality. The changes in timber quality during drying and factors affecting these were studied. Some further experiments were carried out by drying the best quality centre yield sawn timber to a moisture content of 10%.

Both in spruce and pine, the stem form characteristics – taper, slenderness, and breast height form factor – were in accordance with those observed in mineral soil sites of corresponding fertility. Various stem form defects, e.g. crooks and sweep, were common in both tree species. In practice, this means that the stems have to be cut into short logs to meet the quality requirements for saw logs. In pine, the relative length of the living crowns was exceptionally low, which was manifested in a long dead branch section. One explanation for this could be

the dieback and canker fungus of pines (*Gremmeniella abietina*) that infected pine stands in southern Finland in the late 1970s and 1980s. Spruces were characteristically thin-branched.

The origin of wood material was appearent from the following characteristics. Most trees had a narrow-ringed heart, whereas the wood grown after drainage was wide-ringed. An increase in growth due to drainage meant decrease in basic density and latewood proportion. Especially in spruce, high heartwood proportions were found. The amount of compression wood was surprisingly small, which might indicate that it is not a severe problem in managed, mature stands. On average, all of the studied wood properties were similar to those reported from mineral soil sites, but the variation was large. Although spruce stands in this material were relatively old, root rot was unusual. This may be explained by peat soil conditions, which do not favour the spreading of fungi.

Spruce sawn timber was of good quality, decreasing only slightly from butt towards the top of the tree. The quality of sawn timber from pine butt logs was good, but numerous dead and unsound knots lowered the quality of sawn timber from the upper parts of stems. Drying deformations and checking were slight in both tree species in export drying (moisture content 20%), but increased dramatically in joinery drying (moisture content 10%). The main causes were checking and twisting.

Based on the results, the quality of sawn timber from peatland spruces corresponds to that produced by mineral soil sites. Thus, peatland spruce sawn timber may be utilized in the same end-use areas as spruce sawn timber in general, i.e. mainly in construction. Peatland pine sawn timber is slightly poorer than that of upland sites. Sawn timber from butt logs is suited for purposes from construction to visible joinery. The primary uses for pine middle logs are construction and end-uses that are to be painted or covered. No suggestions for the use of pine top logs can be given due to inadequate observations.

Keywords: drained peatlands, timber trees, external properties, wood properties, quality of sawn timber, *Picea abies*, *Pinus sylvestris*

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ABBREVIATIONS AND DEFINITIONS

General

NFI	National Forest Inventory (e.g. NFI8). The number refers to the chronological order of the inventory. The first National Forest Inventory was carried out in 1921–1924.
*Southern Finland**	Land area in Finland between 60 and 65 degrees north (°N)
*Northern Finland**	Land area in Finland between 65 and 70 degrees north (°N)
	* This division does not correspond to that applied in the National Forest Inventory.

Stand and site

Tree species	Norway spruce (*Picea abies* (L.) Karst.) Scots pine (*Pinus sylvestris* L.) Pubescent birch (*Betula pubescens* Ehrh.)
Counted tree	Living tree in a sample plot
Standing sample tree	Standing tree measured for quality characteristics
Felled sample tree	Tree felled for further measurements and experiments
OMaT	*Oxalis-Maianthemum* type
OMT	*Oxalis-Myrtillus* type
MT	*Myrtillus* type
VT	*Vaccinium* type
CT	*Calluna* type (Cajander 1909)
Rhtkg	Old drainage area: Herb-rich type
Mtkg	Old drainage area: *Vaccinium myrtillus* type
Ptkg	Old drainage area: *Vaccinium vitis-idaea* type
Vatkg	Old drainage area: Dwarf-shrub type (see Laine 1989)

Stand and tree characteristics

A	Mean age of trees at stump height in a stand, *years*
a	Age of a tree at stump height, *years*
a_{tod}	Age of a tree at time of drainage, *years*
cr	$= \frac{h - h_c}{h}$, crown ratio
d, dbh, $d_{1.3}$	Diameter at height of 1.3 m from ground level (breast height), *mm* or *cm*
DBH	Diameter class (breast height), *mm* or *cm*
dbs_r	$= \frac{h_c - h_{db}}{h}$, relative length of dead branch section
D_g	Mean diameter of trees weighted by basal area at breast height, *cm*
dk_{max}	Diameter of the largest dead knot of a butt log, *mm*
$d_{0.1h}$	Diameter at 10% height of the stem, *mm* or *cm*
$d_{0.5h}$	Diameter at 50% height of the stem, *mm* or *cm*
d_6	Diameter at 6 m height from ground level (measured), *cm*
d_{6s}	Diameter at 6 m height estimated by spline function, *mm*

f	$= \frac{v}{gh}$, breast height form factor of a tree
F_H	$= \frac{V}{GH}$, breast height form factor of a stand
Form ratio	$= \frac{d_{0.5h}}{d_{0.1h}}$
G	Basal area of a stand, $m^2\ ha^{-1}$
g	Cross-sectional area of a tree at breast height (basal area), m^2
H	Mean tree height in a stand, *m*
h	Tree height, *dm* or *m*
h_c	Crown height (height to the base of the living crown), *dm* (NFI9*)
h_{db}	Dead branch height (height to the base of the dead branch section, branch diameter (o.b.) > 15 mm), *dm* (NFI9*)
i_{30}	Early growth rate (radial increment of the first 30 rings at stump height), *mm*
i_m	Mean growth ring width at stump height, *mm*
k_{max}	Diameter of the largest knot of a butt log measured on the surface of a log, *mm* (NFI9*)
N	Stand density, *number of stems per hectare (n* ha^{-1}*)*
Slenderness	$= \frac{h}{d_{1.3}}$
t_{ad}	Time after drainage, *years*
Taper	$= d_{1.3} - d_6$, *mm* or *cm*
Taper index	$= \frac{d_6}{d_{1.3}}$
V	Stand volume, $m^3\ ha^{-1}$
v	Stem (or log) volume, m^3

Measuring and grading of logs

ABC	Grading of logs according to their location in the stem and quality: Grades A, B, C1, C2
Dead knot	At least one half of the circumference of a knot has no contact with the surrounding wood (NFI9*). The diameter of a knot is measured (regardless of condition of knot) on the surface of a log at right angles to its length (NFI9*).
Mean knot density	Number of knots by knot condition divided by total length of logs, *knots* m^{-1}
NFI9 grading	Grading of logs applied in the 9th National Forest Inventory: Grades 1, 2, 3
o.b.	Measured over bark
Ovalness	The difference of the largest and smallest diameters of a stem divided by their mean
Reject	Logs that do not meet the quality requirements for saw logs (grade D)
Sound knot	At least one half of the circumference of a knot has contact with the surrounding wood.
Spike knot	Knot that is formed by a relic of top or fork of a tree (NFI9*)
Sweep	Greatest deviation found from the straight line drawn from butt and top ends of a log, *mm*
Taper	Expressed as difference in diameter between butt and top ends of a log divided by the log length, *mm* m^{-1}
u.b.	Measured under bark
Unsound knot	Cross-sectional area of a knot is entirely decayed or majority is so decayed that it can be estimated to reach the surface of sawn timber (NFI9*).

* Field work instructions of the 9th National Forest Inventory (Valtakunnan metsien…1998)

Determination of wood density

a_1, a_2	Cross-sectional area at the end of a log, m^2
b_v	Shrinkage from green volume to dry, *% of green volume*
h	Length of a log (section), m
ISO 3131	Determination of density for physical and mechanical tests (ISO 1975)
m_g	Mass of green wood, kg
m_o	Oven-dry mass of wood, kg
m_u	Mass of wood with moisture, kg
ρ_0	$= \frac{m_0}{v_0}$, oven-dry density, $kg\ m^{-3}$
$\rho_{0,g}$	$= \frac{m_0}{v_g}$, basic density, $kg\ m^{-3}$
ρ_g	$= \frac{m_g}{v_g}$, green density, $kg\ m^{-3}$
$\rho_1 \ldots \rho_n$	Mean basic density of a log (bolt), $kg\ m^{-3}$
ρ_{stem}	Mean basic density of a stem calculated by weighing the mean basic density of each log by its volume, $kg\ m^{-3}$
u	$= 100 \times \frac{(m_u - m_0)}{m_0}$, moisture content, *%*
v_0	Volume of oven-dry wood, m^3
v_g	Volume of green wood, m^3
v, $v_1 \ldots v_n$	Volume of a log (bolt, section), m^3
v_{stem}	Total volume of a stem, m^3
v_{total}	Total volume of bolts, m^3

Sawing of logs and drying and grading of sawn timber

AK	Re-sawing phase
Gross value of saw logs	= value of sawn timber + value of sawmill chips + value of bark and sawdust, $€\ m^{-3}$
Log use ratio	Volume of logs (o.b.) needed for one cubic metre of sawn timber
MC	Moisture content, *%* (100 × mass of water per mass of kiln-dried wood)
Net value of saw logs	= value of sawn timber, $€\ m^{-3}$
NS-INSTA 142	Nordic visual stress-grading rules for timber: Grades T3, T2, T1, T0 (NS-INSTA 142 1997)
NT	Nordic Timber (*Blue book*). Grading rules for pine and spruce sawn timber: Grades A (subgrades A1, A2, A3, A4), B, C, D, and grades of wane sawn timber: OKS (*knot-free three sides*), PP (*halvrena side yield*), VL (*schaalboard of export quality*), KL (*schaalboard of domestic quality*) (Pohjoismainen sahatavara 1994)
prEN 13183-2	Method for estimating moisture content of a piece of sawn timber (Resistance method)
Re	Sawn timber that does not meet the requirements of the lowest grade (Reject)
Ripsawing	Ripping, flat cutting
T-grading	Stress-grading rules: Grades T40, T30, T24, T18 (Lipitsäinen 1994)
Yield of sawn timber	Volume of sawn timber from one cubic metre of logs (o.b.)
YK	Block sawing phase

Quality modelling

$F_1 \ldots F_n$	Quality factor of roundwood by logs in a tree
F_{ls}	Quality factor of roundwood of the whole log section of a tree
F_s	Quality factor of roundwood of a stand
Gross volume of sawn timber	The volume of sawn timber determined by the nominal dimension, m^3
gv_{ij}	Gross volume of sawn timber representing grade *i* dimension *j*, m^3
i_{ij}	Indexed value of sawn timber representing grade *i* dimension *j*
Net volume of sawn timber	Volume of sawn timber representing a certain grade after kiln drying. The volume is determined by the nominal dimension, m^3.
nv_{ij}	Net volume of sawn timber representing grade *i* dimension *j*, m^3
$v_1 \ldots v_n$	Gross volume of sawn timber by logs, m^3

Statistical notations

ANOVA	Analysis of variance
b	Bias
b_r	Relative bias
Fitted trend line	Least squares fit calculated through points
G^2	2×log-likelihood test quantity
max.	Maximum value
min.	Minimum value
Moving average	Based on the average value of the variable over a specific number of preceding periods
n	Number of observations
$p < 0.05$	Statistically significant at the risk level of 5%
r	Correlation coefficient
R^2	Coefficient of determination
RIGLS	Restricted iterative generalized least squares method
RMSE	Root mean square error of estimate
$RMSE_r$	Relative root mean square error of estimate
s	Standard deviation
s.e.	Standard error of the mean
$\bar{x}$	Mean

PREFACE

The experimental part of this study was based on the project *Suopuun laatu* carried out at the Department of Forest Resource Management, University of Helsinki. This project formed a part of a study consortium entitled *Structural post-drainage development of peatland stands, quality of wood raw material produced and its suitability for different end-uses*. The study consortium was carried out in co-operation with the Department of Forest Ecology, University of Helsinki. The consortium was linked to the *Finnish Forest Cluster Research Programme (Wood Wisdom 1998–2001).*

The study commenced in spring 1998 under the guidance of Professor Marketta Sipi. Her expertise in the wood processing field and contacts in the sawmill industry were invaluable. I am indebted to her and to the former head of the department, Professor Emeritus Rihko Haarlaa, for providing me with excellent research facilities.

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Juha Rikala

1 INTRODUCTION

1.1 Definitions for Peatland and Peatland Stand

Definitions for wetland ecosystems are numerous (see Paavilainen and Päivänen 1995). The most commonly used terms, *peatland* and *mire*, refer to ecosystems characterized by the accumulation of organic matter leading to the formation of peat (Gore 1983). The more specific terms, *bog*, *fen*, and *swamp*, refer to concepts of trophy and nutrient level of the site (e.g. Paavilainen and Päivänen 1995; Laine and Vasander 1996). In the literature (e.g. Paavilainen and Päivänen 1995), the term *pristine (virgin) peatland* is also used. It usually refers to a site that is totally undisturbed by man.

The term *mire* is mostly used in an ecological context, whereas *peatland* is used to emphasize the connection to forest management. In this study, *peatland* is used to refer to sites drained for forestry (*drained peatlands*). *Undrained peatlands* have only a marginal importance for wood production in Finland, and, for this reason, they are not dealt with here. *Drained peatlands* in this study represent the final stage of succession known as *transformed drained mire* (see Paavilainen and Päivänen 1995). *Peatland stands* refer to stands dominated by Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) timber trees. To differentiate between the tree species and nutrient status of the sites, the terms *spruce mire* (*korpi* in Finnish) and *pine mire* (*räme* in Finnish) are also used. In Finland, the term *peatland* is used even when the peat layer is shallow (< 30 cm) (Laine and Vasander 1996).

1.2 Forest Drainage and Its Role in Wood Production in Finland

Forest drainage improves the growth of trees in sites where an excess of water is the limiting factor for growth. According to Tirkkonen (1952), some forest drainage operations were already carried out in the middle of the 19th century by a few wood processing companies. Systematic forest drainage was started on state-owned land in 1908, on land owned by forest industry companies in the 1910s, and in private forests in 1928, when the first forest improvement law was established (Tuokko 1992).

In the early 1950s, most forest ditches were still dug manually. The first phase in mechanization of forest drainage was the introduction of forest ditch plows (Huikari 1958). During recent decades, tractor diggers and excavators have replaced heavy ditch plows (Paavilainen and Päivänen 1995). The peak in forest drainage was reached at the end of the 1960s, when annually drained area increased to ca 300 000 hectares (Fig. 1). Nowadays, new areas are no longer drained for wood production, instead the focus is on ditch cleaning and complementary ditching.

According to the 8th National Forest Inventory (NFI8), approximately 53% of the peatland area (8.9 million ha) has been drained for forestry (Tomppo 1999; Hökkä et al. 2002). The total area of forestry land in Finland is about 26.3 million hectares, and drained peatlands represent nearly one-fifth of this. In proportion to the total land area, peatlands have been drained for forestry in Finland more than in any other country (see Paavilainen and Päivänen 1995). The annual increment of the growing stock volume in Finnish forests was 55 million m^3 at the beginning of the 1950s, but increased to 75 million m^3 over the course of the next

four decades (Tomppo 1999). According to Tomppo (1999), peatland forestry has been responsible for over one-half of the increase of the annual increment since the early 1950s.

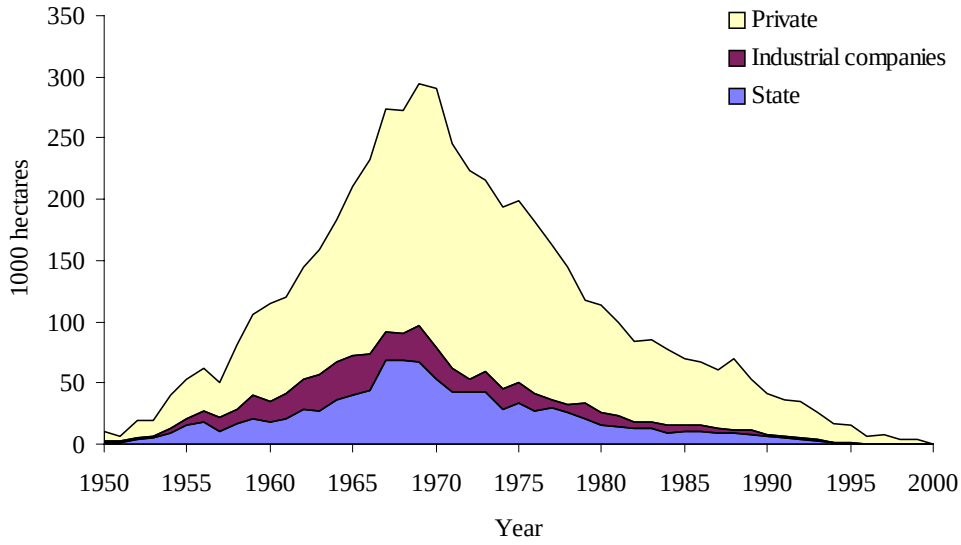


Fig. 1. Forest drainage (First-time ditching) in 1950–2000 by forest owner groups in Finland. Data combined from the statistical yearbooks of forestry (Metsätilastollinen…1994, 2001).

The areal distribution of peatlands in Finland is uneven. Most peatlands are located in Pohjanmaa and in northern Finland. In these areas, drained peatlands play a relatively more important role in wood production than in southern Finland.

In the year 2000, the total cutting removals in the Finnish forests were ca 61.5 million m^3 (Metsätilastollinen…2001). The role of peatlands in Finnish wood production has been evaluated by using large-scale forest scenario modelling (Nuutinen et al. 2000). Scenarios based on the data from the NFI8 indicated a clear increase in cutting possibilities in peatland forests. By the year 2025, the proportion of peatland cuttings is anticipated to increase to over 20%, balancing the decrease of cuttings on mineral soil sites. How accurate these scenarios will be depends mainly on the demand for roundwood in the Finnish forest industry, the volume of roundwood to be imported, and, above all, the demand for wood-based products in the global markets.

In the near future, most of the cutting possibilities on drained peatlands will be in stands dominated by small-sized pine. The wood harvested will mainly be utilized by the pulpwood industry. Stands on old drainage areas – i.e. those drained in the 1920s and 1930s – are reaching or have already reached logging maturity, and thus, their role as a source of roundwood for the mechanical wood processing industry is increasing.

1.3 Spruce and Pine as Raw Material for Mechanical Wood Processing

The primary users of coniferous roundwood in the mechanical wood processing industry, i.e. the wood products industry, are industrial sawmills, small sawmills, plywood and veneer industries, and other wood products industries. In 2001, the sawmill industry accounted for 92.5% and the plywood and veneer industries for 6.4% of total consumption of soft roundwood in the wood products industry (Metsätilastollinen…2002).

Wood consumption in the wood products industry has varied greatly by year. During the last two decades the lowest level in the consumption of soft roundwood, ca 14.9 million m^3, was achieved in 1991. After that, the consumption of soft roundwood increased significantly, reaching an annual high of 31.5 million m^3 in 2000 (Metsätilastollinen…2002). The increase can be explained by an upswing in the economy and in export, and also to some degree by successful national promotion of the use of wood and by its increasing competitiveness in construction. Typical of wood consumption in the forest industry has been the increasing volume of imported roundwood. The volume of imported softwood logs was 0.2 million m^3 in 1991, but already 3.0 million m^3 in 2001 (Metsätilastollinen…2002).

The production of sawn softwood in Finland reached an all-time high of 13.4 million m^3 in 2000 (Metsätilastollinen…2002). This increase in sawn timber production has given rise to concern about the sufficiency of timber-sized roundwood. This concern is reasonable because of the demands for multiple use and conservation of commercial forest areas. Furthermore, mature spruce forests have been harvested quite intensively in southern Finland in recent years. Thinnings in young stands should be extended to ensure sustainable use of Finnish forests.

At present, consumption of thinning wood in the wood products industry is small despite the great potential volume. Small-sized timber has been used, for instance, in environmental construction. According to Boren (2001), mechanical properties of pine and spruce roundwood originating from thinnings meet the requirements of European standards for structural timber. These results are promising from the view of the number of objects that can be made from small-sized peatland timber.

Wood products can be divided into basic products, i.e. sawn timber and wood-based panels (plywood, particleboard, fibreboard), and their primary and secondary processed products. Since the growth of the basic sawmill industry is limited, further processing of sawn timber has become more and more important. A growing field in the wood products industry is Engineered Wood Products (EWP), of which Laminated Veneer Lumber (LVL) and glulam beams are manufactured in Finland. The use of spruce and pine in the wood products industry has varied depending upon the object being manufactured. Spruce has traditionally been used for construction, while pine has dominated in the joinery and furniture industries. Today, however, this division is fading. Spruce now dominates the manufacturing of coniferous plywood, LVL, and glulam beams. Examples of the objects for the Finnish conifers are timber frames, exterior and interior cladding, floors, wooden stairs, doors, window frames, furniture, and packaging.

1.4 External Tree Properties and Sawmill Industry

The most important external quality properties affecting the processability of stems in sawmill industry are stem form, stem form defects, defects on tree surfaces, and branchiness. The size of the stem or log is also a quality factor since it sets limits on the processability and may also affect the profitability of processing.

Stem form is usually described by *taper*, *slenderness*, *form ratio*, and *form factors*, e.g. *breast height form factor*. Stem form information is essential for calculating accurate stem volume. The stem form characteristics are determined as follows (Vuokila 1987):

$$Taper = d_{1.3} - d_6 \tag{1}$$

$$Slenderness = \frac{h}{d_{1.3}} \tag{2}$$

$$Form\ ratio = \frac{d_{0.5h}}{d_{0.1h}} \tag{3}$$

$$Breast\ height\ \ form\ \ factor = f = \frac{v}{gh} \tag{4}$$

, where

$d_{1.3}$ = diameter at breast height (1.3 m)

d_6 = diameter at a height of 6 m

v = stem volume

g = cross-sectional area at breast height (1.3 m)

h = tree height

Taper is the stem form characteristic used most often in forest mensuration. Taper is expressed as the difference between diameters measured at breast height and at 6 metres in trees over 7 metres in height (Tapion taskukirja 2002). *Breast height form factor* determines the ratio between the real stem volume and the cylindrical volume restricted by the cross-sectional area at breast height and tree height. The higher the ratio, the better the stem form. The stem volume is generally determined by volume functions based on regression analysis instead of geometrical forms (Laasasenaho 1982, 1983).

Stem form varies with tree species, geographical location, site, tree age, and crown class (Ilvessalo 1920; Laitakari 1929; Lappi-Seppälä 1929; Nyyssönen 1952; Sirén 1952). It is essential to understand that every silvicultural treatment affecting development of the tree crown also affects stem form development (Larson 1963). After thinning, the stem form of the remaining trees becomes poorer since growth is first allocated to the base of the stem (Nyyssönen 1954; Vuokila 1960, 1965). The opposite effect can be achieved by pruning living branches (Lakari 1920; Lappi-Seppälä 1934, 1937). However, the pruning effect may be short-term, and extensive pruning is not reasonable because of loss of growth (Vuokila 1968). Fertilization also improves the stem form, but the effect is marginal and short-term (Saramäki 1980). According to Gustavsen and Fagerström (1983), form factor correlates negatively with site fertility. A study concerning the development of peatland-originating

Scots pine on mineral soil indicated that the stem form typical of peatland trees depends on site factors, not on the origin of trees (Päivänen 1989).

Stem form defects that most strongly affect the processability of stems are sweep, crooks, forks, and ovalness. Sweep and crookedness are common especially in pine stands regenerated by planting (Uusvaara 1974), but stem form defects are also found in naturally regenerated trees both on mineral soil and peatland (e.g. Tikka 1935; Kalela 1937; Kangas 1962; Verkasalo and Maltamo 2002). Asikainen and Panhelainen (1970a) stated that sweep of saw logs is inconvenient in several ways. Sweep reduces the yield of square-edged sawn timber. Sawn timber from logs with sweep contains slope of grain, which lowers its usability for many purposes. Logs with sweep often contain compression wood, which causes warping and checking in sawn timber and is a serious problem in mechanical wood processing (see also Section 1.5). A severe formation of compression wood causes eccentric growth in trees, which manifests as ovalness. Besides the sweep, ovalness of stem has an effect on the yield of sawn timber. According to Asikainen and Panhelainen (1970b), the sawing direction of a log is decisive. If an oval log is sawn correctly, i.e. in the direction of the maximal diameter, ovalness has no significant effect on the yield of sawn timber. However, in the manufacturing of plywood, ovalness of logs is always harmful since it decreases veneer yield (Kärkkäinen 1978).

Defects on tree surfaces, such as shakes and scars, are commonly caused by frost, forest fire, animals, or man (e.g. Kärkkäinen 2003). Since fungi usually spread into a tree through a wound in the roots, special attention should be paid to the methods and quality of timber harvesting. The area of a stem defect, especially its depth has been found to explain the spread of decay in stems (Kärkkäinen 1971; Isomäki and Kallio 1974).

Branchiness characterizes the incidence of outer branches of a tree. It should be distinguished from the term *knottiness*, which means the incidence of knots in wood material (Heikinheimo 1953). In Finnish, the terms used are *oksikkuus* and *oksaisuus*, respectively. Unfortunately, this distinction is often not very clear among researchers. The factors affecting branchiness in Finnish conifers have been reported in numerous studies (Heikinheimo 1953; Kärkkäinen 1972a; Uusvaara 1974; Kellomäki and Tuimala 1981; Kellomäki 1984; Turkia and Kellomäki 1987; Kellomäki et al. 1992). Site fertility and growing space of a tree have been established to be the most essential factors. According to Kärkkäinen (2003), stand density affects branchiness by affecting stem diameter. If stems of the same size are compared, different stand density has only a marginal effect on the size of the largest living branch. If branches become large, natural pruning takes longer, and the quality of stems becomes poor. Despite a clear connection between site fertility and tree branchiness, site type has not been found to be a good predictor of the internal quality of pines (Heiskanen 1965; Kärkkäinen 1980; Turkia and Kellomäki 1987). For that reason, tree characteristics, such as distance from the ground to the lowest living branch or to a dead branch, have been used as predictors of the quality of sawn timber (Kärkkäinen 1980; Uusitalo 1995). Prediction of quality of sawn timber is discussed in greater detail in Section 1.6.

1.5 Wood Properties and Their Role as Indicators of Wood Quality

The most important wood properties are *annual ring width*, *latewood proportion*, *wood density*, *heartwood proportion*, *juvenile wood*, and *proportion of compression wood*. The content of extractives can sometimes also be useful. The wood properties affect weight, hardness, toughness, and strength of wood products, among others.

Annual ring width describes the growth rate of a tree and is associated with many other wood properties. Narrow-ringed wood close to the pith indicates slow early growth and small branches, and consequently high internal quality (Heiskanen 1954b, 1965). Annual ring width depends on tree species, tree age, site fertility, and seasonal growing conditions, of which temperature sum and precipitation of the growing period are the most important (Henttonen 1984). Within a single tree, the annual ring width can vary markedly, typically decreasing towards the bark, excluding the juvenile phase of the tree (e.g. Mikola 1950; Eklund 1967). In trees grown on drained peatlands, the boundary between the narrow-ringed wood formed before drainage and the wide-ringed wood produced after drainage is often very clear. Ollinmaa (1960, 1981) has reported on some wood properties in these different zones.

Latewood proportion is commonly defined as a pergentage of the annual ring width. In spruce, the width of latewood correlates negatively with annual ring width (e.g. Mikola 1950; Worral 1970). In pine, this relation has been found to be different. Mikola (1950) concluded that broad annual rings in pine were expressly due to vigorous latewood formation. The density of latewood may be threefold the density of earlywood (Kollmann and Côté 1968). High wood density is generally known to have a positive effect on the strength of wood, and thus, a high latewood proportion has a positive effect on the strength properties of timber.

Wood density can be determined from sample discs, sample pieces, or increment cores from standing trees. The average wood density in stems has traditionally been determined from sample discs or cores taken from different heights in a tree since immersing and weighing of logs or stems is laborious. The mercury immersion method introduced by Ericson (1959) has for the most part been abandoned and today volume is mainly determined by water immersion method. Mass of a sample piece is measured with accurate scales. Modern methods for wood density measurements based on X-ray (tomography) and image analysis techniques will probably become widespread in the future (see e.g. Wilhelmsson et al. 2002). Since wood is a hygroscopic material, i.e. it absorbs or loses water, the mass and volume of wood pieces are dependent on the moisture in wood. The following definitions for wood density have been presented by Kärkkäinen (2003):

$$\rho_0 = \frac{m_0}{v_0} \tag{5}$$

$$\rho_{0,g} = \frac{m_0}{v_g} \tag{6}$$

$$\rho_g = \frac{m_g}{v_g} \tag{7}$$

, where

ρ_0 = oven - dry density

$\rho_{0,g}$ = basic density

ρ_g = green density

m = mass

v = volume

Indices = moisture content, % (0 = oven - dry wood, g = green wood)

Wood density is most commonly expressed as basic density, i.e. oven-dry mass per green volume. In older studies, wood density has also been determined as oven-dry density. The relations between these definitions are expressed as follows (Kärkkäinen 2003):

$$\rho_0 = \frac{100\rho_{0,g}}{(100 - b_v)} \tag{8}$$

$$\rho_{0,g} = \frac{(100 - b_v)\rho_0}{100} \tag{9}$$

, where

b_v = shrinkage from green volume to dry (% of green volume)

other symbols as above

Based on a large data from the National Forest Inventory tracts in Finland, the average basic density of knot-free stem wood was found to be 380 kg m^{-3} for spruce and 403 kg m^{-3} for pine (Hakkila 1979). According to Hakkila (1968), the wood density for pine is on average highest in the central parts of Finland, decreasing towards the north, and even more clearly towards the south. The wood density for spruce decreases from north to south along with enhanced growing conditions. Based on Hakkila´s results (1979), wood density increases with increasing tree age and decreases with increasing site fertility. When the mineral soil sites and undrained peatlands were compared, the wood density of spruce was found to be higher on peatlands than on any mineral soil site type. The wood density of pine was higher on peatlands than on *Myrtillus* type but lower than on *Vaccinium* type mineral soil (Hakkila 1979). The negative correlation between site fertility and wood density has also been reported in many other studies both for spruce (Ericson 1966; Hakkila 1966; Hakkila and Uusvaara 1968; Velling 1976; Saranpää 1983; Kärkkäinen and Dumell 1983) and pine (Jalava 1933; Siimes 1938; Uusvaara 1974). According to Saikku (1975a), wood density of pine reaches the highest value when annual ring width equals 0.8 mm. Fertilization of the stand decreases wood density (Saikku 1975a, 1975b; Lindström 1996). The wood density of suppressed and co-dominant spruces is higher than that of dominant spruces (Johansson 1993). Kärkkäinen (1984) reports that the growth rate of a tree does not explain all the variation in wood density between stems but that an inter-tree competition factor is involved in a complicated manner. In Sweden, Wilhelmsson et al. (2002) found that stem diameter, number of annual rings, and climatic indices accounted for 50% and 59% of the basic density variation in spruce and pine, respectively.

Within a single spruce or pine, the wood density increases from pith to bark (Tamminen 1962, 1964; Hakkila 1966, 1979; Uusvaara 1974; Velling 1976; Frimpong-Mensah 1987), in pine, however, clearly more so than in spruce. According to Nylinder (1953), dry density for spruce decreases first near the pith but increases again towards the bark. The changes of wood density in the longitudinal direction of the stem are connected with changes in the radial direction. In tree species where wood density increases from pith to bark, density decreases from butt to top of tree (Kärkkäinen 2003). In pine, the decrease in wood density from butt to top of tree may be more than 100 kg m^{-3} (Jalava 1945; Tamminen 1962; Hakkila 1966; Uusvaara 1974; Björklund and Walfridsson 1993). In spruce, this decrease is small, usually 10-30 kg m^{-3} (Tamminen 1964; Hakkila 1966; Ericson 1966; Hakkila and Uusvaara 1968). The radial and longitudinal variations of wood density are dependent on the density characteristic used (basic density, dry density, green density) (see e.g. Tamminen 1962, 1964). The wood density was determined as basic density in all of the investigations mentioned above, except for Jalava (1933, 1945), Siimes (1938) and Nylinder (1953), where it was determined as dry density. Besides these, Tamminen (1962, 1964) determined wood density as green density.

Heartwood proportion can be expressed as the share of diameter, cross-sectional area, or volume. In pine, heartwood proportion reaches a maximum at a relative height of 20-30% (Lappi-Seppälä 1952; Nylinder 1959, 1961a; Tamminen 1962; Ericson 1966; Hakkila 1967b; Björklund and Walfridsson 1993). In spruce, the corresponding value is slightly lower (Nylinder 1961b; Tamminen 1964; Ericson 1966).

Heartwood proportion is affected by tree age and growth rate. Heartwood proportion correlates negatively with high growth rate, high crown ratio, and dominance of trees (Lappi-Seppälä 1952; Sellin 1991; Koivuniemi 1992; Ojansuu and Maltamo 1995; Björklund 1999). According to Kärkkäinen (1972b), the effect of growth rate on heartwood proportion should be divided into two parts. The heartwood proportion is lower in fast-grown trees than slow-grown trees of the same size but is higher in fast-grown trees than slow-grown trees of the same age. This conclusion is in agreement with the results of Tamminen (1962, 1964).

Heartwood proportion in spruce and pine logs decreases from north to south (Bruun 1967; Hakkila 1968). This is because trees grow more slowly in the north than in the south, and thus, logs of the same size are older in the north. The difference in heartwood proportion between spruce and pine of the same site and tree age has not been investigated thoroughly. However, several studies indicate that the heartwood proportion is generally higher in spruce (Nylinder 1961a, 1961b; Tamminen 1962, 1964; Bruun 1967; Hakkila 1968). High heartwood proportion is usually an advantage for the use of wood. In pine, for example, the heartwood is resistant to decay. In the manufacturing of plywood, dry heartwood can be problematic since it may cause ripping in veneers (Hyyryläinen 1999). The chemical composition, e.g. the amount of extractives, in heartwood and sapwood is distinctly different (Hillis 1987).

In the context of wood transformation, the concept of *juvenile wood* is also presented. Juvenile wood represents the wood near the pith formed by the first 5 to 20 annual rings, which vary among species (Hakkila 1989). The indefiniteness of juvenile wood is due to the continuum in different wood properties (Kärkkäinen 2003). Juvenile wood transforms gradually into heartwood, excluding the top of the tree. The presence of juvenile wood is harmful in mechanical wood processing because of its low density and strength (Saranpää 1994).

Compression wood is glossy and dark. Furthermore, it is heavier, harder, and tougher than normal wood (e.g. Ollinmaa 1955). Timell (1986) states that no conifer can maintain its intrinsic growth habit without compression wood for very long. The presence of compression wood is common in stem and branches, but small amounts can also be found in roots (Timell 1986). Stem compression wood forms in conifers mainly on the lower side of leaning or bent stems. Compression wood is associated with various stem form defects, such as sweep, crookedness, and eccentricity of growth. Tikka (1935) observed a difference in the location of compression wood between spruce and pine. In pine, compression wood was located evenly along the stem, whereas in spruce it occurred more frequently at the base of the tree. Compression wood is closely related to *opposite wood*, which represents the wood formed on the opposite side of compression wood in the stem. Normal wood is placed between compression wood and opposite wood when different wood properties are considered (Timell 1973).

The problems in mechanical wood processing caused by compression wood are connected to defects in colour, distortion, twisting, and checking (e.g. Ollinmaa 1955). Warensjö and Lundgren (1998) observed a clear correlation between amount of compression wood and bow and crook, both in green and kiln-dried spruce sawn timber. According to Timell (1986), the deformations of sawn timber are dependent on the proportion of compression wood, its location, and the ratio of compression wood to normal wood. The higher the amount of compression wood compared with the volume of a sawn piece, the greater the probability of warping. Warping that occurs in sawn timber may also be due to slope of grain, spiral grain, and juvenile wood.

Kärkkäinen and Raivonen (1977) have referred to several studies in which the effect of compression wood on mechanical properties of green and dry wood have been found to be different. Compression strength is higher in green compression wood than in normal wood, when the higher density of compression wood is ignored (Ollinmaa 1959; Cockrell and Knudson 1973). Tensile strength and impact strength are lower in dried compression wood than in normal wood evidently because of extensive shrinkage of dried compression wood in the longitudinal direction (Kärkkäinen and Raivonen 1977). The effect of compression wood on the strength of sawn timber should not, however, be overestimated since knots and slope of grain likely have a stronger impact.

The quality requirements of saw logs (Havutukkien…1993) do not directly restrict the amount of compression wood. However, the maximum allowable sweep limits the incidence of compression wood in saw logs. Severe compression wood is not allowed in spruce logs for the plywood industry (Kuusivaneritukin laatuohje 1998). In the Nordic Timber grading rules (Pohjoismainen sahatavara 1994), a maximum compression wood percentage by volume has been assessed for each grade. It is generally presumed that trees grown on peatland contain more compression wood than trees grown on mineral soil sites based on the abundance of stem form defects observed in peatland trees.

1.6 Prediction of Quality of Sawn Timber

Evaluation and prediction of quality of sawn timber from standing trees or logs has been of interest among researchers for decades in the United States and in the Nordic countries. The aim has been to identify external tree properties that would optimally explain the internal quality. The predictors of internal properties should also be easily measurable. Accurate information about the properties of raw material has become increasingly important in the logistics of wood procurement (Uusitalo 1995).

The models of knottiness of wood material in pine and spruce clearly show a difference between these tree species (Kärkkäinen 1986a) (Fig. 2). It should be noted that the shares of knot-free and dry knot sections by volume are larger than the corresponding areas indicate in Fig. 2. In pine, both the knot-free and dry knot sections are larger than in spruce. Predicting quality of centre yield is difficult because quality changes are very sensitive to the location of battens in the radial direction of the stem (see Fig. 2, left). However, cutting of pine stems into logs based on external properties has proved to be an effective means of influencing the quality of valuable side yield.

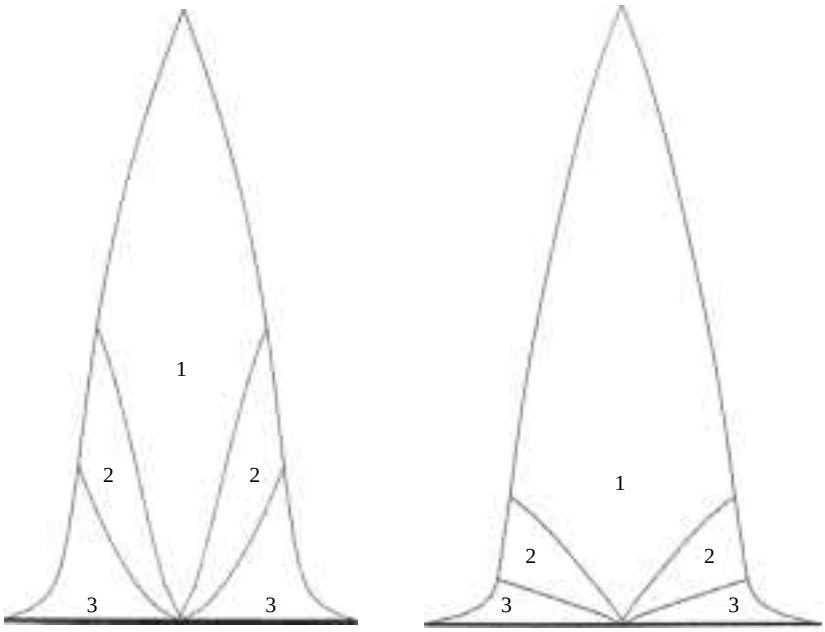


Fig. 2. Longitudinal knot sections of Scots pine (left) and Norway spruce (right) with breast height diameter of 27 cm in southern Finland. 1= sound knot section, 2 = dry knot section, 3 = knot-free section (Redrawn from Kärkkäinen 1986a).

The value relations between saw logs of different grades have been considered in several studies (Heiskanen 1951, 1954a; Heiskanen and Asikainen 1969; Kärkkäinen 1986b; Uusitalo 1989). Since information on value relations of saw logs is only partly of use in production planning, methods suitable for predicting the proportion of a single grade in saw logs or stems have also been applied. Usually, the methods have been based on linear regression (e.g.

Kärkkäinen 1980). The problem lies in the quality of sawn timber being expressed as a categorical variable (i.e. grade). A linear regression model is not very good in this case since a single log, log class, or whole material may be insufficient such that the highest grades in particular are lacking or that only a few observations are included. This may cause bias in the model. Uusitalo (1995) applied logistic regression analysis to predict the probability of a certain grade in a log. Using this method, the problems attributed to categorical values can be avoided.

The grades U/S, V, and VI of the *Green book* (Vientisahatavaran lajitteluohjeet 1979) – initially defined in 1936 – have officially been replaced by the grades of the Nordic Timber, i.e. *Blue book* (Pohjoismainen sahatavara 1994). The prediction of sawn timber fixed to the traditional grades is partly theoretic since in practice the trading of sawn timber does not strictly follow the grading rules but is more or less custom-oriented. Thus, future quality models should be flexible and independent of fixed grades.

1.7 Hypotheses, Aims, and Scope of the Study

Only a few studies have investigated the properties of spruce and pine grown on peatlands. The main reason for this is likely that current cutting removals from peatland stands have been minor compared with total cutting removals from Finnish forests. Peatland stands have merely been responsible for reference material in studies concerning the properties of stands or single trees on mineral soil sites (e.g. Hakkila 1966, 1979). Activity in wood quality research had not increased until the late 1990s, when the importance of peatland stands for future cutting removals was recognized (Tomppo 1999; Nuutinen et al. 2000; Hökkä et al. 2002). At present, the timber harvested from peatlands is mixed with the flood of roundwood going to sawmills or to the pulpwood industry, and thus, its share is unknown. Since the manufacturing of high quality products requires a stricter classification of roundwood, there is also an increased need to uncover the special characteristics of peatland trees affecting mechanical wood processing and the quality of end-use products.

The primary hypothesis of this study is that the growing conditions of peatlands, especially the characteristics of peat soil, affect both the phenotype of trees and wood properties. Trees growing on peatlands are prone to stem form defects and formation of compression wood. Furthermore, wood material is formed heterogeneous on drained peatlands since the growth rate is accelerated by the improved growing conditions. As a result, the wood material produced can be assumed to differ from that of mineral soil sites, where this kind of a drastic change in growing conditions is usually missing. Some features in the wood material may also cause problems in its processing and use. To assess the significance of peatland characteristics on the wood material produced, the results of this study are compared with previous findings from mineral soil sites. Studies based on the measurements of the National Forest Inventories usually consist of a large material, and thus, they represent suitable references both for external and internal characteristics of spruce and pine.

Specific aims of this work are

i) to clarify the most important external and internal quality properties of Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) timber trees growing on drained peatlands,
ii) to compare the quality properties of the trees with those of mineral soil sites to identify out the major differences,
iii) to clarify the quality of sawn timber according to commercial grading rules, and the features determining the grade for sawn pieces,
iv) to assess possible use objects for sawn timber in view of the quality requirements of the most common end-uses of spruce and pine,
v) to assess the overall suitability of peatland stands for the sawmill and joinery industries.

The tree characteristics that best predict the quality of sawn timber are also clarified.

2 MATERIALS AND METHODS

2.1 Study Framework

The study was divided into three parts: 1) external properties of trees, 2) internal properties of trees (wood properties), and 3) quality of sawn timber. Research followed the successive scheme outlined in Fig. 3. Since no reference material from mineral soil sites was collected, all results are compared with previous studies dealing with the same characteristics.

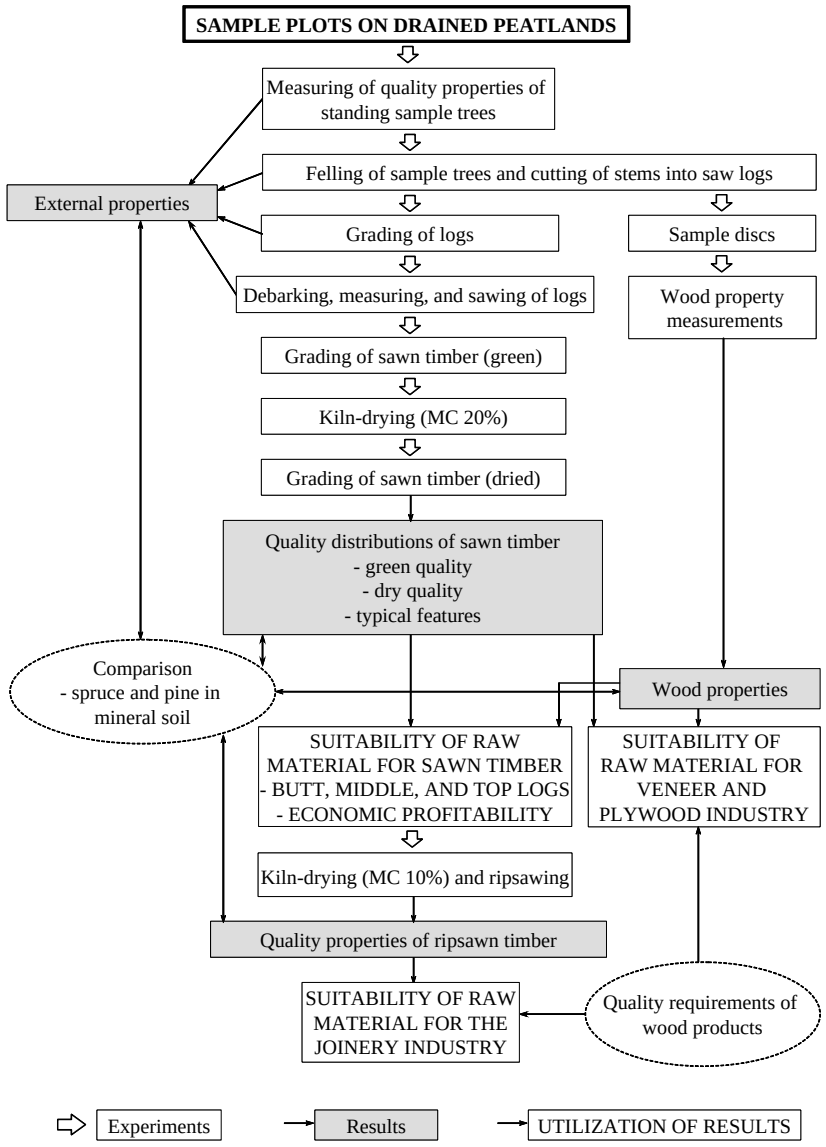


Fig. 3. Progress of the research work.

2.2 Sample Plots

2.2.1 Selection of Sample Plots

The study material was based on stand and tree measurements and test sawing material originating from 20 permanent sample plots. The sample plots – sized 600-2500 m^2 – are located on state-owned land in the research areas of Ruotsinkylä (Vantaa and Tuusula), Vesijako (Padasjoki), and Vilppula (governed by the Finnish Forest Research Institute), and near the Hyytiälä Forestry Station (University of Helsinki) (Fig. 4).

The tree stands chosen represented the first stand after drainage, and they were at the stage of regeneration maturity and dominated by Norway spruce or Scots pine. Other tree species – mainly pubescent birch (*Betula pubescens* Ehrh.) – were allowed if their relative proportions were minor. The site types chosen represented two nutrient levels for both tree species (Finnish term in parentheses): Herb-rich type (Rhtkg) and *Vaccinium myrtillus* type (Mtkg) dominated by spruce, and *Vaccinium vitis-idaea* type (Ptkg) and Dwarf-shrub type (Vatkg) dominated by pine. *Vaccinium myrtillus* and *Vaccinium vitis-idaea* types are further divided into types I and II (see Laine 1989), but for our purposes were considered as combined types. Five sample plots were selected to represent each category. The sample stands had been thinned regularly. The thinnings had been carried out to achieve maximum yield.

