Factors Affecting the Appearance Quality and Visual Strength Grade Distributions of Scots Pine and Norway Spruce Sawn Timber in Finland and North-Western Russia

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Abstract

Logs and center-yield sawn pieces of Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) from three regions in Finland and two regions in north-western Russia were studied for the variation in and predictability of grade distributions. Log and sawn piece properties were measured and statistical analyses conducted on the differences between geographical regions, in particular. Sawn pieces were graded for appearance quality and visual strength, according to the Nordic grading rules, into NT grades and T grades (Finnish application of INSTA 142 rules), respectively. The aim was to find out how accurately it would be possible to predict the grade yields from either the log properties or sawn timber properties using binary, or multinomial regression modeling, and, in particular, whether any regional differences remained thereafter.

The type of the log (vertical position and visual grade) was the most important single factor for both species when predicting grade yield using log properties as predictors. When sawn timber properties were used as predictors, the properties related to knots were the most substantial explanatory variables. Geographical region was not the major factor in predicting grade yield in either approach, but more evident for pine than spruce.

Multinomial regression models were used to predict both appearance quality and visual strength grade distribution. They were able to predict correctly 40-50% of the NT grade and 44-59% of the T grade in individual sawn pieces. Binary regression models were used to predict visual strength grade classes in order to have only two response categories, for example, the two highest grades compared to the two lowest grades. These models were the most accurate predicting correctly 76-83% of the dichotomous grade yield. The models predicting grade yield for pine performed better than the models for spruce.

There appeared significant differences in several log and sawn timber properties between the regions. The grade yields from the Novgorod and Vologda regions were lower than in Finland, in general. For spruce, the between-region differences in log and sawn timber properties were much smaller than for pine.

Key words: *Pinus sylvestris, Picea abies*, sawn timber, appearance grading, visual strength grading, grade yield, Finland, Russia

Introduction

Knowledge of the properties and performance of the raw material is an important factor for timber using industries. Knowledge of the properties and quality distribution of timber aimed for different purposes increases the efficiency of manufacturing and use as the raw material can be allocated to the right product segment as early as possible. Visual and machine grading of logs and sawn timber are standard procedures at sawmills. In addition to sawmills' internal grading, general grading systems have been developed to standardize the classification of timber according to visual appearance or strength (e.g., Boström 1994, Lipitsäinen 1994, Nordic Timber…1994, Lindgren 1997, SFS 2000, SFS 2003, Thelandersson 2003, Glos 2004, Hanhijärvi et al. 2005, Hanhijärvi and Ranta-Maunus 2008).

In grading for visual appearance, the size, quality, and number of knots are the main criteria; larger sound knots are usually allowed compared to dry knots (Nordic Timber… 1994). Miscellaneous technical and processing defects affect the grading as well. The knot properties are the most crucial properties decreasing the grade yield of sawn timber also in strength grading systems. The best predictors of strength are known to be density, knot area ratio, and modulus of elasticity, but these are difficult to measure in the practical sawmill environment (e.g., Lindgren 1997, Johansson 2003). The effect of the size of the board is somewhat contradictory; in all grading systems larger knots are allowed in larger sawn pieces, but the probability that defects appear increases as the size of piece is larger, according to Weibull's weakest link theory (Bodig and Jayne 1982).

Properties of Scots pine sawn timber and the factors affecting it are widely studied for grading purposes in Nordic countries (e.g., Heiskanen 1955, Kärkkäinen 1980, Uusitalo 1995, Boren 2001, Ranta-Maunus 2007). Interest in spruce, compared to pine, emerged later due to the increased use as a raw material (e.g., Asikainen and Heiskanen 1970, Lindgren 1997, Verkasalo et al. 2002, Ranta-Maunus 2007, Verkasalo et al. 2007a, Verkasalo et al. 2007b).

Log properties have become more important in predicting sawn timber quality because of their relatively strong predictive power occurred in several studies and the development of automatic log grading. Using visually or machine measured log properties as predictors were recently studied for sawn timber in Nordic softwoods, for example, by Silvén and Kauppinen 1996, Grundberg and Grönlund 1997, Ranta-Maunus 1999, Chiorescu and Grönlund 2003, Glos 2004, Hanhijärvi et al. 2005, and Hanhijärvi and Ranta-Maunus 2008. Statistical models using different factors as predictors for sawn timber grade yield were developed using logistic regression, for example, by Uusitalo (1995), Jäppinen (2000), Øvrum (2008), and Lyhykäinen et al. (2009).

Uusitalo (1995) used logistic regression in predicting log grade yield from pine logs, from southern Finland, based on Nordic Timber appearance grades (Nordic Timber… 1994). He found that the breast height diameter of the standing trees, height of the lowest dead branch, crown height, and the distance from stump to the end of the first grade butt log were important predictors in determining the proportion of the best timber grade among butt log boards.

Jäppinen (2000) studied the external geometry and other log properties of Norway spruce, in Sweden, as predictors for example Nordic Timber appearance grades and visual stress grades in sawn timber, also by using logistic regression. Log properties such as taper, sweep, and surface unevenness were measured with log scanners and used as predictors along with properties such as density, slope of grain, and knot size. Jäppinen (2