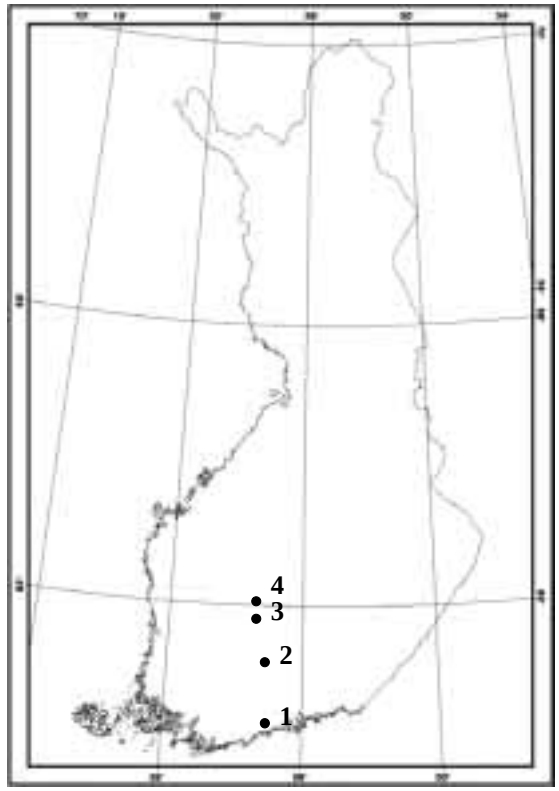


Fig. 4. Location of sample plots: **1** Ruotsinkylä (9 sample plots), **2** Vesijako (2), **3** Hyytiälä (6), and **4** Vilppula (3).

2.2.2 Stand and Tree Measurements

All trees in sample plots, i.e. *counted trees*, were measured for *dbh* (diameter at breast height, i.e. at a height of 1.3 m above ground level). The permanent sample trees (10-40 trees per plot) were measured as *standing sample trees*. These trees were measured for *dbh* (mm), tree height (h, dm), height of the living crown (h_c, dm), dead branch height (h_{db}, dm), and diameter at a height of 6 m (d_6, cm). Tree height and branch height characteristics were measured with a *Vertex* height metre. Diameter at a height of 6 m was measured with a caliper using 1-cm intervals. The cause for termination of a log section was also determined (code, see Appendix 2). The most important stand characteristics are presented in Tables 1 and 2. The data correspond to the date after the last measurements (year 1998) before felling of the trees.

Table 1. Stand characteristics of spruce.

Stand	Location	Site type	Area (ha)	Drainage (year)	A [1] (years)	Tree species	N [2] (stems ha^{-1})	D_g [3] (cm)	G [4] (m^2 ha^{-1})	H [5] (m)	V (o.b.)[6] (m^3 ha^{-1})
18	Ruotsinkylä	Rhtkg	0.2	1929	67	Spruce	420	33.3	34.0	25.6	370.5
						Birch	15	19.3	0.4	22.4	4.3
						Total	435	33.1	34.4	25.5	374.8
25	Ruotsinkylä	Rhtkg	0.2	1933	85	Spruce	385	35.8	36.2	29	466.7
41	Ruotsinkylä	Rhtkg	0.125	1930	119	Spruce	344	33.5	28.3	28.7	372.9
						Birch	16	26.8	0.9	26.6	12.0
						Total	360	33.3	29.2	28.7	384.9
48	Ruotsinkylä	Rhtkg	0.11	1933	61	Spruce	491	27.6	27.9	24.9	329.6
						Birch	9	28.0	0.6	25.2	6.6
						Total	500	27.6	28.5	24.9	336.2
J13	Vilppula	Rhtkg	0.075	1912	115	Pine	53	29.1	3.5	*	*
						Spruce	347	35.2	31.5	29.3	415.0
						Birch	40	23.7	1.7	*	*
						Total	440	34.1	36.7	*	*
13	Ruotsinkylä	Mtkg	0.135	1925	87	Spruce	341	34.7	29.3	28.4	381.4
						Birch	67	24.8	3.1	24.8	36.4
						Total	408	33.8	32.4	28.0	417.8
37	Ruotsinkylä	Mtkg	0.25	1925/-51	71	Spruce	620	25.5	29.3	23.5	323.1
B8	Hyytiälä	Mtkg	0.08	1913	128	Spruce	450	30.4	28.7	23.7	322.0
						Birch	13	11.7	0.1	*	*
						Total	463	30.3	28.8	*	*
B25	Hyytiälä	Mtkg	0.12	1965	119	Pine	150	27.3	7.8	*	*
						Spruce	775	21.6	24.5	20.3	235.0
						Birch	67	19.4	1.9	*	*
						Total	992	22.8	34.2	*	*
22	Vilppula	Mtkg	0.14	1930	68	Pine	57	28.7	3.5	24.2	41.5
						Spruce	329	25.1	12.3	21.9	132.5
						Birch	236	23.5	9.2	21.3	99.2
						Total	622	25.1	23.0	22.0	273.2

* Not measured or determined
[1] Stand age (***A***) is determined as the mean age at stump height of felled sample trees.
[2] ***N*** is the number of the living trees per hectare.
[3] D_g is the mean diameter of trees weighted by the basal area.
[4] ***G*** is the basal area of the living trees per hectare.
[5] ***H*** is the mean height of all sample trees.
[6] ***V* (o.b.)** is the volume of the living trees per hectare.

Table 2. Stand characteristics of pine.

Stand	Location	Site type	Area (ha)	Drainage (year)	*A* [1] (years)	Tree species	*N* [2] (stems ha^{-1})	D_g [3] (cm)	*G* [4] (m^2 ha^{-1})	*H* [5] (m)	*V* (o.b.)[6] (m^3 ha^{-1})
8	Ruotsinkylä	Ptkg	0.075	1929	82	Pine	493	27.9	31.1	24.9	361.5
						Spruce	13	24.7	0.6	23.9	7.3
						Birch	13	26.5	0.7	25.8	8.5
						Total	520	27.8	32.5	24.9	377.3
9	Ruotsinkylä	Ptkg	0.125	1929	81	Pine	624	26.1	30.8	23.3	338.1
						Spruce	24	34.5	1.9	25.8	22.5
						Total	648	26.6	32.7	23.5	360.6
14	Vesijako	Ptkg	0.125	1914	81	Pine	448	25.9	22.0	21.7	217.0
20	Ruotsinkylä	Ptkg	0.075	1926	146	Pine	453	29.4	28.8	22.8	312.1
B21	Hyytiälä	Ptkg	0.2	1955	116	Pine	550	23.4	21.8	19.9	200.0
						Spruce	5	13.2	0.1	10.0	0.4
						Birch	5	15.1	0.1	13.0	0.6
						Total	560	23.3	22.0	19.8	201.0
B13	Hyytiälä	Vatkg	0.09	1915	101	Pine	611	22.1	21.6	18.7	184.0
B14	Hyytiälä	Vatkg	0.12	1915	110	Pine	483	22.2	17.3	18.2	152.0
B15	Hyytiälä	Vatkg	0.12	1915	102	Pine	441	23.6	18.3	19.4	167.0
5A	Vesijako	Vatkg	0.135	1914	168	Pine	444	23.9	18.3	16.8	151.5
XIII	Jaakkoinsuo	Vatkg	0.09	1923	120	Pine	444	22.8	16.8	16.8	136.5

Superscripts as in Table 1.

The stand characteristics were calculated using KPL software developed at the Finnish Forest Research Institute (Heinonen 1994). Stand age is only suggestive since age variation within a stand was usually large. One spruce stand in Ruotsinkylä (48) had been regenerated by planting, while other stands had been naturally regenerated. Most spruce stands had a natural admixture of pubescent birch (Table 1).

Ten timber-sized trees were felled from each sample plot. The minimum diameter at breast height was set at 19 cm for spruces and 17 cm for pines. The selection of sample trees in a plot was based on its DBH distribution. Trees fulfilling the minimum diameter were grouped into 2-cm classes. The percentage of trees in each diameter class formed a weight of the sample trees to be felled (10). The trees to be felled were then sampled randomly within each diameter class. An example of the method used is presented in Fig. 5.

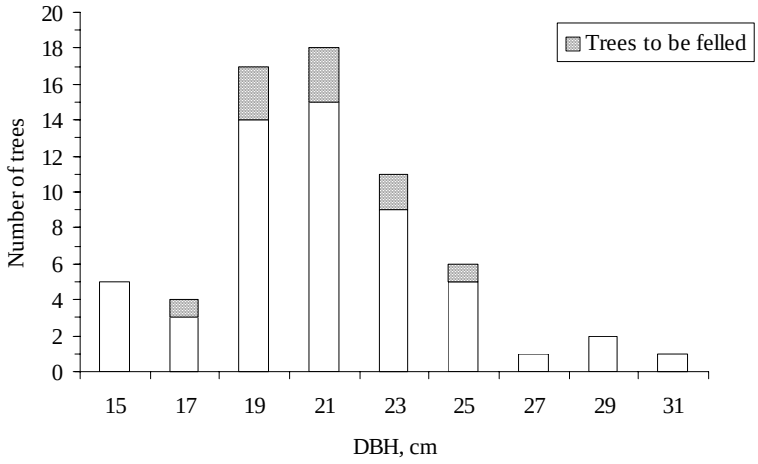


Fig. 5. DBH distribution of the trees on sample plot B13. The number of trees to be felled in a diameter class has been marked with hatched lines.

2.2.3 Scaling of Felled Sample Trees and Quality Grading of Logs

Felled sample trees were measured for the same external characteristics as standing sample trees. Tree height and branch height characteristics were measured by measuring tape. The stems were cut into lengths by a professional forest worker following the quality requirements for saw logs (see Appendix 1). Each log was marked so that its origin could be traced afterwards. Sample discs were taken in connection with scaling from the butt end of each log and from the top end of the top log. Tree top discs were taken at intervals of 2 m to a diameter of 7 cm. In spruce, one disc and in pine two discs were taken from each cut. The sample discs were marked indicating north and a code representing the sample plot, sample tree, and sample height.

Both the spruce and pine logs were graded according to their external properties. Pine logs were graded as in practice by using ABC grading, where grade A represents knotless butt logs, grade C1 butt logs with knots, grade C2 middle logs with dry knots, and grade B top logs with sound knots. The logs, which did not fulfill the quality requirements of these grades, were graded to grade D (see Appendix 1). This method was applied to spruce logs with some modifications. Furthermore, the spruce logs were graded according to the grading rules for softwood logs used in the 9th National Forest Inventory. These rules resemble the grading rules for saw logs introduced by Heiskanen and Siimes (1959).

Dead knots are often found inside the living crown of spruce. The proportion of dead knots was estimated separately. If their proportion was under 25% of the total knot number, the log was graded as grade B, otherwise as grade C2. The largest knots of a log were determined by the condition of knots: sound knot, dead knot, unsound knot, spike knot, buckle, and uncovered knot. In pine logs, the total number of knots ($\varnothing \geq 7$ mm) was counted one by one according to the condition of knots. In spruce, the number of knots was not counted. Knot sizes were measured at right angles to the longitudinal direction of logs on a clean-limbed surface.

2.2.4 Determination of Stem Volume

Stem volume for a sample tree was determined by the volume functions introduced by Laasasenaho (1982). The volume functions for spruce (Equation 10) and pine (Equation 11) are based on d, d_6, and h.

$$v = 0.208043 \times d^2 - 0.0149567 \times d^2 \times h - 0.000114406 \times d^3 \times h + 0.000436781 \times d^2 \times h^2 + 0.133947 \times \left(d^2 + d \times d_6 + d_6^2\right) + 0.0374599 \times d_6^2 \times (h - 6) \quad (10)$$

$$v = 0.268621 \times d^2 - 0.0145543 \times d^2 \times h - 0.0000478628 \times d^3 \times h + 0.000334101 \times d^2 \times h^2 + 0.0973148 \times \left(d^2 + d \times d_6 + d_6^2\right) + 0.0440716 \times d_6^2 \times (h - 6) \quad (11)$$

, where

d = diameter at breast height, cm

d_6 = diameter at a 6 m height, cm

h = tree height, m

A stem volume estimate can also be produced by taper curves. The taper curve models (see Laasasenaho 1982) are based on diameters measured at the following relative heights of a tree: 1, 2.5, 5, 7.5, 10, 15, 20, 30, 40, 50, 60, 70, 80, and 90%. At the base of the stem, where taper curve is more irregular than in other parts of the stem, diameters should be measured at short distances to achieve an accurate estimate of stem volume. In this study, a proper stem analysis was not carried out, instead diameter information was obtained from the points where the stem was cut. Besides these diameters, the dbh (mm) of each tree was known (Fig. 6). The diameter of a height of 6 m was not taken into account in this context because of the lower accuracy (cm).



Fig. 6. Sample taper curve of a pine stem (dbh = 278 mm, h = 251 dm).

The taper curves were constructed by spline functions for each tree. Fortran-based software was used to estimate the stem diameter at 1-dm intervals. The total stem volume was

calculated by summing the volumes of these 1-dm sections, which were determined by the formula for a truncated cone (Equation 12). Spline functions were utilized to obtain an accurate estimate (mm) for the diameter at a height of 6 m (d_{6s}).

$$v = \frac{h}{3}(a_1 + \sqrt{a_1 a_2} + a_2) \tag{12}$$

, where

v = volume of a section, m^3

h = length of a section, m

a_1, a_2 = cross-sectional area at the end of a section, m^2

2.3 Wood Property Measurements

Sample discs were measured for the following wood properties: *annual ring width*, *latewood proportion*, *heartwood proportion*, *proportion of compression wood*, and *basic density*. Defects, such as shakes and decay, were also registered. The material comprised 764 spruce and 684 pine sample discs.

Annual ring width was measured both in the south and north directions from the pith by a growth ring measuring device. Each ring was measured separately for the width of earlywood and latewood tissues. *Latewood proportion* relating to the sample disc was calculated by taking into account the distance of the growth ring from the pith. The distinction between earlywood and latewood tissues is usually based on Mork´s definition (1928), which states that latewood tissue in conifers begins at the point where the cell wall in the tangential direction between two cells exceeds the width of cell lumen in the radial direction. The rule cannot be followed strictly, however, since the magnification required is quite high making measurements slow and laborious. Here the demarcation between earlywood and latewood tissues was made by the difference in colour.

Heartwood proportion was calculated by dividing the heartwood area by the total cross-sectional area of the disc. The corresponding areas were based on the mean of the minimum and maximum diameters of the characteristics.

Proportion of compression wood was estimated as a percentage of the total cross-sectional area of a disc as follows:

1. 0%
2. 1-10%
3. 11-20%
4. 21-30%
5. 31-40%
6. 41-50%
7. > 50%

Stem ovalness usually correlates with compression wood. Ovalness of sample discs was determined as the difference between the largest and smallest diameters of a disc divided by the mean of these diameters.

Wood density was determined as basic density, i.e. ovendry mass per green volume. The variation in basic density was studied both in the radial and longitudinal directions in the stem. The mean basic density was calculated for stems and sample plots. The method for determining the basic density varied between the tree species. In spruce, the basic density was measured and calculated from the pith to the south direction. A wood bar 30 mm in width was sawn from the pith to the bark and cut uniformly into pieces of 25-40 mm in length depending on the total length of the bar (Fig. 7). The mean basic density for a spruce sample disc was calculated by weighting each piece with the cross-sectional area of disc represented by it.

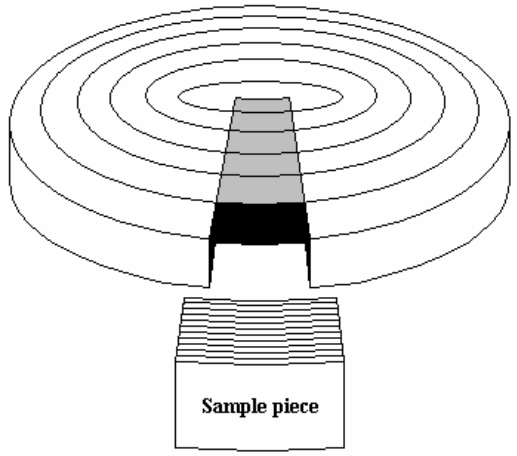


Fig. 7. Sampling of wood density in spruce discs.

In pine stems, the longitudinal variation of basic density was studied from whole sample discs. The variation of basic density in the radial direction in pine stems, as in spruce, was based on sample pieces taken from pith to bark. However, the wood bar was 25 mm in width and the basic density was determined both in the south and north directions. The bar was divided uniformly into sample pieces of 20 mm in size. Sample pieces containing both heartwood and sapwood were divided into separate pieces. The sample pieces taken represented knot-free wood.

Procedure for the determination of basic density and moisture content:

1. Weighing of green sample pieces (or discs) by accurate scales → **green mass**.
2. Determination of volume of sample pieces by *a water immersion method* → **green volume**.
3. Drying of sample pieces in an oven at a temperature of 103°C for 48 hours: ISO 3131 (ISO 1975).
4. Weighing of dried sample pieces (or discs) by accurate scales → **dry mass**.

Basic density was calculated according to Equation 6.

The mean basic density for a bolt was calculated by weighting the densities of butt and top end discs with their cross-sectional areas. The mean basic density for a stem was calculated by weighting basic densities of the bolts with their volumes (Equation 13).

$$\rho_{stem} = \frac{(\rho_1 v_1 + ... + \rho_n v_n)}{v_{total}} \quad (13)$$

, where

ρ_{stem} = mean basic density of a stem, $kg\ m^{-3}$

$\rho_1 ... \rho_n$ = mean basic density of a bolt, $kg\ m^{-3}$

$v_1 ... v_n$ = volume of a bolt, m^3

v_{total} = total volume of bolts, m^3

The log volumes (u.b.) were obtained from a log scaler in connection with the sawing procedure. The volumes of bolts of pulpwood were calculated by the formula for a truncated cone (see Equation 12). The mean basic density represents the part of a stem from which sample discs were taken. Thus, tree tops under a diameter of 7 cm were ignored. Their influence on the mean basic density of a stem is, however, insignificant because of their minor volume. Estimates of basic density were usually extended to a relative height of 90%. An estimate of the mean basic density for a stand was determined by weighting the basic densities of sample trees with their volumes. The moisture content of sample pieces (discs) was calculated using Equation 14.

$$u = \frac{100(m_u - m_0)}{m_0} \quad (14)$$

, where

u = moisture content, %

m_u = mass of wood with moisture

m_0 = oven - dry mass of wood

2.4 Sawing Experiments

2.4.1 Stages

The sawing experiments were carried out at Pori College of Forestry in the municipality of Kullaa, western Finland, following an industrial process.

The sawing experiments consisted of the following stages:

1. Measuring of logs by a log scaler.
2. Sawing of logs according to Nordic practices.
3. Marking of sawn timber.
4. Grading of green sawn timber.
5. Kiln-drying of sawn timber to a moisture content of ca 20% (export dry).
6. Grading of kiln-dried sawn timber.
7. Kiln-drying of sawn timber to a moisture content of ca 10% (joinery dry) and ripsawing.

The stages of the sawing experiments are discussed in more detail in the following sections.

2.4.2 Measuring of Logs

The logs were measured before and after debarking by an optical log measuring device, *Elmes*, where the scanning of logs is based on 3D laser measurements. The logs were measured for length (cm), volume (dm^3), top diameter (0.1 mm), sweep (mm), and taper (mm). Accuracy of the characteristics is presented in parentheses. Sweep was determined as the maximum deviation from the sideline drawn through top and butt ends of a log. Taper was determined as difference in diameter between butt and top ends of a log divided by the log length ($mm\ m^{-1}$).

2.4.3 Sawing of Logs and Marking of Sawn Timber

The logs were sawn according to Nordic practices (*double cut*), where the first phase is *a block sawing phase* and the second *a re-sawing phase*. The sawing was done using a double-band saw with chipping canters. In the first phase (Fig. 8, left), the two opposite sides of a log were processed with chipping canters and the side yield was divided into boards. In the second phase, the sides were processed with chipping canters, the side yield was divided into boards, and the centre yield was divided into 2, 3, or 4 battens (Fig. 8, right). The number of cuts depended on the blade settings used. In both phases, the boards continued to edging. The edging of boards was controlled by a laser beam, but the operator of the edger ultimately decided the width of a board.

For pine, two collections of blade settings were used: butt logs grade A and other logs (grades B, C1, C2, and D). Spruce logs were sawn by one collection of blade settings (independent of log quality). Most top diameter classes of logs contained alternative blade settings. To make it easier to carry out the kiln-drying experiments, blade settings yielding sawn pieces of the same thicknesses were applied when possible. The blade settings chosen were those commonly used in the Finnish sawmill industry (see Appendix 3). The sawn timber was

marked by its location in the log (view from butt end) (Fig. 8). Log number was included in the code to enable tracing of the origin of a sawn piece afterwards (e.g. 1-S1).

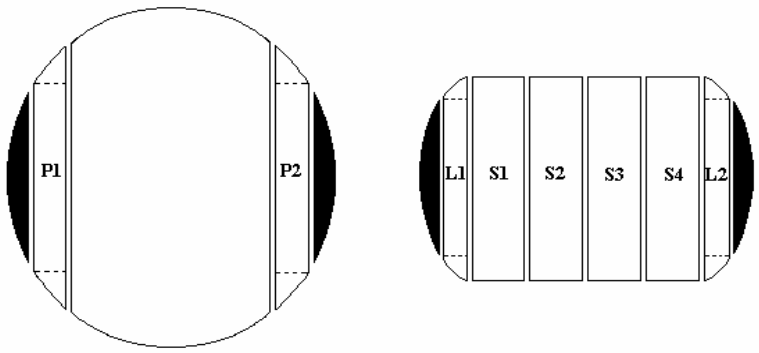


Fig. 8. Sample of the marking of sawn timber: block sawing phase (left), re-sawing phase (right).

2.4.4 Grading of Sawn Timber

The sawn pieces were graded as green and kiln-dried according to the grading rules of Nordic Timber (Pohjoismainen sahatavara 1994). Dried centre yield was also graded according to the stress grading rules of NS-INSTA 142 (NS-INSTA 142 1997) and T-grading (Lipitsäinen 1994). An experienced grader was responsible for all gradings of sawn timber. Value ratios of pine sawn timber introduced by Metsäteho Oy were applied in grading (Nordic Timber) of sawn timber of both tree species (Appendix 4).

Nordic Timber includes the main grades A, B, C, and D, of which A is the highest, containing subgrades A1, A2, A3, and A4. Besides these grades, Nordic Timber also defines wane grades as *schaalboards* (VL or KL), *knot-free three sides* (OKS), and *halvrena side yield* (PP). Abbreviations used in the study are presented in parentheses. Schaalboards were divided into export quality (VL) and domestic quality (KL) according to the proportion of wane. Nordic Timber defines wane centre yield as *halvrena centre yield*.

The quality of side yield was studied in two ways: including wane and excluding wane. The first case represents the quality produced by the sawing process, where wane is a defect lowering the quality of sawn timber. The share of wane in sawn timber depends, for instance, on the blade settings used. The second case represents the internal quality of logs, in which knots and other natural defects determine the quality of sawn timber. In other words, the sawn timber was graded as though no wane existed. The pieces of sawn timber that failed to meet the quality requirements of the grading rules were classified as rejects (Re). The sawn timber originating from saw logs of grade D was ignored.

Stress grading is based on correlations between features of sawn timber and the bending strength observed. The most important defects lowering bending strength are knots, disturbance of grain, shakes, compression wood, and decay. The grades of the visual stress grading rules of NS-INSTA 142 are T3 (30), T2 (24), T1 (18), and T0 (14), in descending order of strength. The characteristic values of bending strength (N mm^{-2}=MPa) are presented

in parentheses. In T-grading, the highest grade is T40, followed by T30, T24, and T18. The grade directly shows the characteristic value of bending strength.

A special form was used in the grading of sawn timber (Appendix 5). The following information was filled out on this form:

- Code of a sawn piece
- Tree species
- Dimensions of a sawn piece (thickness, width, length)
- Grading (NT green, NT dried, T-grading, NS-INSTA 142)
- Grade of a sawn piece and corresponding length
- Primary feature determining grade (code, Appendix 6)
- Location of feature (face, edge, arris)
- Size(s) and number of feature(s)
- Cause for cutting (code, Appendix 6)

2.4.5 Drying of Sawn Timber

The sawn timber was dried to a moisture content of ca 20% (export drying) in chamber kilns at Pori College of Forestry by optimal drying schemes based on dimensions of sawn timber. Since the volumes of sawn timber of certain thicknesses were small, some dimensions were combined to reach the optimal loading of the chamber (e.g. 63 and 75 mm in thickness). The drying schedules, constructed by the VTT (Technical Research Centre of Finland), were Schema 2 (centre yield) and Schema 3 (boards); these are presented in Appendix 8.

2.4.6 Joinery Drying and Ripsawing of Centre Yield

To study the suitability of sawn timber for joinery, the sawn timber was kiln-dried from a moisture content of ca 20% to ca 10%. The material for the experiments consisted of export dried sawn timber 50 and 75 mm in thickness of grade A quality (Nordic Timber). The ripsawing experiments were carried out after joinery drying to study the magnitude of internal stresses.

Progress of the experiments:

1. Cutting of a sawn piece according to the section of grade A.
2. Measuring of moisture content in the middle and ends of a sawn piece (prEN 13183-2 1998).
3. Measuring of shakes and deformations before the joinery drying.
4. Loading of sawn timber for drying.
5. Drying of sawn timber to a moisture content of ca 10% (Schema 2).
6. Grading of sawn timber, inspection of features lowering the quality, and measuring of deformations.
7. Ripsawing of sawn timber into 2 or 3 pieces by a circular saw (see Fig. 9).
8. Marking of sawn pieces and measuring of dimensions, deformations, and shakes.

The drying deformations were determined from 94 spruce and 53 pine sawn pieces. The corresponding total volumes were 5.0 m^3 and 1.5 m^3. The ripsawing of sawn pieces yielded 236 pieces of spruce and 109 pieces of pine.

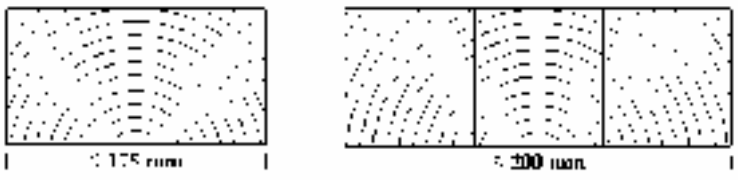


Fig. 9. Ripsawing of centre yield.

2.5 Determination of Value of Roundwood as Sawn Timber

2.5.1 Stand-Level

A *quality factor of roundwood* was determined for each stand to compare between-stand variation in quality of sawn timber. The quality factor of roundwood represents the mean value of sawn timber on a stand, as the centre yield size 50 × 100 mm of grade A is assigned a value of 100 (see Appendix 4). The quality factor of roundwood was determined as follows (Equation 15):

$$F_s = \frac{\sum (nv_{ij} \times i_{ij})}{\sum gv_{ij}} \tag{15}$$

, where

F_s = quality factor of roundwood of a stand

nv_{ij} = net volume of a sawn piece representing grade i dimension j, m^3

i_{ij} = indexed value of a sawn piece representing grade i dimension j

gv_{ij} = gross volume of a sawn piece representing grade i dimension j, m^3

Gross volume represents the volume of a sawn piece before grading. In grading of sawn timber, the length-grade combination that maximizes the value of a sawn piece is chosen. To be able to do this, the value ratios of sawn timber have to be known. The grading yields the *net volume* of a sawn piece. The volumes were calculated by nominal dimensions, thus the shrinkage in drying was ignored.

The quality factor of roundwood was calculated in three ways:

1. Value of kiln-dried centre yield
2. Value of kiln-dried side yield
3. Value of kiln-dried centre yield + side yield, i.e. total yield

Gross value and *sawing value of logs* were also determined for each stand. The gross value of logs was determined as follows:

$$\begin{aligned}\textit{Gross value of logs } (€\ m^{-3}) = {} & \textit{value of sawn timber} + \textit{value of by-products} = \\ & \textit{value of sawn timber} + \textit{value of sawmill chips} + \\ & \textit{value of bark and sawdust}\end{aligned} \quad (16)$$

Since the price of sawn timber is not fixed but varies according to many factors, such as demand, the gross values of logs were calculated using several price levels: 170, 180, 190, 200, 210, and 220 € m^{-3}. The price levels represent the price of centre yield size 50 × 100 mm of grade A (see Appendix 4). The price of by-products was set at 50, 55, or 60 € m^{-3}. The price of by-products is based on an interview (Ali-Raatikainen 2003). The sawing value of logs was determined as follows:

$$\begin{aligned}\textit{Sawing value of logs } (€\ m^{-3}) = {} & \textit{value of sawn timber} = \\ & \textit{gross value of logs - value of by-products}\end{aligned} \quad (17)$$

2.5.2 Tree-Level

The quality factor of roundwood was determined for the butt log, F_1 (Equation 18), and for the whole log section, F_{ls} (Equation 19), of each tree. The method is the same as for stand-level (see Section 2.5.1). The quality factor F_{ls} was determined as a weighted mean.

$$F_1 = \frac{\sum(nv_{ij} \times i_{ij})}{\sum gv_{ij}} \quad (18)$$

, where

F_1 = quality factor of roundwood of a butt log

nv_{ij} = net volume of a sawn piece representing grade i dimension j, m^3

i_{ij} = indexed value of a sawn piece representing grade i dimension j

gv_{ij} = gross volume of a sawn piece representing grade i dimension j, m^3

$$F_{ls} = \frac{(F_1 \times v_1 + ... + F_n \times v_n)}{(v_1 + ... + v_n)} \quad (19)$$

, where

F_{ls} = quality factor of roundwood of the log section in a stem

$F_1 ... F_n$ = quality factors of roundwood by logs in a tree

$v_1 ... v_n$ = gross volumes of sawn timber by logs, m^3

2.6 Statistical Methods

The variation in wood properties was studied at three levels: within a stem, between stems, and between stands. Statistical analyses were carried out by the means of *ANOVA*, analysis of variance (SAS 1990). Furthermore, the tree characteristics best predicting the quality of sawn timber were clarified. Before construction of models, the correlations between tree variables were studied by correlation matrix. The correlation coefficients were calculated as follows:

$$r = \frac{s_{xy}}{s_x s_y} \tag{20}$$

, where s_{xy} is the covariance between variables X and Y, and s_x and s_y the standard deviations of the variables (Equations 21-23).

$$s_{xy} = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{n - 1} \tag{21}$$

$$s_x = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{(n-1)}} \tag{22}$$

$$s_y = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{(n-1)}} \tag{23}$$

, where x_i and y_i are values observed, $\bar{x}$ and $\bar{y}$ means of values observed, and n the number of observations (Ranta et al. 2002).

In the models constructed, the quality factor of roundwood was the dependent variable. Since the dependent variable yields continuous values, a linear regression analysis could be applied (see Uusitalo 1995). The parameters were estimated by using *MLwiN* software (Goldstein et al. 1998), which estimates the fixed and random parameters simultaneously with the restricted iterative generalized least square (*RIGLS*) method. The models were constructed by entering the variables into the model one by one. The likelihood ratio test was applied to test the significance of each added predictor. The value of *-2×log-likelihood* was used as an indicator of the overall goodness-of-fit of the models. The reliability of models was evaluated by means of root mean square error, *RMSE* (Equation 24), *relative RMSE* (Equation 25*), systematic error*, i.e. *bias* (Equation 26), and *relative bias* (Equation 27).

$$RMSE = \left(\sum_{i=1}^{n} \frac{(y_i - \hat{y}_i)^2}{n} \right)^{0.5} \tag{24}$$

$$RMSE_r = \left(\sum_{i=1}^{n} \frac{\left(\frac{y_i - \hat{y}_i}{\hat{y}_i} \right)^2}{n} \right)^{0.5} \quad (25)$$

$$b = \sum_{i=1}^{n} \frac{(y_i - \hat{y}_i)}{n} \quad (26)$$

$$b_r = \sum_{i=1}^{n} \frac{\left(\frac{y_i - \hat{y}_i}{\hat{y}_i} \right)}{n} \quad (27)$$

, where y_i is the value observed, $\hat{y}_i$ the value predicted, and n the number of observations.

The general form of the regression equation is:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k + \varepsilon \quad (28)$$

, where Y is the dependent variable, $X_{1...k}$ the independent variables, $\beta_{1...k}$ the parameters of independent variables, α the constant, and ε the error term of random variation (Ranta et al. 2002).

3 RESULTS

3.1 External Properties

3.1.1 Tree Size and Stem Form Characteristics

All trees exceeding 5 cm at breast height are included in the DBH distributions presented in Fig. 10. The material comprised 665 spruces and 584 pines. The mean diameter of all counted spruces was 27.5 cm, and the mean diameter weighted with basal area (D_g) 31.0 cm. For pine, these characteristics were 23.2 cm and 25.0 cm, respectively. As the Fig. 10 shows, the variation in DBH distribution of spruce was extremely large, even though the relative proportions of the smallest and the largest trees were minor.

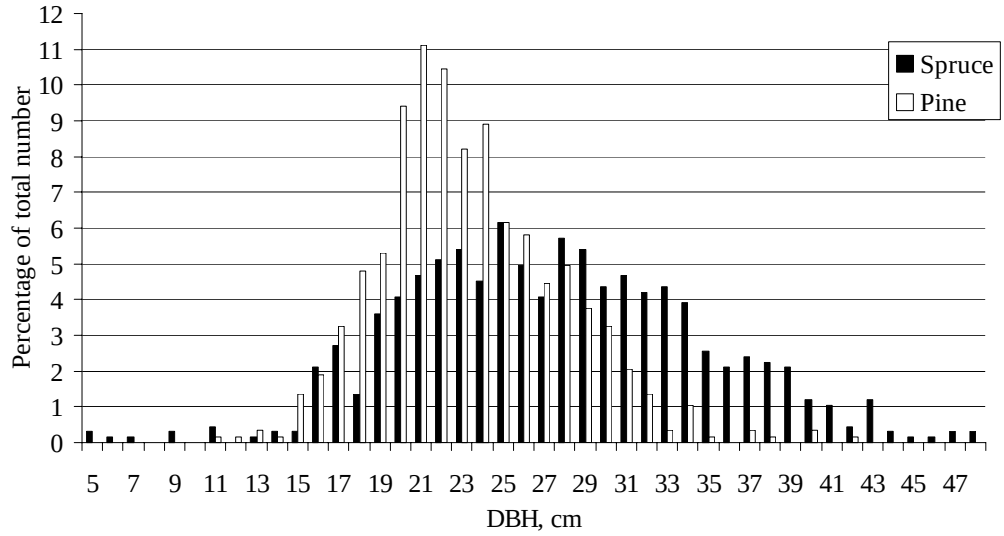


Fig. 10. DBH distributions formed by all counted trees.

The mean tree height for all spruce sample trees (n = 291) was 25.2 m. For pine (n = 296) the corresponding value was 20.3 m. The tree height distributions are presented in Fig. 11. The mean volume (o.b.) of spruce and pine stems, determined by the volume functions (Equations 10 and 11), was 819 dm^3 (s = 452) and 468 dm^3 (s = 230), respectively.

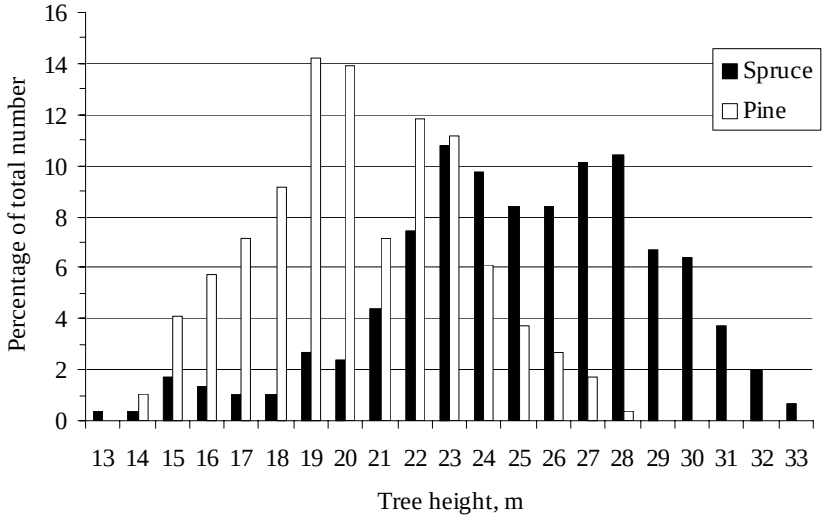


Fig. 11. Tree height distributions of spruce and pine sample trees.

Taper of all spruce and pine sample trees is presented in Fig. 12. The mean taper was 4.3 cm (s = 1.7) in spruce stems and 4.8 cm (s = 1.3) in pine stems. Some spruce stems (Sample plot 25) had extensive butt swellings, which caused abnormal (> 9 cm) taper.

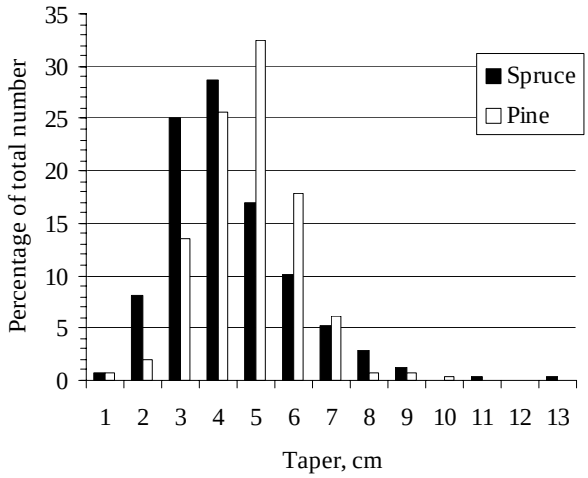


Fig. 12. Taper of spruce and pine sample trees.

The linear dependence between diameter at breast height (*dbh*) and taper of stems is presented in Figs 13 and 14. In felled trees, the taper was determined utilizing taper curves (see Fig. 6). In spruce, the dbh accounted for 31% of the variation of taper in standing sample trees and for

37% in felled sample trees (Fig. 13). In pine, the shares were 23% and 45%, respectively (Fig. 14).

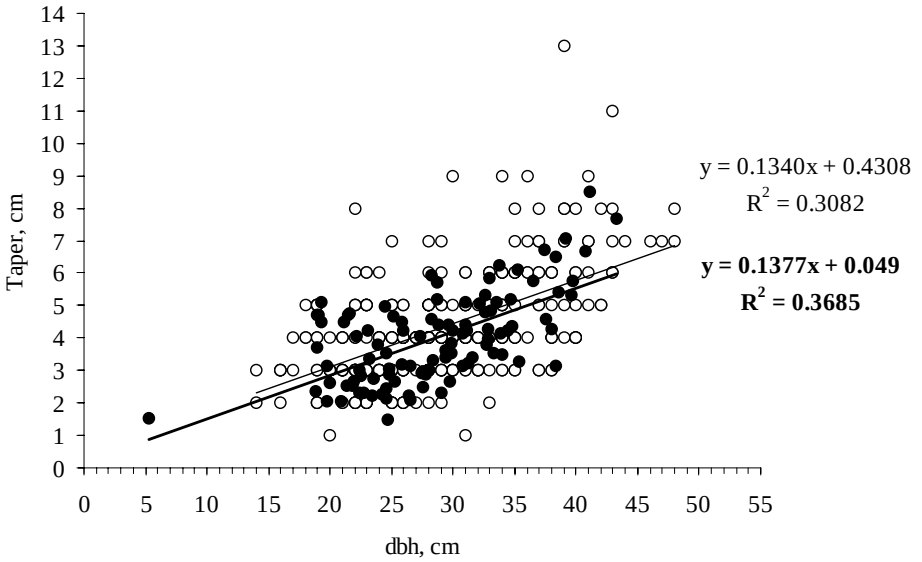


Fig. 13. Linear relationships between diameter at breast height and taper for spruce stems. All sample trees marked with white circles, felled trees with black circles. Equations with R^2 are presented.

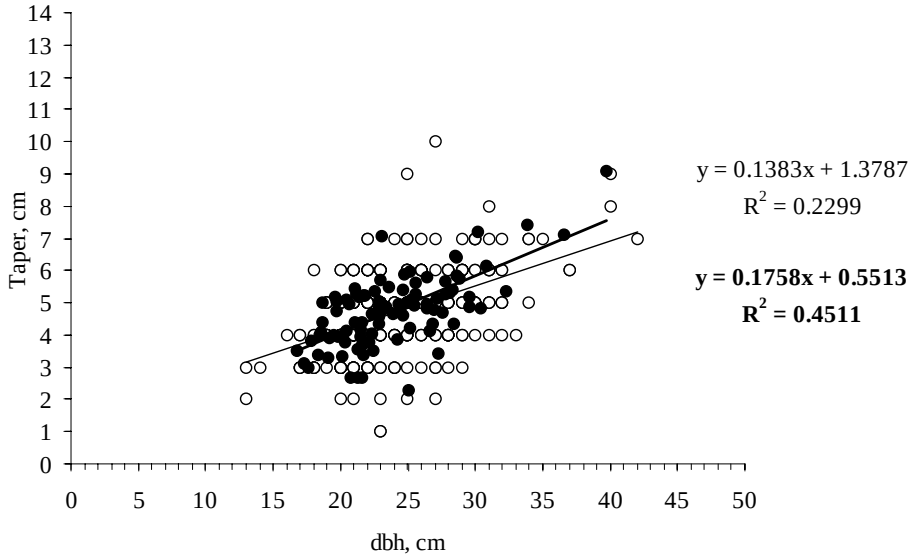


Fig. 14. Linear relationships between diameter at breast height and taper for pine stems. All sample trees marked with white circles, felled trees with black circles. Equations with R^2 are presented.

The distributions of breast height form factors of spruce and pine stems are presented in Fig. 15. The stem volume was based on volume functions introduced by Laasasenaho (1982) (Equations 10 and 11). The mean breast height form factor averaged 0.458 (s = 0.039) in spruce and 0.466 (s = 0.037) in pine. The slenderness of all spruce sample trees averaged 0.88 (s = 0.11). In pine sample trees, the slenderness was on average 0.85 (s = 0.12). The stem form of spruce grown on *Vaccinium myrtillus* (Mtkg) type was slightly better than that of spruce grown on Herb-rich type (Rhtkg) when taper, breast height form factor, and slenderness were concerned. For pine, taper and breast height form factor were better on poorer site type (Vatkg). Slenderness of pine was better on more fertile site type (Ptkg).

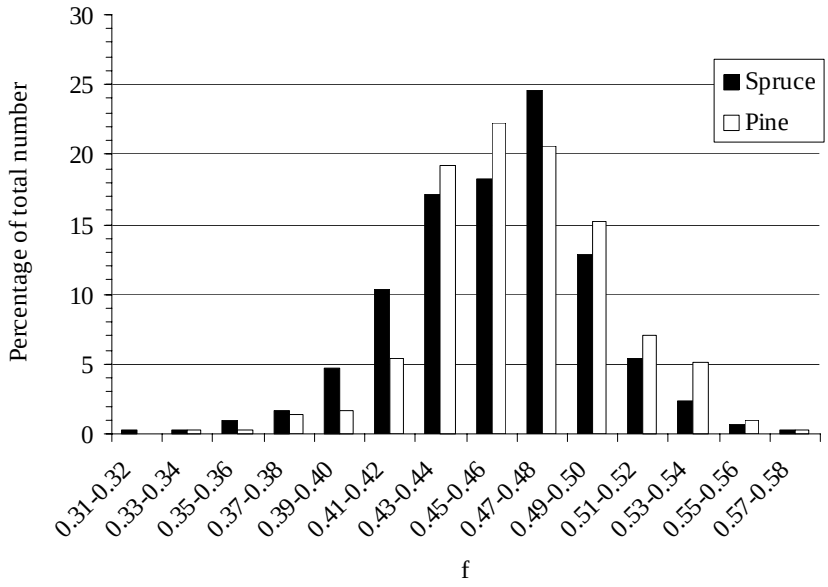


Fig. 15. Distributions of breast height form factor of spruce and pine sample trees.

3.1.2 Branch Height Characteristics

Tree height, crown height, and dead branch height of felled trees are presented in Figs 16 and 17. The same characteristics for all sample trees are presented in Figs 18 and 19. The size and type of knots are considered in more detail in Section 3.1.7.

Crown height of spruce varied greatly within a stand, whereas for pine it was relatively constant (Figs 16 and 17). Dead branchiness of spruce (knot diameter > 15 mm) typically reached the base of the tree. The mean crown ratio of spruces was 0.637 (s = 0.098) indicating that the trees were vigorous (Fig. 20). By contrast, crown ratios of pines were remarkably low, 0.360 (s = 0.072) on average. For more than 70% of pines, the crown ratio was under 0.40, which is generally considered to be the minimum for a healthy, vigorous tree. Factors reducing the width of the living crown in peatland pines are discussed in Section 4.1.

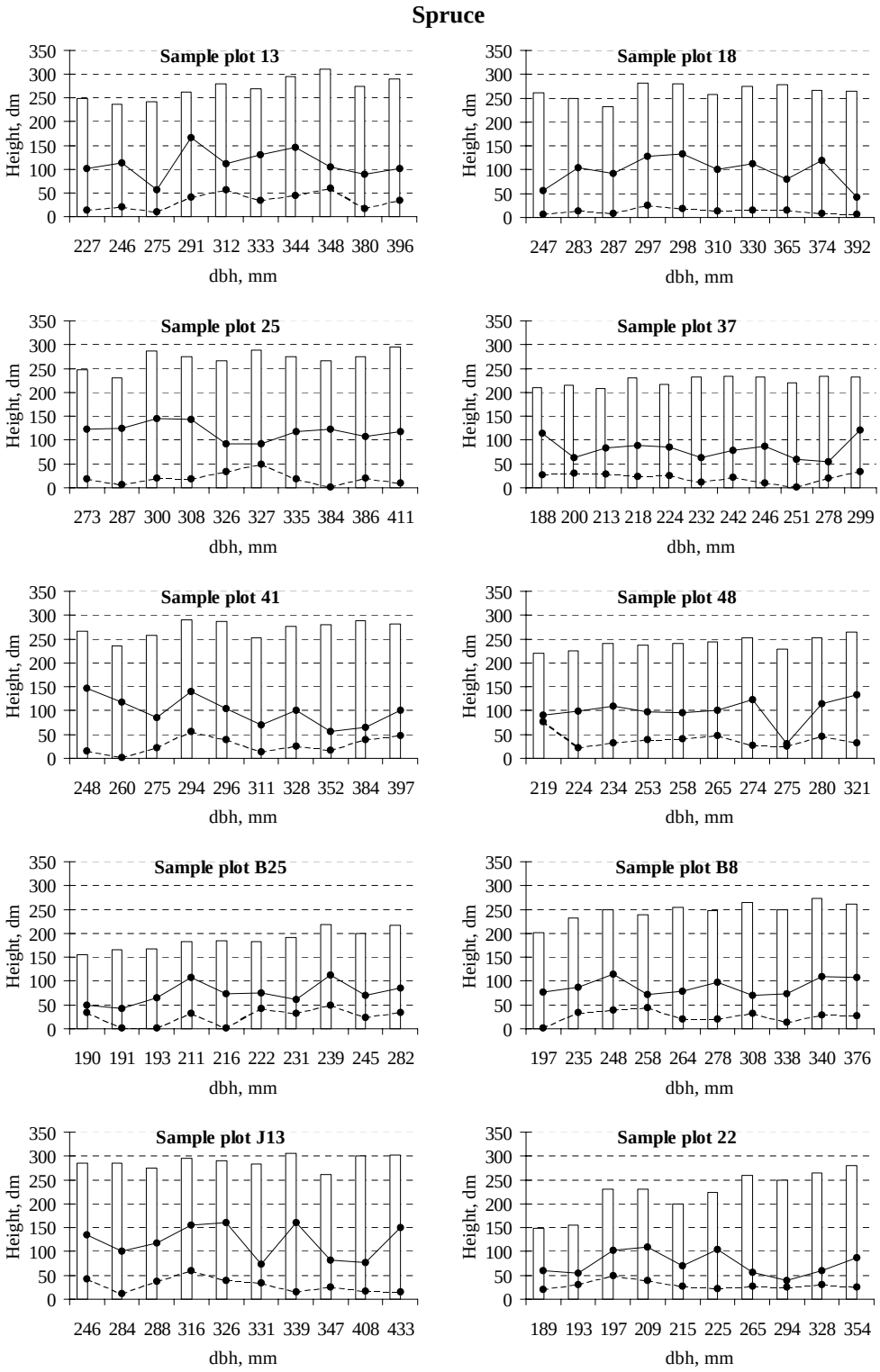


Fig. 16. Tree height (bar), crown height (solid line), and dead branch height (dashed line) of felled spruce sample trees by sample plots. The trees are presented in ascending order of dbh.

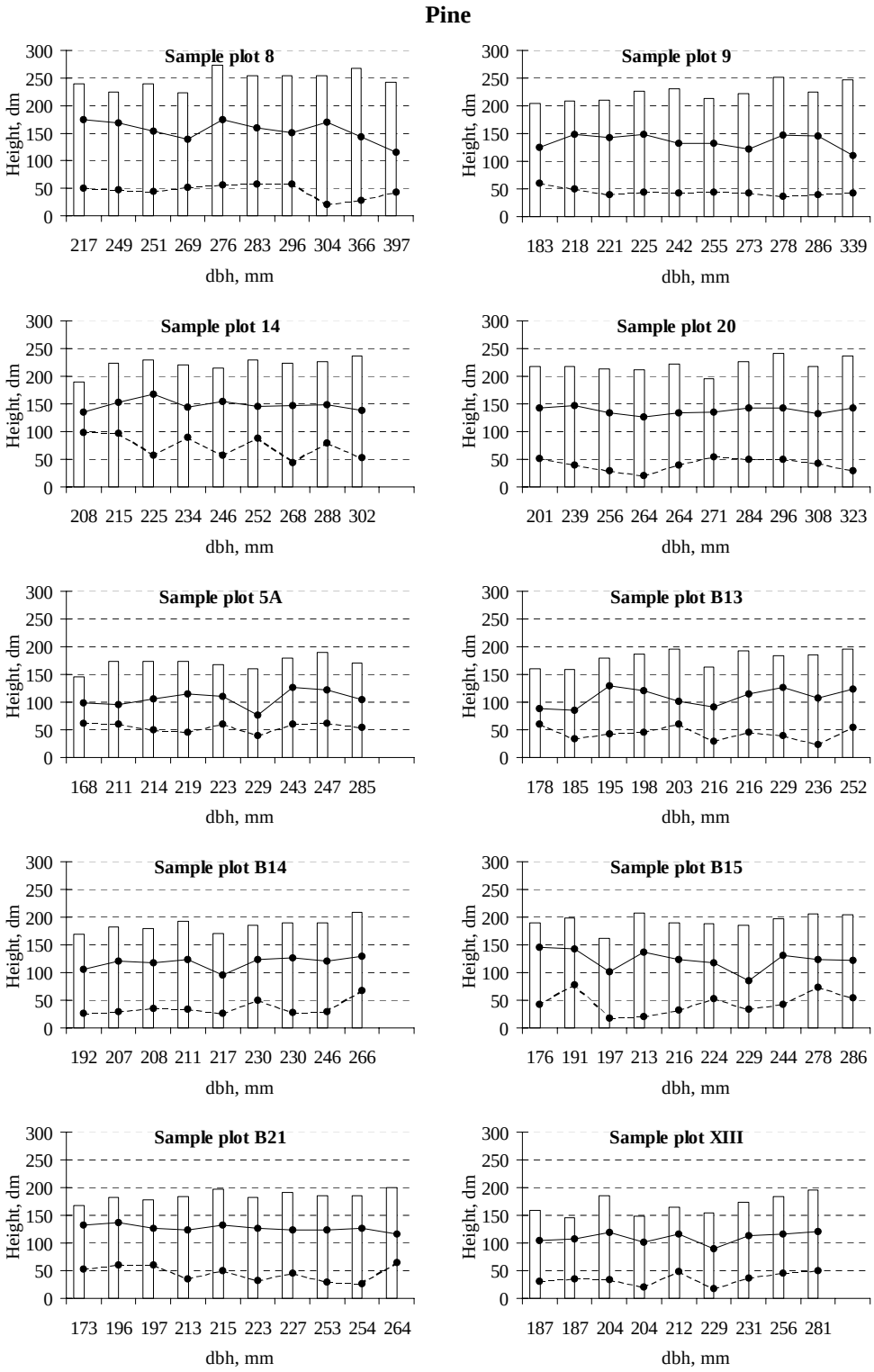


Fig. 17. Tree height (bar), crown height (solid line), and dead branch height (dashed line) of felled pine sample trees by sample plots. The trees are presented in ascending order of dbh.

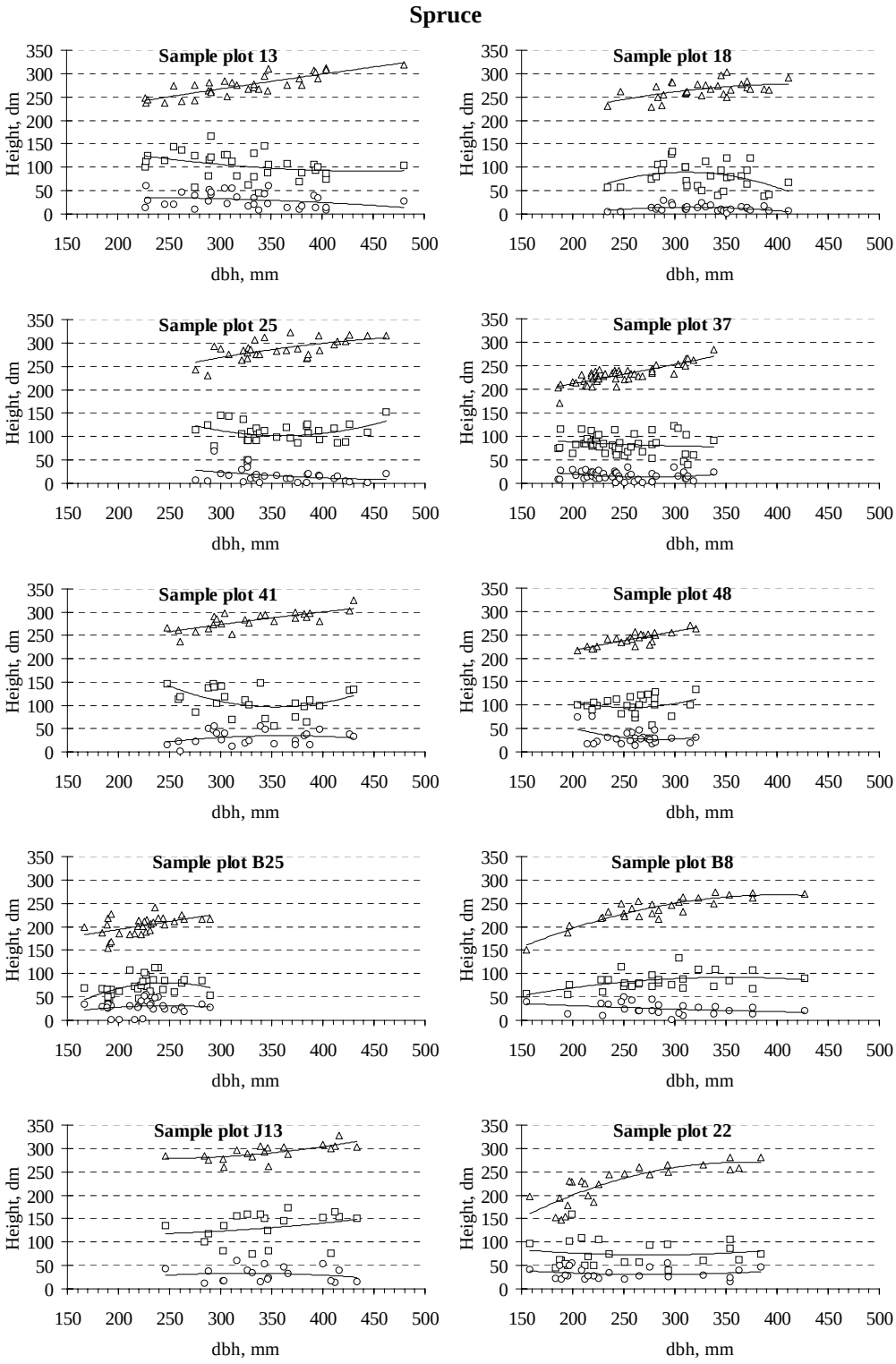


Fig. 18. Tree height (triangle), crown height (square), and dead branch height (circle) of all spruce sample trees (standing + felled trees) by sample plots. Fitted trend lines are presented.

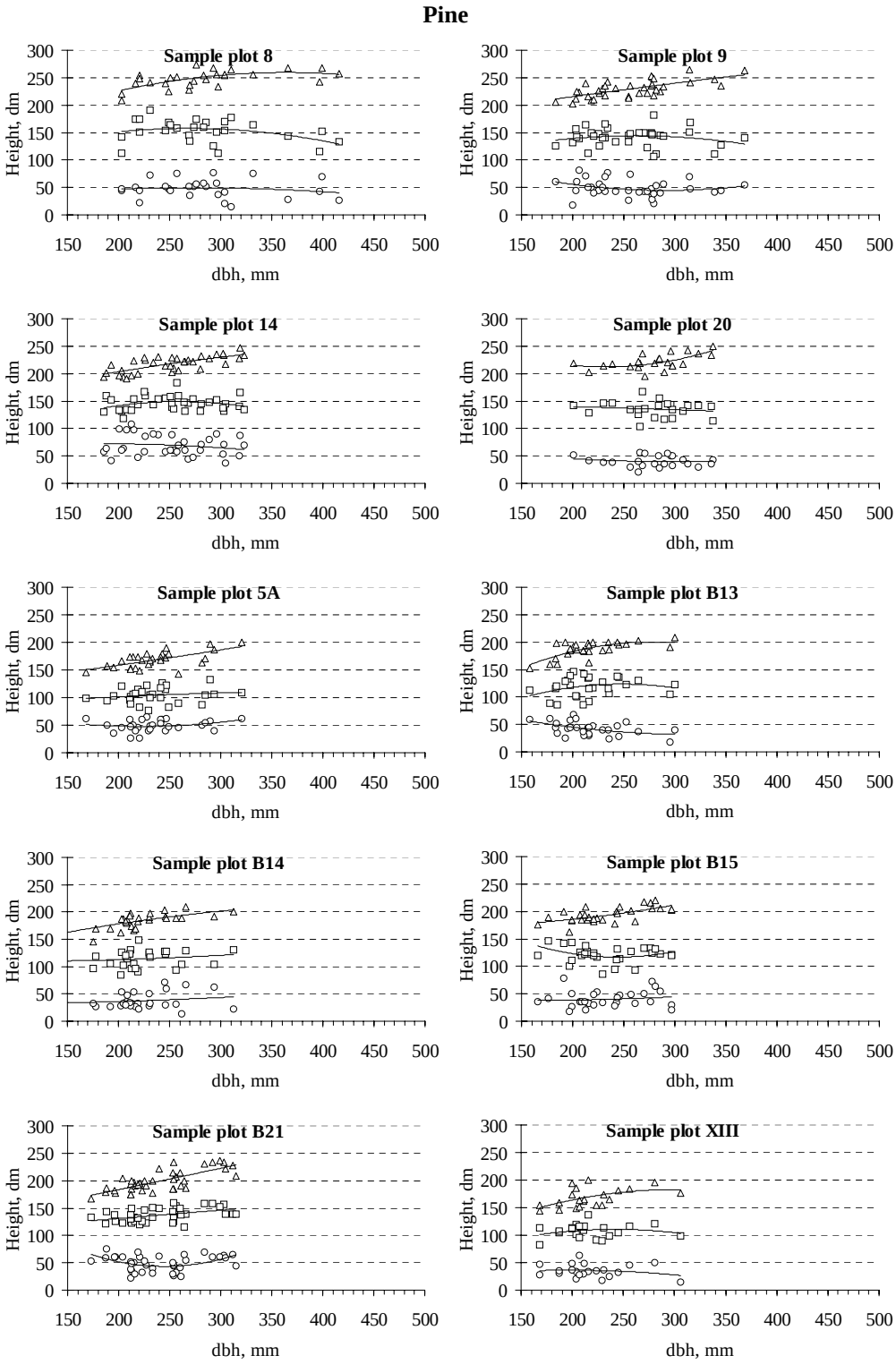


Fig. 19. Tree height (triangle), crown height (square), and dead branch height (circle) of all pine sample trees (standing + felled trees) by sample plots. Fitted trend lines are presented.

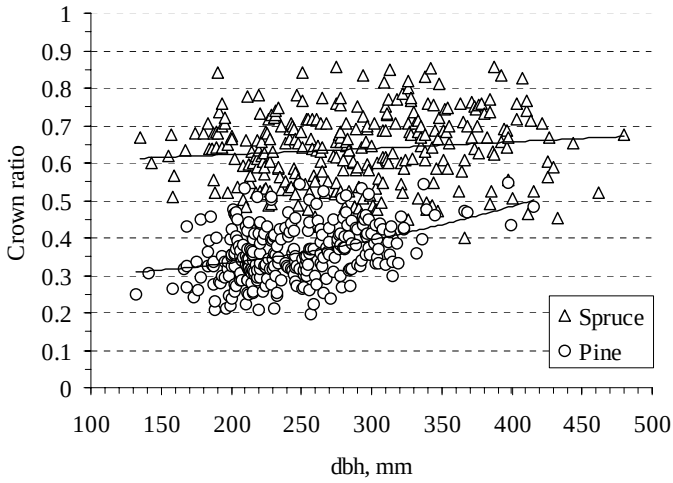


Fig. 20. Crown ratios of spruces and pines by the diameter at breast height. Fitted trend lines are presented.

3.1.3 Saw Timber Proportion

Saw timber proportion (saw timber percentage) depends on dbh, taper, tree height, stem form defects, and branchiness. The three first characteristics refer to the *theoretical maximum saw timber proportion* (based on minimum diameter). When the external quality requirements – stem form defects and branchiness – are taken into account, the outcome is the real, i.e. *quality-based*, saw timber proportion. The quality requirements for saw logs are presented in Appendix 1.

The diameter-based saw timber proportion was calculated by dividing the stem volume over the minimum diameter by the total stem volume. The quality-based saw timber section represented a volume, in which jump butts and jump cuts were reduced. The saw logs of grade D were also subtracted from the saw timber volume.

An example of the difference between the two concepts of saw timber proportion is illustrated in Fig. 21. The solid line at a height of 153 dm represents the end of the quality-based log section and the dashed line at a height of 163 dm the diameter-based end of the log section (150 mm). The saw timber proportions of this stem in the two cases were 88% and 91%, respectively. The volumes were calculated by the means of taper curves.



Fig. 21. Sample termination of log section in a pine stem. The dashed line represents the height of minimum diameter (o.b.) and the solid line the height of termination of log quality.

In spruce, the cause for termination of log section was the minimum diameter (16 cm, o.b.) in 75% of stems. In 20% of stems, the log section terminated before the minimum top diameter because of crooks, in 2% because of large branches, and in 3% because of other defects. In pine, the cause for the termination of log section was minimum diameter (15 cm, o.b.) in 65%, crooks in 29%, large branches in 3%, and other defects in 3% of stems. Saw timber proportions of all felled trees are presented in Fig. 22. As the figure shows, the difference between these two characteristics was smaller in spruce than in pine. Morover, the pattern of the theoretical saw timber proportion differed slightly between the tree species due to differences in tree size (dbh and height), stem form, and minimum diameter (15/16 cm).

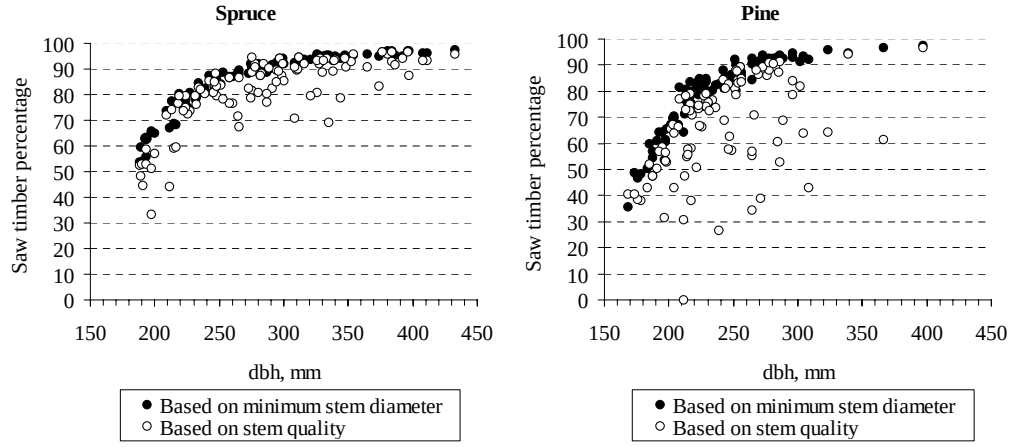


Fig. 22. Saw timber percentages of spruce (left) and pine (right) stems.

3.1.4 Height Growth of Trees

The mean annual height growth was determined by dividing the tree height by its age at butt height. The mean height growth of a tree is a quality factor of timber since it corresponds to the mean distance between branch whorls, thus affecting the number of knots in logs, and consequently, in sawn timber. The height growth was significantly ($p < 0.05$) higher in more fertile stands of both tree species. In fact, the relationship is not so simple since the history of silvicultural treatments (time of drainage and thinnings) of the stands should also be taken into consideration. The mean annual height growth of all felled trees is presented in Fig. 23.

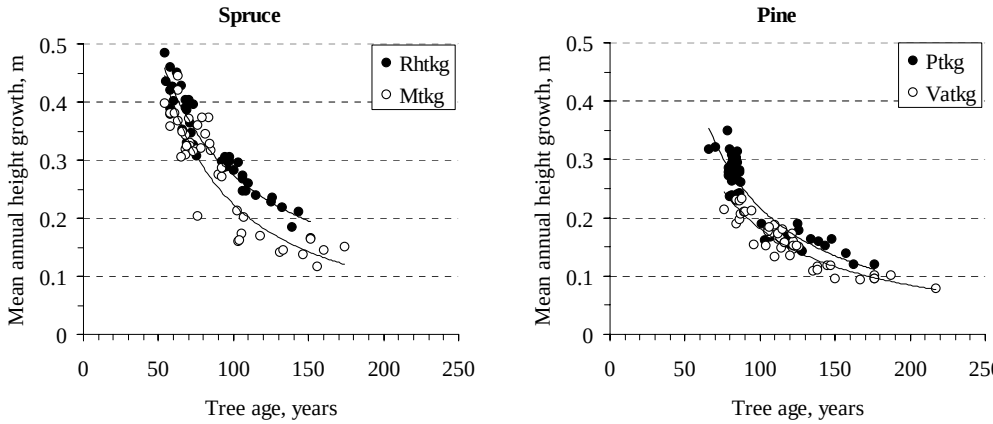


Fig. 23. Mean annual height growth of spruces (left) and pines (right) by site type. Fitted trend lines are presented.

3.1.5 Size and Quality of Logs

The material comprised 304 spruce and 208 pine logs. The volumes of saw logs (o.b.) were 75.8 m^3 and 32.1 m^3, respectively. ABC grading yielded the quality distributions presented in Figs 24 and 26. Some logs did not meet the requirements of saw logs (see Appendix 1) because of oversized spike or dead knots. For this reason, 4 spruce and 16 pine logs were classified as grade D (reject). These logs are not included in the quality distributions. The rejected logs were sawn normally, but the quality of sawn timber was studied separately.

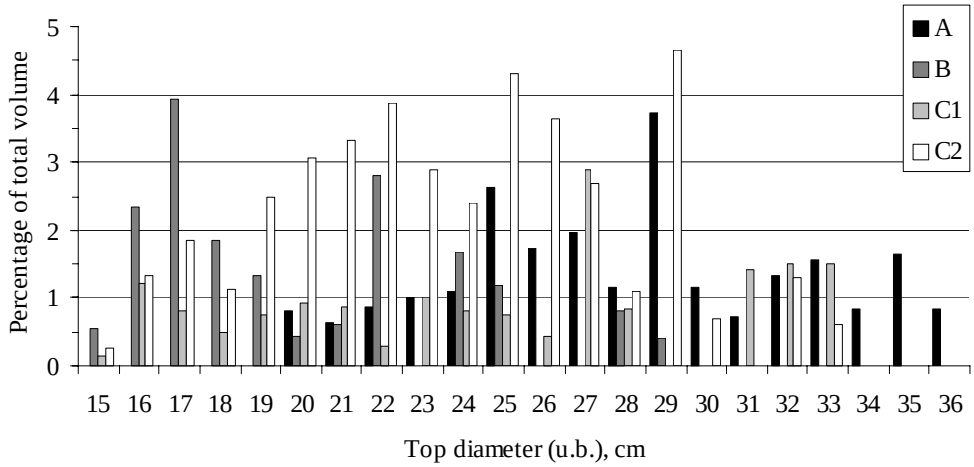


Fig. 24. Quality distribution of spruce logs graded according to ABC grading.

The proportion of knotless spruce butt logs (grade A) was 24% of total log volume. The proportions of butt logs with dead knots (grade C1), middle logs with dead knots (grade C2), and top logs with sound knots (grade B) were 24, 41, and 18%, respectively. Some differences in log quality between the site types were found. The volume proportion of grade A was somewhat higher in *Vaccinium myrtillus* type (Mtkg) than in Herb-rich type (Rhtkg). By contrast, the proportion of grade C2 was higher in Herb-rich type than in *Vaccinium myrtillus* type.

The grading of softwood logs used in NFI9 is based on three quality classes: 1, 2, and 3. Distinct from ABC grading, the quality classes of NFI9 are not bound to the location of the log in the stem (see Appendix 1). NFI9 grading yielded the quality distribution of spruce logs presented in Fig. 25.

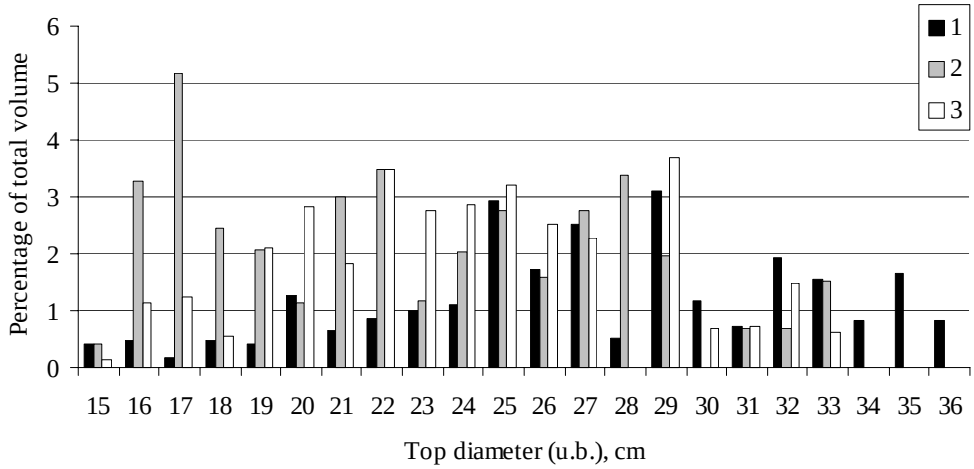


Fig. 25. Quality distribution of spruce logs graded according to NFI9 grading.

Correspondence between the two different grading systems used is presented in Table 3. The table indicates how the ABC grades are distributed (% of number of logs) into the NFI9 quality classes. As mentioned before, quality classification of spruce saw logs is generally not applied in wood procurement. To get a reasonable benefit from the log classification, the internal properties should clearly be different between log sections. Differences in knottiness of saw logs are considered in Section 3.1.7. The relationships between location of log in the stem and quality of sawn timber are considered in Section 3.3.2.

Table 3. Correspondence between ABC grading and NFI9 grading.

ABC	NFI9	
Grade	Quality class	Proportion, %
A	1	96
	2	2
	3	2
C1	1	17
	2	49
	3	34
C2	1	5
	2	29
	3	66
B	1	1
	2	98
	3	1

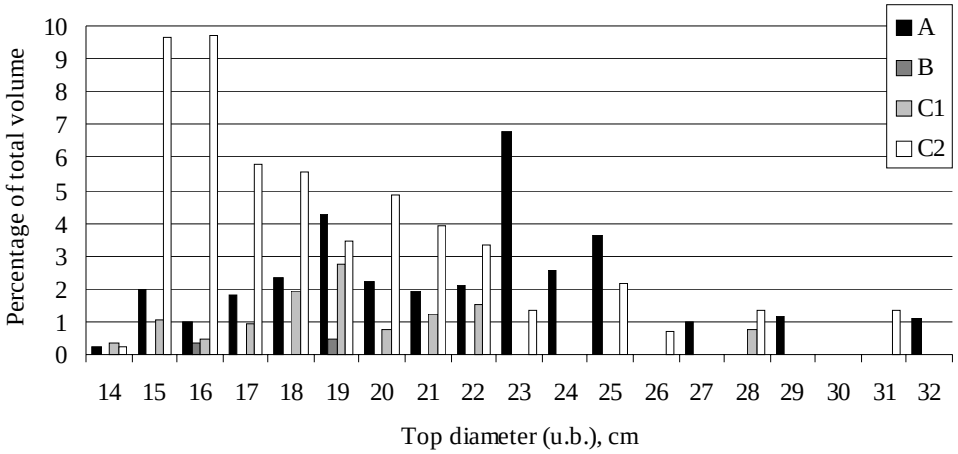


Fig. 26. Quality distribution of pine saw logs according to ABC grading.

The pine logs were distributed into classes as follows: A 34%, C1 12%, C2 53%, and B 1% of total log volume. Noteworthy are the large proportion of middle logs with dead knots and the lack of top logs with sound knots. For pine, the volume proportions of grade A did not differ between the site types. However, the proportion of grade C1 was clearly higher in Dwarf-

shrub type (Vatkg) than in *Vaccinium vitis-idaea* type (Ptkg). By contrast, the proportion of grade C2 was higher in *Vaccinium vitis-idaea* type than in Dwarf-shrub type.

The mean length of all spruce logs was 47 dm, butt logs 49 dm, middle logs 47 dm, and top logs 45 dm. The mean over bark volume of all spruce logs was 249 dm^3 (s = 118). For butt logs, the mean volume was 319 dm^3 (s = 144). The mean length of pine logs was 42 dm, which equals the length of grade A butt logs. The mean length of grade C1 logs was 40 dm and grade C2 logs 44 dm. For top logs, the mean length was 34 dm. The over bark volume for all pine logs averaged 154 dm^3 (s = 62). For butt logs, the mean was 175 dm^3 (s = 67). Log length distributions are presented in Fig. 27.

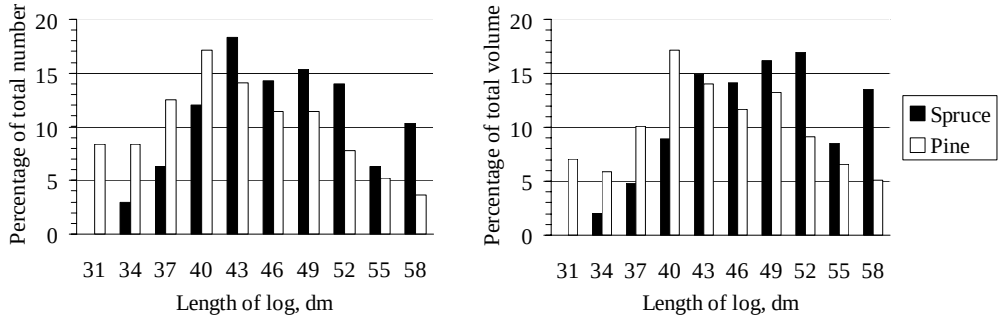


Fig. 27. Log length distributions relative to the total number (left) and total volume (right).

3.1.6 Exterior Shape of Logs

Exterior shape of logs was described with sweep and taper. The values were obtained from the log scaler. Sweep observed in unbarked and debarked logs is presented in Figs 28 and 29. As these figures show, debarking only slightly decreased the sweep in logs. The shortest logs also had the most sweep. The effect of sweep on the usability of a saw log is dependent on the log´s diameter. For this reason, a greater sweep is allowed in large logs (see Appendix 1).

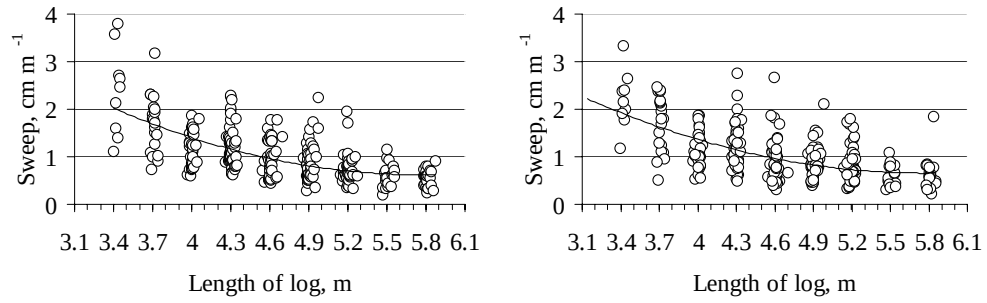


Fig. 28. Sweep in unbarked (left) and debarked (right) spruce logs measured by the log scaler. Fitted trend lines are presented.

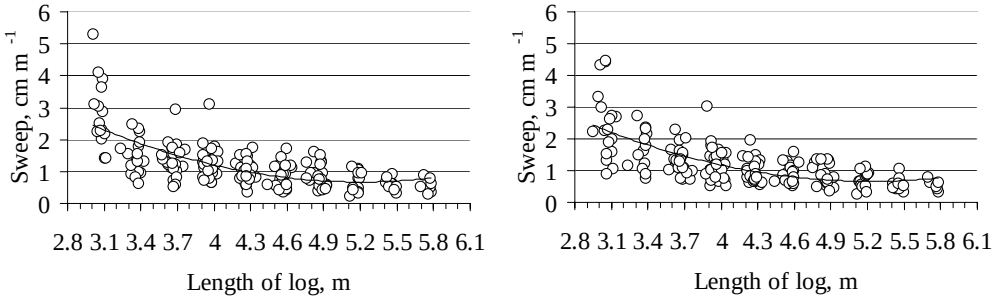


Fig. 29. Sweep in unbarked (left) and debarked (right) pine logs measured by the log scaler. Fitted trend lines are presented.

The sweep was also studied by the location of the log in the stem: butt logs (grades A and C1), middle logs (C2), and top logs (B). When all spruce logs over 20 cm of top diameter (o.b.) were allowed a sweep of 2 cm per metre and other logs 1 cm per metre, the criteria was met by 73% of all logs (see Fig. 30). When a maximum sweep of 2 cm per metre was allowed, the proportion of logs meeting the requirements increased to 85%. The corresponding proportion of volume was 89%.

The pine butt logs clearly had more sweep than other logs (Fig. 31). When all pine logs over 20 cm of top diameter (o.b.) were allowed a sweep of 2 cm per metre and other logs 1 cm per metre, the criteria was only met by 53% of all logs. According to the measurements of the log scaler, a considerable proportion of the logs would not have met the quality requirements of saw logs.

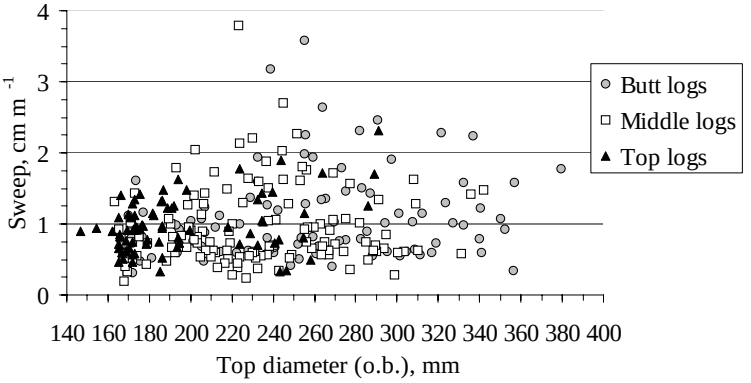


Fig. 30. Sweep in spruce logs by location of log in the stem.

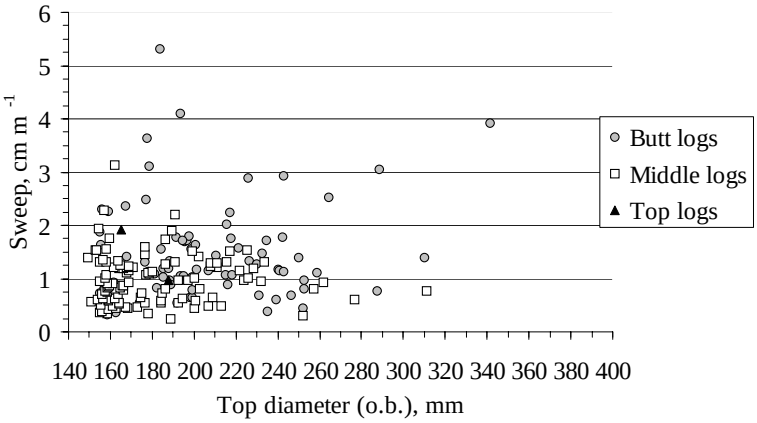


Fig. 31. Sweep in pine logs by location of log in the stem.

Taper of logs is presented in Figs 32 and 33. Taper was slightly smaller in debarked logs in both tree species. The accuracy and reliability of the measurements obtained from the log scaler are discussed in Section 4.5.

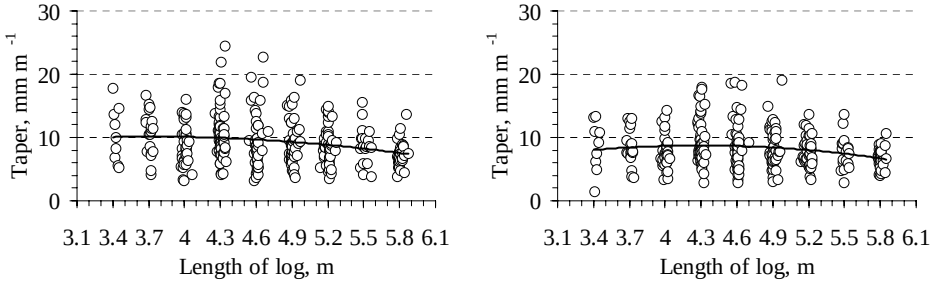


Fig. 32. Taper in unbarked (left) and debarked (right) spruce logs measured by the log scaler. Fitted trend lines are presented.

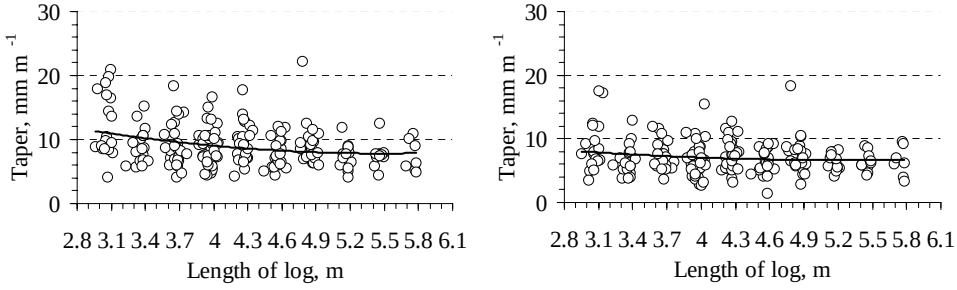


Fig. 33. Taper in unbarked (left) and debarked (right) pine logs measured by the log scaler. Fitted trend lines are presented.

3.1.7 Knottiness of Logs

The maximum size of knots in logs by log grade and condition of knot is presented in Figs 34-40. Linear regression of the knot diameter on the top diameter of log is shown. Pine top logs were ignored since only two such logs existed.

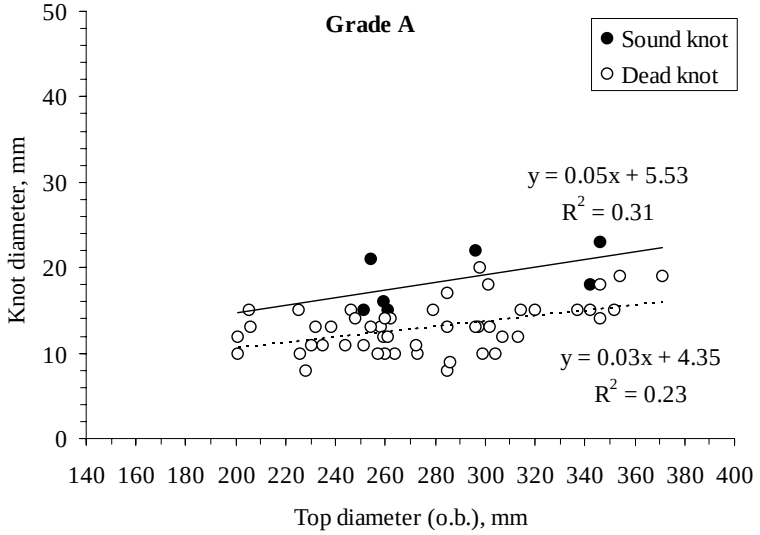


Fig. 34. Maximum diameter of knots in grade A spruce butt logs. The linear relationships between knot diameter and top diameter (o.b.) of log with equation and R^2 are presented.

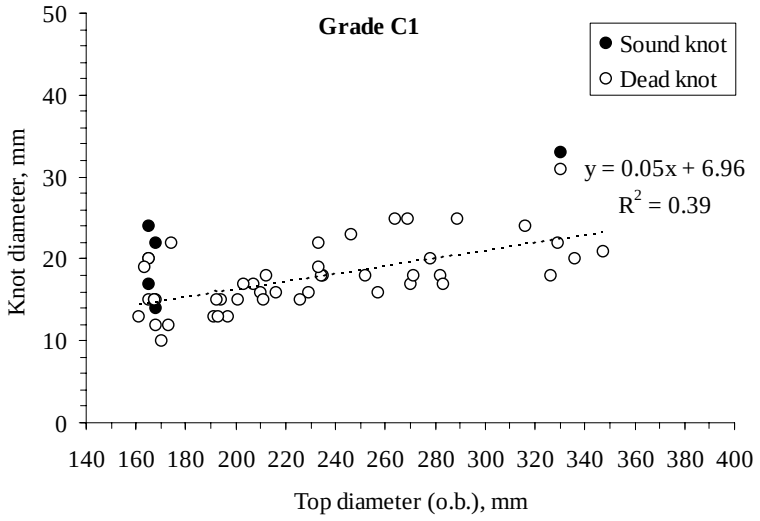


Fig. 35. Maximum diameter of knots in grade C1 spruce butt logs. The linear relationship between knot diameter and top diameter (o.b.) of log with equation and R^2 is presented.

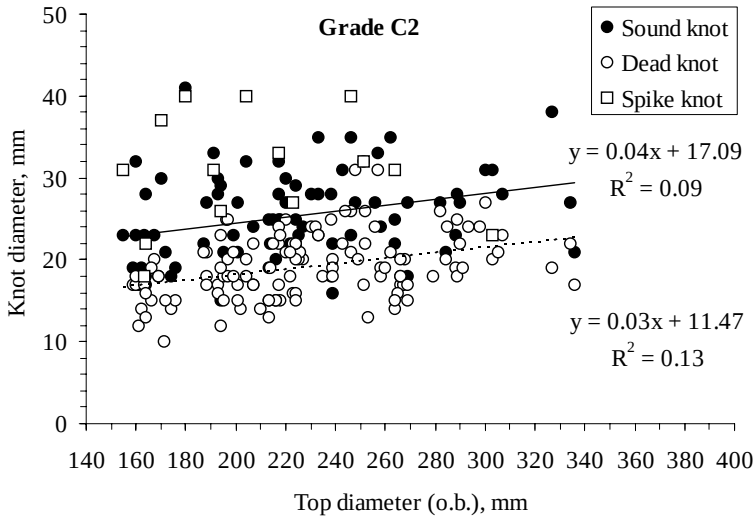


Fig. 36. Maximum diameter of knots in spruce middle logs (C2). The linear relationships between knot diameter and top diameter (o.b.) of log with equation and R^2 are presented.

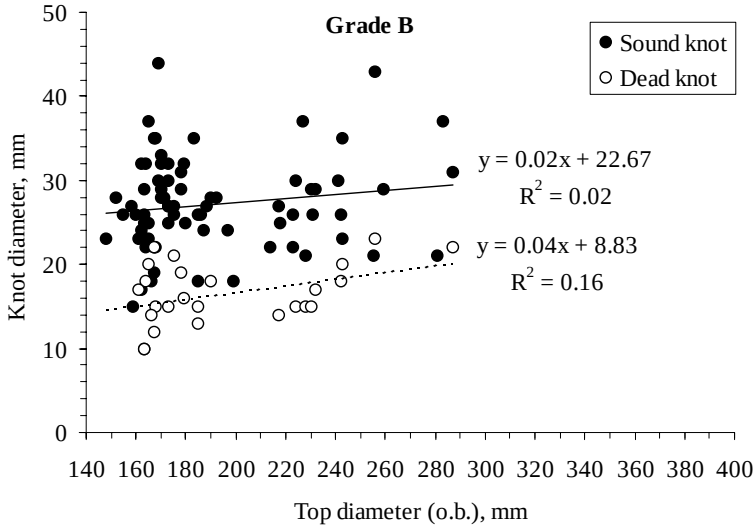


Fig. 37. Maximum diameter of knots in spruce top logs (B). The linear relationships between knot diameter and top diameter (o.b.) of log with equation and R^2 are presented.

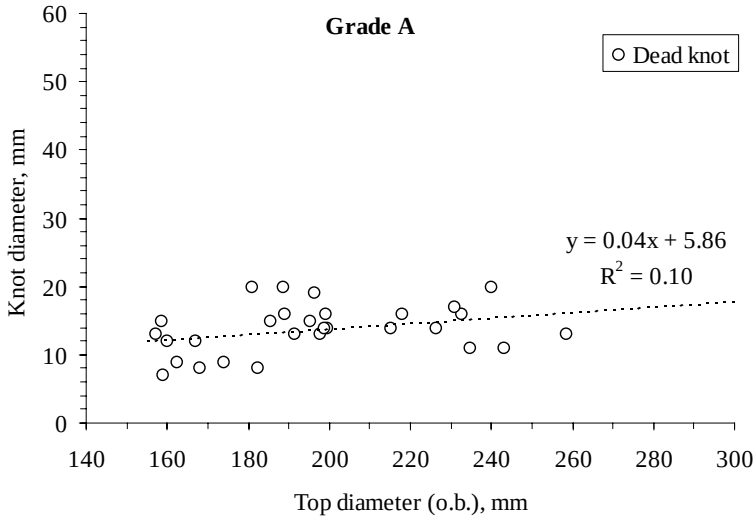


Fig. 38. Maximum diameter of knots in grade A pine butt logs. The linear relationship between knot diameter and top diameter (o.b.) of log with equation and R^2 is presented.

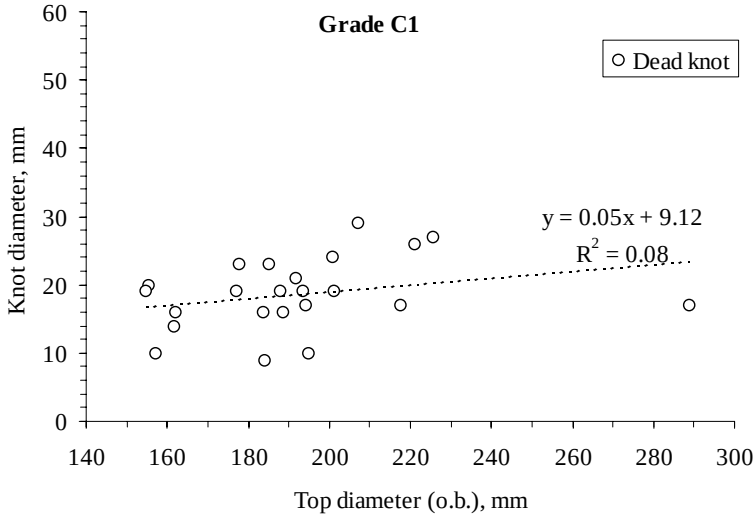


Fig. 39. Maximum diameter of knots in grade C1 pine butt logs. The linear relationship between knot diameter and top diameter (o.b.) of log with equation and R^2 is presented.

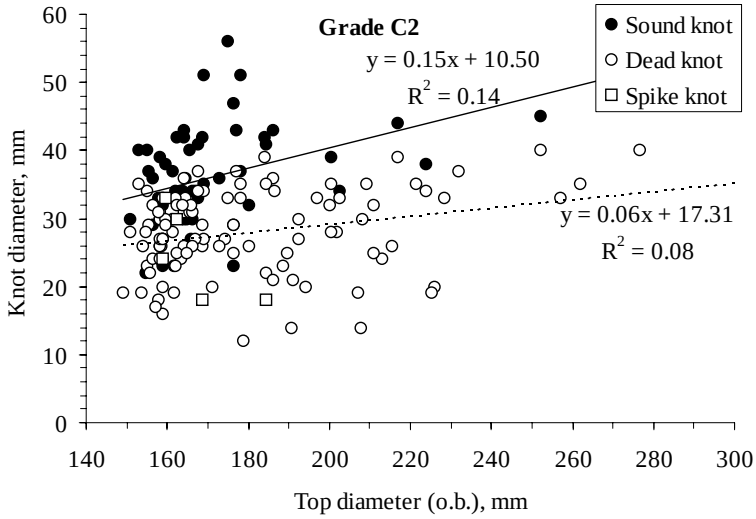


Fig. 40. Maximum diameter of knots in pine middle logs (C2). The linear relationships between knot diameter and top diameter (o.b.) of log with equation and R^2 are presented.

The mean maximum knot diameters for spruce and pine logs are presented in Tables 4 and 5. Dead and unsound knots are combined.

Table 4. Diameter of maximum knot in spruce logs by knot condition.

		Knot diameter, mm			
Condition of knot	*n*	*min.*	*max.*	$\bar{x}$	*s*
Sound knot	171	14	44	26	6
Dead and unsound knot	244	8	31	17	4
Spike knot	14	18	40	31	7

Table 5. Diameter of maximum knot in pine logs by knot condition.

		Knot diameter, mm			
Condition of knot	*n*	*min.*	*max.*	$\bar{x}$	*s*
Sound knot	65	22	56	37	8
Dead and unsound knot	176	7	55	26	10
Spike knot	6	18	33	24	6

Since the knots in pine logs (∅ ≥ 7 mm) were counted one by one, the knottiness of logs could be expressed as *the mean knot density* (number of knots by knot condition divided by total length of logs). The size of knots was ignored, thus each knot had an equal weight. Besides visible knots, buckles and uncovered knots were also considered. The mean knot density is presented by grades of logs (Fig. 41).

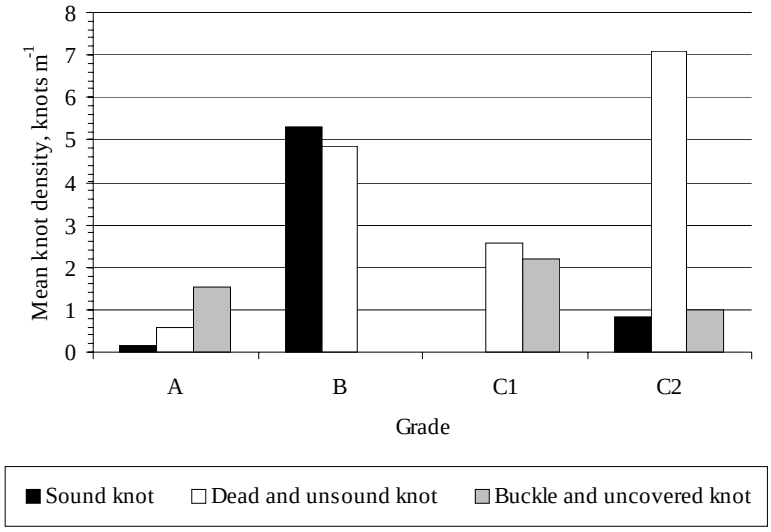


Fig. 41. Mean knot density in log section of pine stems by log grade.

The highest knot densities were found, as could be expected, in middle and top logs. Buckles and uncovered knots were observed to some extent, especially in butt logs.

3.1.8 Other Defects of Logs

Surface defects in spruce stems were very rare. Resin flow and scars were observed in 2% of logs. By contrast, surface defects were observed in about 8% of pine logs (covered scars 4%, open scars 3%, surface checks 0.5%). The proportion of compression wood is considered in more detail in Section 3.2.4.

3.2 Wood Properties

3.2.1 Annual Ring Width

The variation in annual ring width was considered both in longitudinal and radial directions in the stems. The annual ring width (volume weighted) was on average 2.36 mm for spruce (2.49 mm in Herb-rich type and 2.18 mm in *Vaccinium myrtillus* type) and 1.58 mm for pine (1.69 mm in *Vaccinium vitis-idaea* type and 1.39 mm in Dwarf-shrub type). The relative tree height accounted for only 9% of the variance in ring width of spruce, whereas in pine the share was 34%. The variation pattern of ring width also differed between spruce and pine. In pine, an increasing linear relationship was found between relative height and ring width, while in spruce the ring width reached its maximum at a relative height of 60-70%, decreasing towards the top of the tree. The variation in ring width is presented by relative height class in Table 6.

Table 6. Mean ring width with standard deviation according to relative height class in spruce and pine stems.

Relative height, %	Ring width, mm			
	Spruce		Pine	
	$\bar{x}$	s	$\bar{x}$	s
0-5	1.90	0.68	1.19	0.40
6-10	1.91	0.62	1.15	0.40
11-20	2.35	0.55	1.36	0.49
21-30	2.08	0.57	1.34	0.35
31-40	2.37	0.67	1.50	0.46
41-50	2.44	0.64	1.57	0.32
51-60	2.44	0.64	1.67	0.35
61-70	2.52	0.65	1.85	0.40
71-80	2.48	0.57	1.94	0.37
81-90	2.27	0.42	1.93	0.38
91-95			2.07	0.10

Variation in ring width in trees grown on drained peatlands was considerable. An example of the variation pattern of radial growth in a spruce is provided in Fig. 42. The butt diameter of the tree at the time of drainage can easily be deduced from the figure. Before drainage, the annual radial increment had been on average less than 1 mm but had rapidly increased manyfold after drainage, reaching a maximum of nearly 6 mm at butt height. The decreasing trend of ring width in the radial direction of the stem can clearly be observed in the upper parts of the stem. The tree was 30.3 m in height and 146 years old at the time of felling. The site was initially ditched in 1912.

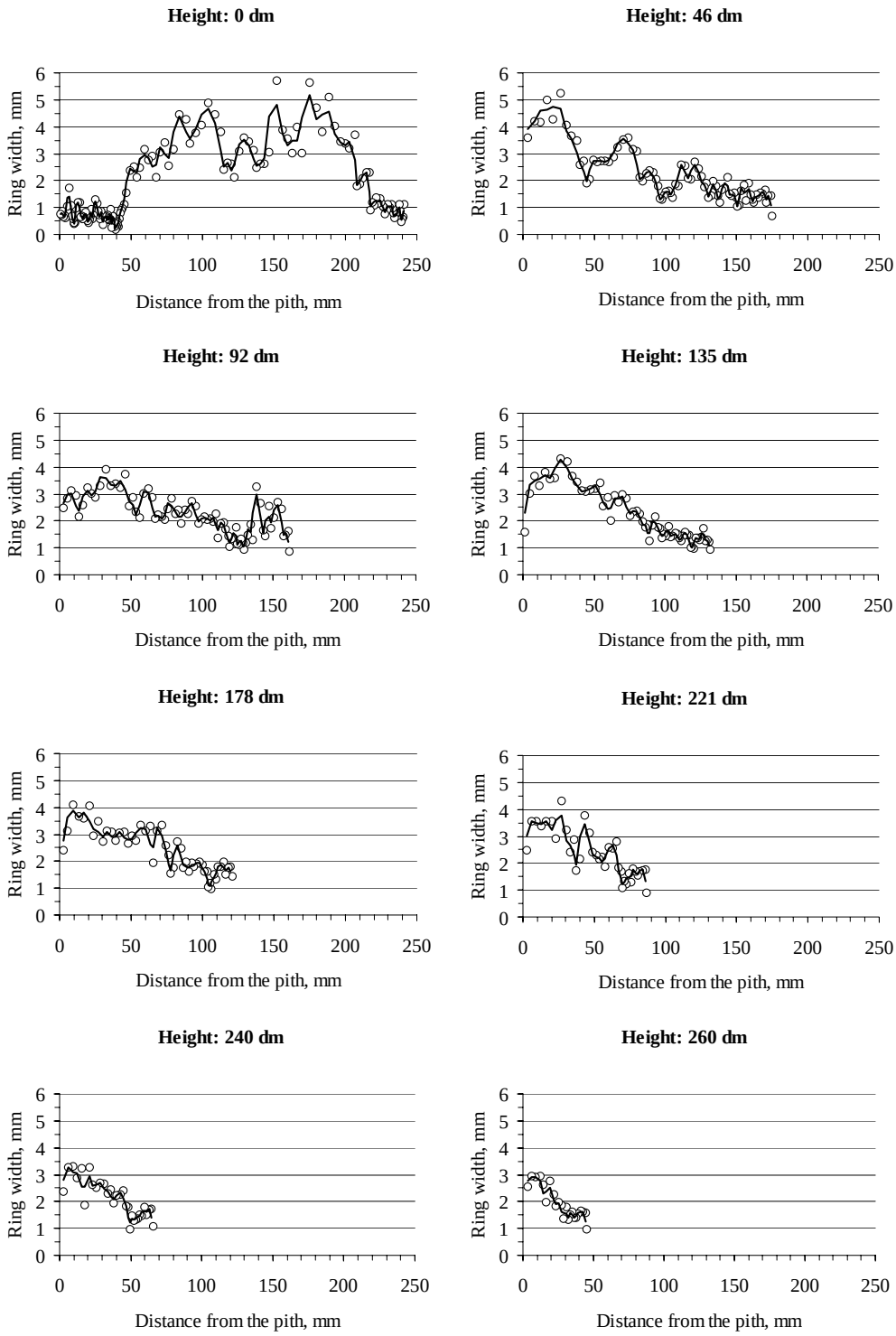


Fig. 42. Radial variation in ring width in a spruce stem. Trend is presented as a moving average.

The effect of drainage on mean ring width was studied from sample discs that contained wood grown both before and after drainage. Since the peatland sites were mainly ditched when the trees were small-sized (dbh usually < 5 cm), only the sample discs originating from the base of the trees (butt log) were considered. The standard deviation (*s*) is presented when more than three trees were included (Tables 7 and 8).

Table 7. Effect of drainage on mean ring width in spruce (stump height).

Sample plot	Site type	No. of trees	Ring width, mm			
			Before drainage		After drainage	
			$\bar{x}$	*s*	$\bar{x}$	*s*
25	Rhtkg	9	0.68	0.21	2.73	0.79
41	Rhtkg	6	0.32	0.12	2.14	0.55
48	Rhtkg	1	0.68		2.29	
J13	Rhtkg	10	0.60	0.29	1.96	0.39
13	Mtkg	8	1.58	0.48	2.10	0.43
B8	Mtkg	8	0.37	0.13	2.02	0.53
B25	Mtkg	10	0.84	0.21	1.48	0.75
22	Mtkg	3	0.40		1.74	

Table 8. Effect of drainage on mean ring width in pine (stump height).

Sample plot	Site type	No. of trees	Ring width, mm			
			Before drainage		After drainage	
			$\bar{x}$	*s*	$\bar{x}$	*s*
8	Ptkg	9	1.20	0.45	2.05	0.35
9	Ptkg	9	0.85	0.26	1.77	0.39
20	Ptkg	8	0.71	0.25	1.40	0.40
B21	Ptkg	10	1.01	0.18	1.09	0.37
B13	Vatkg	6	0.31	0.07	1.37	0.16
B14	Vatkg	8	0.34	0.13	1.31	0.17
B15	Vatkg	8	0.39	0.17	1.41	0.29
5A	Vatkg	10	0.46	0.08	0.99	0.17
XIII	Vatkg	5	0.46	0.20	1.28	0.31

The average ring width after drainage was usually two or three times the ring width before drainage but had increased sixfold in sample plot 41 (spruce). In pine stems, the relative increase in ring width was clearly larger in sample plots of Dwarf-shrub type (Vatkg) than *Vaccinium vitis-idaea* type (Ptkg) due to the very low growth rate before drainage of the former. The response of radial growth to drainage varied between trees and stands. It typically took from 5 to 15 years for a tree to reach its maximum radial growth after drainage.

It was not possible to directly study the effect of drainage on height growth since sample discs were taken at fairly long intervals. The observations from pine stems, which had attained a height of at least 31 dm (minimum length for a butt log) before drainage, indicated that the annual height growth had varied between 5 and 20 cm depending on site type. In some pine stems, the annual height growth had increased two- or threefold just after drainage. However,

when taking into account the whole period of time after drainage, the difference in annual height growth was attenuated.

3.2.2 Latewood Proportion

Latewood proportion, i.e. latewood percentage, was considered both in relation to sample disc volume and ring width. Average latewood proportion from volume was nearly the same in both tree species but varied markedly between sample discs. In spruce discs, the average latewood proportion was 21.1%, ranging from 9.9% to 38.5% (s = 5.1). The corresponding value in pine discs was 20.7% (9.8-40.3%, s = 5.0).

The variation pattern between latewood proportion of volume and relative sample height was different between the tree species (Fig. 43). In spruce, the latewood proportion was totally independent of sample height, whereas in pine the sample height accounted for 30% of variation in latewood proportion. Latewood proportion in spruce and pine sample discs at different height classes is presented in Table 9.

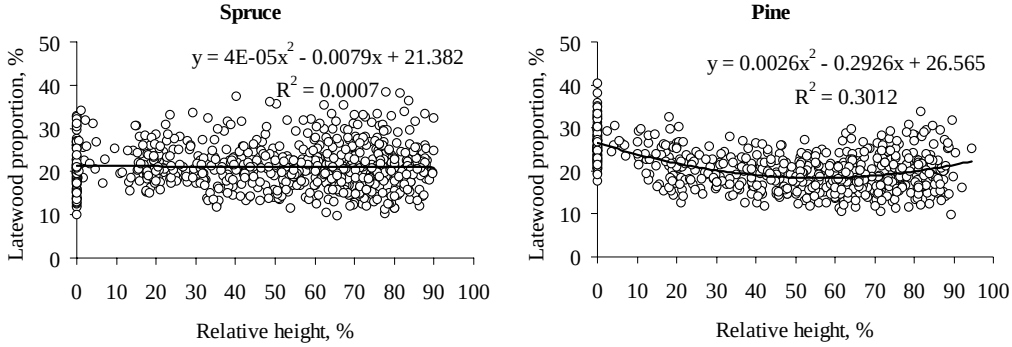


Fig. 43. Variation pattern of latewood proportion of volume in the longitudinal direction of the stem in spruce (left) and pine (right). Fitted trend lines with equations and R^2 are presented.

Table 9. Latewood proportion of ring width in spruce and pine sample discs by relative height.

Relative height, %	Latewood proportion, %			
	Spruce		Pine	
	$\bar{x}$	s	$\bar{x}$	s
0	20.5	5.2	26.6	4.5
1-25	22.3	4.3	22.3	4.4
26-50	21.2	5.1	19.1	3.4
51-75	20.7	5.2	18.7	4.1
76-100	21.3	5.5	20.1	4.8

The relationship between latewood proportion and annual ring width in a spruce sample plot is illustrated in Fig. 44. The latewood proportion was greatest when ring width was narrow (0-3 mm). In broader rings, the average latewood proportion was nearly constant. It is

noteworthy that the variation in latewood proportion between rings of the same width was great.

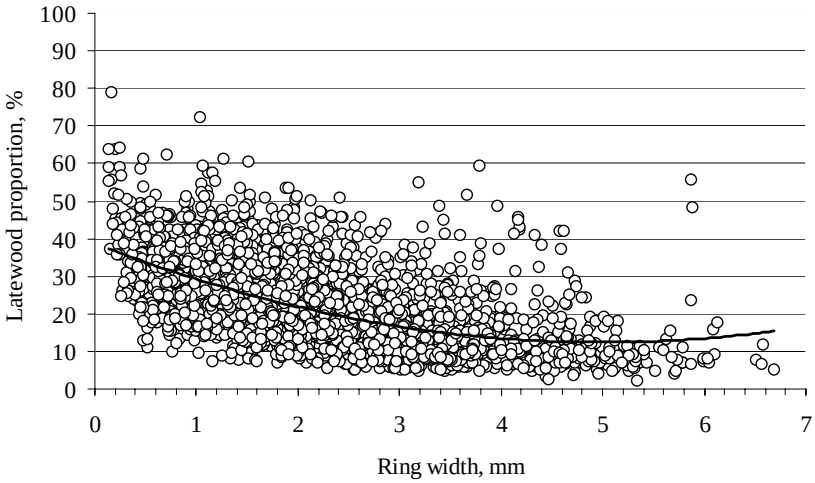


Fig. 44. Relationships between latewood proportion and ring width in a spruce stand (ca 3500 observations). A fitted trend line is also presented.

The latewood proportion of ring width in spruce was generally about 30% higher in wood grown before drainage (Table 10).

Table 10. Latewood proportion of ring width in spruce at stump height before and after drainage.

Sample plot	Site type	No. of trees	Latewood proportion, %			
			Before drainage		After drainage	
			$\overline{x}$	s	$\overline{x}$	s
25	Rhtkg	9	29.2	4.6	21.5	5.4
41	Rhtkg	6	39.3	6.0	24.5	3.2
48	Rhtkg	1	31.2		21.2	
J13	Rhtkg	10	30.8	5.4	20.0	1.6
13	Mtkg	8	29.9	5.4	22.8	4.0
B8	Mtkg	8	34.4	5.5	22.7	2.3
B25	Mtkg	10	29.8	6.5	18.1	2.8
22	Mtkg	3	39.0		26.5	

Since ring width decreases from pith to bark and width of latewood tissue in spruce is nearly constant, the latewood proportion of ring width increases towards bark (Fig. 45). The same tree is presented in Fig. 42. Latewood proportion of ring width in pine at stump height before and after drainage is presented in Table 11.

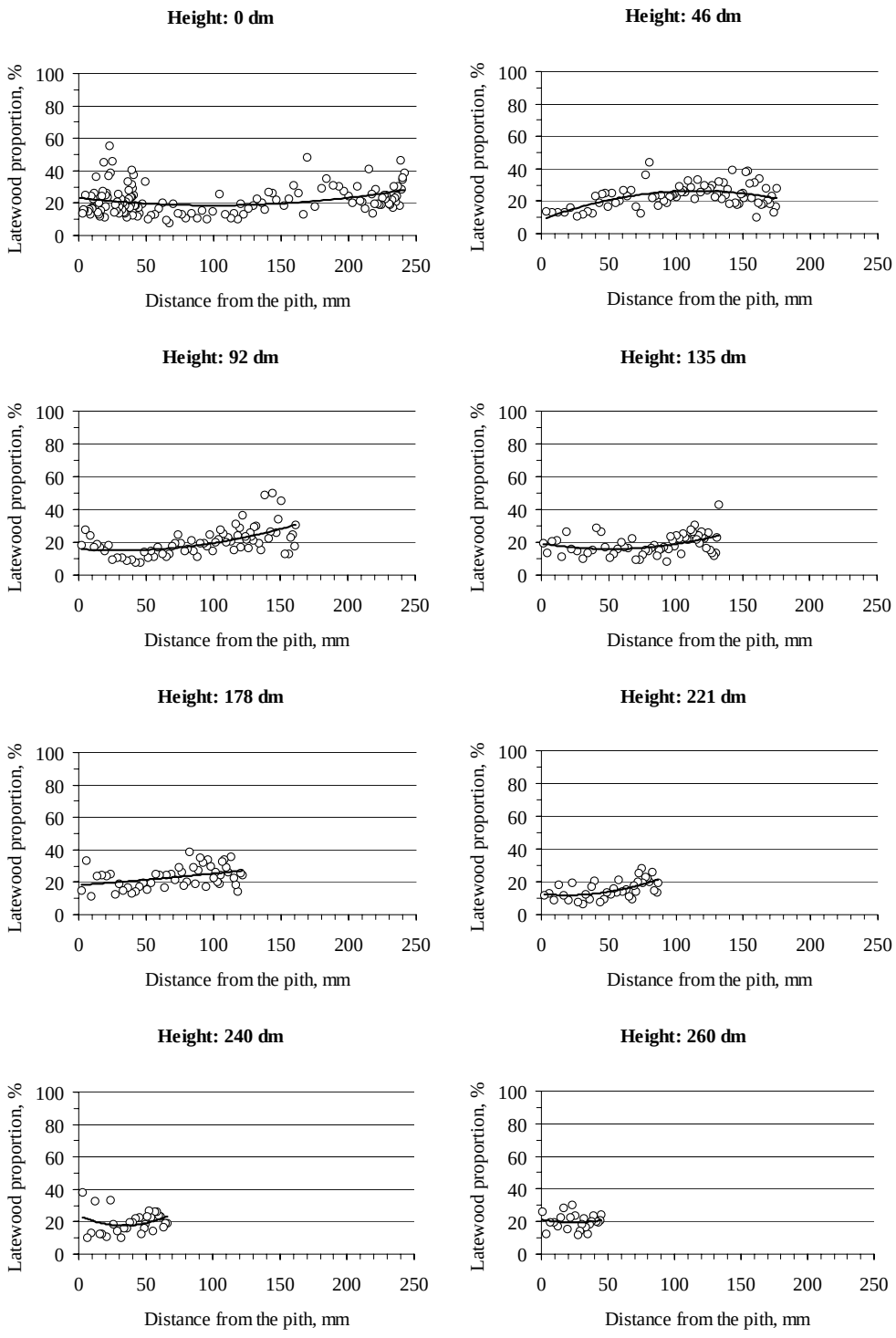


Fig. 45. Variation pattern of latewood proportion of ring width in the radial direction in a spruce stem. Fitted trend lines are presented.

Table 11. Latewood proportion of ring width in pine at stump height before and after drainage.

Sample plot	Site type	No. of trees	Latewood proportion, %			
			Before drainage		After drainage	
			$\bar{x}$	s	$\bar{x}$	s
8	Ptkg	9	27.4	5.6	33.4	2.3
9	Ptkg	9	30.6	6.4	33.8	3.3
20	Ptkg	8	31.5	7.4	32.7	5.7
B21	Ptkg	10	23.7	3.4	26.0	5.3
B13	Vatkg	6	25.9	4.0	24.4	3.4
B14	Vatkg	8	30.6	5.4	26.1	4.1
B15	Vatkg	8	30.7	7.2	25.8	1.9
5A	Vatkg	10	26.0	5.5	27.0	4.3
XIII	Vatkg	5	30.2	7.8	26.4	2.4

Differences in latewood proportion between sample plots were slight in both tree species (Table 12). However, in spruce sample plot 41, the latewood proportion was significantly ($p < 0.05$) higher than in sample plots 18, 25, 48, and B8. Likewise, in pine sample plots 9 and 20 the latewood proportion was significantly ($p < 0.05$) higher than in other sample plots. In spruce, site type had no significant effect on latewood proportion. By contrast, latewood proportion of pine was significantly higher ($p < 0.05$) in the more fertile site type (Ptkg).

Table 12. Latewood proportion of volume by sample plots.

Sample plot	Tree species	No. of discs	Latewood proportion, %	
			$\bar{x}$	s
18	Spruce	76	20.2	5.6
25	Spruce	85	20.4	5.0
41	Spruce	62	23.1	5.0
48	Spruce	77	20.4	5.1
J13	Spruce	77	22.3	4.0
13	Spruce	73	22.9	5.9
37	Spruce	77	20.5	5.6
B8	Spruce	70	20.3	3.9
B25	Spruce	63	21.1	4.0
22	Spruce	72	20.4	5.7
8	Pine	75	21.9	5.0
9	Pine	72	23.3	4.3
14	Pine	77	19.1	5.5
20	Pine	73	23.5	5.3
B21	Pine	66	19.1	4.2
B13	Pine	66	19.8	4.7
B14	Pine	62	19.5	4.3
B15	Pine	61	20.6	4.1
5A	Pine	63	19.6	4.7
XIII	Pine	30	18.8	5.2

3.2.3 Heartwood Proportion

Heartwood proportion was found to be highest in spruce stems at a relative height of 10-20% when the percentage was determined from cross-sectional area, and at a relative height of 15-25% when determined from stem diameter (Fig. 46). In pine, the maximum heartwood proportion was at a relative height of 20-30% using both methods (Fig. 47). The diameter of heartwood was equal or greater at stump height than in the upper parts of stem; thus, the decrease in heartwood percentage towards the butt was caused by butt swellings. Relative height accounted for 67% to 77% of the variance in heartwood proportion depending on tree species and method of determination.

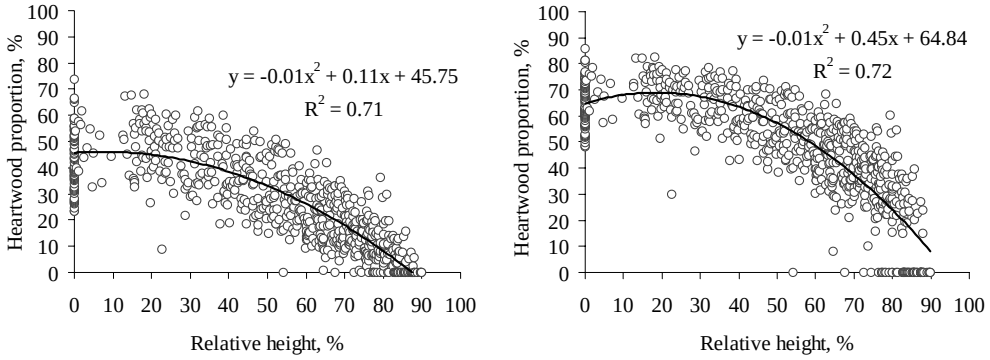


Fig. 46. Variation pattern of heartwood proportion in the longitudinal direction of the stem in spruce. Heartwood proportion was determined both from cross-sectional area (left) and stem diameter (right). Fitted trend lines with equations and R^2 are presented.

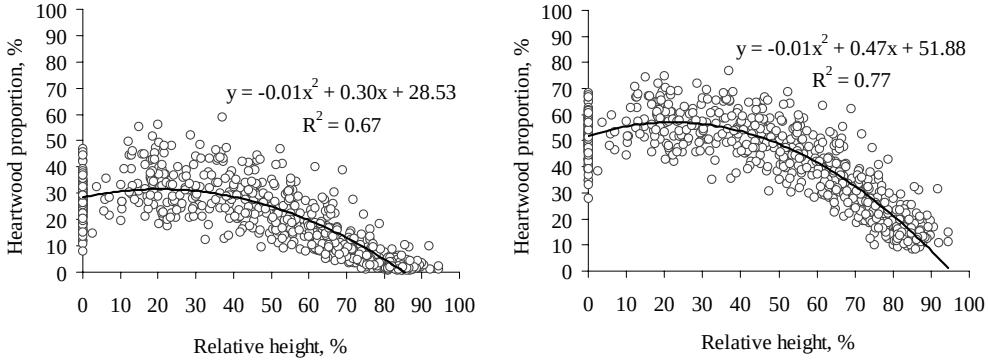


Fig. 47. Variation pattern of heartwood proportion in the longitudinal direction of the stem in pine. Heartwood proportion was determined both from cross-sectional area (left) and stem diameter (right). Fitted trend lines with equations and R^2 are presented.

The average heartwood proportion of volume was 38.8% (s = 8.4) in spruce stems and 27.7% (s = 7.6) in pine stems. Thus, a clear difference in heartwood proportion was observed between tree species. An estimate of heartwood proportion for a sample plot was calculated as a mean of sample trees (Table 13). Tukey´s tests were performed to determine whether significant (p < 0.05) differences in heartwood proportion between stands existed. These

results are also given in Table 13. An estimate for a stem was not determined unless measurement data were perfect. For this reason, the number of stems in most sample plots deviates from the original 10.

Table 13. Heartwood proportion of volume by sample plots.

Sample plot	Tree species	Site type	No. of stems	Heartwood proportion, % $\bar{x}$	Heartwood proportion, % s	Stand-to-stand variation ($p < 0.05$)
18	Spruce	Rhtkg	6	32.5	5.6	
25	Spruce	Rhtkg	3	48.9	5.6	B25, 18, 48, 37
41	Spruce	Rhtkg	3	34.2	3.2	
48	Spruce	Rhtkg	7	32.0	5.8	
J13	Spruce	Rhtkg	6	49.1	9.3	B25, 41, 18, 48, 37
13	Spruce	Mtkg	8	47.6	2.7	B25, 41, 18, 48, 37
37	Spruce	Mtkg	7	30.3	5.6	
B8	Spruce	Mtkg	9	41.1	5.6	37
B25	Spruce	Mtkg	9	34.7	4.5	48, 37
22	Spruce	Mtkg	9	42.0	5.8	
8	Pine	Ptkg	10	34.0	3.2	B13, B14, B15, 5A
9	Pine	Ptkg	9	28.8	6.6	
14	Pine	Ptkg	8	29.2	7.2	
20	Pine	Ptkg	10	33.0	8.7	
B21	Pine	Ptkg	10	30.9	7.3	
B13	Pine	Vatkg	10	23.2	6.9	
B14	Pine	Vatkg	9	23.6	7.3	
B15	Pine	Vatkg	10	23.9	3.6	
5A	Pine	Vatkg	8	23.5	8.7	
XIII	Pine	Vatkg	9	25.9	6.5	

The average heartwood proportion in spruce saw logs was 40.8% (s = 13.6). The following heartwood proportions were obtained when the logs were grouped according to their location from tree base: 1st log 52.4% (s = 12.6), 2nd log 42.1% (s = 10.5), 3rd log 35.2% (s = 10.2), 4th log 29.4% (s = 8.3), 5th log 21.7% (s = 4.8). The average heartwood proportion in pine logs was 31.9% (s = 6.8). In pine, the following proportions were obtained: 1st log 34.0% (s = 9.2), 2nd log 31.7% (s = 8.7), 3rd log 28.6% (s = 6.8), 4th log 22.3% (s = 4.4). The proportions presented are merely suggestive since the number and length of logs varied between stems.

The sapwood thickness of spruce butt logs was on average 37.5 mm (s = 9.8) measured from the top of logs. In other spruce logs, the sapwood thickness averaged 41.1 mm (s = 8.3). Stem diameter and number of rings at a certain height accounted for ca 33% of the variance in sapwood thickness in a log section of spruce. In pine butt logs, the sapwood thickness averaged 41.2 mm (s = 7.8). The location of pine logs yielded the following values: 2nd log 39.6 mm (s = 7.3), 3rd log 43.7 mm (s = 7.3), 4th log 50.0 mm (s = 8.4). These results are also only suggestive for the reason mentioned above. The maximum heartwood proportion in pine was found at a relative height of 20% to 30% (see Fig. 47). This explains the finding that sapwood thickness was smaller at the top of second logs than at the top of butt logs. Stem diameter and age at a certain height accounted for ca 21% of the variance in sapwood thickness in a log section of pine.

3.2.4 Proportion of Compression Wood

Results concerning the incidence of compression wood were based on visual classification of spruce and pine sample discs. The area of compression wood is given as a proportion of the total disc area (Table 14). Compression wood was observed in about 13% of spruce sample discs. Findings were typically made at the base of stems, but to some extent, compression wood was observed in all stem parts. Approximately half of the observations were in the butt log section (0-6 m). In pine, about 18% of discs contained compression wood. About 80% of the observations were in the butt log section, and thus, the incidence of compression wood at stem base was greater in pine than spruce.

Table 14. Proportion of compression wood in spruce and pine sample discs.

Proportion of compression wood of disc area, %	Proportion of number of discs, %	
	Spruce	Pine
0	86.8	82.2
1-10	7.9	10
11-20	2.8	5
21-30	2	2.6
31-40	0.1	0.2
41-50	0.4	0
>51	0	0

Ovalness of stem was determined as the difference between the largest and the smallest diameter of a disc divided by the average of these diameters. Ovalness was highest at stump height (Fig. 48). In the upper parts of the spruce stems, ovalness averaged 4%. For pine, ovalness was slightly greater in the upper parts of the stem.

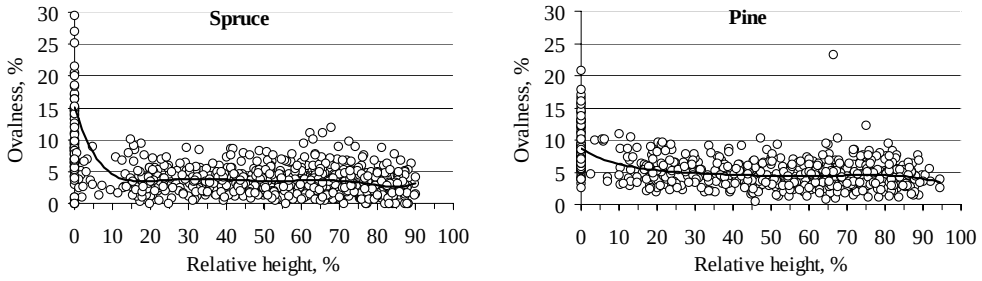


Fig. 48. Variation pattern of ovalness in the longitudinal direction of the stem in spruce (left) and pine (right). Fitted trend lines are presented.

3.2.5 Basic Density

In spruce, the basic density of all discs averaged 379.0 kg m^{-3}, with a standard deviation of 33.9 kg m^{-3}, i.e. 8.9% of the mean. The variation pattern of basic density in the longitudinal direction of the stem is illustrated in Fig. 49. The figure shows that basic density of single discs varied greatly – from 300 kg m^{-3} to over 500 kg m^{-3} – but seemed to be nearly constant

from stump height to top of tree. However, the basic density in the uppermost quarter (over 75% of relative height) was significantly ($p < 0.05$) higher than in other parts of the stem.

The relative height as a single variable accounted only for 3% of the variance in basic density. When the mean annual ring width and latewood proportion of the disc were entered as new variables, the degree of determination increased to 0.31.

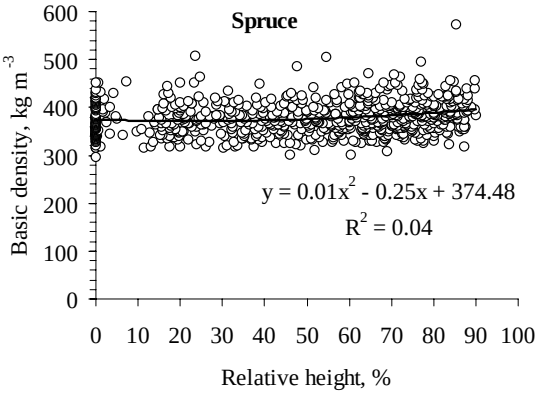


Fig. 49. Variation pattern of basic density in the longitudinal direction of the stem in spruce. A fitted trend line with equation and R^2 is presented.

In pine, the basic density of all discs averaged 405.0 kg m^{-3}, with a standard deviation of 39.6 kg m^{-3}, i.e. 9.8% of the mean. The variation pattern of basic density is illustrated in Fig. 50. The values ranged from ca 330 kg m^{-3} to 540 kg m^{-3}, with the highest values being measured from the base of the stems and the lowest at tree top. The basic density in the stump height of pine stems averaged 460 kg m^{-3}, which is almost 90 kg m^{-3} higher than in spruce. Annual ring width and latewood proportion accounted for 49% of the variance in basic density of pine. The curves indicating the average basic density of spruce and pine intersect each other at a relative tree height of 70% (cf. Figs 49 and 50). This means that basic density of pine was on average higher below this point.

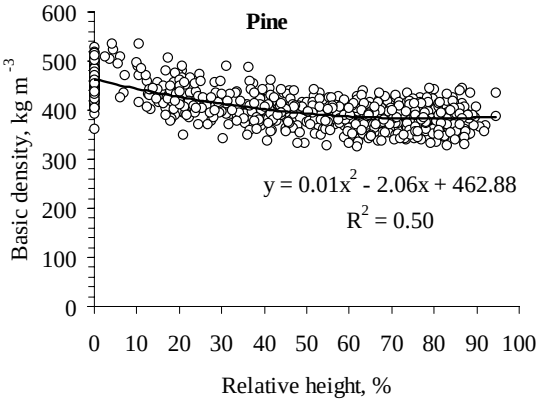


Fig. 50. Variation pattern of basic density in the longitudinal direction of the stem in pine. A fitted trend line with equation and R^2 is presented.

The radial variation pattern of basic density is illustrated according to relative height class in Figs 51 and 52. The main trend in both tree species was that basic density increased from pith to bark. However, the relative difference in basic density between pith and bark decreased towards the top of the tree. In the uppermost part of the stems, the basic density showed a decline near bark. The basic density was highest near the pith at the base of the stem, which in most cases represented wood grown before drainage. In spruce, the basic density of small sample pieces ranged from 280 kg m^{-3} to 630 kg m^{-3}. In pine, the variation was even greater – from 310 kg m^{-3} to 780 kg m^{-3}.

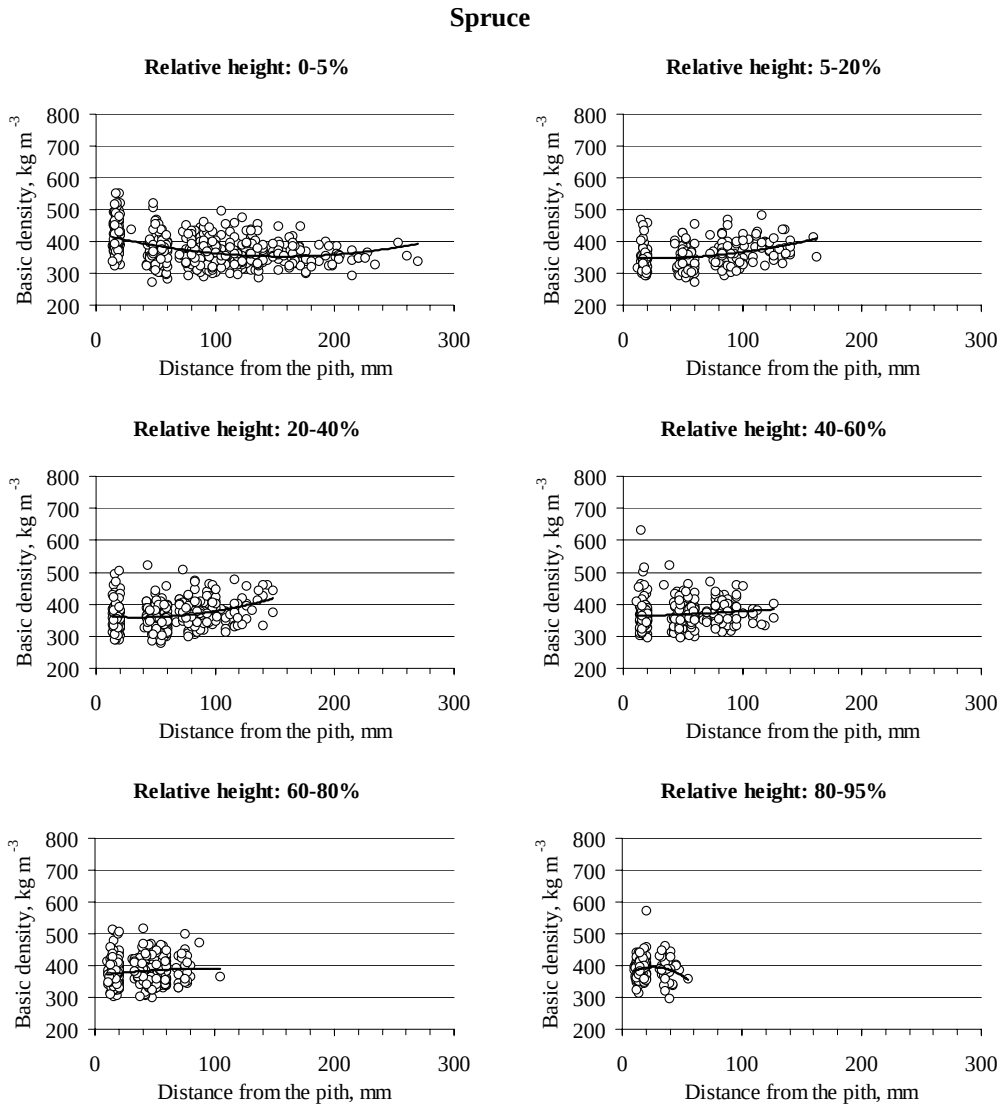


Fig. 51. Variation patterns of basic density in the radial direction of the stem in spruce. Fitted trend lines are presented.

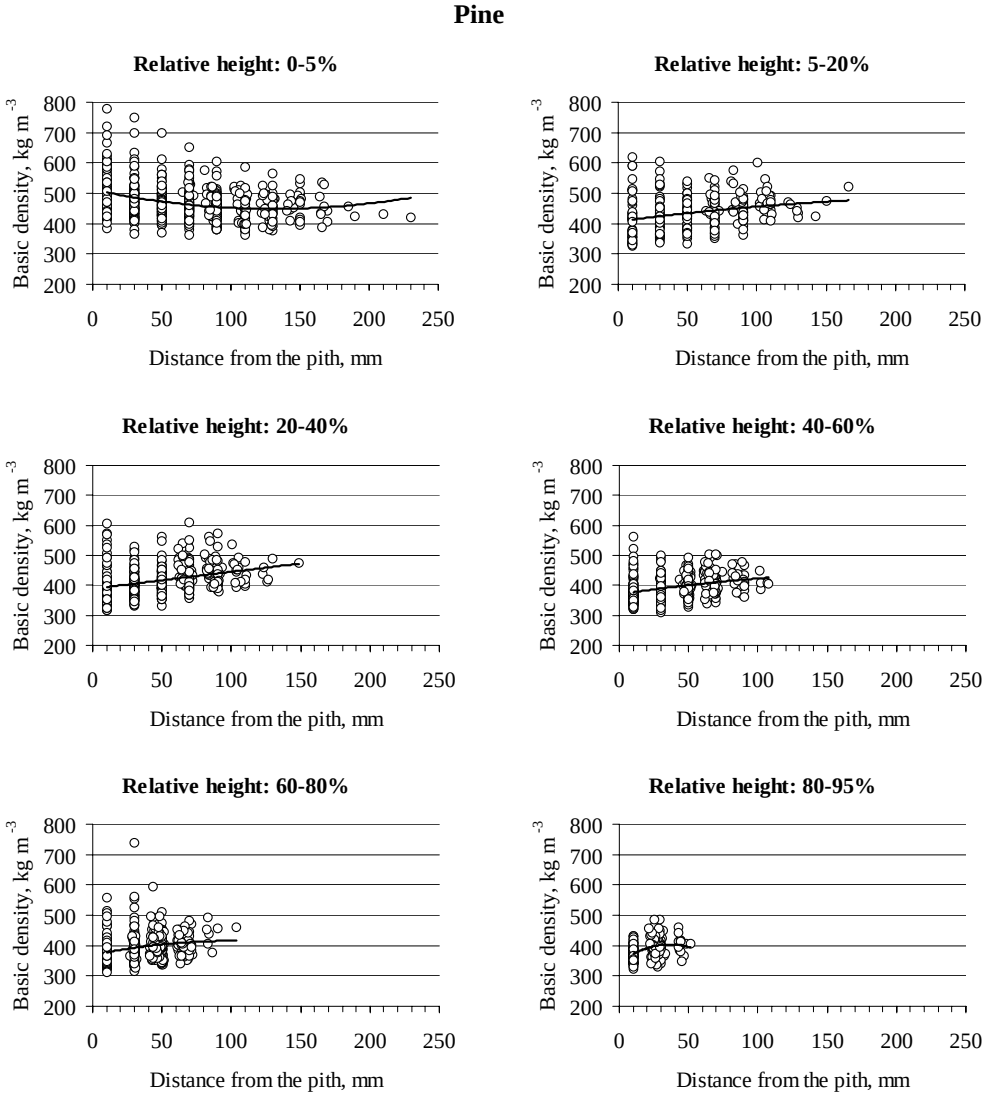


Fig. 52. Variation patterns of basic density in the radial direction of the stem in pine. Fitted trend lines are presented.

The volume of wood grown before drainage was small in the sampled stems since the trees had mostly been small-sized at the time of drainage. A more extensive analysis of the effect of drainage on the variation in basic density could be carried out only in one spruce sample plot (B25). These trees were 70 to 120 years old and 10 to 12 m high at the time of drainage. The basic density near the pith in this stand was on average more than 100 kg m^{-3} higher than near bark (Fig. 53, left). At a relative height of 20% to 30% (top of the butt log), no difference in the radial direction was, however, observed (Fig. 53, right). Thus, drainage had a significant effect on basic density only at the base of stems. At stump height, wood grown before drainage was 20% to 30% denser than wood grown after drainage. A similar analysis could not be carried out in pine since the share of wood grown before drainage in the sampled stems was very small in most stands. Several sample pieces of wood grown before drainage

were obtained only from trees of sample plot B21. In this stand, the basic density at stump height averaged 519 kg m^{-3} before drainage and 452 kg m^{-3} after drainage, i.e. the relative difference was ca 13%.

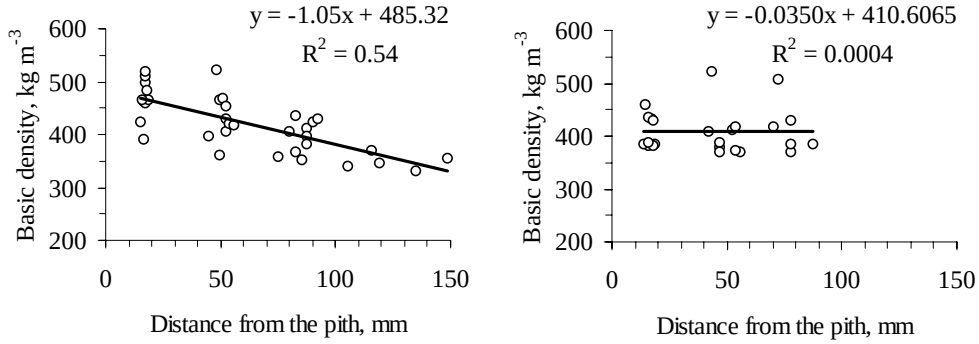


Fig. 53. An example of the changes in basic density in the radial direction of spruce stems at stump height (left) and at a relative height of 20-30% (right). Fitted linear trend lines with equation and R^2 are presented.

The mean basic density in spruce stems averaged 375.0 kg m^{-3}, with a standard deviation of 28.5 kg m^{-3}, i.e. 7.6% of the mean. In pine stems, the respective values were 418.5 kg m^{-3}, 25.8 kg m^{-3}, and 6.2%.

In both tree species, the stem-to-stem variation was larger than the stand-to-stand variation (Tables 15 and 16). In spruce, the basic density of sample plot B25 was significantly ($p < 0.05$) higher than that of sample plots 18 and 22. Site type had no significant ($p < 0.05$) effect on basic density. By contrast, for pine no significant ($p < 0.05$) differences were found between the sample plots, but a significant difference was present between pines grouped by site type. The mean basic density of pines grown on sites of *Vaccinium vitis-idaea* type (Ptkg) was 422.5 kg m^{-3} ($s = 25.1$) and on sites of Dwarf-shrub type (Vatkg) 414.5 kg m^{-3} ($s = 26.8$).

Table 15. Variation in basic density within a stand and between stands in spruce.

Sample plot	Site type	$\bar{x}$, kg m^{-3}	*min.*, kg m^{-3}	*max.*, kg m^{-3}	s, kg m^{-3}	* $\bar{x}$, kg m^{-3}
18	Rhtkg	360.0	320.6	393.8	20.0	355.5
22	Mtkg	363.7	328.2	398.7	21.1	358.8
B8	Mtkg	367.6	332.8	403.6	25.2	361.4
25	Rhtkg	368.1	335.2	411.3	24.1	367.3
37	Mtkg	368.5	320.5	424.9	32.1	361.8
48	Rhtkg	369.9	321.1	400.1	21.8	367.2
13	Mtkg	380.0	327.6	444.7	37.9	374.1
J13	Rhtkg	381.3	337.8	426.3	25.4	377.8
41	Rhtkg	385.2	347.3	423.2	25.2	387.3
B25	Mtkg	405.9	364.0	444.0	27.6	408.4
		Between stems				Between stands
$\bar{x}$		**375.0**				**372.0**
s		**28.5**				**16.0**

* Estimate of basic density of a stand. The basic density of each felled tree was weighted with its volume.

Table 16. Variation in basic density within a stand and between stands in pine.

Sample plot	Site type	$\bar{x}$, kg m^{-3}	*min*., kg m^{-3}	*max.*, kg m^{-3}	*s*, kg m^{-3}	* $\bar{x}$, kg m^{-3}
XIII	Vatkg	402.9	358.2	437.0	22.1	405.5
B15	Vatkg	404.4	356.9	449.7	27.3	402.3
B13	Vatkg	413.7	381.2	456.5	26.2	410.3
B14	Vatkg	413.8	381.7	453.4	22.2	416.2
20	Ptkg	418.6	384.9	453.3	22.8	416.0
B21	Ptkg	418.6	368.3	453.0	27.8	419.2
8	Ptkg	420.1	388.4	449.1	21.0	417.3
9	Ptkg	428.3	400.0	470.1	24.0	424.1
5A	Vatkg	433.3	401.9	487.2	24.9	432.7
14	Ptkg	437.0	397.6	482.5	30.4	431.7
		Between stems				Between stands
$\bar{x}$		**419.2**				**417.5**
s		**26.2**				**10.1**

* Estimate of basic density of a stand. The basic density of each felled tree was weighted with its volume.

Variation in basic density was also examined according to location of the log in the stem. The basic density of spruce butt logs averaged 374.3 kg m^{-3} (s = 31.5). For other logs, the basic density was on average 370.7 kg m^{-3} (s = 28.9) and for bolts of pulpwood 383.2 kg m^{-3} (s = 32.0). The basic density of pulpwood from tree tops and jump butts was equal. In pine butt logs, the basic density was on average 446.5 kg m^{-3} (s = 30.0) and in other logs 406.9 kg m^{-3} (s = 27.2). The basic density of pulpwood from tree tops averaged 388.8 kg m^{-3} (s = 26.7). The highest basic density of 462.5 kg m^{-3} (s = 36.7) was found in jump butts.

Variation in moisture content (mass of water in wood per oven-dry mass of wood) between spruce and pine sample discs is illustrated in Figs 54 and 55. The moisture content for spruce discs was calculated from small sample pieces by weighting each piece with the cross-sectional area of disc it represented. The moisture content in spruce ranged from 25% to 205% and in pine from 60% to 190%. The moisture content increased from butt to top of tree simultaneously with the decrease in proportion of dry heartwood. Since spruce contains more heartwood than pine, its moisture content is on average lower. Variation in spruce disc was clearly higher than that of pine.

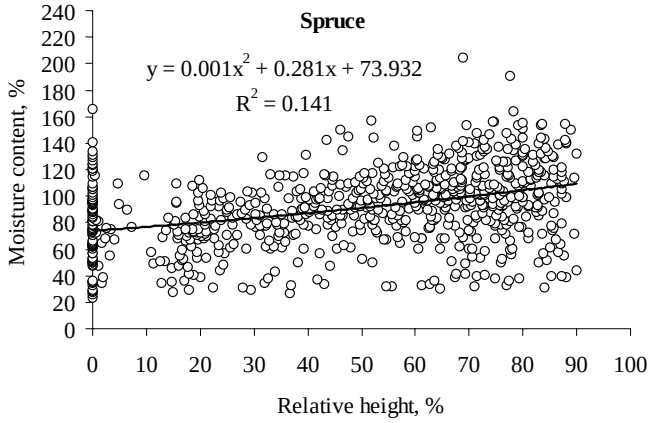


Fig. 54. Variation pattern of moisture content (% of dry mass) in sample discs of spruce (calculated from small sample pieces). Fitted trend line with equation and R^2 is presented.

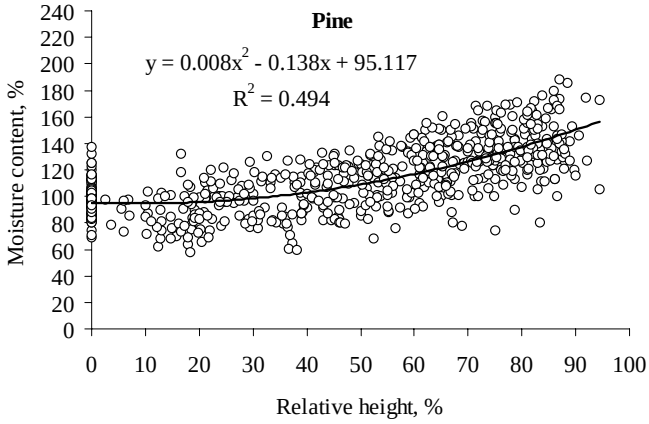


Fig. 55. Variation pattern of moisture content (% of dry mass) in sample discs of pine. Fitted trend line with equation and R^2 is presented.

3.3 Sawn Timber

3.3.1 Yield of Sawn Timber

The yield of sawn timber was determined from all logs that were sawn, including grade D. The log volumes given by the log scaler were utilized in the calculations. The total volume of sawn timber was based on the nominal dimensions of sawn pieces. Characteristics of the sawing experiments are presented in Tables 17 and 18.

The over bark (o.b.) log volume was 9.2% higher than under bark (u.b.) log volume in both tree species. The yield of sawn timber was 0.53 in spruce and 0.52 in pine. The yield of the sawing experiments is presented in detail in Appendix 7.

Table 17. Data from the sawing experiments in spruce.

Spruce								
No. of logs: 304				Sawn timber (green)				
volume, m^3				volume, m^3				
o.b.	mean	u.b.	mean	boards	centre yield	total	yield of sawn timber	log use ratio
75.751	0.249	69.837	0.230	12.420	27.760	40.180	0.530	1.885

Table 18. Data from the sawing experiments in pine.

Pine								
No. of logs: 208				Sawn timber (green)				
volume, m^3				volume, m^3				
o.b.	mean	u.b.	mean	boards	centre yield	total	yield of sawn timber	log use ratio
32.053	0.154	29.248	0.141	5.186	11.541	16.727	0.522	1.916

3.3.2 Quality Distributions of Sawn Timber

3.3.2.1 Sawn Timber Graded According to Nordic Timber Rules

Quality distributions of the centre yield are presented in Figs 56 and 57 and the side yield in Figs 58-61. Grade A is presented both as a whole and divided into four subgrades. Sawn timber from grade D logs was not included.

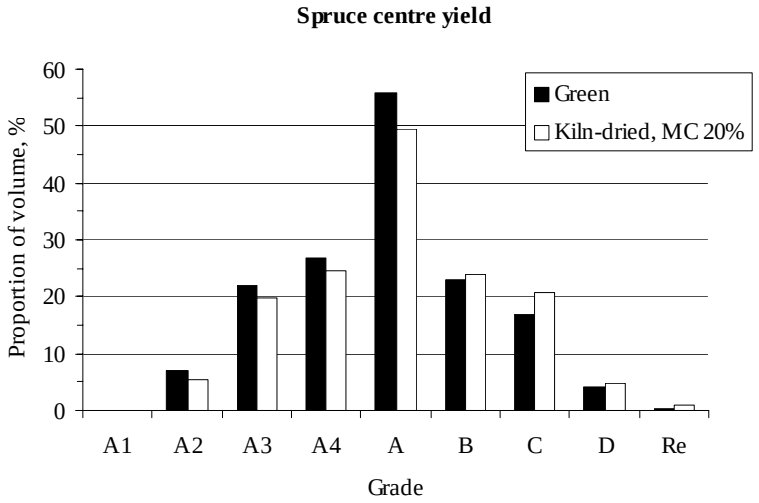


Fig. 56. Quality distributions of spruce centre yield according to the grading rules of Nordic Timber.

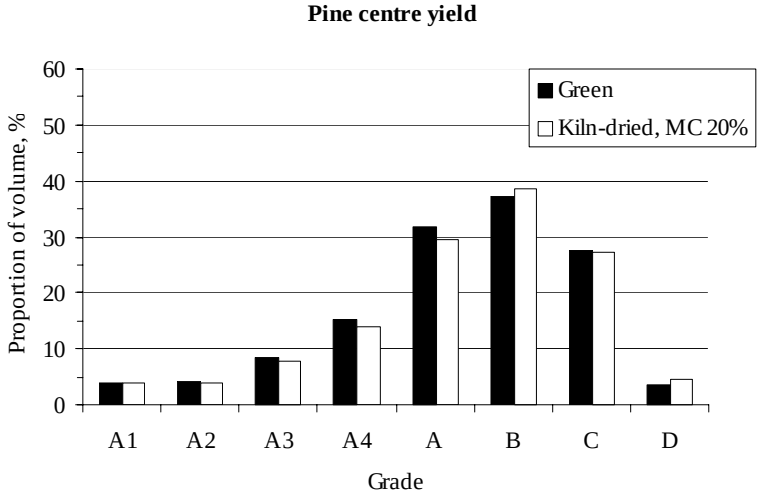


Fig. 57. Quality distributions of pine centre yield according to the grading rules of Nordic Timber.

The quality distributions of spruce and pine centre yield were dissimilar. The proportion of grade A of dried centre yield was about 50% in spruce and about 30% in pine. The proportion of grade A1 in pine centre yield was slightly under 5%. On the whole, drying deformations and fissures of centre yield were slight in both tree species.

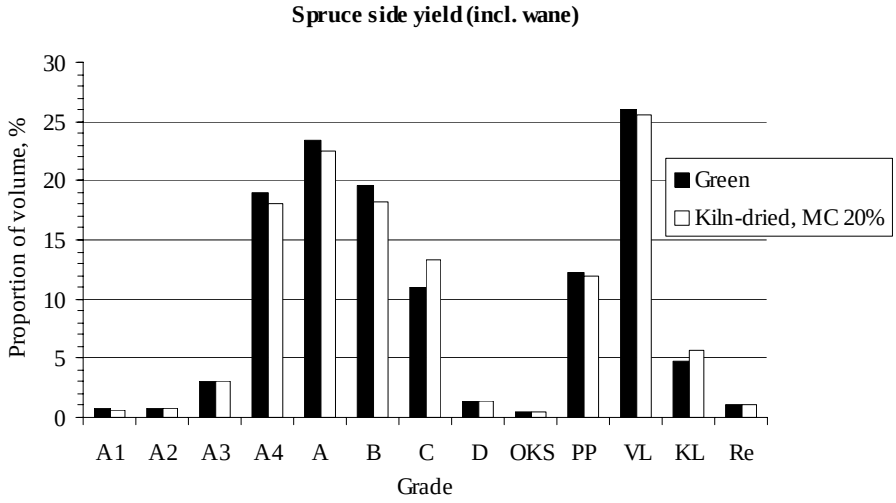


Fig. 58. Quality distributions of spruce side yield according to the grading rules of Nordic Timber (including wane, i.e. sawn timber was graded regarding wane as a defect).

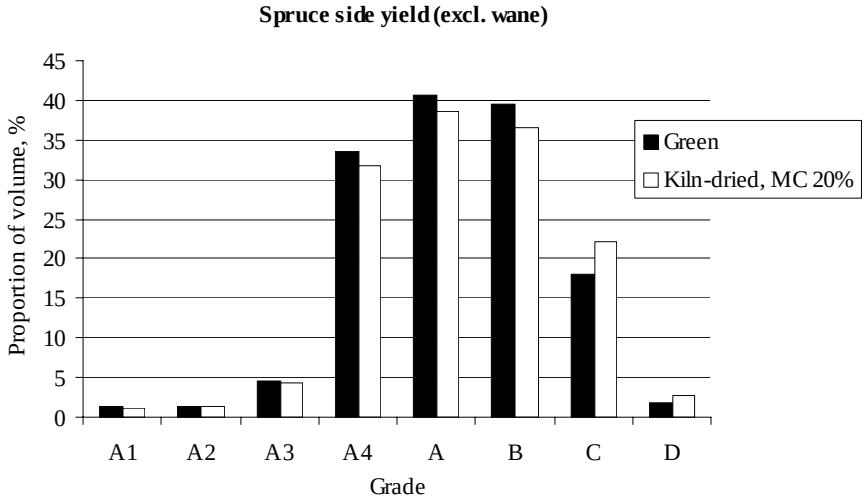


Fig. 59. Quality distributions of spruce side yield according to the grading rules of Nordic Timber (graded as square-edged, i.e. sawn timber was graded as though no wane existed).

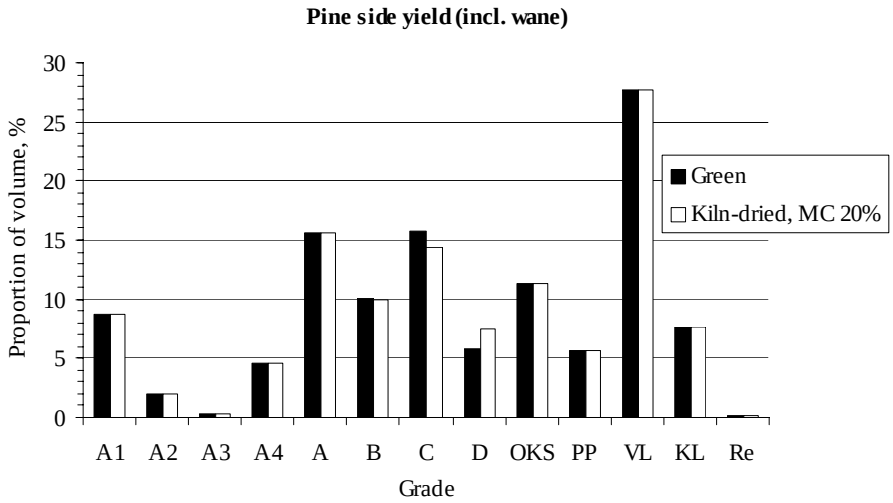


Fig. 60. Quality distributions of pine side yield according to the grading rules of Nordic Timber (including wane, i.e. sawn timber was graded regarding wane as a defect).

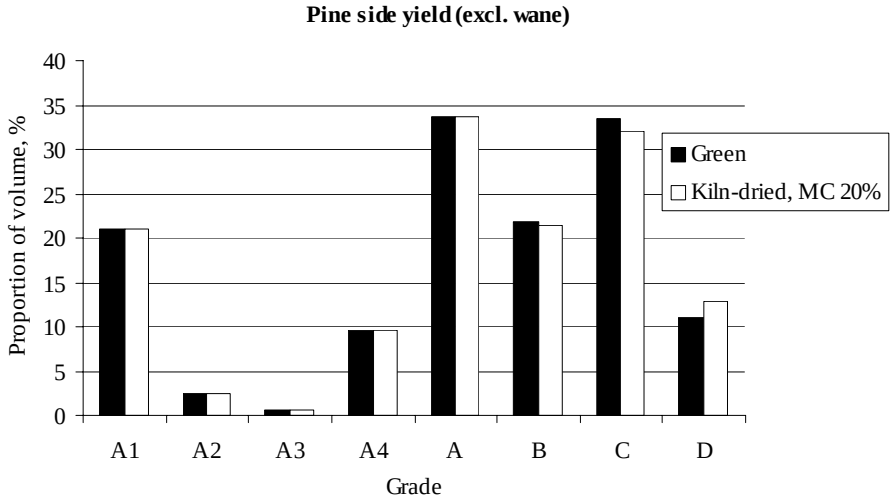


Fig. 61. Quality distributions of pine side yield according to the grading rules of Nordic Timber (graded as square-edged, i.e. sawn timber was graded as though no wane existed).

The proportion of wane side yield was clearly higher in pine than in spruce (see Figs 58 and 60). Excluding wane, the proportion of grade A kiln-dried side yield was 38% in spruce and 33% in pine. Quality lowering during drying was slight in both tree species.

The quality of sawn timber depended strongly on its location in the stem. In spruce, the proportion of grade A centre yield was 57% in butt logs, 47% in middle logs, and 38% in top logs (Fig. 62). In pine, the proportion of grade A centre yield was 45% in butt logs and 18% in middle logs (Fig. 63).

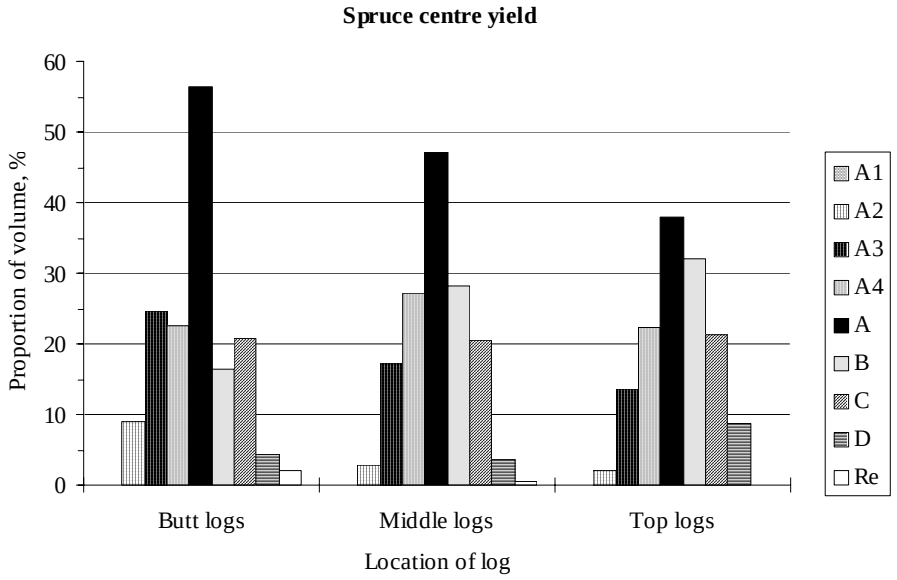


Fig. 62. Quality distributions of spruce centre yield according to log location (Nordic Timber, kiln-dried to a moisture content of 20%).

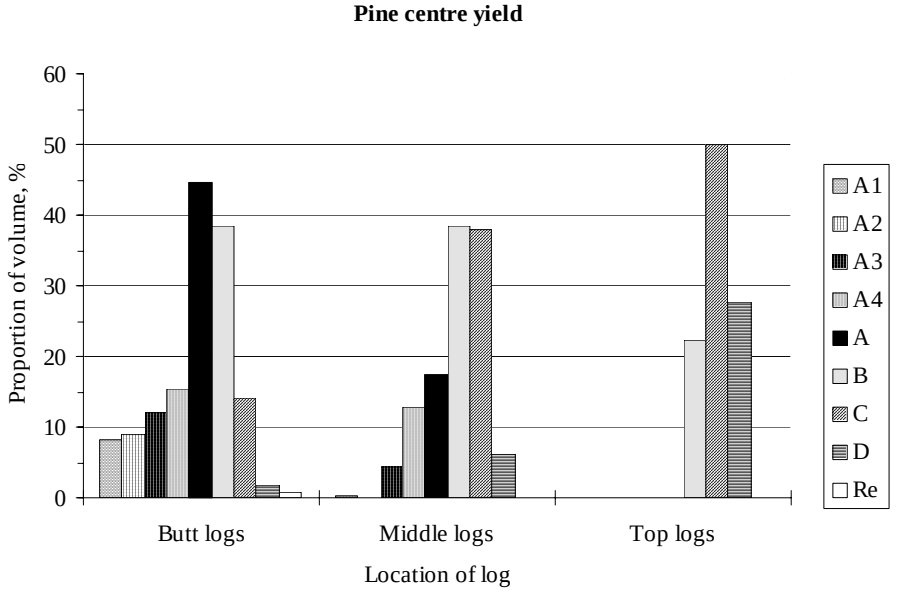


Fig. 63. Quality distributions of pine centre yield according to log location (Nordic Timber, kiln-dried to a moisture content of 20%).

The decrease in quality towards tree top was stronger in side yield than in centre yield (Figs 62-65). Especially in pine, the trend was clear because of the knotless base of trees.

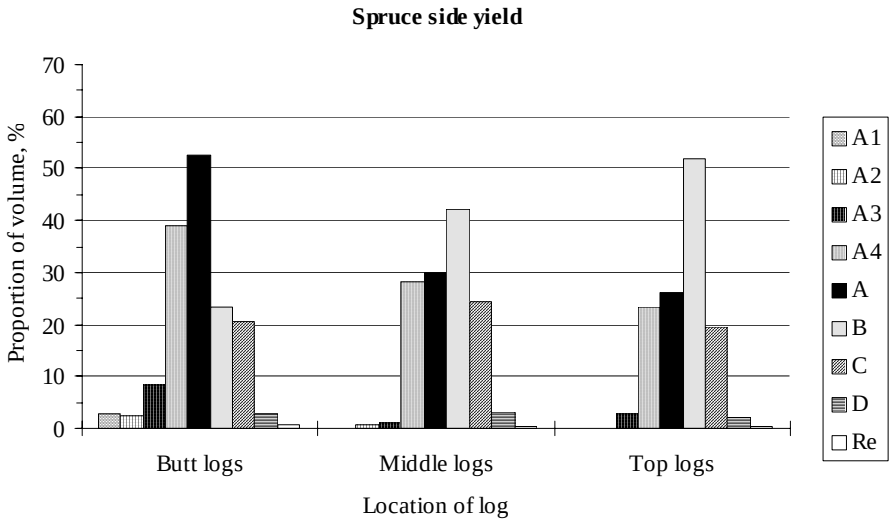


Fig. 64. Quality distributions of spruce side yield according to log location (Nordic Timber, kiln-dried to a moisture content of 20%).

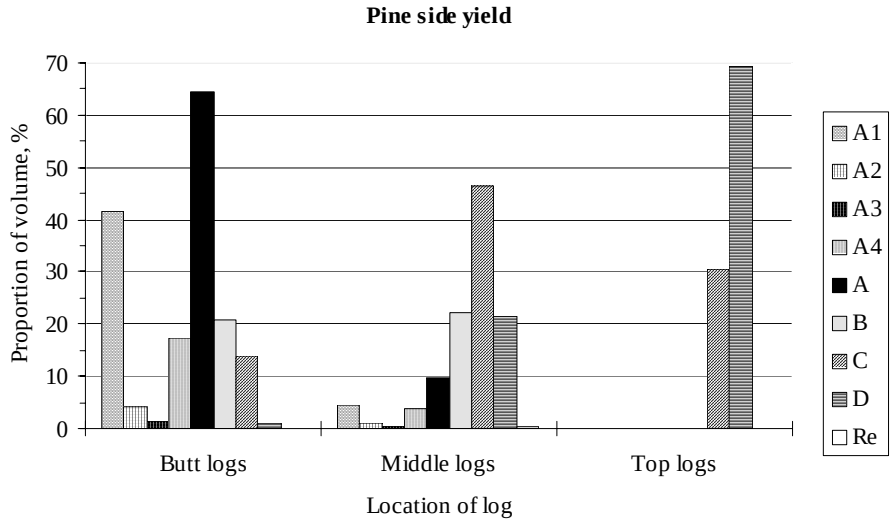


Fig. 65. Quality distributions of pine side yield according to log location (Nordic Timber, kiln-dried to a moisture content of 20%).

3.3.2.2 Centre Yield Graded According to Stress Grading Rules

In spruce, about 85% of the centre yield volume exceeded the characteristic bending strength of 24 N mm^{-2} (T-grading). In pine, the corresponding proportion was 72% (Fig. 66).

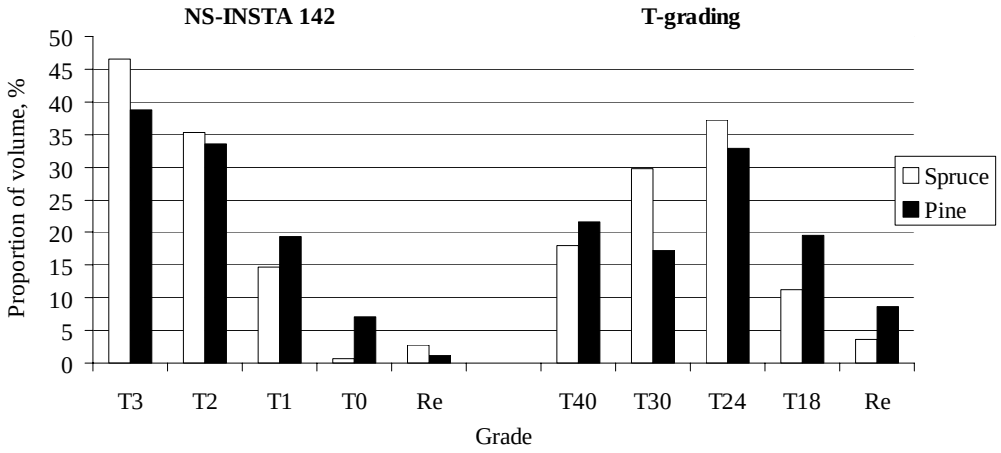


Fig. 66. Quality distributions of centre yield according to the stress grading rules of NS-INSTA 142 and T-grading.

The general distributions hide the variation in quality of sawn timber in the longitudinal direction of the stem. In spruce, the proportion of best grade decreased towards the top of the tree. However, no dramatic decrease in quality can be seen since the proportion of sawn timber of the two best grades (T3 and T2) was about 90% in butt logs (log grades A and C1 combined), 80% in middle logs, and 70% in top logs (Fig. 67). In pine, the decrease in quality towards the top of the tree was strong (Fig. 68).

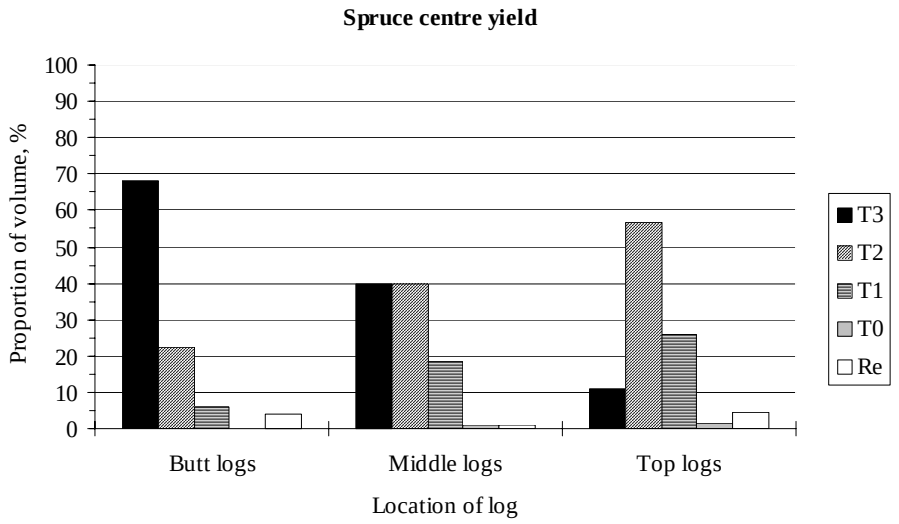


Fig. 67. Quality distributions of spruce centre yield according to log location (NS-INSTA 142).

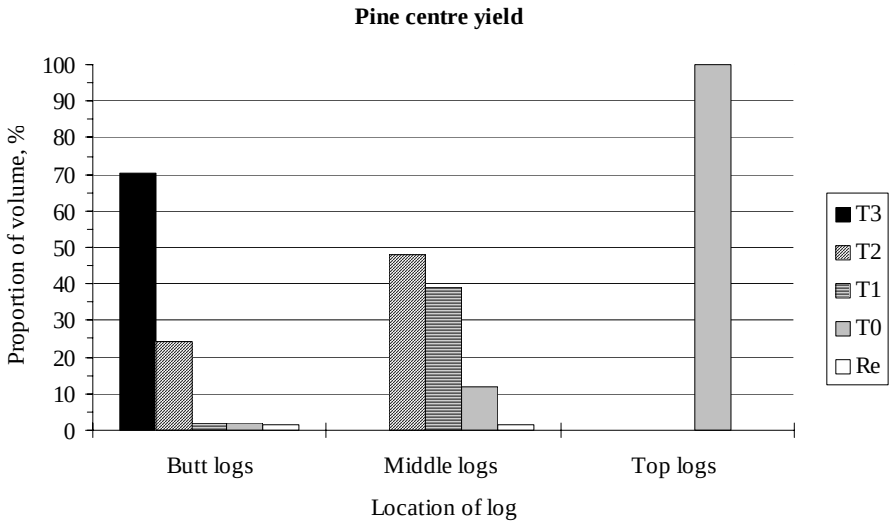


Fig. 68. Quality distributions of pine centre yield according to log location (NS-INSTA 142).

3.3.3 Properties Affecting the Quality of Sawn Timber

The primary feature determining the grade of each kiln-dried sawn piece that did not meet the requirements of grade A1 was inspected. In spruce centre yield, the highest grade did not exist, while in pine centre yield the grade A1 accounted for 4% of the total number of sawn pieces.

Sound knots (51% of total number) were clearly the most common features determining the grade for a piece of spruce centre yield (Fig. 69, left). Deformations and fissures of sawn timber accounted for 8% of the primary features in spruce centre yield. In pine, the most important features were dead knots (36%), sound knots (31%), and unsound knots (17%) (Fig. 69, right). Deformations accounted for 3% of the primary features in pine centre yield. The incidence of compression wood was insignificant in both tree pieces, which was consistent with the observations from sample discs.

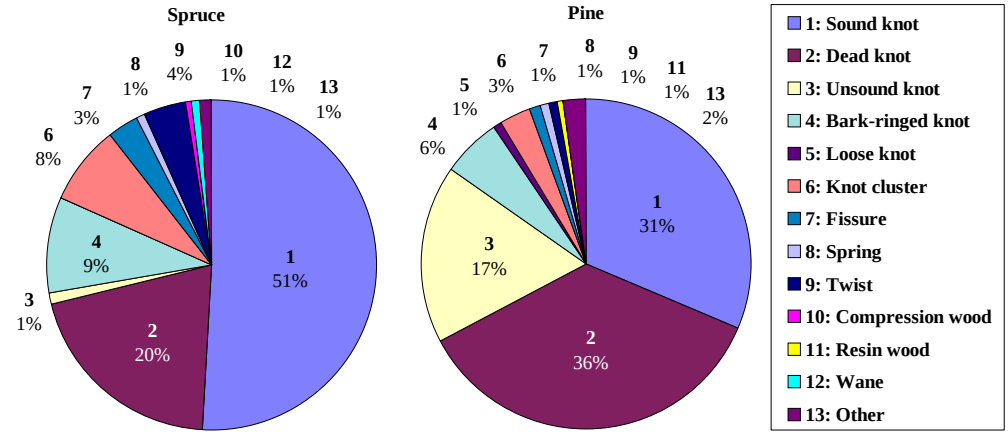


Fig. 69. Primary feature determining the grade (Nordic Timber) for a kiln-dried piece of spruce (left) and pine (right) centre yield (proportion of total number).

Grade A1 accounted for 1% of the total number of sawn pieces in spruce side yield, while in pine the corresponding share was 16%. The two primary features determining the grade in spruce boards were dead knots (44%) and sound knots (34%). The next features in order of importance were bark-ringed knots (7%), loose knots (6%), and unsound knots (3%) (Fig. 70, left). In pine boards, the primary features were dead knots (36%), unsound knots (17%), and sound knots (16%) (Fig. 70, right). Wane was also common. The share of reject due to wane was, however, insignificant. The shares of drying deformations, fissures, and compression wood were minor.

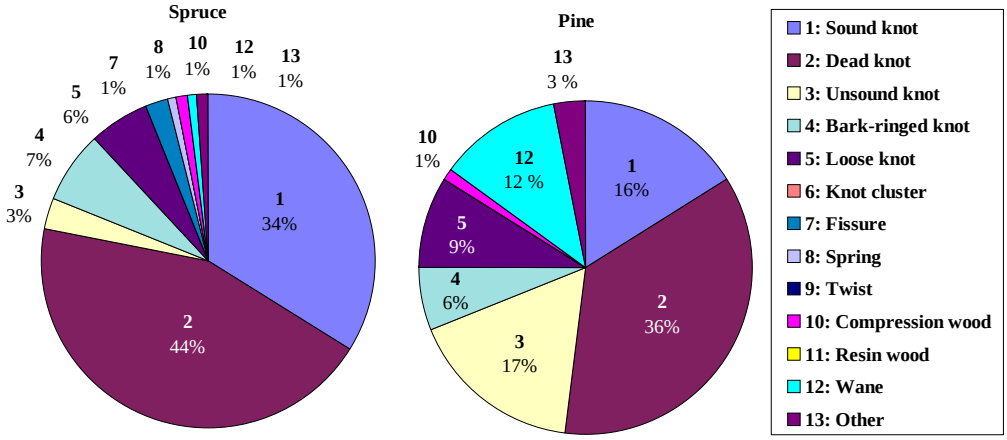


Fig. 70. Primary feature determining the grade (Nordic Timber) for a kiln-dried piece of spruce (left) and pine (right) side yield (proportion of total number).

3.3.4 Drying to 10% Moisture Content and Ripsawing

Joinery drying caused critical checks and deformations, and thus, a decrease in quality in both tree species (Fig. 71). In spruce, the volume of grade A decreased to less than one-half of the original volume (MC 20%). In pine, the change was even more striking. From 94 inspected spruce sawn pieces, 46 represented a lower grade after joinery drying: 23 pieces because of checks, 16 because of twist, 5 because of cup, and 2 because of spring (Fig. 72, left). From 53 pine sawn pieces, 34 represented a lower grade after joinery drying: 16 because of checks, 8 because of twist, 2 because of cup, 5 because of bow, and 3 because of spring (Fig. 72, right). The quality-lowering causes were the same in both tree species, excluding bow.

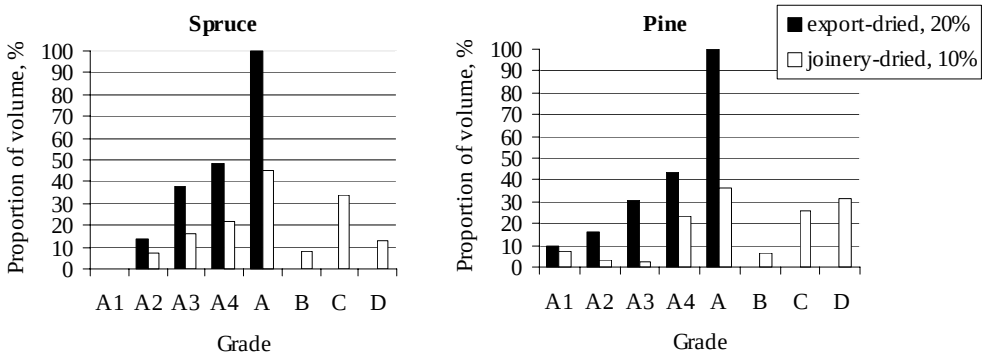


Fig. 71. Quality distributions of spruce (left) and pine (right) centre yield before and after joinery drying (Nordic Timber).

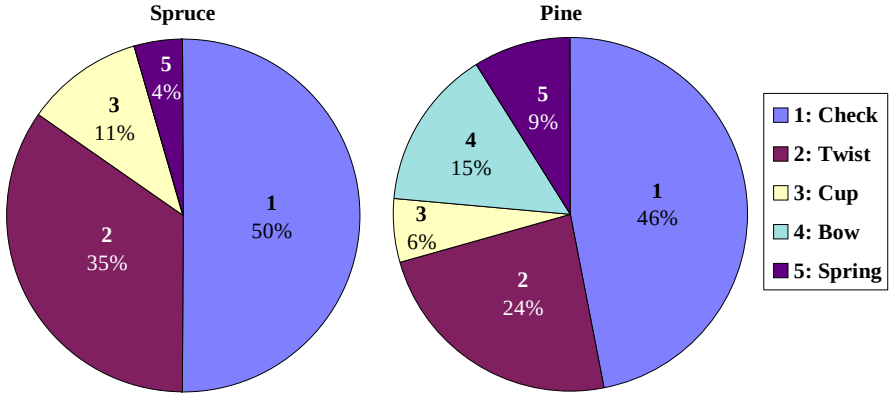


Fig. 72. Primary features lowering the quality in joinery-dried spruce (left) and pine (right) centre yield (proportion of total number).

The features observed in ripsawn pieces are presented in Fig. 73. The pieces containing two or three features were combined into groups, thus, the incidence of individual features was larger than the figure indicates. Twist, spring, and checks were the most common features in both tree species.

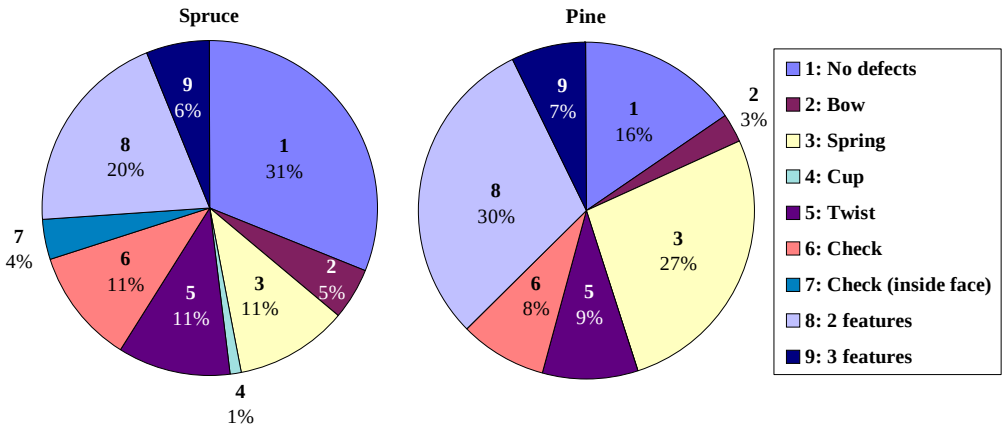


Fig. 73. Features in ripsawn spruce (left) and pine (right) pieces (proportion of total number).

The number and value of the wood features observed in joinery-dried sawn pieces and ripsawn pieces are presented in Tables 19 and 20. The coefficient refers to the relative change in number of features. For example, a coefficient of 2.06 (= 31 per 6 per 2.51) (Table 19) expresses that the proportion of spruce pieces containing bow increased over twofold after ripsawing. In both tree species, spring in particular increased markedly in ripsawn pieces. Cup, by contrast, was insignificant. Check on inside face was observed as a new feature. Here inside face is referred to the inside face of the original piece.

Table 19. Sawn timber features before and after ripsawing in spruce.

	Sawn pieces		**Ripsawn pieces**		
Feature	$\bar{x}$	No. of pieces	$\bar{x}$	No. of pieces	Coefficient
Bow, mm	7.8	6	9.0	31	2.06
Spring, mm	7.3	4	8.6	62	6.18
Cup, %	2.0	29	19.5	2	0.03
Twist, %	11.1	36	14.5	59	0.65
Check, %	43.1	42	29.4	64	0.61
Check (inside face), %	0	0	29.1	20	
Total		117		238	
Number of pieces		**94**		**236**	**Ratio: 2.51**

Table 20. Sawn timber features before and after ripsawing in pine.

	Sawn pieces		**Ripsawn pieces**		
Feature	$\bar{x}$	No. of pieces	$\bar{x}$	No. of pieces	Coefficient
Bow, mm	13.5	10	17.6	23	1.12
Spring, mm	5.7	6	12.3	57	4.61
Cup, %	2.4	16		0	
Twist, %	8.5	20	12.2	30	0.73
Check, %	52.0	26	32.2	25	0.47
Check (inside face), %	0	0	31.3	7	
Total		78		142	
Number of pieces		**53**		**109**	**Ratio: 2.06**

3.4 Value of Roundwood as Sawn Timber

3.4.1 Value of Roundwood on Stand-Level

The mean value of one cubic metre of o.b. roundwood as sawn timber, i.e. the *quality factor*, was determined for each stand (see Section 2.5.1, Equation 15). The quality factor of 100 corresponds to the value of centre yield 50 × 100 mm of grade A. The results are presented in ascending order of quality factor of the total yield (Figs 74 and 75). The estimates of the quality-based saw timber percentages of the stands are also presented. In spruce, the difference between the highest and lowest quality factors was about 20%, in pine stands 24%. The quality factors of pine stands were slightly higher than those of spruce stands. This was mainly due to the higher proportion of valuable side yield of pine. Stand characteristics, such as site type, stand density, or mean dbh, did not explain the variation in quality factors. It should be noted that the quality factors here represent only those sections of stems that met the quality requirements of saw logs. For instance, in pine stand 5A, the material consisted mostly of butt logs, which explains the high value of side yield.

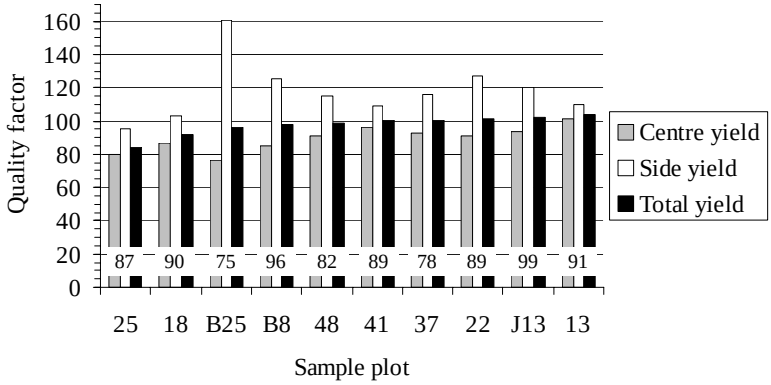


Fig. 74. Quality factors of roundwood in spruce stands. Estimates of the quality-based saw timber percentages of the stands are also presented.

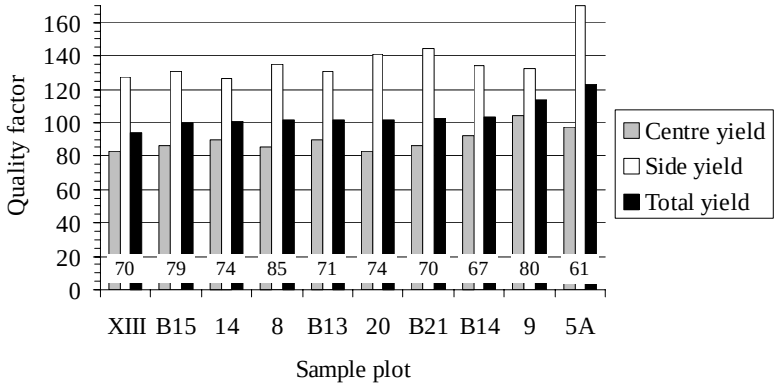


Fig. 75. Quality factors of roundwood in pine stands. Estimates of the quality-based saw timber percentages of the stands are also presented.

3.4.2 Gross Value and Sawing Value of Logs

To provide an accurate description of the value of saw logs in sawmills, two different characteristics were determined: gross value and sawing value of logs. The former corresponds to the value of sawn timber and by-products, the latter to the value of sawn timber alone (see Section 2.5.1, Equations 16 and 17). The gross value of sawn timber is presented as a set of six hypothetical price levels of sawn timber and three price levels of by-products (Tables 21 and 22). The price of sawn timber represents the value of grade A centre yield size 50 × 100 mm, to which the other grades and dimensions of sawn pieces are proportioned (see Appendix 4). The calculations were based on the following set-up:

Price of sawn timber, € m^{-3}: 170, 180, 190, 200, 210, 220
Quality factor of roundwood by sample plots: 92-123 (see Figs 74 and 75)
Yield of sawn timber by sample plots: 0.46-0.56
Price of by-products (€ m^{-3}): 50, 55, 60

Table 21. Gross value of spruce logs (€ m^{-3}).

	Price of sawn timber, € m^{-3}																	
	170			180			190			200			210			220		
Sample	Price of by-products, € m^{-3}																	
plot	50	55	60	50	55	60	50	55	60	50	55	60	50	55	60	50	55	60
18	110.68	112.84	115.01	115.92	118.08	120.25	121.16	123.32	125.48	126.40	128.56	130.72	131.64	133.80	135.96	136.88	139.04	141.20
25	101.73	103.96	106.19	106.39	108.63	110.86	111.06	113.30	115.53	115.73	117.97	120.20	120.40	122.64	124.87	125.07	127.31	129.54
41	115.24	117.53	119.81	120.67	122.96	125.25	126.10	128.39	130.68	131.54	133.83	136.11	136.97	139.26	141.55	142.40	144.69	146.98
48	114.69	116.93	119.17	120.12	122.36	124.60	125.55	127.79	130.03	130.98	133.22	135.46	136.40	138.65	140.89	141.83	144.07	146.31
J13	113.16	115.60	118.03	118.39	120.82	123.26	123.61	126.05	128.48	128.83	131.27	133.70	134.06	136.49	138.93	139.28	141.72	144.15
13	123.01	125.13	127.25	129.00	131.12	133.24	134.98	137.10	139.23	140.97	143.09	145.21	146.96	149.08	151.20	152.95	155.07	157.19
37	119.97	122.09	124.21	125.78	127.90	130.02	131.59	133.71	135.83	137.40	139.52	141.64	143.21	145.33	147.45	149.02	151.14	153.26
B8	105.35	107.96	110.58	110.01	112.62	115.24	114.67	117.29	119.90	119.33	121.95	124.56	123.99	126.61	129.22	128.66	131.27	133.88
B25	95.07	98.07	101.08	98.90	101.90	104.90	102.73	105.73	108.73	106.55	109.56	112.56	110.38	113.38	116.38	114.21	117.21	120.21
22	108.40	111.01	113.63	113.24	115.85	118.47	118.07	120.69	123.30	122.91	125.53	128.14	127.75	130.36	132.98	132.59	135.20	137.82
Mean	110.73	113.11	115.50	115.84	118.22	120.61	120.95	123.34	125.72	126.07	128.45	130.83	131.18	133.56	135.94	136.29	138.67	141.05

Table 22. Gross value of pine logs (€ m^{-3}).

	Price of sawn timber, € m^{-3}																	
	170			180			190			200			210			220		
Sample	Price of by-products, € m^{-3}																	
plot	50	55	60	50	55	60	50	55	60	50	55	60	50	55	60	50	55	60
8	117.62	119.85	122.09	123.22	125.46	127.69	128.83	131.06	133.30	134.43	136.67	138.90	140.04	142.27	144.51	145.64	147.87	150.11
9	130.12	132.33	134.53	136.48	138.68	140.89	142.84	145.04	147.25	149.20	151.40	153.60	155.56	157.76	159.96	161.91	164.12	166.32
14	114.42	116.77	119.12	119.77	122.12	124.47	125.12	127.47	129.82	130.46	132.81	135.16	135.81	138.16	140.51	141.16	143.51	145.86
20	114.85	117.21	119.57	120.22	122.58	124.94	125.59	127.95	130.31	130.96	133.32	135.68	136.33	138.69	141.05	141.70	144.05	146.41
B21	109.54	112.16	114.78	114.45	117.06	119.68	119.35	121.97	124.59	124.26	126.87	129.49	129.16	131.78	134.39	134.07	136.68	139.30
B13	110.04	112.59	115.14	115.02	117.57	120.11	119.99	122.54	125.09	124.97	127.51	130.06	129.94	132.49	135.04	134.91	137.46	140.01
B14	112.00	114.54	117.08	117.09	119.63	122.17	122.18	124.73	127.27	127.28	129.82	132.36	132.37	134.91	137.45	137.46	140.00	142.55
B15	110.10	112.59	115.08	115.12	117.60	120.09	120.13	122.62	125.10	125.14	127.63	130.12	130.15	132.64	135.13	135.17	137.66	140.14
5A	136.32	138.61	140.90	142.99	145.29	147.58	149.67	151.96	154.25	156.34	158.63	160.92	163.01	165.30	167.59	169.68	171.97	174.26
XIII	100.41	103.11	105.80	104.73	107.43	110.12	109.05	111.75	114.44	113.37	116.07	118.76	117.69	120.39	123.08	122.01	124.71	127.40
Mean	115.54	117.98	120.41	120.91	123.34	125.77	126.27	128.71	131.14	131.64	134.07	136.51	137.01	139.44	141.87	142.37	144.80	147.24

When the same prices and value ratios were applied to both tree species, the gross value of pine logs was 4.80-6.20 € m^{-3} higher than that of spruce logs. The difference is attenuated, however, since the value of spruce sawmill chips is slightly higher than the value of pine sawmill chips.

The relative decrease in gross values of logs was studied by reducing the yield of sawn timber by 5, 10, and 15% (Table 23). The relative decrease in gross value was greater the higher the value of sawn timber and smaller the higher the value of by-products. The decreases were linear since other factors were unchanged.

Table 23. Relative decrease in gross value of spruce logs (left) and pine logs (right) as the yield of sawn timber declines.

Sample plot	Decline in yield of sawn timber 5 %		10 %		15 %	
	min.	*max.*	*min.*	*max.*	*min.*	*max.*
18	-2.39	-3.17	-4.78	-6.35	-7.17	-9.52
25	-2.17	-3.00	-4.35	-6.00	-6.52	-9.00
41	-2.50	-3.24	-4.99	-6.49	-7.49	-9.73
48	-2.48	-3.24	-4.97	-6.47	-7.45	-9.71
J13	-2.46	-3.21	-4.92	-6.41	-7.38	-9.62
13	-2.64	-3.37	-5.28	-6.73	-7.93	-10.10
37	-2.58	-3.32	-5.17	-6.64	-7.75	-9.97
B8	-2.29	-3.06	-4.57	-6.11	-6.86	-9.17
B25	-2.03	-2.81	-4.06	-5.62	-6.10	-8.43
22	-2.36	-3.11	-4.72	-6.23	-7.08	-9.34

Sample plot	Decline in yield of sawn timber 5 %		10 %		15 %	
	min.	*max.*	*min.*	*max.*	*min.*	*max.*
8	-2.54	-3.28	-5.09	-6.57	-7.63	-9.85
9	-2.77	-3.46	-5.54	-6.91	-8.31	-10.37
14	-2.48	-3.23	-4.96	-6.46	-7.44	-9.69
20	-2.49	-3.24	-4.98	-6.47	-7.47	-9.71
B21	-2.39	-3.14	-4.77	-6.27	-7.16	-9.41
B13	-2.39	-3.15	-4.79	-6.29	-7.18	-9.44
B14	-2.44	-3.18	-4.88	-6.36	-7.31	-9.54
B15	-2.39	-3.15	-4.79	-6.30	-7.18	-9.45
5A	-2.87	-3.53	-5.74	-7.05	-8.61	-10.58
XIII	-2.16	-2.95	-4.33	-5.90	-6.49	-8.85

The sawing value of logs (value of sawn timber) was calculated by assigning the price of 190 € m^{-3} to grade A centre yield size 50 × 100 mm and prices according to the value ratio table of sawn timber to the other grades (see Appendix 4). Grade D sawn timber was not priced. The sawing values of spruce and pine logs are presented according to the o.b. diameter of logs (Figs 76 and 77, left). Pine top logs were excluded because of too few observations. Part of the variation in sawing values came from the variation in log lengths. To eliminate this variation, the values were proportioned to the mean log length of spruce (4.7 m) and pine (4.2 m) (Figs 76 and 77, right). The mean sawing values of spruce logs presented by the log sections were only slightly unequal. In contrast to spruce, the mean sawing values of pine logs differed from each other already in small top diameters, which indicates the importance of log classification in pine.

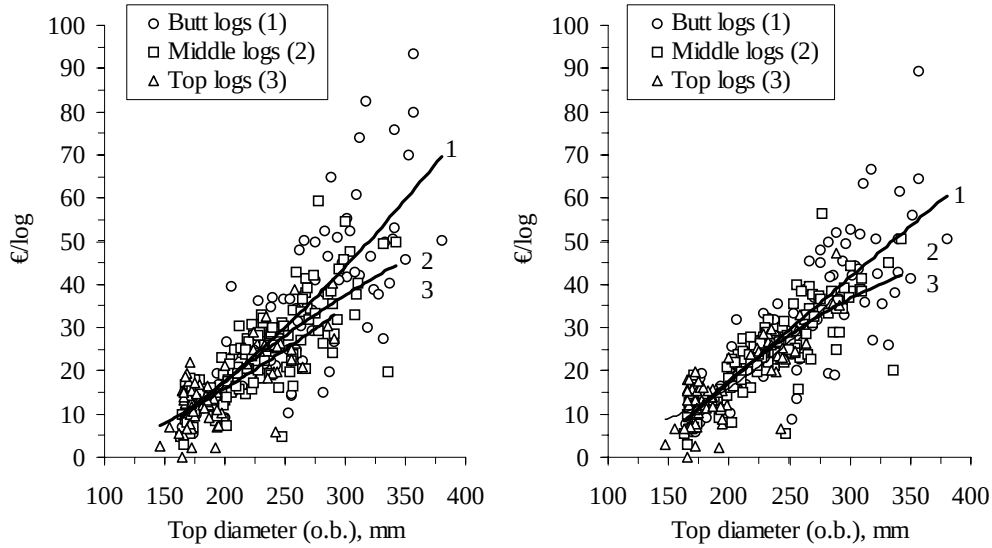


Fig. 76. Sawing values of spruce logs by log section without log length correction (left) and with log length correction (right). Fitted trend lines are presented.

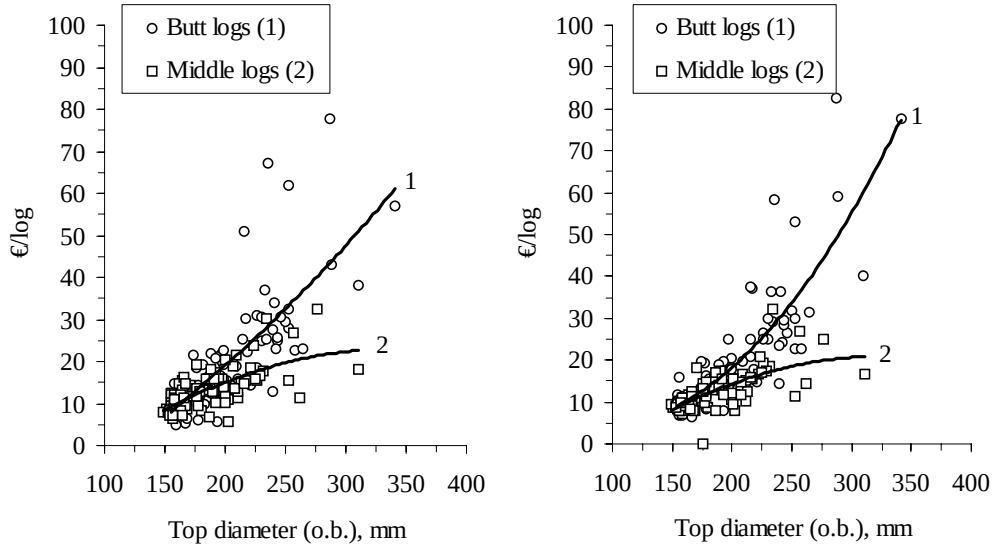


Fig. 77. Sawing values of pine logs by log section without log length correction (left) and with log length correction (right). Fitted trend lines are presented.

3.5 Stem Characteristics as Predictors of Quality of Sawn Timber

3.5.1 Value of Roundwood on Tree-Level

The quality factors of roundwood (see Section 2.5.2) are presented in Figs 78 and 79. The broken line at 1.0 corresponds to the value of the quality of grade A (50 × 100 mm).

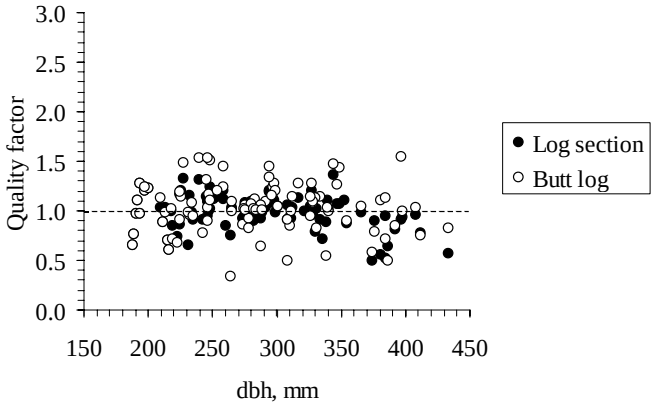


Fig. 78. Quality factors of spruce roundwood.

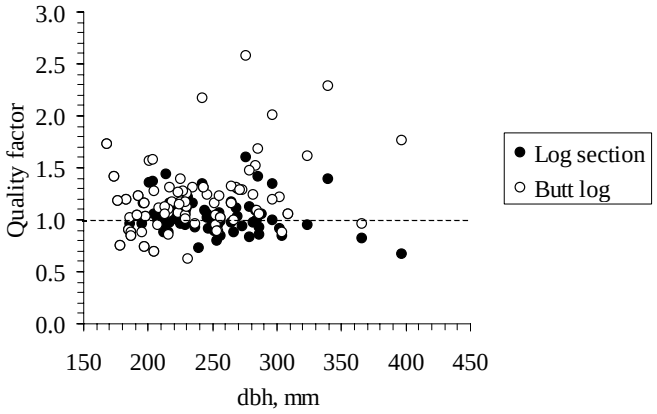


Fig. 79. Quality factors of pine roundwood.

The quality factor of spruce and pine butt logs averaged 1.04 and 1.21, respectively. The corresponding values for log section were 0.99 and 1.05. Variation in quality factor was greatest in pine butt logs. The quality factors were independent of dbh.

3.5.2 Relationships between Stem Characteristics

A correlation analysis of stem characteristics was carried out to study the relationships between possible predictors of quality of sawn timber (Tables 24 and 25). Knowing the importance of growth rate on general quality, two characteristics were determined at stump

height: one representing the mean growth ring width and another representing the early growth rate (radial growth of the first 30 rings). Stump height was used as the basis of measurements because it was the only fixed height in all trees.

The two main characteristics predicting the quality of pine sawn timber, dead branch height and growth rate (e.g. Heiskanen 1954b, 1965; Kärkkäinen 1980; Uusitalo 1994, 1995), showed a slight correlation, while in spruce the correlation between these characteristics was very weak. From the point of view of modelling, this may be seen as an advantage if both variables were entered in the model. Growth rate also correlated weakly with measured knot diameters.

Table 24. Correlation coefficients between the studied spruce stem characteristics (n = 92-101).

Characteristic	dbh	h	h_c	cr	h_{db}	dbs_r	a	t_{ad}	a_{tod}	i_m	i_{30}	dk_{max}	k_{max}
dbh	1.000												
h	0.801	1.000											
h_c	0.265	0.502	1.000										
cr	0.118	-0.044	-0.880	1.000									
h_{db}	-0.033	0.156	0.229	-0.190	1.000								
dbs_r	0.027	0.113	0.765	-0.823	-0.370	1.000							
a	0.144	0.000	0.047	-0.053	-0.122	0.115	1.000						
t_{ad}	0.297	0.506	0.182	0.062	0.016	0.019	-0.100	1.000					
a_{tod}	0.012	-0.202	-0.034	-0.066	-0.116	0.091	0.927	-0.466	1.000				
i_m	0.455	0.421	0.055	0.149	0.014	-0.084	-0.767	0.269	-0.784	1.000			
i_{30}	0.096	0.147	0.058	0.006	0.184	-0.082	-0.701	0.144	-0.677	0.750	1.000		
dk_{max}	0.269	0.029	-0.083	0.101	-0.488	0.165	0.078	0.079	0.036	0.140	-0.127	1.000	
k_{max}	0.270	0.019	-0.211	0.238	-0.530	0.057	0.112	0.066	0.073	0.099	-0.165	0.928	1.000

Table 25. Correlation coefficients between the studied pine stem characteristics (n = 52-95).

Characteristic	dbh	h	h_c	cr	h_{db}	dbs_r	a	t_{ad}	a_{tod}	i_m	i_{30}	dk_{max}	k_{max}
dbh	1.000												
h	0.693	1.000											
h_c	0.302	0.777	1.000										
cr	0.439	0.143	-0.503	1.000									
h_{db}	0.341	0.462	0.438	-0.056	1.000								
dbs_r	-0.412	-0.167	0.272	-0.662	-0.642	1.000							
a	-0.066	-0.414	-0.331	-0.052	-0.074	-0.088	1.000						
t_{ad}	-0.081	-0.110	-0.196	0.200	0.020	-0.177	0.011	1.000					
a_{tod}	-0.027	-0.334	-0.222	-0.130	-0.079	-0.006	0.910	-0.403	1.000				
i_m	0.563	0.669	0.411	0.258	0.270	-0.181	-0.709	-0.023	-0.641	1.000			
i_{30}	0.540	0.723	0.555	0.098	0.445	-0.189	-0.601	-0.125	-0.500	0.775	1.000		
dk_{max}	0.252	-0.134	-0.154	0.062	-0.273	0.121	0.185	-0.193	0.243	-0.105	-0.150	1.000	
k_{max}	0.252	-0.134	-0.154	0.062	-0.273	0.121	0.185	-0.193	0.243	-0.105	-0.150	1.000	1.000

3.5.3 Quality Models

3.5.3.1 Quality Models of Spruce

Both in spruce butt logs (Model 1) and in log sections (Model 2), the quality factor was best predicted by a model in which squared dbh, tree height, and the largest knot in the butt log were entered as independent variables (Table 26).

Table 26. Quality models for spruce and their reliability.

Model	Variable	Constant	Coefficient	*s.e.*	G^2	*RMSE*	$RMSE_r$	*b*	b_r	R^2
1		0.78443		0.234739						
	dbh^2		-0.000003	0.000001						
	h		0.002889	0.001044						
	dk_{max}		-0.015154	0.005929						
					-19.900	0.246	0.339	0.020	-0.042	0.235
2		0.81074		0.162945						
	dbh^2		-0.000003	0.000001						
	h		0.002396	0.002396						
	dk_{max}		-0.009015	0.004116						
					-85.909	0.181	0.201	-0.026	-0.057	0.287

The quality factors of spruce could be predicted with low bias. The determination of degree remained, however, quite low because of great variation in dependent variables. The estimates ranged mainly from 0.8 to 1.2 (Fig. 80). The figure shows that the lowest values were overestimated and the highest underestimated.

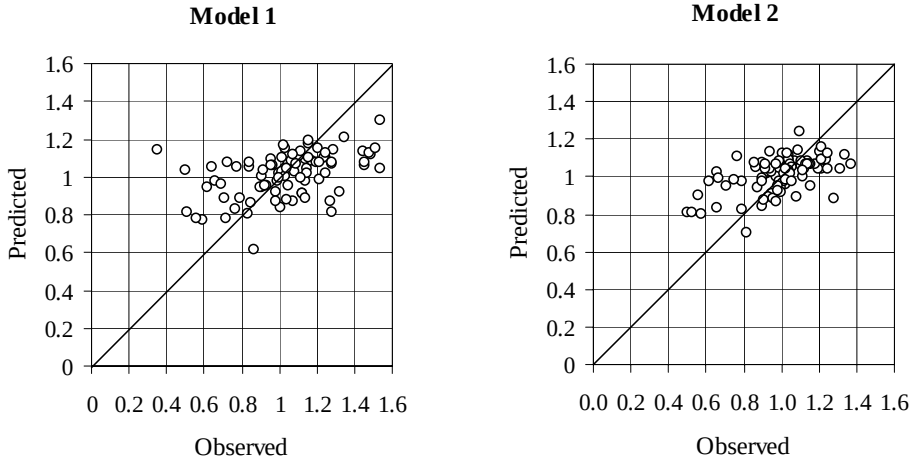


Fig. 80. Quality factors of spruce: observed vs. predicted by the models.

3.5.3.2 Quality Models of Pine

In pine butt logs (Model 3), the quality factors were best predicted by the ratio between dead branch height and relative length of dead branch section and by tree height (Table 27). In log sections (Model 4), the best predictors for quality factors were dead branch height and mean growth rate at stump height.

Table 27. Quality models for pine and their reliability.

Model	Variable	Constant	Coefficient	*s.e.*	G^2	*RMSE*	$RMSE_r$	*b*	b_r	R^2
3		0.15786		0.231585						
	h_{db}/dbs_r		0.002280	0.000771						
	h		0.004286	0.001208						
					19.853	0.339	0.272	-0.002	-0.070	0.334
4		1.05557		0.067554						
	h_{db}		0.006143	0.001334						
	i_m		-0.169466	0.046301						
					-66.447	0.188	0.157	-0.000044	-0.023	0.244

In pine models, the biases were also low. The observed quality factors ranged from 0.7 to 2.6 in pine butt logs. The highest values could not be predicted accurately, but they were underestimated (Fig. 81).

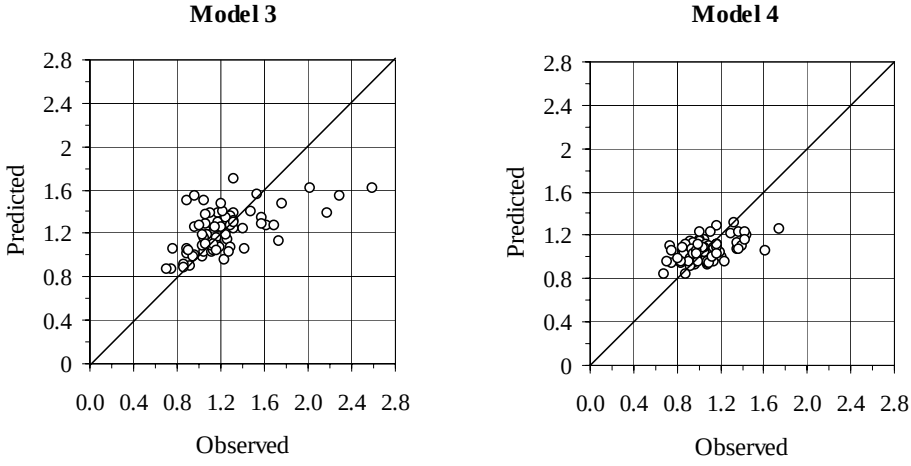


Fig. 81. Quality factors of pine: observed vs. predicted by the models.

4 DISCUSSION

4.1 External Properties of Trees and Saw Logs

External properties of trees were studied according to tree size (dbh, h, and v), stem form, branchiness and knottiness, stem form defects, saw timber proportion, and decay, all of which have a direct or indirect influence on the usability of roundwood in mechanical wood processing. Tree size was included in external quality factors because it affects the processability of logs and the efficiency of wood procurement in general. It is not very clear which characteristics should be considered to belong to external properties. Knottiness usually represents an internal quality characteristic. However, knots on the log surface are still regarded as external characteristics. Here decay was considered an external quality characteristic, although it might also be seen as an internal quality characteristic.

External properties of the Finnish spruce – branchiness, knottiness, and stem form – has been examined in numerous studies (e.g. Sirén 1952; Asikainen and Heiskanen 1970; Hakkila et al. 1972; Kärkkäinen 1972a, 1986a, 1986b; Päivinen 1978; Laasasenaho 1982; Gustavsen and Fagerström 1983; Koivuniemi 1992; Verkasalo and Leban 1996; Uusvaara 1997; Verkasalo and Maltamo 2002). External properties of pine has been studied both in young pine stands and mature stands (e.g. Heiskanen 1965; Asikainen and Heiskanen 1970; Hakkila et al. 1972; Uusvaara 1974; Kärkkäinen 1980, 1986a, 1986b; Laasasenaho 1982; Turkia and Kellomäki 1987; Kellomäki et al. 1992; Uusitalo 1994, 1995; Uusvaara 1997). The investigations for pine have focused on the relationship between log grade and quality of sawn timber. Despite the large number of investigations, few results are fully comparable to this study due to the different methods and measurements used. Differences in factors attributed to the material, such as geographical location, site type, tree age, and stand density, also impair comparability of results.

The mean diameter over bark weighted with basal area (D_g), mean height, and mean volume of the spruce stems was 31.0 cm, 25.0 m, and 0.82 m^3, respectively. In Herb-rich type the D_g was 33.8 cm and in *Vaccinium myrtillus* type 27.5 cm. According to the results of the 8th National Forest Inventory, the D_g for spruce in mature spruce dominated stands (development class 6) in southern Finland was 26.0 cm (Tomppo et al. 2001). Thus, the spruce of this material can be considered very large-sized. The large size of the trees indicates high productivity of the drained spruce mires. Also high growth potential had been guided to the most vigorous trees by intensive management. The D_g, mean tree height, and mean stem volume for pine was 25.0 cm, 20.3 m, and 0.47 m^3, respectively. A clear difference was present in the mean diameters (D_g) between sites of *Vaccinium vitis-idaea* type (26.3 cm) and Dwarf-shrub type (23.0 cm). According to Tomppo et al. (2001), the D_g for pine in mature pine dominated stands in southern Finland was 28.5 cm, and thus, the pines of this study were clearly smaller than on average in mature stands. One has to bear in mind that these kinds of comparisons are merely suggestive since there is large variation behind the mean values due to various factors, as mentioned in the preceding paragraph.

Some earlier studies offer more detailed references for stem size and form. Verkasalo and Maltamo (2002) studied quality properties of spruce both on drained peatlands and mineral soil sites in four geographical regions in Finland: Southern Finland (coast), Southern Finland (inland), Suomenselkä, and Savo. The material comprised 240 felled sample trees. Some stem characteristics between this study and the reference study (regions combined) are presented in Table 28. The size of the trees in the two southernmost regions (coast and inland), which best

correspond to the geographical location of this study material, is presented in Table 29. The diameter growth and especially the stem volume were similar to or even higher in this study than those on drained mires or mineral soil sites of the reference study (Table 28). No remarkable deviations in slenderness (h/dbh) of stems between these two studies or between site types in the reference study were observed. The highest slenderness was found in the trees of the planted stands. Taper was higher in this study, especially on the more fertile stands, where the trees had grown large. Some of the largest trees had great taper. In general, this is not exceptional since very large trees (dbh > 45 cm) are usually thick-butted (see e.g. Uusvaara 1997).

Table 28. Selected stem characteristics of spruce in this study and in Verkasalo and Maltamo (2002).

	This study				**Verkasalo and Maltamo (2002)**					
					Drained mire (naturally regenerated)		OMT-MT (naturally regenerated)		OMT-MT (planted)	
	Mtkg		Rhtkg							
Stem characteristic	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*
a , years	91	34	87	25	115	23	94	25	64	10
dbh , cm	26.1	5.8	31	5.3	26.1	5.0	28	6.5	26.2	5.2
h , m	23.1	3.8	26.6	2.4	22	2.9	23.2	2.9	23.4	3.0
Slenderness	0.90	0.1	0.87	0.1	0.87	0.1	0.86	0.1	0.91	0.1
Taper , cm	3.6	1.1	4.4	1.5	3.3	1.0	3.4	1.2	3.3	1.0
v , dm^3	648	371	938	337	627	299	742	375	668	323

Table 29. Selected stem characteristics of spruce in southern Finland (1: coast, 2: inland) in Verkasalo and Maltamo (2002).

Site type	Geographical location	*dbh* , cm		*a* , years		*h* , m		*v* , dm^3	
		$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*
Drained mire	1	27.6	6.8	89	27	23.9	3.0	769	424
(naturally	2	27.1	4.9	99	34	23.0	2.7	715	324
regenerated)									
OMT-MT	1	30.6	8.3	86	24	24.4	2.6	930	501
(naturally	2	26.9	6.5	81	28	23.4	3.4	698	371
regenerated)									
OMT-MT	1	24.9	4.9	66	10	24.1	3.2	653	337
(planted)	2	24.3	4.5	57	12	22.3	2.4	528	233

Uusvaara (1997) studied the external properties of spruce and pine timber trees along the southwest and south coasts of Finland and on the Åland Islands. The study material consisted of mineral soil sites, excluding the Åland Islands, where 6% of the sample plots had been classified as peatland. The material comprised 1169 pines and 638 spruces. A clear regional variation was present in stem form of pine. The best stem form was found along the south coast and the worst on the Åland Islands, where stem form is evidently poorer because of the maritime climate. For spruce, the taper did not differ significantly between regions. The primary stem form characteristics for spruce and pine in this study and in Uusvaara (1997) are

compared in Table 30. In this study, the slenderness averaged 0.88 for spruce and 0.85 for pine. Slenderness of the trees grown on the coastal area is clearly poorer than that of the inland areas of southern Finland, even though the comparison using mean values is not fully reliable. Furthermore, the effect of the maritime climate on stem form is evidently stronger than the effect of soil type.

Table 30. Mean values of some stem characteristics in this study and in Uusvaara (1997).

	This study		**Uusvaara (1997)**					
			South coast		Southwest coast		Åland Islands	
Stem characteristic	Spruce	Pine	Spruce	Pine	Spruce	Pine	Spruce	Pine
dbh , cm	27.5	23.2	27.0	27.2	27.1	27.9	27.2	30.4
h , m	25.0	20.3	20.8	19.5	21.3	18.8	20.4	18.5
Taper , cm	4.3	4.8	4.3	5.7	4.2	6.1	4.5	6.9

Stem form has also been described by taper index, which is expressed as the ratio of d_6 to dbh. According to Verkasalo and Leban (1996), the taper index was 0.818 for Finnish spruce and 0.802 for Finnish pine. In this study, the taper indices were 0.852 and 0.805, respectively. The clearly lower taper index for spruce reported by Verkasalo and Leban can be explained by the nature of the material. The limited material (30 stems) also comprised spruces with poor stem form from a stand of *Vaccinium vitis-idaea* type, which is naturally a more typical site for pine than spruce. In general, the taper of spruce and pine in this study were consistent with the results from large investigations reported by Päivinen (1978) and Kärkkäinen (1980).

To assess the suitability of volume functions (Laasasenaho 1982) for peatland trees, the volume estimates (see Section 2.2.4, Equations 10 and 11) were compared with those based on stem curves. The comparisons are presented in Figs 82 and 83. Since the diameter at a height of 6 m (d_6) was measured at 1-cm intervals in the field, a more precise characteristic (d_{6s}, mm) was estimated by means of spline functions.

The results implied that the volume functions underestimate the real stem volume in this material. The difference was larger in spruce than in pine. In spruce, the relative difference remained constant, being independent of the dbh, whereas in pine the difference decreased with increasing dbh. The results are not fully reliable, however, due to the limited number of measurement points at the base of the sample trees. Dbh was measured for each tree, but the exact point for this diameter in a felled stem was not known afterwards. In any case, the results may indicate that the actual stem volume for trees grown on peatlands cannot be estimated accurately with general volume functions. This is due to the different stem form at the base of the stem, especially in spruces (see Fig. 84). The stem form typical of trees growing on soft, moist peat soil can be explained by the need for a tree to enlarge its base to maintain its vertical growing position. To be able to analyse the deviations in stem form by soil type, the stem curves should be compared in a large material by DBH class.

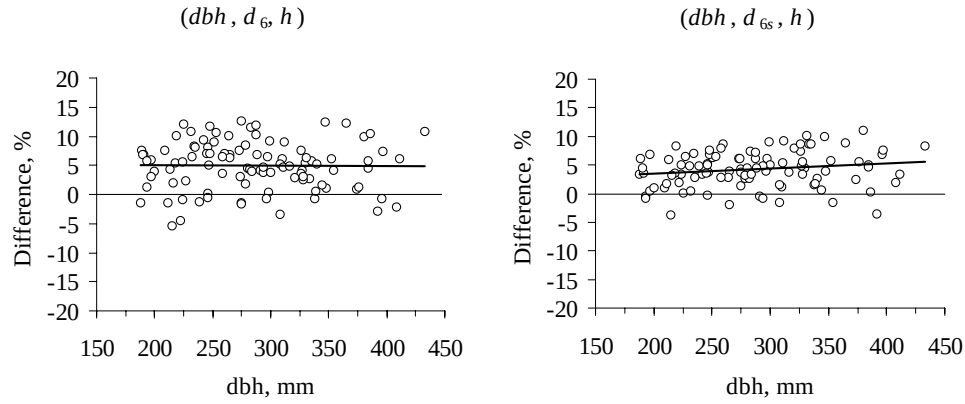


Fig. 82. Relative difference between volume estimates of spruce stems determined by spline functions and volume functions (Laasasenaho 1982) based on measured d_6 (left) and estimated d_{6s} (right). Fitted linear trend lines are presented.

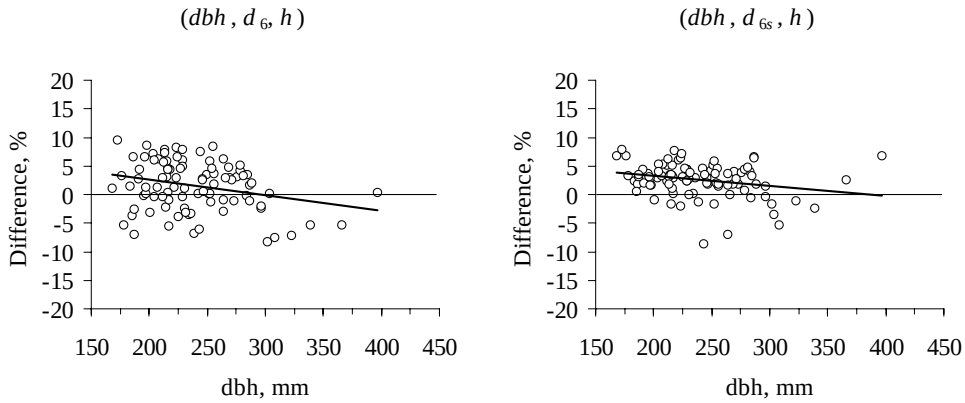


Fig. 83. Relative difference between volume estimates of pine stems determined by spline functions and volume functions (Laasasenaho 1982) based on measured d_6 (left) and estimated d_{6s} (right). Fitted linear trend lines are presented.



Fig. 84. A typical base of a spruce on a drained mire (86 years after initial ditching). Ground level has lowered due to drainage (Photo: Juha Rikala).

The stem form has been modelled on stand-level (Gustavsen and Fagerström 1983). The study material was based on the measurements of the 3rd National Forest Inventory. The breast height form factor (F_H) models for spruce (Equation 29) and pine stands (Equation 30) for southern Finland have been expressed as follows:

$$F_H = 0.48163 + 0.05424 \times (3.10 - \ln H)^{2.3} \quad (29)$$

$$F_H = 0.47945 + 0.06054 \times (3.18 - \ln H)^{1.8} - 0.01387 \times X \quad (30)$$

, where

H = mean tree height of the stand weighted by the basal areas of the trees

$X = 0$, if the site is MT or more fertile, otherwise $X = 1$

According to Gustavsen and Fagerström (1983), the mean breast height form factor was 0.492 (s = 0.0289) for spruce stands and 0.508 (s = 0.0423) for pine stands in southern Finland. The mean breast height form factors for spruce and pine stems in this study were 0.458 (s = 0.0391) and 0.466 (s = 0.0362), respectively. The values are not fully comparable since tree height affects the form factor such that the higher the trees the lower the form factor. The logarithmic transformations of the functions require mean tree height of the stand not exceeding a certain limit originating from the material. In the model for spruce (Equation 29), this limit is 22.1 m and in that for pine (Equation 30) 24.0 m. The limits were exceeded by

nine spruce stands and one pine stand, and thus, these functions are only partly applicable to this material.

The mean tree height of the pine ranged from 17.1 m to 23.3 m with an F_H of 0.477-0.469 (see Fig. 85). The values were systematically lower in Gustavsen and Fagerström (1983). This might be an indication of a slightly worse stem form of pine originating from peatlands.

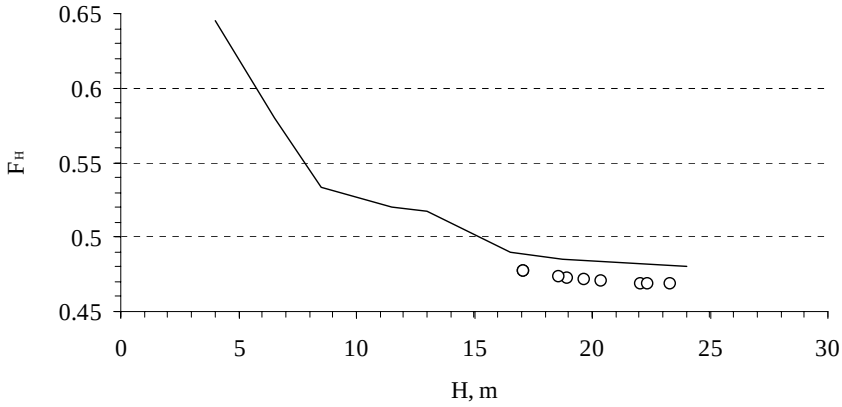


Fig. 85. Breast height form factor in pine stands as a function of mean tree height in southern Finland (Redrawn from Gustavsen and Fagerström 1983). The breast height form factors of the pine stands in this study are marked with circles.

The stem form of timber-sized spruces and pines grown on old drainage areas do not seem to differ remarkably from that of mineral soil sites. The results indicate, however, that peatland spruces are more buttressed. Although the stem form deviations between trees grown on undrained peatlands and drained peatlands have not been systematically studied, one may suggest that stem form, e.g. slenderness is clearly better in the latter case. This is supported by the general observations of poor height growth of trees growing on undrained peatlands.

In this study, branchiness of trees was described by crown height (distance from ground to base of living crown), length of living crown, and dead branch height (distance from ground to base of dead branch section). Size, number, and type of knots were measured on a clear limbed surface of the logs, thus, in principle, they represented knottiness.

Crown height was found to vary more within spruce stands than within pine stands. This can be explained by spruce tolerating little light enabling the formation of a multilayered stand and trees of different size, whereas pine is a light-demanding species. Branchiness of spruce and pine has been considered in a large study (Hakkila et al. 1972). The material comprised 1479 spruces and 1424 pines in southern Finland and 340 spruces and 864 pines in northern Finland from the tracts of the National Forest Inventory (NFI data). Since the material was large, the findings can be assumed to give a reliable estimate of the average branchiness of Finnish conifers. The results are presented in Figs 86 and 87. One should bear in mind that the curves presented do not represent growth processes of a single tree but rather the mean level of the characteristics at the time of measurements.

The spruces originating from drained peatlands (Studies 1 and 2) were clearly higher in a certain DBH class than the spruces of the NFI data (Fig. 86). The crown ratios ranged from 0.55 to 0.85, with the highest values being observed in the NFI data. By comparison, the crown ratio for spruce in southern Finland reported by Hakkila (1966, 1979) was 0.68 and 0.80, respectively. According to Uusvaara (1997), the crown ratio for spruce was 0.776 along the south coast, 0.750 along the southwest coast, and 0.645 on the Åland Islands. Perhaps most interesting was the observation that the relative length of the dead branch section (dbs_r) was much greater in peatland spruces (0.27) than in the NFI data (0.12-0.15 in timber-sized trees) (Fig. 88). The same trend was observed as the peatland spruces were compared with Uusvaara´s material, where the corresponding ratio was 0.106 along the south coast, 0.114 along the southwest coast, and 0.277 on the Åland Islands.

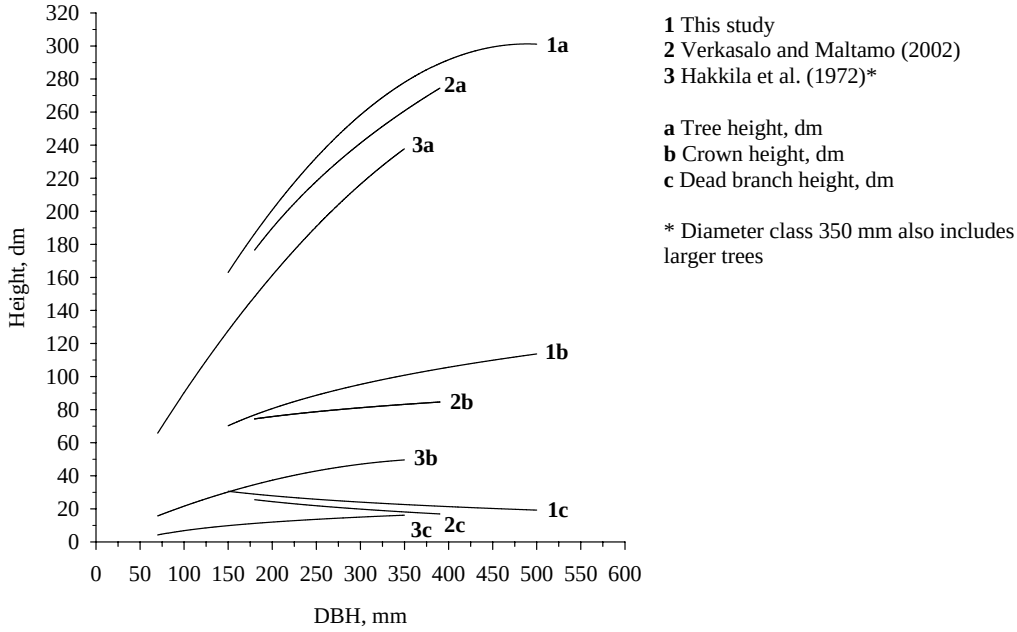


Fig. 86. Tree height, crown height, and dead branch height of spruce in southern Finland in this study, in Verkasalo and Maltamo (2002), and in Hakkila et al. (1972).

The pines of this study were also clearly higher in a certain DBH class than the pines of the NFI data (Fig. 87). The difference between the height curves was 2-3 m depending on the DBH. The most remarkable difference between the studies was found in crown ratios. The crown ratio of timber-sized pines averaged 0.36 in this study, but 0.53 in the NFI data. The crown ratios for pine reported by Hakkila (1966, 1979) were 0.44 and 0.54, respectively. According to Uusvaara (1997), the crown ratio for pine was 0.472 along the south coast, 0.461 along the southwest coast, and 0.457 on the Åland Islands. In this study, the crown ratio increased with increasing dbh, while in the NFI data no such trend was observed. High stand density could not explain the low crown ratios observed since the trees had been grown relatively sparsely. Neither were nutrient deficiencies observed. One explanation for the exceptionally low crown ratios may be dieback and canker fungus of pines (*Gremmeniella abietina*), which infected pine stands in southern Finland, especially in the late 1970s and the 1980s. Low-lying sites with cool, moist air, such as pine mires, are particularly susceptible to

these infections. The fungus has usually been associated with young pine stands (Kurkela 1981; Aalto-Kallonen and Kurkela 1985), but it might also impair the vigour of tree crowns in older stands.

The shape of the crown height curve for pine was similar to the curve reported by Hakkila et al. (1972). The dead branch height curve was, however, completely different from that of the NFI data, where the dead branch height increased linearly with increasing dbh (Fig. 87**)**. The reason for this is the dissimilarity of the materials. Hakkila´s material can be considered representative, whereas this study material had some specific characteristics. Dead branch height can only remain stable or ascend, never descend, as trees grow older. This is because new branches will not develop in this part of stem. The largest trees of this material apparently belonged to an older population and had grown sparsely, which explaines the low dead branch height. The relative length of the dead branch section was 0.41 on average, while in NFI data it ranged from 0.20 to 0.28 in timber-sized trees. According to Uusvaara (1997), the relative length of the dead branch section was 0.272 along the south coast, 0.242 along the southwest coast, and 0.317 on the Åland Islands.

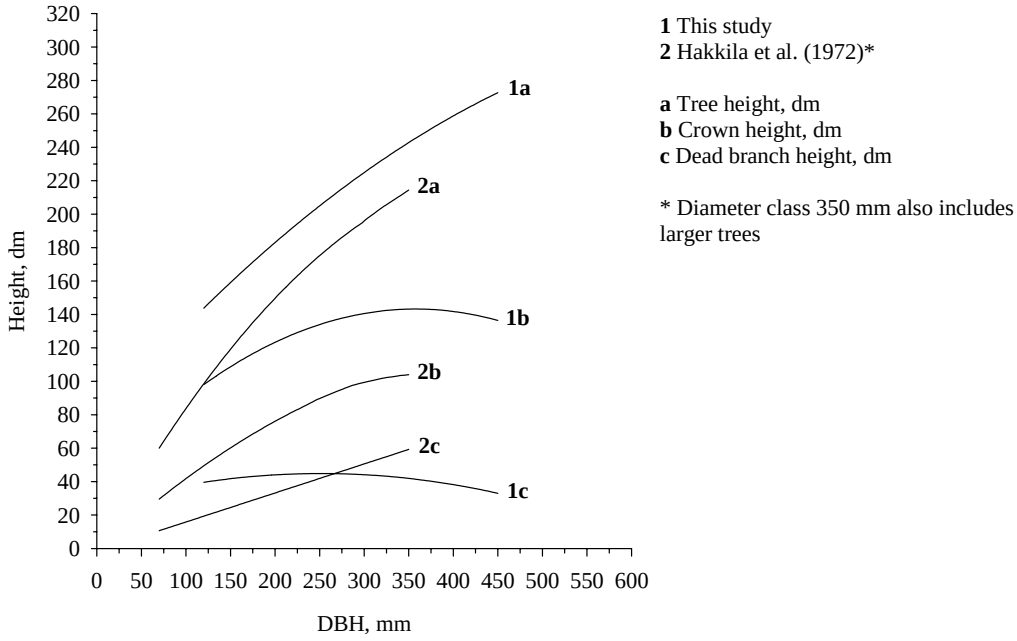


Fig. 87. Tree height, crown height and dead branch height of pine in southern Finland in this study and in Hakkila et al. (1972).

Laasasenaho (1997) has suggested that the present definition for the base of the living crown[1)] should be modified because the length of the living crown does not correlate sufficiently well with the volume growth of the tree. According to Laasasenaho, better estimates for tree growth would be obtained if the crown base was determined to the branch whorl where at least two live branches exist. This is probably true since the lowest branch whorls have no significant effect on the volume growth of a tree (Vuokila 1968). However, modification of the definition would cause problems in comparing new and old results. Furthermore, the determination of the base of the living crown in standing trees might be more laborious.

Comparisons of tree branchiness indicate that the branch structure in peatland trees deviates from that of trees growing in mineral soil sites. The relative length of the living crown is lower in peatland trees and the relative length of the dead branch section correspondingly higher. Crown height and dead branch height are affected by stand density and silvicultural treatments, which made comparison of results between studies problematic. Some uncertainty was also caused by the methods for determining dead branch height varying between studies.

In the study reported by Verkasalo and Maltamo (2002), the knot diameters were measured from branch base over bark, whereas in this study they were measured on clear-limbed stems. This probably explains most of the difference in knot diameters between these studies (see Table 31). Based on visual observations in this study, peatland spruces were assumed to be exceptionally thin-branched. This assumption is not, however, supported by the results of Verkasalo and Maltamo (2002), where the differences in knot sizes between site types were minor. Thus, it may be concluded that soil type (peatland or mineral soil) is not decisive but branch size is affected by site fertility and stand density, as previous studies have shown (e.g. Kellomäki and Tuimala 1981; Kellomäki 1984).

Table 31. Some knot characteristics of spruce in this study and in Verkasalo and Maltamo (2002).

	This study				**Verkasalo and Maltamo (2002)**					
					Drained mire (naturally regenerated)		OMT-MT (naturally regenerated)		OMT-MT (planted)	
	Mtkg		Rhtkg							
Knot characteristic	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*
Largest knot of log section, mm										
Dead knot in butt log, mm	14.5	3.4	16.3	4.9	19.0	7.4	18.9	6.0	18.6	6.8
Dead knot in other log, mm	18.6	4.4	20.5	6.0	26.2	10.0	25.3	9.2	23.5	5.6
Sound knot in other log, mm	24.8	5.6	27.1	5.4	31.8	6.1	34.2	9.1	30.0	5.5

In the NFI data (Hakkila et al. 1972), branch diameter was determined over bark at 70% of tree height. The thickest branches in spruce ranged from 24 to 36 mm in diameter. The diameters of the data did not represent the whole log section, however, since the thickest branches in spruce are found at 50% of tree height or even lower (Hakkila et al. 1972; Kärkkäinen 1972a). In the NFI data, the largest branches in pines ranged from 32 mm to 66 mm. In this study, the largest knots in saw logs ranged from 7 mm to 56 mm. The results are not fully comparable because the methods used were different.

[1)] A branch whorl where at least one live branch exists and the whorl is succeeded by no more than one branch whorl with dead branches.

Stem form defects, such as crooks and sweep, were not measured from standing trees, but sweep was measured from logs by a log scaler. Unfortunately, the method used did not reliably describe sweep (see Section 3.1.6). Different stem form defects were common both in spruce and pine. Just how severe or exceptional the stem form defects are in peatland stands compared with mineral soil stands is difficult to assess. In any case, stem form defects in pine are more crucial than in spruce because of their smaller size. Sweep in saw logs can be minimized by modern curve sawing techniques, which does not, however, eliminate compression wood in these logs. In practice, trees grown on peatlands have to be cut into short logs because of crooks and sweep, especially at the base of stems. The suitability of peatland trees for the sawmill industry would be increased if the stems could also be cut into lengths of less than 3 m. On the other hand, very short logs may be problematic from the point of view of end-use.

Taper was smaller in debarked logs than in unbarked logs since the thickness of bark decreases towards the top of a tree. This is particularly true of pine butt logs, in which the bark is much thicker at the butt end, but also holds for spruce logs (Hakkila 1967a; Jonsson and Nylinder 1990; Melkas 1999).

Saw timber proportion of the stems was considered by comparing the log section meeting the quality requirements for saw logs with the theoretical maximum (limited only by the minimum top diameter). The comparisons showed that for spruce the quality-based saw timber proportion was slightly smaller than the theoretical maximum, whereas for pine the defects – crooks and branchiness (knottiness) – clearly decreased the saw timber proportion. According to Verkasalo and Maltamo (2002), the saw timber proportion of spruce stands did not differ by site type. The comparisons of saw timber proportions between studies are not reliable since results are highly dependent on the quality requirements of saw logs, and furthermore, on the number of alternative log lengths.

Ovalness of stems was studied from the sample discs. Ovalness was highest in the base of the trees, being almost constant above 20% of relative tree height in both tree species. The findings differed from those presented by Tiihonen (1961), who suggested that the ovalness of pine increases again at the top of the tree. Ovalness has been found to correlate with eccentricity of pith, and consequently, with incidence of compression wood (Timell 1986). In this study, the high ovalness of the spruces at stump height can mostly be explained by the effect of excessive root collars, although some compression wood was also observed.

According to Kärkkäinen (2003), slight ovalness should not be considered to be a defect since trees are very seldom perfectly round. Kärkkäinen (1975) reported that the ovalness of pine logs in northern Finland, determined as the difference between the largest and smallest diameters in relation to their mean, was about 5%. Geographical location has been suggested to affect the ovalness such that trees growing in northern Finland are more oval than those growing in southern Finland (Kärkkäinen 2003). Kärkkäinen (2003) concluded that ovalness is common in mires because of leaning trees. In this study, the ovalness of spruce logs, determined as in Kärkkäinen (1975), averaged 1.9%. In pine logs, the corresponding value was 2.4%. Thus, according to these results, ovalness of saw logs originating from peatlands does not seem to be exceptionally great.

Root rot caused by *Heterobasidion parviporum* is the most crucial defect in old spruce stands in southern Finland resulting in considerable economic losses, while root rot in pine (*Heterobasidion annosum*) is less significant. Although the spruce stands of this study were old, root rot was unusual. In pine stands, root rot was not observed at all. It has been

suggested that the conditions on peat soils – acidity, high moisture, and oxygen deficiency of peat – prevent root rot from spreading. This assumption is supported by the findings of Kangas (1952), Tamminen (1985), and Redfern (1998). Large butt swellings are usually supposed to indicate rot in a tree since rotten trees tend to strengthen the base of stems. While this phenomenon was observed in this material, excessive butt swellings in peatland spruces were due to soil characteristics rather than tree rot.

4.2 Wood Properties

Slow growth is perhaps the feature most often assumed to characterize the wood properties of peatland trees. There is, however, no clear definition of slow growth, with it varying between tree species and the requirements of the end-use objects. Nordic Timber (Pohjoismainen sahatavara 1994) defines slow growth as the mean ring width in a sawn piece of softwood being less than 2.5 mm, which by experience has been found to correlate with high quality.

In this study, the mean ring width was 2.36 mm for spruce and 1.58 mm for pine (sample discs, volume-weighted). The mean ring width of spruce and pine was compared with that of other Finnish studies (Table 32). According to Wilhelmsson et al. (2002), the mean ring width for Swedish spruce and pine was 2.33 mm and 1.64 mm, respectively.

Table 32. Mean ring width of spruce and pine. A comparison between studies.

Study	**Material**	**Ring width, mm**	
		Spruce $\bar{x}$	Pine $\bar{x}$
This study	Sample discs (volume-weighted)		
	All	2.36	1.58
	Herb-rich type	2.49	
	Vaccinium myrtillus type	2.18	
	Vaccinium vitis-idaea type		1.69
	Dwarf-shrub type		1.39
Verkasalo and Maltamo (2002)	Drained mire		
	Butt logs	1.83	
	Other logs	2.12	
	Small-sized logs	2.10	
	Mineral soil, OMT-MT (naturally regenerated)		
	Butt logs	2.27	
	Mineral soil, OMT-MT (planted)		
	Butt logs	3.05	
Hakkila and Rikkonen (1970)	Discs from pulpwood logs	2.14	
Hakkila (1968)	Increment cores from pulpwood	1.7	1.4
Hakkila (1966)	Increment cores (trees of all sizes)	1.59	1.41

The comparison results indicate that the trees of this study did not represent an exceptionally slow or fast average growth rate. The mean values are not, however, very reliable for comparisons since variation in ring width is usually large. For example, the mean ring width of spruce discs ranged from 0.65 mm to 4.18 mm in this material. The corresponding range was 0.34-2.93 mm in pine discs. The variation was even greater between individual rings.

Previous studies have shown that ring width decreases from pith to bark, excluding the juvenile phase (e.g. Mikola 1950; Eklund 1967). In principle, the longer the distance from pith to a new ring, the greater the volume produced. Tree size is restricted by genetic and environmental factors, and the ring width cannot remain the same as the tree grows larger. On the other hand, a decreasing ring width in the radial direction does not necessarily indicate a decline in volume growth.

The distance from the tree to the nearest ditch, tree size, and age have been suggested to affect the magnitude of increase in growth after drainage (e.g. Heikurainen and Kuusela 1962; Seppälä 1969). An analysis of the factors influencing the increase in growth after drainage was not carried out in this study.

The latewood proportion was 21.1% for spruce and 20.7% for pine determined from the disc volume. Previous studies have shown that in spruce the absolute amount of latewood is independent of ring width, i.e. latewood proportion correlates negatively with annual ring width (Mikola 1950; Worral 1970). The same phenomenon was found in this study. In pine, the variation pattern of latewood proportion in the longitudinal direction of the stem differed from spruce, as shown in Fig. 43. Some difference can also be seen when the latewood proportion of ring width is compared between wood produced before drainage and after drainage (Table 11). Site type seems to be decisive. In sample plots of *Vaccinium vitis-idaea* type (Ptkg), the latewood proportion was higher in rings grown after drainage, while in sample plots of Dwarf-shrub type (Vatkg) this phenomenon did not hold true. Thus, the latewood proportion of pine stems grown on Dwarf-shrub type did not follow the rule “the broader the ring, the higher the latewood proportion” suggested by Mikola (1950). The reason for this can be understood when a relative increase in growth due to drainage is considered. The relative growth response to drainage was clearly stronger in trees grown on Dwarf-shrub type than on *Vaccinium vitis-idaea* type (see Table 8). Since the absolute width of latewood in rings grown after drainage did not increase in proportion to ring width, the latewood proportion decreased in trees grown on Dwarf-shrub type. On the other hand, the increase in latewood proportion after drainage on *Vaccinium vitis-idaea* type supports the assumption that latewood proportion is higher in broader rings (Mikola 1950).

In earlier studies, the latewood proportion has mainly been determined as a share of the ring width (Table 33). In Jalava´s material (1933), the latewood proportion for pines grown on mires was lower than that of pines grown on mineral soil sites. This might be attributed to a lower growth rate of the pines grown on mires. Considering the elements of uncertainty in the determination of the latewood proportion and the variety of methods used, no further conclusions should be drawn about the differences between results.

Table 33. Mean latewood proportion of spruce and pine. A comparison between studies.

Study	Method	Latewood proportion, %	
		Spruce $\overline{x}$	Pine $\overline{x}$
This study	Proportion of disc volume	21.1	20.7
Wilhelmsson et al. (2002)	Proportion of ring area (volume) Reflectance method	21.8	23.9
Hakkila (1966)	Proportion of ring width	17.3	24.5
Mikola (1950)	Proportion of ring width		21-44
Jalava (1945)	Proportion of ring width	13.9	28-29
Siimes (1938)	Proportion of ring width (sapwood/heartwood)		22.3/19.9
Jalava (1933)	Proportion of ring width (sapwood/heartwood)		29.0-32.8/26.0-26.7

Heartwood percentage was determined as a proportion of diameter and cross-sectional area at various heights in a tree, and as a proportion of volume in logs and stems. The results concerning the relative tree height where heartwood proportion reaches its maximum were in accordance with previous studies (Lappi-Seppälä 1952; Nylinder 1956, 1959, 1961a, 1961b; Tamminen 1962, 1964; Ericson 1966; Hakkila 1967b; Björklund and Walfridsson 1993).

In spruce discs, the heartwood proportion determined from cross-sectional area ranged from 0 to 73.9%. In pine, the corresponding range was 0-59.2%. In the Swedish material, the variation in heartwood proportions was even larger, ranging from 0 to 88% for spruce and from 0 to 63% for pine (Wilhelmsson et al. 2002). In this study, the average heartwood proportion of stem volume was 38.8% (s = 8.4) for spruce and 27.7% (s = 7.6) for pine. In earlier studies, the heartwood proportion has mainly been determined as a proportion of volume in saw logs or saw log sections (Table 34). The results of a Swedish study (Björklund and Walfridsson 1993) are also presented in this table.

The comparisons provided no clear evidence that the heartwood proportions of peatland trees are higher than those of trees grown on mineral soil sites, even though the mean heartwood proportion of spruce butt logs was high. The factors affecting heartwood formation should be considered separately. For instance, advanced tree age, slow growth rate, and suppressed position have been found to correlate with high heartwood proportion (Lappi-Seppälä 1952; Tamminen 1962, 1964; Sellin 1994). In this study, however, tree age and mean ring width at stump height proved to be poor predictors of heartwood proportion. In spruce, these variables accounted only for 6% and in pine 11% of variance in heartwood proportion. On the other hand, the results indicate that slow growth should not be regarded as a characteristic of trees grown on drained peatlands since the growth rate is usually low only before drainage. How this slow early growth succeeded by a rapid increase in growth affects heartwood formation in trees was not clarified in this study.

Table 34. Mean heartwood proportion of volume in spruce and pine. A comparison between studies.

Study	Material	Heartwood proportion, %			
		Spruce		Pine	
		$\bar{x}$	s	$\bar{x}$	s
This study	Stems	38.8	8.4	27.7	7.6
	Butt logs	52.4	12.6	34.0	9.2
	Other logs	36.4	11.1	30.3	8.3
	Whole log section	40.8	13.6	31.9	8.9
Verkasalo and Maltamo (2002)	Drained mires				
	Butt logs	42.0	10.8		
	Upper log section	33.3	11.7		
Björklund and Walfridsson (1993)	Butt log			34.0	11.1
	Second log			31.4	11.1
	Third log			21.2	10.9
Kellomäki (1981)	Butt logs			35.6	12.9
	Other logs			28.8	12.6
	Whole log section			32.5	13.2
Hakkila and Rikkonen (1970)	Pulpwood logs	33.5			
Bruun (1967)	Saw logs	19.7-51.6			

Compression wood was observed in the stems much less than expected. Apparently this was at least partly due to the stands being intensively managed. It can safely be assumed that unmanaged or young stands contain relatively more compression wood when the proportion of compression wood is estimated from stand volume. The incidence of compression wood has been found to correlate with stem form defects, such as crooks and sweep (e.g. Tikka 1935; Uusvaara 1974). The more severe the stem form defects in trees, the more probable the incidence of compression wood. One may conclude that the problem of compression wood will increase in future since more roundwood will be harvested from planted stands, where the tree quality – especially at the base of the stem – is poorer than in naturally regenerated stands (see Uusvaara 1974). On the other hand, the proportion of compression wood in saw logs can be effectively restricted by stringent requirements for straightness. There are few studies concerning the incidence of compression wood between stands or site types. According to Verkasalo and Maltamo (2002), the compression wood percentage in drained mires was 10.5 (s = 7.0) for spruce butt logs and 4.8 (s = 5.0) for other logs. The percentages were slightly higher on drained peatlands than in mineral soil sites. Taken together, the findings indicate that compression wood is not a severe problem in managed, mature spruce stands.

Wood density is an important wood property, mainly because it correlates with ring width and latewood proportion, and consequently, indicates wood strenghtness. Previous studies have mainly examined wood density in mineral soil sites. In some studies, reference material has also been collected from peatlands (e.g. Hakkila 1966, 1979; Boholm 1999; Verkasalo and Maltamo 2002). The longitudinal variation patterns of wood density in this study are compared with those presented by Hakkila (1979) in Fig. 88. Hakkila´s results (1979) are

based on the material from the 5th National Forest Inventory. The curves given by Hakkila (1979) concerned trees from 40 to 80 years of age, and thus, the trees were on average younger than the trees in this study. The results of this study showed that wood grown before drainage was usually 10 to 30% denser than that grown after drainage. Thus, it is somewhat confusing that the basic density is lower in the base of the stems in the peatland spruces than in Hakkila´s study. This might be explained by the low proportion of wood produced before drainage in the peatland spruces, and by the high growth rate after drainage.

The basic density of pine was slightly higher in this study than in Hakkila (1979). The density of pine did not follow the declining trend towards the top of the tree that Hakkila presented. The latewood proportion of pine increased slightly in the uppermost quarter of stem, which might partly explain the trend in this study (Fig. 88). The most probable explanation is, however, the effect of knotwood, which may have been minimized in Hakkila´s study. The same might also be true of spruce. The variation patterns in the radial direction of the stem are in accordance with earlier studies concerning both spruce (e.g. Tamminen 1964; Hakkila 1966) and pine (e.g. Tamminen 1962; Hakkila 1966; Uusvaara 1974). The results of basic density are compared to previous studies in Table 35.

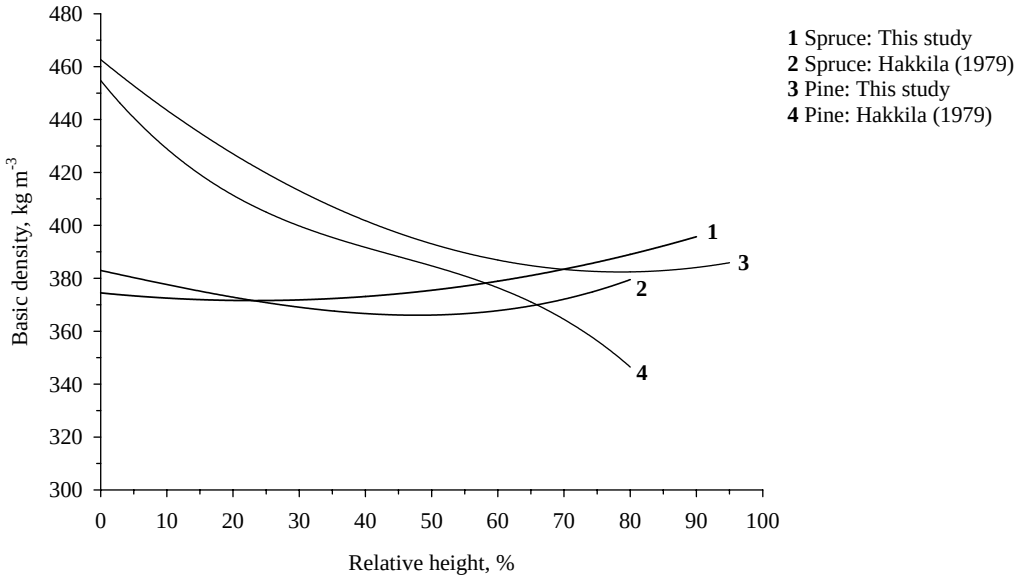


Fig. 88. Variation patterns of wood density in the longitudinal direction of the stem in this study and in Hakkila (1979).

Table 35. Basic density of spruce and pine. A comparison between studies.

Mean basic density, kg m^{-3} (standard deviation in parentheses)									
		Spruce				Pine			
*	Site type	Stem	Butt log	Other log	All logs	Stem	Butt log	Other log	All logs
I	Rhtkg-Mtkg	**375.0** (28.5)	**374.3** (31.5)	**370.7** (28.9)	**371.9** (29.8)				
	Ptkg-Vatkg					**418.5** (25.8)	**446.5** (30.0)	**406.9** (27.2)	**423.3** (34.4)
II	All sites	**383** [1] (37)				**398** [1] (40.1)			
III	Drained mire, (naturally regenerated)		**377.8** (33.8)	**363.6** [2] (69.6)					
	OMT-MT, (naturally regenerated)		**383.0** (30.7)	**375.1** [2] (57.3)					
	OMT-MT, planted		**365.8** (29.1)	**350.7** [2] (76.4)					
IV	OMT	**370.5** (27.0)							
	MT	**384.7** (27.0)							
	Drained mire	**380.4** (32.5)							
V	Not reported						**448**	**409** (2nd log) **394** (3rd log)	**425**
VI	Not reported				**373.4** (28.5)				
VII	Not reported				**380.7** (31.6)				
VIII	OMaT-VT (including mires)	**379.7** [3] (32.3)							
	OMaT-VT	**393** [4]							
	Mires	**414** [4]							
	OMT-CT (including mires)					**403.4** [3] (28.4)			
	OMT-CT					**416** [4]			
	Mires					**414** [4]			
IX	OMT	**344** [5] (23)				**378** [5] (21)			
X	VT					**437** [6]			
XI	Not reported				**381**				
XII	OMT-VT	**386.8** (30.0)				**408.6** (32.8)			
	OMT-MT				**370** (23)				**420** (30)
	VT				**382** (22)				**433** (37)
	Undrained mire				**385** (34)				**393** (18)

[1] Mean of sample discs

[2] Log section above butt log (5 m) to a diameter of 16 cm (stem-to-stem variation presented in parentheses)

[3] Determined from standing trees

[4] Trees aged more than 101 years

[5] Trees aged 44 years (basic density determined at dbh)

[6] Dominant trees aged 55-118 years (basic density determined at dbh)

* Studies:

I This study
II Verkasalo and Maltamo (2002)
III Wilhelmsson et al. (2002)
IV Boholm (1999)
V Björklund and Walfridsson (1993)
VI Kärkkäinen and Dumell (1983)
VII Saranpää (1983)
VIII Hakkila (1979)
IX Velling (1976)
X Velling (1974)
XI Hakkila and Rikkonen (1970)
XII Hakkila (1966)

The comparison shows that the mean basic density of spruces and pines grown on drained peatlands is similar to that of mineral soil sites, especially when the relatively high variation within studies is taken into consideration. Undrained mires are an exception to this, yielding somewhat higher basic densities (Hakkila 1979). In young trees of fertile site types, by contrast, the basic density is low (see Velling 1976). Growth rate (fertility of the site) seems to explain most of the basic density variation.

4.3 Yield and Quality of Sawn Timber

The yield of sawn timber in the sawing experiments was 0.53 for spruce and 0.52 for pine. One should bear in mind that the yield of sawn timber is affected by several factors, such as diameter of logs, form of logs, sawing practice, blade settings, and sawing device used. Yield of sawn timber should not be compared without taking these factors into consideration. The high yield of sawn timber can be explained by the maximal blade settings used. On the other hand, "tight" blade settings increased the share of wane sawn timber, which also must be noted in comparisons. Sawmills integrated with the pulpwood industry have the possibility of regulating the yield of sawn timber to maximize the overall profitability of production. Thus, comparison of the results to practice is not relevant if the circumstances are dissimilar. According to Eilavaara (1994), the yield of sawn timber in the sawmill industry was 0.44 on average (corresponds to the log use ratio of 2.27). In the sawing of small-sized logs, log use ratio is clearly higher. Bark percentage, which was determined as the difference in volumes between unbarked and barked logs, was 9.2 in both tree species. These percentages are consistent with those reported for spruce and pine by Heiskanen and Rikkonen (1976).

To evaluate how the log material of this study differed from the average in the sawmill industry, the material was compared with that of a large sawmill in southern Finland (Nordberg 2000) (Table 36). In 2000, the sawmill had two sawing lines: a main line and a line for small-sized logs. Only logs exceeding an 18-cm top diameter over bark (o.b.) were processed in the main line. In the line for small-sized logs, the top diameter ranged from 10 to 21 cm (o.b.).

Table 36. Mean log volumes (o.b.) in this study and in a large sawmill in southern Finland (data from the year 2000).

	Mean log volume over bark, dm^3			
	Spruce		Pine	
	This study	Sawmill	This study	Sawmill
All logs	249		154	
Main line (top dimeter > 18 cm)	280	316	190	284
Line for small-sized logs (10-21 cm)		136		124

As Table 36 shows, the mean log volume in this study was lower than in the sawmill, both for spruce and pine. For spruce, the difference between mean log volumes was rather small. In contrast to spruce, the mean volume of pine logs was clearly lower than that in the sawmill. The difference can be explained by the unfavourable diameter distribution of logs as well as by the lower mean length of logs. The mean log volume particularly on the poor sites (Dwarf-

shrub type) in this study was low. The comparison indicates that mature spruce stands growing on drained peatlands are potential raw material for the sawmill industry as far as mean log volume is concerned. The size of pine logs, however, may be near the minimum for profitable sawing.

According to Hakala (1992), financial outcome is strongly dependent on the top diameter of logs (Fig. 89). Similar results concerning both spruce and pine have been reported by Heiskanen and Asikainen (1969) and Usenius et al. (1987). However, the dependence between top diameter of logs and profitability of sawing is fading since the sawmills are increasingly switching over from bulk sawing to custom-oriented products.

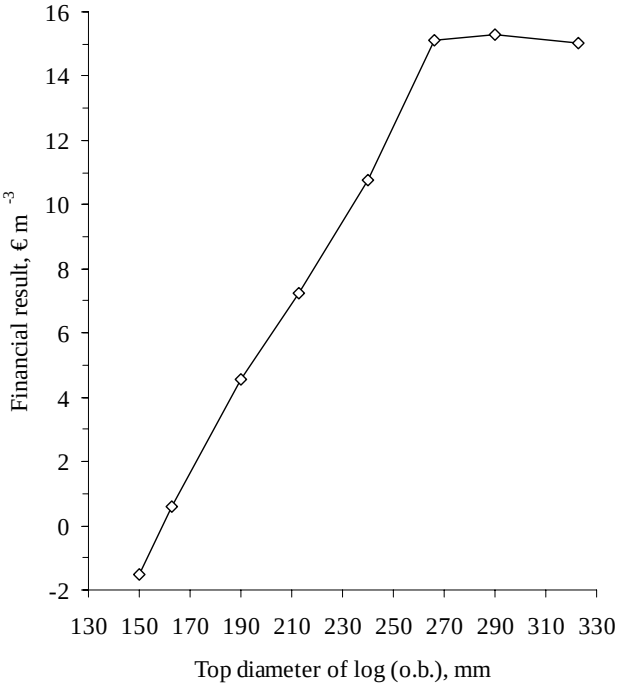


Fig. 89. Financial result of sawing per log diameter (o.b.) (redrawn from Hakala 1992).

The quality of timber is known to vary between geographical regions; for instance, along the coastal areas of Finland, the quality is lower than inland. Hakala (1992) suggested that the low quality of sawn timber in his material was mostly the result of the unfavourable location of the wood procurement area of the sawmill (coastal area of Etelä-Pohjanmaa). With regard to large industrial sawmills, the origin of roundwood may be different from the location of the sawmill since in addition to domestic roundwood, these sawmills also use exported roundwood. The quality of spruce sawn timber in this study and in a large sawmill in southern Finland (Silen 1999) is compared in Figs 90 and 91.

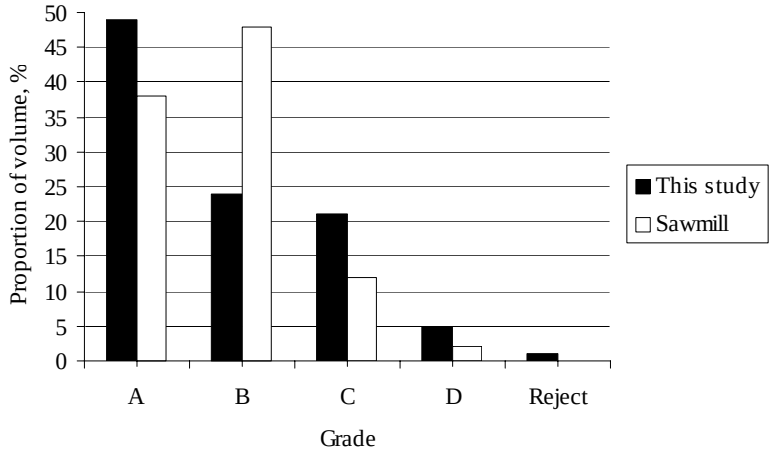


Fig. 90. Quality distribution of centre yield of spruce (Nordic Timber, kiln-dried) in this study and in a large sawmill in southern Finland.

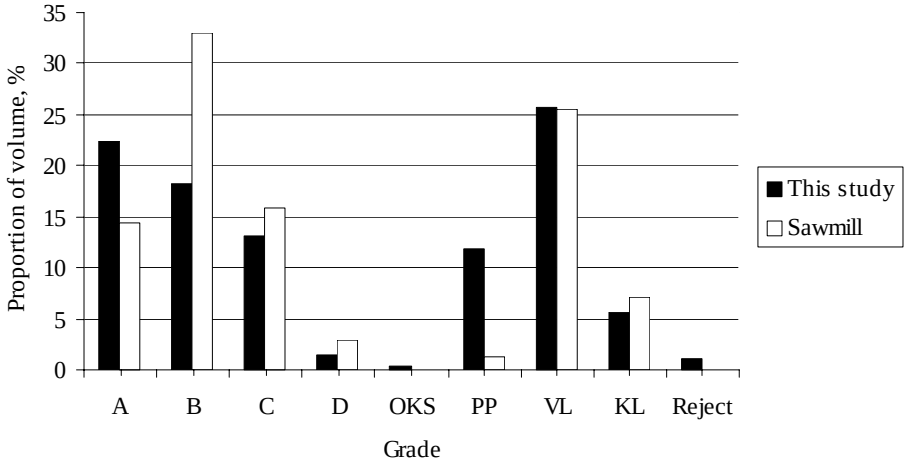


Fig. 91. Quality distribution of side yield of spruce (Nordic Timber, kiln-dried) in this study and in a large sawmill in southern Finland.

The comparison reveals some differences in quality distributions. Most significant is the high proportion of grade A centre yield in this study (Fig. 90). A similar trend is observed for side yield. The difference would be even more apparent if the proportions of wane schaalboards graded as *knot-free three sides* (OKS) and *halvrena side yield* (PP) were added to grade A. However, because the material of this study was relatively small, the results are merely suggestive. Nonetheless, the high quality potential of spruce stands grown on drained peatlands is highlighted.

Based on the results of the sawing experiments, the spruce sawn timber originating from drained peatlands can be utilized in the same end-use areas as spruce sawn timber in general (see Table 37). The main end-use for Finnish spruce is construction. Peatland spruce might be expected to be especially suited for this purpose since the quality distributions of the stress-graded sawn timber turned out to be very good. Although no experiments concerning rotary peeling of logs were carried out, peatland spruces might also be suitable for the manufacturing of laminated veneer lumber (LVL) and plywood due to their relatively large size. However, some characteristics of the oldest peatland spruces – thick buttiness, dead knottiness, and high proportion of heartwood – may lower their usability in the plywood industry. Thick buttiness reduces the yield of veneer and also causes slope of grain. Dry knots tend to loose during the manufacturing process, causing holes which then have to be patched. Dry heartwood causes ripping of veneer.

The quality of pine sawn timber was somewhat lower than that of spruce, but probably near the average quality of mineral soil sites. Since the quality of sawn timber decreased dramatically from the base towards the top of the tree, its suitability for various end-uses has to be considered by location on the log. According to the observations of this study, the quality of sawn timber from butt logs of peatland pines is high. On the other hand, the knotless base of pine stems is often short, 3-4 m, and thus, the yield of high quality is quite low. In principle, sawn timber from pine butt logs may be used for various purposes, from construction to visible joinery. The main uses for middle logs are construction, end-uses to be painted or covered, and formwork. The knots in middle logs were relatively small-sized and the quality of stress-graded sawn timber was moderate. The proportion of sound knotty sawn timber, knotty pine, was found to be very low in peatland trees. The main reason for this is the exceptionally short living crown of the trees. The quality of sawn timber from the few top logs in this study was poor. The results concerning sawing value of logs supported the practice: quality grading of pine stems is reasonable, while in spruce no significant benefit is obtained by log classification based on the location of log.

Drying deformations were slight in both tree species in export drying (moisture content of 20%). Thus, the wide variations in growth rate inside trees were not manifested in deformations. However, the drying deformations increased dramatically in joinery drying, i.e. around a moisture content of 10%. Whether these were merely chance observations could not be evaluated since no reference material was collected. One may conclude, however, that the drying deformations and fissures are not as severe in homogeneous, evenly grown wood material. Specific experiments are needed in this area before making any further conclusions.

It would have been interesting to investigate how the transition zone from narrow-ringed wood to wide-ringed wood affected the properties and quality of sawn timber. However, the sawing of logs according to these zones would have been very laborious if not impossible. In some studies, small specimens have been taken from these zones (see Ollinmaa 1960, 1981).

Table 37. Examples of end-use areas for the different grades of sawn timber (Pohjoismainen sahatavara 1994).

END-USE AREAS	A				B	C	D
	A1	A2	A3	A4			
Visible joinery	■	■	■	■	■		
Sawn timber for construction			■	■	■	■	
Formwork, underflooring							■
Mouldings	■						
Interior cladding		■	■	■			
Linings, handrails			■	■	■		
Slating battens and strips					■	■	
Europallets					■		
Disposable pallets						■	■
Packaging material						■	■
Flooring boards	■	■	■	■	■		
Covered floorings					■	■	■
T & G Schaalboards						■	
Fencing					■		
Covered internal cladding					■	■	
Wind and snow fences					■		
Schaalboards						■	
Boat building, decking	■	■	■	■			
Handicrafts	■						
Sauna material	■	■	■	■	■		
Knotty sawn timber			■	■	■	■	
Window and door frames			■	■	■		
Furniture and glulam panels				■	■	■	

The size, number, and condition of knots are the most critical features determining the quality of sawn timber (Pohjoismainen sahatavara 1994). Thus, the most effective means to affect the quality of sawn timber is to change the size and number of branches in living trees. If the self-pruning rate of trees has been slow, the quality of the stems can be improved by manual pruning. In Finland, only young pine stands are pruned to improve their quality. The pruning of spruce stems has thus far not been recommended because of their susceptibility to rot. However, according to Tuimala et al. (2002), the quality of spruce could also be improved by pruning if carried out carefully. The stems are usually pruned to a maximum height of 6 m, which corresponds to the butt log section. A hypothetical example of the effect of pruning on the inner knot structure in a stem is illustrated in Fig. 92.

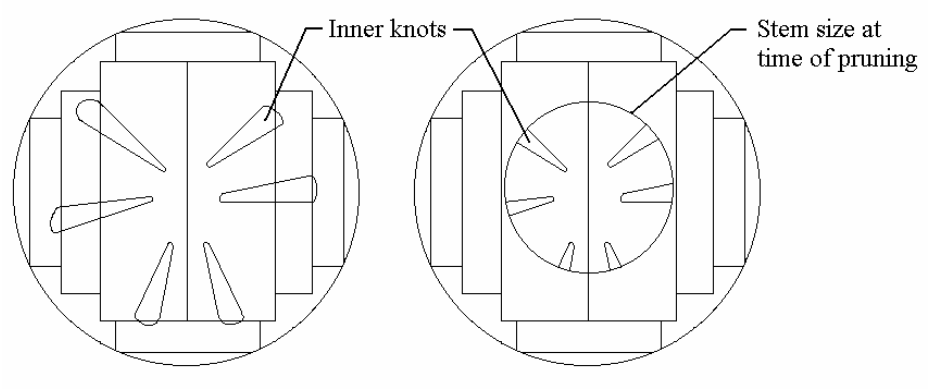


Fig. 92. An example of the inner knot structure in an unpruned (left) and pruned (right) stem. The sawn piece divisions are based on hypothetical blade settings of 19-150-19 (mm) in the block sawing phase and 19-25-50-50-25-19 (mm) in the re-sawing phase. The sawing pattern corresponds to a minimum stem diameter of 220 mm under bark.

The value of sawn pieces of knot-free side yield may be fourfold the value of sawn pieces including knots (see Appendix 4). Thus, the value of stems as sawn timber is highly dependent on the volume of the knot-free cylinder. The best result in young pine stands would be obtained if the trees of the best external quality were pruned after drainage, before the strongest increase in radial growth. Further recommendations for pruning of peatland trees cannot be given in this context, other than emphasizing the need for an economic analysis.

4.4 Stem Characteristics as Predictors of Quality of Sawn Timber

Quality of sawn timber is usually evaluated by quality distributions. Information on the proportions of various grades may be adequate to describe the general quality of roundwood as sawn timber. More precise information on the value of sawn timber may, however, be needed for comparisons. To compare the value of stands, stems, and single logs as sawn timber, a special characteristic, the quality factor of roundwood, was determined. The quality factor represented the mean value of sawn timber of the log section when value ratios of different grades and yield of sawn timber were taken into account. The value of by-products was ignored in this context. The results obtained may be utilized in future as a reference material if the same method is used. Only the stem section meeting the requirements of saw logs was considered. To determine total values of the trees or stands, the proportions of timber assortments must be taken into consideration.

The quality factors of roundwood were used to determine the tree characteristics best predicting the quality of sawn timber in butt logs and in the whole log section. In spruce, the best predictors were squared dbh, tree height, and diameter of the largest dead knot in the butt log. The best predictors of quality of pine butt logs were tree height and the ratio of dead branch height to relative length of dead branch section. Optimal predictors for the quality of the whole log section of pine were dead branch height and mean growth rate at stump height. The results were not surprising since dbh, height of the lowest dead branch, and height of the living crown have been found the best predictors of quality of pine sawn timber (e.g.

Heiskanen 1954b; Kärkkäinen 1980; Uusitalo 1995). Early growth rate was not a good predictor of quality, although it unquestionably affects the size of knots. This was also concluded in Uusitalo´s study (1995).

Probably most interesting was the question of whether trees containing wood produced before and after drainage were of poorer internal quality (quality of sawn timber) than trees containing only wood grown after drainage. A clear answer to this was not given by the method applied. However, the proportion of wood grown before drainage was on average so low in this material that it likely had little effect on quality. Presumably, the quality of the trees representing the second generation after drainage is better than that of the first generation since the wood produced is more homogeneous.

The models constructed accounted for only 23.5-33.4% of the variance in quality factors. One reason for this may be that the quality factors were based on kiln-dried sawn timber. Although knots were the main defects determining the quality of sawn timber, drying deformations and fissures caused variation of quality factors that could not be explained by the chosen external tree characteristics. The low degrees of determination were not very surprising since the prediction of the quality of sawn timber has also been found to be doubtful in previous studies (e.g. Kärkkäinen 1980; Uusitalo 1995). Some of the predictors included in models are not easily measurable, and thus, may be inappropriate for practical purposes.

4.5 Reliability and Generalizability of Results

The study material was based on measurements, gradings, and classifications in the field, sawmill, and laboratory. Measurement errors were possible in all of these phases. Probably the most problematic was determination of the correct base for measurements of dbh and tree height in spruces because the origin of the tree might be clearly higher than ground level (see Fig. 84). Thus, there was a risk of measuring the dbh of spruces at a point lower than 1.3 m from the actual base, resulting in excessively high stem volumes. The magnitude of the error can be assessed by comparing the stem volume estimates, where the measurement of dbh is based 1) on ground level and 2) on the height of the uppermost root collar (see Laasasenaho 1982, 1983). The first case yielded a 2.5-7% higher stem volume than the second case (Fig. 93).

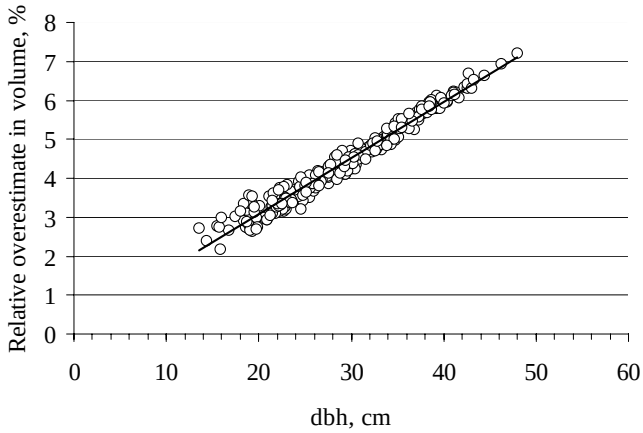


Fig. 93. Relative overestimate for the spruce stem volume when the dbh is measured from ground level but calculated by a volume function based on the height of the uppermost root collar. A fitted trend line is presented.

The correspondence between tree height measurements obtained by the Vertex height meter and by measuring tape is presented in Fig. 94. The results are not fully comparable since the exact height of the tree cut was not known when the tree height was measured. By taking into account this uncertainty, the accuracy of tree height measurements was approximately ± 2% of the actual tree height measured by an experienced measurer. This result is consistent with Suunto height meter measurements (see Tapion taskukirja 2002). It should be noted that the errors in dbh and height measurements are transferred to most stem characteristics.

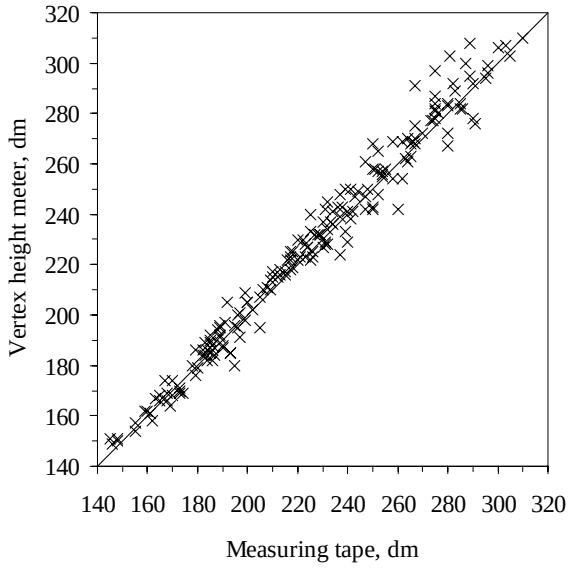


Fig. 94. Correspondence between tree height measurements obtained by a Vertex height meter and those by measuring tape.

The saw logs were measured for length, top diameter, volume, taper, and sweep with an optical log scaler (*Elmes*) both before and after debarking. The log scaler was calibrated at set intervals to ensure reliability of measurements. All characteristics other than sweep could be controlled for by manual measurements carried out during fieldwork. Significant differences were not observed. Log length in particular was measured accurately by the log scaler. The results were consistent with those presented in Marjomaa (1995), where the accuracy of the three most used optical measuring devices, including Elmes, were compared. The accuracy of sweep measurements was found to be poor, deviating from –18 mm to +25 mm from the actual value in spruce logs and from –26 mm to +36 mm in pine logs. The error was concluded to come from the shaking of the conveyor. The problem with log scalers such as Elmes is not so much the accuracy of the sweep measurement as the method by which it is determined. The measurement based on the maximum deviation from sideline drawn via butt and top ends of a log seldom corresponds to the sweep measurement based on the centre line of a log, instead overestimating the sweep. This is a particular problem in peatland saw logs, where various form defects are common.

Annual ring width, latewood proportion, heartwood proportion, basic density, and proportion of compression wood were measured in the laboratory. Methods based on image analysis, such as *WinDendro*, were not used; wood properties were measured by traditional equipment. Ring width was measured with a manual ring width measuring device. Ring width can usually be measured very accurately, but the point where earlywood transforms into latewood has to be estimated, and thus, the demarcation is highly dependent on the measurer. For this reason, the results concerning latewood proportion are merely suggestive. The same is also true of the estimates for compression wood as this border may also be obscure. Heartwood formation can quite easily be detected in green discs, and therefore, these results are usually reliable. Various dyeing methods can also be used to separate sapwood and heartwood (see e.g. Kärkkäinen 1972b). Heartwood proportion for a stem was calculated with spline functions. The results contain some uncertainty because of the limited number of samples at the base of stems. Likewise the wood density estimates for stems include uncertainty. Wood density experiments comprised weighing of sample pieces as green and dried and determination of the volume of green sample pieces by immersing them in water. In principle, the method used gives accurate results if carried out carefully. The incidence of knot wood might increase the basic density estimates in the tree crown area.

Each sawn piece was graded separately. Furthermore, knot size and other features were measured. Comprehensive measurements made it possible to strictly follow the grading rules of Nordic Timber (Pohjoismainen sahatavara 1994). The same person was responsible for all gradings ensuring consistent results. A similar level of precision cannot be obtained in sawn timber grading in industrial sawmills.

The sites in this study represented Herb-rich type (Rhtkg) and *Vaccinium myrtillus* type (Mtkg) for spruce and *Vaccinium vitis-idaea* type (Ptkg) and Dwarf-shrub type (Vatkg) for pine. Five sample plots were chosen from each type. How well this uniform set-up represents the site type distribution and future cutting possibilities on drained peatlands may be evaluated using the results of the 8th National Forest Inventory. According to Hökkä et al. (2002), 36% of the area of drained spruce mires on forest land in southern Finland corresponds to Herb-rich type and 55% to *Vaccinium myrtillus* type. In drained pine mires, 53% of the area corresponds to *Vaccinium vitis-idaea* type and 34% to Dwarf-shrub type. When the yield potential of these sites is taken into consideration, one may conclude that sample plots of spruce on Herb-rich type were slightly over-represented. For pine, sample plots on Dwarf-shrub type were clearly over-represented. How this disproportion affects the

generalizability of the results is not clear. However, since only a few properties differed significantly by site type, the error is probably minor.

The study material collected – measurements from 600 standing trees of which 200 were felled, measured and cut into 500 sawlogs and 1400 sample discs – may be considered as adequate in relation to the aims of the study. The material originated from intensively managed stands where the aim had been maximum yield. This probably had not resulted in optimal tree quality. However, various defects, such as severe stem form defects and compression wood are even more common in unmanaged stands on drained peatlands, to say nothing of virgin mires. The results should therefore not be generalized to represent the average quality of peatland stands in southern Finland; the specific characteristics of the study material must be taken into consideration. To ascertain representative results from quality properties, one should utilize measurements from large-scale inventories (e.g. National Forest Inventory).

5 CONCLUSIONS

Information about the properties of wood material harvested from mature stands on drained peatlands was sought. The stands represented the first post-drainage tree generation, i.e. most trees contained wood produced both before and after drainage. Although new areas are no longer drained for wood production, the characteristics of the first post-drainage tree generation will continue to be relevant for decades to come on drained peatlands in Finland (see Fig. 1).

The hypothesis that the characteristics of peat soil are reflected in the properties of wood material produced is partly true. Stem form defects, such as sweep and crookedness, are common in peatland trees, decreasing the saw timber proportion of stems. Stem form of peatland trees does not deviate significantly from that of mineral soil sites, although peatland spruce seems to be more buttressed. The largest difference between peatland trees and trees growing on mineral soil sites can be found in tree branchiness. The study indicates that the relative length of the living crown of peatland trees is lower. The length of the relative dead branch section, by contrast, is clearly higher in peatland trees. These characteristics affect the distributions of log quality, which are dominated by dry knotted middle logs. This concerns especially peatland pine. Wood properties of peatland trees appear to be consistent with those observed in the Finnish conifers on average. However, the large variation in ring width and wood density is specific to peatland trees. The amount of compression wood seems to be insignificant in managed peatland stands.

Despite the stem form defects and dead branchiness, the quality of peatland spruce sawn timber may be regarded as being of very high quality, corresponding to that of mineral soil sites. For pine, sawn timber of high quality may be expected only from the base of the stems since the quality of upper parts of stems is usually poor. The wide variations in growth rate appear to be manifested only in the quality of joinery-dried sawn timber, i.e. in low moisture contents. Further conclusions should not be drawn from these results since no reference material was available. More research is needed in this field.

The quality of wood material produced is only one factor affecting the usability and value of peatland stands for industrial use (Fig. 95). The overall profitability of wood processing is also affected by the costs of wood harvesting and haulage. These costs are usually higher on peatlands than on upland sites because of smaller out-turns, low bearing capacity, and long off-road haulage. Most of the timber harvesting on peatlands has until now been carried out on frozen soil conditions, which places demands on the storage of roundwood to avoid storage defects. Suitable machinery for harvestings on peatlands has already been developed, and thus, the problems in timber harvesting are not technical but economic (see e.g. Högnäs 1997). The characteristics of peatland stands mentioned above stress the importance of careful planning of timber harvesting.

The structural characteristics of peatland stands – spacing, clumping, and large diameter variation of trees – remain unchanged several decades after drainage (Sarkkola 2000; Sarkkola et al. 2003). The silvicultural guidelines applied in mineral soil stands may not be optimal for peatland stands with regard to yield and quality of wood produced. Consequently, future research should focus on the silvicultural operations in peatlands.

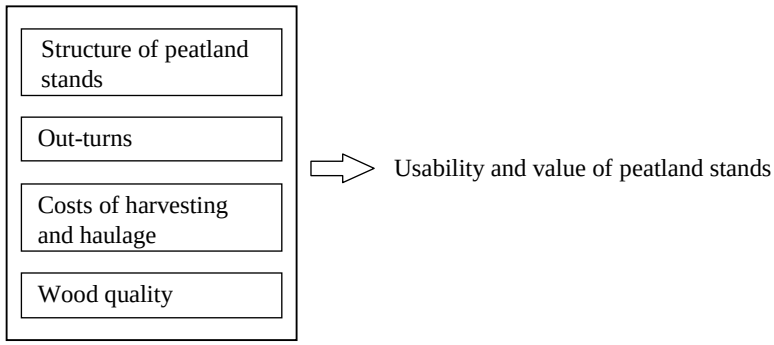


Fig. 95. Main factors affecting the usability and value of peatland stands in the wood processing industry.

Wood quality forms an essential component in the evaluation of profitability of drainage investments. Results of this study indicate a high quality potential for managed peatland stands. These findings should motivate improving the growth and quality of young tree stands by silvicultural operations, such as thinnings and improvement ditchings, although the immediate financial outcome may be low, possibly even negative. There is, however, no shortcut of growing timber trees of high quality. Well-managed peatland stands should also be regarded as a national obligation taking into account the already considerable financial input into forest amelioration during the past few decades. This is, after all, a matter of choices and values. The high potential productivity of the Finnish peatlands supporting tree growth should not be wasted but instead directed towards wood production, thus contributing to the sustainable use of our forests.

REFERENCES

Aalto-Kallonen, T. & Kurkela, T. 1985. Gremmeniella disease and site factors affecting the condition and growth of Scots pine. Seloste: Versosyöpätauti ja ympäristö männyn kuntoon ja kasvuun vaikuttavina tekijöinä. Communicationes Instituti Forestalis Fenniae 126: 1-28.

Asikainen, K. & Heiskanen, V. 1970. Havusahatukkien laadun mukaiset arvosuhteet. Summary: The value relationships of coniferous sawlogs on the basis of their quality. Communicationes Instituti Forestalis Fenniae 70(3): 1-77.

Asikainen, K. & Panhelainen, A. 1970a. Tukin lenkouden vaikutus sahaustulokseen. Summary: The effect of the sweep of the log on the sawing yield. Paperi ja Puu 52(4a): 219-230.

Asikainen, K. & Panhelainen, A. 1970b. Tukin soikeuden vaikutus sahaustulokseen. Summary: The effect of the ovalness of the log on the sawing yield. Paperi ja Puu 52(6): 395-402.

Björklund, L. 1999. Identifying heartwood-rich stands or stems of *Pinus sylvestris* by using inventory data. Silva Fennica 33(2): 119-129.

Björklund, L. & Walfridsson, E. 1993. Tallvedens egenskaper i Sverige – Torr-rådensitet, kärnvedhalt, fuktighet och barkhalt. Summary: Properties of Scots pine wood in Sweden – Basic density, heartwood, moisture and bark content. The Swedish University of Agricultural Sciences. Department of Forest Products, Report No. 234: 1-67.

Boholm, M. 1999. Densitetsvariationen i granstammen och dess inverkan på slutproduktens kvalitet. Thesis for M.Sc. graduation. University of Helsinki. Department of Forest Resource Management. 52 p.

Boren, H. 2001. Factors affecting the knottiness, twisting and mechanical properties of pith enclosed round and sawn timber of Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) from thinnings in southern Finland. Finnish Forest Research Institute, Research Papers 807: 1-164.

Bruun, H.H. 1967. Maamme selluloosateollisuuden havupuun runkohalkaisijasta ja iästä. Kemian Teollisuus 24(1): 20-22.

Cajander, A.K. 1909. Über Waldtypen. Acta Forestalia Fennica 1: 1-175.

Cockrell, R.A. & Knudson, R.M. 1973. A comparison of static bending, compression and tension parallel to grain and toughness properties of compression wood and normal wood of giant sequoia. Wood Science and Technology 7(4): 241-250.

Eilavaara, E.J. 1994. Nyt puhutaan sivutuotteista. Osat I ja II. Puumies 8/1994: 7-8. Puumies 9/1994: 17-18.

Eklund, B. 1967. Om tillväxtens årliga variation hos tall och gran jämte betydelsen av hänsynstagande härtill. Summary: Annual variation of increment in pine and spruce. Silva Fennica 1(4): 1-22.

Ericson, B. 1959. A mercury immersion method for determining the wood density of increment core sections. Meddelanden från Statens skogsforskningsinstitut. Avdelningen för skogsproduktion. Rapporter Nr 1: 1-31.

Ericson, B. 1966. Gallringens inverkan på vedens torr-råvolymvikt, höstvedhalt och kärnvedhalt hos tall och gran. Summary: Effect of thinning on the basic density and content of latewood and heartwood in Scots pine and Norway spruce. Skogshögskolan. Institutionen för skogsproduktion. Rapporter och Uppsatser Nr 10: 1-116.

Frimpong-Mensah, K. 1987. Fibre length and basic density variation in the wood of Norway spruce (*Picea abies* (L.) Karst.) from northern Norway. Norsk institutt for skogforskning. Meddelelser fra Norsk institutt for skogforskning 40(1): 1-25.

Goldstein, H., Rasbash, J., Plewis, I., Draper, D., Browne, W., Yang, M., Woodhouse, G. & Healy, M. 1998. A user's guide to MLwiN. Version 1.0. Multilevel Models Project. Institute of Education. University of London. 140 p.

Gore, A.J.P. 1983. Introduction. In: Gore A.J.P. (ed.). Mires: swamp, bog, fen and moor. Ecosystems of the world, vol 4A. Elsevier scientific publishing company, Amsterdam – Oxford – New York, 1-34.

Gustavsen, H.G. & Fagerström, H. 1983. Brösthöjdsformtalets variation i tall-, gran- och björkbestånd. Summary: The variation of the breast height form factor for pine, spruce and birch stands in Finland. Tiivistelmä: Männyn, kuusen ja koivun muotolukujen vaihtelu. Folia Forestalia 576: 1-32.

Hakala, H. 1992. Mäntytukkien sahauksen järeyden mukainen taloudellinen tulos ja siihen vaikuttavia tekijöitä. Summary: Financial result of sawing pine logs as influenced by top diameter and other associated factors. Acta Forestalia Fennica 226: 1-74.

Hakkila, P. 1966. Investigations on the basic density of Finnish pine, spruce and birch wood. Communicationes Instituti Forestalis Fenniae 61(5): 1-98.

Hakkila, P. 1967a. Vaihtelumalleja kuoren painosta ja painoprosentista. Summary: Variation patterns of bark weight and bark percentage by weight. Communicationes Instituti Forestalis Fenniae 62(5): 1-37.

Hakkila, P. 1967b. Puun laadun vaikutuksesta sulfaattisellua valmistettaessa. Summary: On wood quality in sulphate pulping of Scots pine. Paperi ja Puu 49(7): 461-464.

Hakkila, P. 1968. Geographical variation of some properties of pine and spruce pulpwood in Finland. Communicationes Instituti Forestalis Fenniae 66(8): 1-60.

Hakkila, P. 1979. Wood density survey and dry weight tables for pine, spruce and birch stems in Finland. Communicationes Instituti Forestalis Fenniae 96(3): 1-59.

Hakkila, P. 1989. Utilization of Residual Forest Biomass. Springer-Verlag. Berlin – Heidelberg – New York – London – Paris – Tokyo – Hong Kong. 568 p.

Hakkila, P., Laasasenaho, J. & Oittinen, K. 1972. Korjuuteknisiä oksatietoja. Summary: Branch data for logging work. Folia Forestalia 147: 1-15.

Hakkila, P. & Rikkonen, P. 1970. Kuusitukit puumassan raaka-aineena. Summary: Spruce logs as raw material of pulp. Folia Forestalia 92: 1-16.

Hakkila, P. & Uusvaara, O. 1968. On the basic density of plantation-grown Norway spruces. Communicationes Instituti Forestalis Fenniae 66(6): 1-23.

Havutukkien mitta- ja laatuvaatimukset. 1993. Metsäliitto, Vilppulan saha. Moniste. 1 p.

Heikinheimo, O. 1953. Puun rungon luontaisesta karsiutumisesta. Summary: On natural pruning of tree stems. Communicationes Instituti Forestalis Fenniae 41(5): 1-39.

Heikurainen, L. & Kuusela, K. 1962. Revival of the tree growth after drainage and its dependence on the tree size and age. Communicationes Instituti Forestalis Fenniae 55(8): 1-15.

Heinonen, J. 1994. Koealojen puu- ja puustotunnusten laskentaohjelma – KPL. Käyttöohje. Metsäntutkimuslaitoksen tiedonantoja 504: 1-80.

Heiskanen, V. 1951. Mäntysahatukkien laadun mukaisista arvosuhteista. Silva Fennica 69: 92-103.

Heiskanen, V. 1954a. Tutkimuksia mäntytukkipuun laatuluokitustavoista ja niiden tarkkuudesta. Summary: Investigations into pine tree grading method and their accuracy. Commucationes Instituti Forestalis Fenniae 44(1): 1-132.

Heiskanen, V. 1954b. Vuosiluston paksuuden ja sahatukin laadun välisestä riippuvuudesta. Summary: On the interdependence of annual ring width and sawlog quality. Communicationes Instituti Forestalis Fenniae 44(5): 1-31.

Heiskanen, V. 1965. Puiden paksuuden ja nuoruuden kehityksen sekä oksaisuuden välisistä suhteista männiköissä. Summary: On the relations between the development of the early age and thickness of trees and their branchiness in pine stands. Acta Forestalia Fennica 80(2): 1-62.

Heiskanen, V. & Asikainen, K. 1969. Havusahatukkien järeyden mukaiset arvosuhteet ja hinnoitteluperusteet. Summary: The value relationships and pricing principles of coniferous sawlogs on the basis of their diameter. Communicationes Instituti Forestalis Fenniae 69(3): 1-122.

Heiskanen, V. & Rikkonen, P. 1976. Havusahatukkien kuoren määrä ja siihen vaikuttavat tekijät. Summary: Bark amount in coniferous sawlogs and factors affecting it. Folia Forestalia 250: 1-67.

Heiskanen, V. & Siimes, F.E. 1959. Tutkimus mäntysahatukkien laatuluokituksesta. Summary: A study regarding the grading of pine saw logs. Paperi ja puu 41(8): 359-368.

Henttonen, H. 1984. The dependence of annual ring indices on some climatic factors. Seloste: Vuosilustoindeksien riippuvuus ilmastotekijöistä. Acta Forestalia Fennica 186: 1-38.

Hillis, W.E. 1987. Heartwood and tree exudates. Springer-Verlag, Berlin – Heidelberg – New York – London – Paris – Tokyo. 268 p.

Högnäs, T. 1997. Puunkorjuu turvemaalla. Metsähallituksen aikaisemman kokeilutoiminnan tuloksia. Metsähallitus, Metsätalouden kehittämisyksikkö, Tiedote 2: 1-13.

Hökkä, H., Kaunisto, S., Korhonen, K.T., Päivänen, J., Reinikainen, A. & Tomppo, E. 2002. Suomen suometsät 1951–1994. Metsätieteen aikakauskirja 2B/2002: 201-357.

Huikari, O. 1958. Metsäojituksen koneellistamisesta. Referat: Über die Mechanizierung der Waldentwässerung. Communicationes Instituti Forestalis Fenniae 50(5): 1-93.

Ilvessalo, Y. 1920. Tutkimuksia metsätyyppien taksatorisesta merkityksestä nojautuen etupäässä kotimaiseen kasvutaulujen laatimistyöhön. Referat: Untersuchungen über die taxatorische Bedeutung der Waldtypen, Hauptsächliche auf den Arbeiten für die Aufstellung der neuen Ertragstafeln Finnlands fussend. Acta Forestalia Fennica 15(3): 1-157 + appendices

ISO 1975. Wood – Determination of density for physical and mechanical tests. ISO 3131. International Organization for Standardization. 4 p.

Isomäki, A. & Kallio, T. 1974. Consequences of injury caused by timber harvesting machines on the growth and decay of spruce (*Picea abies* (L.) Karst.). Seloste: Puunkorjuun aiheuttamien vaurioiden vaikutus kuusen lahoamiseen ja kasvuun. Acta Forestalia Fennica 136: 1-25.

Jalava, M. 1933. Suomalaisen männyn lujuusominaisuuksista. Summary: Strength properties of Finnish pine (*Pinus silvestris*). Communicationes Instituti Forestalis Fenniae 18(7): 1-187.

Jalava, M. 1945. Suomalaisen männyn, kuusen, koivun ja haavan lujuusominaisuuksista. Summary: Strength properties of Finnish pine, spruce, birch and aspen. Communicationes Instituti Forestalis Fenniae 33(3): 1-66.

Johansson, K. 1993. Influence of initial spacing and tree class on the basic density of *Picea abies*. Scandinavian Journal of Forest Research 8(1): 18-27.

Jonsson, L. & Nylinder, M. 1990. Tallbarkens tjocklek längs stammen – Funktioner för aptering. Summary: Bark thickness along stems of pine – Functions for determination of diameter under bark. The Swedish University of Agricultural Sciences. Department of Forest Products, Report No. 212: 1-41.

Kalela, A. 1937. Zur Synthese der experimentellen Untersuchungen über Klimarassen der Holzarten. Seloste: Puulajien ilmastorotuja koskevista kokeellisista tutkimuksista. Communicationes Instituti Forestalis Fenniae 26(1): 1-448.

Kangas, E. 1952. Maannousemasienen (*Polyporus annosus* Fr.) esiintymisestä, tartunnasta ja tuhoista Suomessa. Referat: Über Auftreten, Infektion und Schäden des Wurzelschwamms (*Polyporus annosus* Fr.) in Finnland. Communicationes Instituti Forestalis Fenniae 40(33): 1-34.

Kangas, E. 1962. Über Krummstämmingkeit und Verzweigung der finnischen Kiefer. Communicationes Instituti Forestalis Fenniae 55(15): 1-16.

Kärkkäinen, M. 1971. Lahon leviäminen puunkorjuun aiheuttamista kuusen runko- ja juurivaurioista. Summary: Decay following logging injury in stems and roots of Norway spruce. Silva Fennica 5(3): 226-233.

Kärkkäinen, M. 1972a. Havaintoja kuusen oksaisuudesta. Summary: Observations on the branchiness of Norway spruce. Silva Fennica 6(2): 90-115.

Kärkkäinen, M. 1972b. Kuusen ja männyn sydänpuuosuudesta. Summary: On the proportion of heartwood in Norway spruce (*Picea abies*) and Scots pine (*Pinus silvestris* L.). Silva Fennica 6(3): 193-208.

Kärkkäinen, M. 1975. Pohjoissuomalaisten mäntytukkien soikeus. Summary: Ovalness of pine logs in northern Finland. Silva Fennica 9(4): 251-258.

Kärkkäinen, M. 1978. Viilusaannon teoreettinen malli. Summary: Theoretical model for the veneer yield. Communicationes Instituti Forestalis Fenniae 95(2): 1-42.

Kärkkäinen, M. 1980. Mäntytukkirunkojen laatuluokitus. Summary: Grading of pine sawlog stems. Communicationes Instituti Forestalis Fenniae 96(5): 1-152.

Kärkkäinen, M. 1984. Effect of tree social status on basic density of Norway spruce. Silva Fennica 18 (2): 115-120.

Kärkkäinen, M. 1986a. Malli männyn, kuusen ja koivun puuaineen oksaisuudesta. Abstract: Model of knottiness of wood material in pine, spruce, and birch. Silva Fennica 20(2): 107-116.

Kärkkäinen, M. 1986b. Mänty- ja kuusirunkojen arvosuhteet. Abstract: Value relations of pine and spruce stems. Silva Fennica 20(2): 117-127.

Kärkkäinen, M. 2003. Puutieteen perusteet. Metsälehti Kustannus. 451 p.

Kärkkäinen, M. & Dumell, O. 1983. Kuusipuun taivutuslujuuden riippuvuus tiheydestä ja vuosiluston leveydestä Etelä- ja Pohjois-Suomessa. Summary: Effect of basic density and growth ring width on the bending strength of spruce wood from south and north Finland. Silva Fennica 17(2): 123-135.

Kärkkäinen, M. & Raivonen, M. 1977. Reaktiopuun mekaaninen lujuus. Summary: Mechanical strength of reaction wood. Silva Fennica 11(2): 87-96.

Kellomäki, S. 1981. Mäntysahatukkien ja sydänpuuosuuden yhteys tukin ulkoisiin tunnuksiin. Folia Forestalia 489: 1-13.

Kellomäki, S. 1984. Havaintoja puuston kasvatustiheyden vaikutuksesta mäntyjen oksikkuuteen. Summary: Observations on the influence of stand density on branchiness of young Scots pines. Silva Fennica 18(2): 101-114.

Kellomäki, S. & Tuimala, A. 1981. Puuston tiheyden vaikutus puiden oksikkuuteen taimikko- ja riukuvaiheen männiköissä. Summary: Effect of stand density on branchiness of young Scots pines. Folia Forestalia 478: 1-27.

Kellomäki, S., Lämsä, P., Oker-Blom, P. & Uusvaara, O. 1992. Männyn laatukasvatus. Summary: Management of Scots pine for high quality timber. Silva Carelica 23: 1-133.

Koivuniemi, J. 1992. Kuusen sydän- ja mantopuun määrä ja sen vaikutus tilavuuskasvuun. Licentiate thesis. University of Helsinki. Department of Forest Resource Management. 109 p. + appendices.

Kollmann, F. & Côté, W.A., Jr. 1968. Principles of wood science and technology. I Solid wood. Springer-Verlag, Berlin – Heidelberg – New York. 592 p.

Kurkela, T. 1981. Versosyöpä (*Gremmeniella abietina*) riukuasteen männiköissä. Summary: Canker and die-back of Scots pine at pre-commercial stage caused by *Gremmeniella abietina*. Folia Forestalia 485: 1-12.

Kuusivaneritukin laatuohje 1998. Laatija Väinö Hirvonen. UPM-Kymmene Metsä. Moniste. 1 p.

Laasasenaho, J. 1982. Taper curve and volume functions for pine, spruce and birch. Seloste: Männyn, kuusen ja koivun runkokäyrä- ja tilavuusyhtälöt. Communicationes Instituti Forestalis Fenniae 108: 1-74.

Laasasenaho, J. 1983. Pystypuiden rungon tilavuuden uudet laskentamenetelmät. Metsä ja Puu 10: 8-10.

Laasasenaho, J. 1997. Puun elävän latvuksen alarajan määrittämisestä ja käytöstä. Metsätieteen aikakauskirja 1/1997: 135-138.

Laine, J. 1989. Metsäojitettujen soiden luokittelu. Summary: Classification of peatlands drained for forestry. Suo 40: 37-51.

Laine, J. & Vasander, H. 1996. Ecology and vegetation gradients of peatlands. In: Harri Vasander (ed.). Peatlands of Finland. Finnish Peatland Society. Gummerus Printing: 10-19.

Laitakari, E. 1929. Über die Fähigkeit der Bäume sich gegen Sturmgefahr zu schützen. Acta Forestalia Fennica 34(34): 1-29.

Lakari, O.J. 1920. Tutkimuksia kuusen karsimisesta. Referat: Untersuchungen über die Ästung der Fichte. Communicationes Instituti Forestalis Fenniae 2(4): 1-43.

Lappi-Seppälä, M. 1929. Untersuchungen über die Schlankheit der Kiefer. Acta Forestalia Fennica 34(42): 1-13.

Lappi-Seppälä, M. 1934. Karsimisesta ja sen metsänhoidollisesta merkityksestä. Referat: Über die Ästung und ihre waldbauliche Bedeutung. Acta Forestalia Fennica 40(25): 607-618.

Lappi-Seppälä, M. 1937. Karsimisesta arvopuun kasvatusta silmällä pitäen. Referat: Über Ästung mit Beachtung der Erziehung von Qualitätsholz. Silva Fennica 42: 120-136.

Lappi-Seppälä, M. 1952. Männyn sydänpuusta ja runkomuodosta. Referat: Über Verkernung und Stammform der Kiefer. Communicationes Instituti Forestalis Fenniae 40(25): 1-26.

Larson, P. R. 1963. Stem form development of forest trees. Forest Science Monograph 5: 1-42.

Lindström, H. 1996. Basic density of Norway spruce. Part II. Predicted by stem taper, mean growth ring width, and factors related to crown development. Wood and Fiber Science 28(2): 240-251.

Lipitsäinen, R. 1994. Lujuuslajitteluohjeet: T40, T30, T24, T18. Lujuuslajittelukurssit, Julkaisu nro 2/94. VTT Rakennustekniikka, Puutekniikka. 30 p.

Marjomaa, J. 1995. Tukin mittaus optisella tukkimittarilla. Abstract: Log measurement using an optical measuring device. Metsäteho katsaus 1/1996: 1-7.

Melkas, T. 1999. Kuusen kuoren paksuuden mallittaminen runkokäyrän avulla. Thesis for M.Sc. graduation. University of Helsinki. Department of Forest Resource Management. 66 p. + appendices.

Metsätilastollinen vuosikirja. 1994. Yearbook of Forest Statistics. Aarne, M. (ed.). Metsäntutkimuslaitos. Gummerus Kirjapaino Oy. Jyväskylä. 348 p.

Metsätilastollinen vuosikirja. 2001. Finnish Statistical Yearbook of Forestry. Peltola, A. (ed.). Metsäntutkimuslaitos. Vammalan kirjapaino Oy. Vammala. 374 p.

Metsätilastollinen vuosikirja. 2002. Finnish Statistical Yearbook of Forestry. Peltola, A. (ed.). Metsäntutkimuslaitos. Vammalan kirjapaino Oy. Vammala. 378 p.

Mikola, P. 1950. Puiden kasvun vaihtelusta ja niiden merkityksestä kasvututkimuksissa. Summary: On variations in tree growth and their significance to growth studies. Communicationes Instituti Forestalis Fenniae 38(5): 1-131.

Mork, E. 1928. Die Qualität des Fichtenholzes unter besonderer Rücksichtsnahme auf Schleif- und Papierholz. Papier-Fabr 26: 741-747.

NS-INSTA 142, Nordiske regler for visuell styrkesortering av trelast. 1997. Nordic visual grading rules for timber. Oslo. Norges Standardiseringsforbund. 28 p.

Nuutinen, T., Hirvelä, H., Hynynen, J., Härkönen, K., Hökkä, H., Korhonen, K.T. & Salminen, O. 2000. The Role of Peatlands in Finnish Wood Production – an Analysis Based on Large-scale Forest Scenario Modelling. Silva Fennica 34(2): 131-153.

Nylinder, P. 1953. Volymviktsvariationer hos planterad gran. Summary: Variation in density of planted spruce. Meddelanden från Statens skogsforskningsinstitut: 43(3): 1-44.

Nylinder, P. 1959. Synpunkter på produktionens kvalitet. Summary: A study on quality production. Skogshögskolan. Institutionen för virkeslära. Rapporter och Uppsatser U2: 1-19.

Nylinder, P. 1961a. Om träd- och vedegenskapers inverkan på råvolymvikt och flytbarhet. I Tall. Summary: Influence of tree features and wood properties on basic density and buoyance. I Scots pine (*Pinus silvestris*). Skogshögskolan. Institutionen för virkeslära. Rapporter och Uppsatser Nr R 35: 1-36 + tabeller.

Nylinder, P. 1961b. Om träd- och vedegenskapers inverkan på råvolymvikt och flytbarhet. II Gran. Summary: Influence of tree features and wood properties on basic density and buoyance. II Norway spruce (*Picea abies*). Skogshögskolan. Institutionen för virkeslära. Rapporter och Uppsatser Nr R 36: 1-39 + tabeller.

Nyyssönen, A. 1952. Puiden kasvusta ja sen määrittämisestä harsintamänniköissä. Summary: On tree growth and its ascertainment in selectively cut Scots pine stands. Communicationes Instituti Forestalis Fenniae 40(4): 1-20.

Nyyssönen, A. 1954. Hakkauksilla käsiteltyjen männiköiden rakenteesta ja kehityksestä. Summary: On the structure and development of Finnish pine stands treated with different cuttings. Acta Forestalia Fennica 60(4): 1-194.

Ojansuu, R. & Maltamo, M. 1995. Sapwood and heartwood taper in Scots pine stems. Canadian Journal of Forest Research 25: 1928-1943.

Ollinmaa, P.J. 1955. Havupuiden lylypuun rakenteesta ja ominaisuuksista. Summary: On the structure and properties of coniferous compression wood. Paperi ja Puu 37(11): 544-549.

Ollinmaa, P.J. 1959. Reaktiopuututkimuksia. Summary: Study on reaction wood. Acta Forestalia Fennica 72(1): 1-54.

Ollinmaa, P.J. 1960. Eräistä ojitetuilla soilla kasvavan puun fysikaalisista ominaisuuksista. Summary: On certain physical properties of wood grown on drained swamps. Acta Forestalia Fennica 72(2): 1-24.

Ollinmaa, P.J. 1981. Eräistä ojitetuilla soilla kasvavan puun fysikaalisista ominaisuuksista. Summary: On certain physical properties of wood grown on drained swamps. Silva Fennica 15(3): 347-358.

Paavilainen, E. & Päivänen, J. 1995. Peatland Forestry: Ecology and principles. Springer-Verlag, Berlin – Heidelberg – New York. 248 p.

Päivänen, J. 1989. Rämemäntyalkuperien kehityksestä kangasmaalla. Summary: Development of mire originated Scots pine on mineral soil. Suo 40(1): 3-10.

Päivinen, R. 1978. Kapenemis- ja kuorimallit männylle, kuuselle ja koivulle. Summary: Taper and bark thickness models for pine, spruce and birch. Folia Forestalia 353: 1-32.

Pohjoismainen sahatavara. 1994. Mänty- ja kuusisahatavaran lajitteluohjeet. Suomen Sahateollisuusmiesten Yhdistys, Föreningen Svenska Sågverksmän, Treindustriens Tekniske Forening. Jyväskylä. 64 p.

prEN 13183-2. 1998. Round and sawn timber. Method of measurement of moisture content. Part. 2: Method for estimating moisture content of a piece of sawn timber (Resistance method).

Ranta, E., Rita, H. & Kouki, J. 2002. Biometria. Tilastotiedettä ekologeille. 8. painos. Helsinki. Yliopistopaino. 569 p.

Redfern, D.B. 1998. The effect of soil on root infection and spread by *Heterobasidion annosum*. In: Root and Butt Rots of Forest Trees. 9th International Conference on Root and Butt Rots. Carcans-Maubuisson (France), September 1-7, 1997. INRA Editions, Les Colloques, no. 89. Institut National de la Recherche Agronomique, Paris: 267-274.

Saikku, O. 1975a. The effect of fertilization on the basic density of Scots pine (*Pinus silvestris* L.). Lyhennelmä: Lannoituksen vaikutuksesta männyn (*Pinus silvestris* L.) puuaineen tiheyteen. Communicationes Instituti Forestalis Fenniae 85(3): 1-49.

Saikku, O. 1975b. Typpilannoituksen vaikutuksesta kuusen, männyn ja koivun puuaineen tiheyteen. The effect of nitrogen fertilization on the basic density of Scots pine (*Pinus silvestris*), Norway spruce (*Picea abies*) and common birch (*Betula verrucosa*). Communicationes Instituti Forestalis Fenniae 85(5): 1-23.

Saramäki, J. 1980. Typpilannoituksen vaikutus männyn runkomuotoon. Summary: The effect of nitrogen fertilization on the stem form of Scots pine. Communicationes Instituti Forestalis Fenniae 99(4): 1-46.

Saranpää, P. 1983. Puuaineen tiheyden ja vuosiluston leveyden vaikutus kuusen iskutaivutuslujuuteen Etelä- ja Pohjois-Suomessa. Summary: The influence of basic density and growth ring width on the impact strength of spruce wood from south and north Finland. Silva Fennica 17(4): 381-388.

Saranpää, P. 1994. Basic density, longitudinal shrinkage and tracheid length of juvenile wood of *Picea abies* (L.) Karst. Scandinavian Journal of Forest Research 9: 68-74.

Sarkkola, S. 2000. Kuusivaltaisten korpipuustojen rakenteen kehitys ojituksen jälkeen. Thesis for M.Sc. graduation. University of Helsinki. Department of Forest Ecology. 86 p. + appendices.

Sarkkola, S., Alenius, V., Hökkä, H., Laiho, R., Penttilä, T. & Päivänen, J. 2003. Changes in structural inequality in Norway spruce stands on peatland sites after water-level drawdown. Canadian Journal of Forest Research 33: 222-231.

SAS/STAT User´s Guide. 1990. Version 6, Fourth Edition, Volumes 1 and 2. SAS Institute Inc. Cary, NC, USA. 1848 p.

Sellin, A. 1991. Variation in sapwood thickness of *Picea abies* in Estonia depending on the tree age. Scandinavian Journal of Forest Research 6: 463-469.

Sellin, A. 1994. Sapwood-heartwood proportion related to tree diameter, age, and growth rate in *Picea abies*. Canadian Journal of Forest Research 24: 1022-1028.

Seppälä, K. 1969. Kuusen ja männyn kasvun kehitys ojitetuilla turvemailla. Summary: Post-drainage growth rate of Norway spruce and Scots pine on peat. Acta Forestalia Fennica 93: 1-88.

Siimes, F.E. 1938. Suomalaisen mäntypuun rakenteellisista ja fysikalista ominaisuuksista. Summary: On the structural and physical properties of Finnish pine wood. Puutekniikan tutkimuksen kannatusyhdistys ry. Julkaisuja 29: 1-221.

Sirén, G. 1952. Hakkuun vaikutuksesta kuusipuun rakenteeseen ojitetuilla korpimailla. Summary: On the effect of releasing cutting upon wood structure of spruce on peat-moors. Communicationes Instituti Forestalis Fenniae 40(32): 1-36.

Tamminen, P. 1985. Butt-rot in Norway spruce in southern Finland. Seloste: Kuusen tyvilahoisuus Etelä-Suomessa. Communicationes Instituti Forestalis Fenniae 127: 1-52.

Tamminen, Z. 1962. Fuktighet, volymvikt m.m. hos ved och bark. I Tall. Summary: Moisture content, density and other properties of wood and bark. I Scots pine. Skogshögskolan. Institutionen för virkeslära. Rapporter och Uppsatser Nr R 41: 1-118.

Tamminen, Z. 1964. Fuktighet, volymvikt m.m. hos ved och bark. II Gran. Summary: Moisture content, density and other properties of wood and bark. II Norway spruce. Skogshögskolan. Institutionen för virkeslära. Rapporter och Uppsatser Nr R 47: 1-124.

Tapion taskukirja. 2002. Kustannusosakeyhtiö Metsälehti. 24. painos. Gummerus Kirjapaino Oy, Jyväskylä. 555 p.

Tiihonen, P. 1961. Tutkimuksia männyn kapenemistaulukoiden laatimiseksi. Referat: Untersuchungen über die Aufstellung der Ausbauchungstafeln für Kiefer. Communicationes Instituti Forestalis Fenniae 53(1): 1-120.

Tikka, P.S. 1935. Puiden vikanaisuuksista Pohjois-Suomen metsissä. Referat: Über die Schadhaftigkeiten der Bäume in den Wäldern Nord-Finnlands. Acta Forestalia Fennica 41(1): 1-371.

Timell, T.E. 1973. Studies on opposite wood in conifers. Part II: Histology and ultrastructure. Wood Science and Technology 7(2): 79-91.

Timell, T.E. 1986. Compression Wood in Gymnosperms. Vol 1-3, Springer-Verlag, Berlin – Heidelberg – New York – Tokyo. 2150 p.

Tirkkonen, O.O.J. 1952. Suomen metsäojitus 1900-luvun alkupuoliskolla. Summary: Forest Swamp Drainage in Finland in the First Half of the 20th Century. Silva Fennica 72: 1-103.

Tomppo, E. 1999. Forest resources of Finnish peatlands in 1951–1994. International Peat Journal 9: 38-44.

Tomppo, E., Henttonen, H. & Tuomainen, T. 2001. Valtakunnan metsien 8. inventoinnin menetelmä ja tulokset metsäkeskuksittain Pohjois-Suomessa 1992–94 sekä tulokset Etelä-Suomessa 1986–92 ja koko maassa 1986–94. Metsätieteen aikakauskirja 1B/2001: 99-248.

Tuimala, A., Lehtimäki, J., Repola, J. & Sairanen, P. 2002. Kuusen pystykarsinta. Kuusen laatu ja arvo. Vuosina 1994–2001 toteutettujen tutkimusten loppuraportti, Saranpää, P. & Verkasalo, E. (toim.). Metsäntutkimuslaitoksen tiedonantoja 841: 49-59.

Tuokko, K. 1992. Metsänparantajat kansakunnan asialla 1908–1988. Saarijärven Offset Oy. 509 p.

Turkia, K. & Kellomäki, S. 1987. Kasvupaikan viljavuuden ja puuston tiheyden vaikutus nuorten mäntyjen oksien läpimittaan. Folia Forestalia 705: 1-16.

Usenius, A., Halinen, M., Hemmilä, P. & Sommerdahl, K.O. 1987. Sahapuurunkojen apteerauksen kehittäminen. VTT, puulaboratorio. Tutkimuksia 491: 1-116.

Uusitalo, J. 1989. Sahatavaran arvon ennustaminen mäntytukkileimikosta. Thesis for M.Sc. graduation. University of Helsinki. Department of Business Economics of Forestry. 45 p.

Uusitalo, J. 1994. Sahatavaran ennustaminen mäntytukkirungoista. Summary: Predicting lumber quality of pine stems. University of Helsinki. Department of Forest Resource Management. Publications 3: 1-53.

Uusitalo, J. 1995. Pre-harvest measurement of pine stands for sawing production planning. University of Helsinki, Department of Forest Resource Management, Publications 9: 1-96.

Uusvaara, O. 1974. Wood quality in plantationgrown Scots pine. Lyhennelmä: Puun laadusta viljelymänniköissä. Communicationes Instituti Forestalis Fenniae 80(2): 1-105.

Uusvaara, O. 1997. Havutukkipuuston ulkoinen laatu Suomen etelä- ja lounaisrannikolla ja Ahvenanmaalla. Metsäntutkimuslaitoksen tiedonantoja 664: 1-25.

Valtakunnan metsien 9. inventointi (VMI9). Maastotyön ohjeet 1998. Etelä-Suomi. 150 p.

Velling, P. 1974. Männyn (*Pinus silvestris* L.) puuaineen tiheyden fenotyyppisestä ja geneettisestä vaihtelusta. Symmary: Phenotypic and genetic variation in the wood basic density of Scots pine (*Pinus silvestris* L.). Folia Forestalia 188: 1-29.

Velling, P. 1976. Mänty- ja kuusiprovenienssien puuaineen tiheyden vaihtelusta. Summary: The wood basic density variation of pine and spruce provenances. Folia Forestalia 257: 1-32.

Verkasalo, E. & Leban, J.M. 1996. External quality of the saw timber stock of Scots pine and Norway spruce in Finland and France. Tiivistelmä: Suomen ja Ranskan mänty- ja kuusitukkipuuston ulkoinen laatu. Paperi ja Puu – Paper and Timber 78(5): 313-322.

Verkasalo, E. & Maltamo, M. 2002. Ojitettujen korpien ja kivennäismaiden kuusitukkirunkojen ja puuaineen laatu- ja arvoerot. Kuusen laatu ja arvo. Vuosina 1994–2001 toteutettujen tutkimusten loppuraportti, Saranpää, P. & Verkasalo, E. (toim.). Metsäntutkimuslaitoksen tiedonantoja 841: 71-90.

Vientisahatavaran lajitteluohjeet. 1979. Suomen Sahateollisuusmiesten Yhdistys. Helsinki. 52 p.

Vuokila, Y. 1960. Männyn kasvusta ja sen vaihteluista harventaen käsitellyissä ja luonnontilaisissa metsiköissä. Summary: On growth and its variations in thinned and unthinned Scots pine stands. Communicationes Instituti Forestalis Fenniae 52(7): 1-38.

Vuokila, Y. 1965. Puiden paksuuskasvun reaktioista harvennushakkuiden seurauksena. Summary: On growth reactions of trees to intermediate cuttings. Metsätaloudellinen Aikakauslehti 5: 197-199.

Vuokila, Y. 1968. Karsiminen ja kasvu. Summary: Pruning and increment. Communicationes Instituti Forestalis Fenniae 66(5): 1-61.

Vuokila, Y. 1987. Metsänkasvatuksen perusteet ja menetelmät. Toinen painos. WSOY:n graafiset laitokset. Porvoo. 258 p.

Warensjö, M. & Lundgren, C. 1998. Samband mellan tjurved och formfel hos gran – En studie vid Limmareds sågverk. Summary: Impact of compression wood on deformation of sawn wood of spruce (*Picea abies* (L.) Karst.). The Swedish University of Agricultural Sciences, Department of Forest Products. Report No. 255: 1-38.

Wilhelmsson, L., Arlinger, J., Spångberg, K., Lundqvist, S.-O., Grahn, T., Hedenberg, Ö. & Olsson, L. 2002. Models for predicting wood properties in stems of *Picea abies* and *Pinus sylvestris* in Sweden. Scandinavian Journal of Forest Research 17: 330-350.

Worral, J. 1970. Interrelationships among some phenological and wood property variables in Norway spruce. Tappi 53(1): 58-63.

Other:

Ali-Raatikainen, A. 2003. An interview with the member companies of the Finnish Sawmills in January 2003.

Hyyryläinen, E. 1999. An interview at the plywood mill of Pellos 1 (Schauman Wood Oy) on the 13th of October 1999.

Nordberg, H. 2000. An interview at Vierumäen Teollisuus on the 8th of November 2000.

Silen, J. 1999. An interview at Tolkkinen Sawmill on the 13th of September 1999.

Total of 166 references

APPENDICES

Appendix 1. Quality gradings of logs used in the study. (1/3)

Pine logs (ABC grading):

Grade	General description	Top diameter (cm, over bark) min.	Top diameter (cm, over bark) max.	Largest knot (cm) dead knot	Largest knot (cm) spike knot	Largest knot (cm) sound knot	Length (dm)
A	Butt log, knob-free	15	*	2.0	2.0	2.0	37 (31)** … 58
B	Sound knotted top log	15	*	*	*	*	37 (34)** … 58
C1	Butt log (C)	15	*	4.0	4.0	*	37 (34)** … 58
C2	Other log Dead knotted middle or top log	15	*	4.0	4.0	*	37 (34)** … 58

* not limited
** auxiliary length

Sweep and crooks
- sweep allowed 1 cm/m (in grade A 2 cm/m in diameter classes 20+ cm)
- top crooks or twist not allowed

Resinous wounds, scars, harvesting damages, splitting, other technical defects
- allowed outside the top cylinder of a log

Decay, blue stain, worm holes, shakes, foreign objects
- not allowed in logs

Spruce logs (modified from ABC grading):

Grade	General description	Top diameter (cm, over bark) min.	max.	Largest knot (cm) dead knot	spike knot	sound knot	Length (dm)
A	Butt log, knob-free	20	*	2.0	2.0	2.0	37 (34)** … 58
B	Sound knotted top log	16	*	*	*	*	37 (34)** … 58
C1	Butt log (C)	16	*	4.0	4.0	*	37 (34)** … 58
C2	Other log	16	*	4.0	4.0	*	37 (34)** … 58
	Dead knotted middle or top log						

* not limited
** auxiliary length

Sweep and crooks
- sweep allowed 1 cm/m (in grade A 2 cm/m in diameter classes 20+ cm)
- top crooks or twist not allowed

Resinous wounds, scars, harvesting damages, splitting, other technical defects
- allowed outside the top cylinder of a log

Decay, blue stain, worm holes, shakes, foreign objects
- not allowed in logs

Spruce logs (grading applied in the 9th National Forest Inventory):

Type of knot/defect	Diameter at the point of defect, cm	Grade 1	Grade 2	Grade 3
Sound knot, mm	< 19.5	10	40	40
	19.5-28.4	15	50	50
	≥ 28.5	20	60	60
Dead knot, mm	< 28.5	15	15 (40)[1]	40
	≥ 28.5	20	20 (50)[1]	50
Spike knot, mm		not allowed	not allowed	40
Unsound knot, mm		not allowed	not allowed	30
Sweep, cm/m	< 28.5	1	1	1
	≥ 28.5	1.5	1.5	1.5
Knob		not allowed	small ones allowed	
Resinous wound, < half of the circumference		not allowed	allowed outside the top cylinder	
Other technical defects		not allowed	allowed outside the top cylinder	

[1] Allowed occasionally at the base of a normal-sized log. A branch without living needles, located inside the living crown or directly under the living crown, is often a sound knot in sawn timber.

Appendix 2. Primary cause for log cutting.

Diameter:

11 Taper
12 Minimum top diameter of log
13 Maximum length of log

Change in quality:

21 Large sound knot or whorl
22 Large dead knot, unsound knot, spike knot, or knob
3 Crook
4 Sweep
5 Forked stem
6 Other defect

Appendix 3. Blade settings used in sawing experiments. (1/3)

The top diameters of logs under bark and the dimensions of sawn pieces are given in millimetres. The side board model expresses the number and dimensions of sawn pieces in the block sawing phase (YK) and re-sawing phase (AK). For example, code 4 in the collection of blade settings for grade A pine butt logs means that the re-sawing phase yields four side boards, of which the outermost are 25 mm in thickness and the innermost 19 mm in thickness.

Blade settings for grade A pine butt logs:

Top diameter of log (under bark)	Blade setting of centre yield	Side board model	
		YK	AK
200	50x150/2		2
205	50x150/2	1	2
210	32x150/4	2	1
	50x150/2	1	3
220	75x125/2	2	1
	63x150/2	2	2
	32x150/4	2	2
230	75x150/2	2	2
	63x175/2	1	2
	32x150/4	2	2
240	38x150/4	2	2
	50x200/2		5
	63x175/2	1	3
250	50x175/3	2	2
	38x150/4	2	2
260	63x200/2	1	5
	38x175/4	2	2
270	75x200/2	2	4
	50x200/3	2	3
	32x200/4	2	5
280	38x200/4	2	3
	50x200/3	2	4
290	32x225/4	1	5
	38x200/4	2	4
	50x225/3	2	5
	75x225/2	2	5
300	38x225/4	2	5
	50x225/3	2	5
	75x225/2	2	5
310	50x200/4	2	2
320	50x200/4	2	3
330	50x225/4	2	4
350	50x250/4	2	5

YK = block sawing phase
AK = re-sawing phase

Side board model:

1	**19**
2	**25**
3	**19,19**
4	**25,19**
5	**25,25**

Blade setting of centre yield:

thickness x width/ex-log

Blade settings for other pine logs:

Top diameter of log (under bark)	Blade setting of centre yield	Side board model	
		YK	AK
135	38x100/2		1
145	44x100/2		1
155	50x100/2	1	
160	50x100/2	1	1
175	50x125/2		2
180	50x125/2	1	2
195	50x150/2		2
205	50x150/2	1	2
210	50x150/2	1	3
220	75x125/2	2	2
230	75x150/2	2	2
240	38x150/4	2	2
	50x200/2		5
250	75x175/2	2	2
	38x150/4	2	2
260	63x200/2	1	5
	50x225/2		5
270	75x200/2	2	4
	50x200/3	2	3
280	50x200/3	2	4
	75x200/2	2	4
290	50x225/3	1	5
	75x225/2	1	5
300	50x225/3	2	5
	75x225/2	2	5
310	50x225/4	2	2
320	50x200/4	2	3
330	50x225/4	2	4
350	50x250/4	2	5

YK = block sawing phase
AK = re-sawing phase

Side board model:

1	**19**
2	**25**
3	**19,19**
4	**25,19**
5	**25,25**

Blade setting of centre yield:

thickness x width/ex-log

Blade settings for spruce logs:

Top diameter of log (under bark)	Blade setting of centre yield	Side board model	
		YK	AK
135	38x100/2		
145	44x100/2		
160	44x100/2	51	51
	50x100/2	51	
170	44x125/2		51
180	50x125/2		51
190	44x150/2		51
200	63x125/2	51	51
	50x150/2		51
210	63x150/2	51	51
	44x175/2		52
220	63x150/2	51	51
	50x175/2		52
	44x150/3	51	51
230	75x150/2	51	51
240	63x175/2	51	51
	50x200/2		52
	38x150/4	51	51
250	75x175/2	51	51
	50x200/2		52
260	63x200/2	51	52
270	75x200/2	51	52
280	50x200/3	51	52
	38x200/4	51	52
290	75x225/2	51	52
	44x200/4	51	51
	50x225/3	51	52
300	75x225/2	51	52
	38x225/4	51	52
310	44x225/4	51	52
	38x225/4	51	52
320	44x225/4	51	52
330	75x250/2	51	53
	50x225/4	51	53
	38x250/4	51	52
350	75x250/2	51	53
	38x250/4	51	53

YK = block sawing phase
AK = re-sawing phase

Side board model:

51	**22**
52	**22,22**
53	**22,22,22**

Blade setting of centre yield:

thickness x width/ex-log

Main blade settings shaded

Appendix 4. Value ratio table of sawn timber used in the study (based on a study carried out by Metsäteho Oy).

		Grades (Nordic Timber)									
Thickness	Width	**A1**	**A2**	**A3**	**A4**	**A**	**B**	**C**	**OKS/PP**	**VL**	**KL**
19	100	415	264	197	169	194	105	61	219	156	94
	125	455	289	217	186	213	108	64	219	156	94
	150	455	289	217	186	213	111	64	219	156	94
25	100	341	217	162	139	159	98	61	188	125	81
	125	342	218	163	140	160	100	64	188	125	81
	150	374	238	178	153	175	106	64	188	125	81
	175	374	238	178	153	175	106	64	188	125	81
	200	388	247	185	158	181	106	64	188	125	81
38	100	261	166	125	107	119	92	75			
	125	282	179	135	115	128	92	75			
	150	282	179	135	115	128	92	75			
	175	282	179	135	115	128	94	75			
	200	292	186	139	120	133	97	75			
50	100	220	140	105	90	**100**	91	77			
	125	230	147	110	94	105	91	77			
	150	251	160	120	103	114	84	72			
	175	251	160	120	103	114	84	72			
	200	261	166	125	107	119	88	72			
	225	272	173	130	111	123	91	72			
63	125	248	158	118	101	113	84	72			
	150	251	160	120	103	114	84	72			
	175	251	160	120	103	114	87	72			
	200	261	166	125	107	119	88	72			
75	150	251	160	120	103	114	84	72			
	200	261	166	125	107	119	88	72			
	225	272	173	130	111	123	91	72			

The value ratio table does not include all dimensions of sawn timber. Thus, for instance, the values of centre yield size 50 × 100 mm were applied also for size 44 × 100 mm. The grade D sawn timber was not priced since it has no commercial value. In principle, at least the value of sawmill chips should be given to grade D sawn timber.

Appendix 5. Form used in grading of sawn timber.

									Sijainti			Koko			
Koodi	PL	Paksuus	Leveys	Pituus	Lajittelu	Laatu	Em. pituus	Ominaisuus	Lape	Syrjä	Särmä	Koko	Määrä	Katk.syy	Lisätietoja
					Tuore-NT										
					Kuiva-NT										
					T-lujuus										
					INSTA										
Koodi	PL	Paksuus	Leveys	Pituus	Lajittelu	Laatu	Em. pituus	Ominaisuus	Lape	Syrjä	Särmä	Koko	Määrä	Katk.syy	Lisätietoja
					Tuore-NT										
					Kuiva-NT										
					T-lujuus										
					INSTA										
Koodi	PL	Paksuus	Leveys	Pituus	Lajittelu	Laatu	Em. pituus	Ominaisuus	Lape	Syrjä	Särmä	Koko	Määrä	Katk.syy	Lisätietoja
					Tuore-NT										
					Kuiva-NT										
					T-lujuus										
					INSTA										
Koodi	PL	Paksuus	Leveys	Pituus	Lajittelu	Laatu	Em. pituus	Ominaisuus	Lape	Syrjä	Särmä	Koko	Määrä	Katk.syy	Lisätietoja
					Tuore-NT										
					Kuiva-NT										
					T-lujuus										
					INSTA										
Koodi	PL	Paksuus	Leveys	Pituus	Lajittelu	Laatu	Em. pituus	Ominaisuus	Lape	Syrjä	Särmä	Koko	Määrä	Katk.syy	Lisätietoja
					Tuore-NT										
					Kuiva-NT										
					T-lujuus										
					INSTA										
Koodi	PL	Paksuus	Leveys	Pituus	Lajittelu	Laatu	Em. pituus	Ominaisuus	Lape	Syrjä	Särmä	Koko	Määrä	Katk.syy	Lisätietoja
					Tuore-NT										
					Kuiva-NT										
					T-lujuus										
					INSTA										
Koodi	PL	Paksuus	Leveys	Pituus	Lajittelu	Laatu	Em. pituus	Ominaisuus	Lape	Syrjä	Särmä	Koko	Määrä	Katk.syy	Lisätietoja
					Tuore-NT										
					Kuiva-NT										
					T-lujuus										
					INSTA										

Translation:

Koodi: code for the sawn piece
PL: tree species, spruce or pine
Paksuus: timber thickness, mm
Leveys: timber width, mm
Pituus: timber length, cm
Lajittelu: grading rules (NT green, NT dried, T-grading, NS-INSTA 142)
Laatu: grade for the sawn piece
Em. pituus: timber length corresponding to the grade
Ominaisuus: primary feature determining the grade for the sawn piece (code, see Appendix 6)
Sijainti: location of the feature (face, edge, arris)
Peruste: size or number of the feature
Katk. syy: cause for cut (code, see Appendix 6)
Lisätietoja: more information

Appendix 6. Codes for the features of sawn timber used in the study.

Code	Nordic Timber	T-grading	NS-INSTA 142	Code
11	sound knot			**11**
121	dead knot			**121**
122	loose knot/knot hole			**122**
13	bark-ringed knot			**13**
14	unsound knot			**14**
15	knot cluster		knot cluster	**15**
16	vertical knot	vertical knot	splay knot with small angle	**16**
171	arris knot		arris knot	**171**
172	edge knot	edge knot	edge knot	**172**
173	face knot	face knot	face knot	**173**
181	splay knot		splay knot	**181**
182	spike knot			**182**
19	sum of knot sizes	sum of knot sizes	sum of knot sizes	**19**
21	drying check	drying check	check	**21**
211	check, not through		check, not through	**211**
212	check, going through		check, going through	**212**
213	check, through arris		check, through arris	**213**
22	ring shake	ring shake	ring shake	**22**
23			hair surface check	**23**
24	heart shake	heart shake		**24**
25	split from crosscutting	split from crosscutting		**25**
31	bow	bow	bow	**31**
32	spring	spring	spring	**32**
33	cup	cup	cup	**33**
34	twist	twist	twist	**34**
41	resin pocket	resin pocket	resin pocket	**41**
42	bark pocket	bark pocket	rind gall	**42**
43	scar	scar		**43**
51	slope of grain	slope of grain	slope of grain	**51**
52	top rupture	top rupture	top rupture	**52**
53	compression wood	compression wood	compression wood	**53**
54	curly grain	curly grain	curly grain	**54**
61	resin wood	resin wood	resin wood	**61**
62	water stain	water stain		**62**
63	log blue stain	log blue stain		**63**
64	blue stain	blue stain	blue stain	**64**
65	mould			**65**
66	bark-brown		brown stain	**66**
67	weathering		weathering	**67**
68	insect damage	insect damage	insect damage	**68**
69	bark	bark	bark	**69**
71	dote	dote	dote	**71**
72	rot	rot	rot	**72**
73		width of annual ring	width of annual ring	**73**
74		wood density		**74**
75		latewood proportion		**75**
81	wane	wane	wane	**81**
82	handling damage		handling damage	**82**

Appendix 7. Sawn timber by dimensions in the sawing experiments.

Spruce sawn pieces					Pine sawn pieces				
thickness	width	m^3	rm, m*	pcs	thickness	width	m^3	rm, m*	pcs
22	100	5.282	2400.85	544	19	75	1.623	1139.25	285
22	115	0.572	226.2	51	19	100	0.653	343.9	78
22	125	3.437	1249.65	275	19	125	0.118	49.75	12
22	150	2.659	805.8	172	19	150	0.136	47.6	11
22	175	0.819	212.65	44	25	75	0.899	479.65	120
22	200	0.340	77.3	16	25	100	0.923	369.15	92
22	225	0.119	23.95	5	25	125	0.473	151.45	37
	Total	**13.227**	**4996.4**	**1107**	25	150	0.293	78.2	17
					25	175	0.054	12.4	3
					25	200	0.163	32.55	9
44	100	2.174	494.2	108		**Total**	**5.336**	**2703.9**	**664**
44	125	1.151	209.25	46					
44	150	1.322	200.25	44					
44	200	1.035	117.65	24	38	100	0.092	24.3	6
44	225	1.775	179.3	36	38	150	0.696	122.1	28
50	125	0.954	152.7	32	44	100	1.337	303.85	73
50	200	2.007	200.65	44	50	100	2.376	475.1	109
50	225	1.214	107.9	20	50	125	2.097	335.55	84
63	125	1.752	222.45	48	50	150	2.245	299.35	70
63	150	3.819	404.1	86	50	200	0.289	29.95	8
63	175	1.458	132.2	30	50	225	0.287	25.5	6
63	200	1.716	136.2	28	75	125	1.015	108.3	26
75	150	1.852	164.6	36	75	150	0.538	47.85	12
75	175	2.401	182.95	40	75	175	0.197	15	4
75	200	1.565	104.35	22	75	200	0.372	24.8	6
75	225	1.207	71.55	14		**Total**	**11.541**	**1811.65**	**432**
75	250	0.358	19.1	4			**16.878**	**4515.55**	**1096**
	Total	**27.760**	**3099.4**	**662**					
		40.987	**8095.8**	**1769**					

Grand total	m^3	rm, m*	pcs
	57.865	**12611.4**	**2865**

* rm = running metre

Appendix 8. Drying schedules.

Schema 2: centre yield
Schema 3: side yield

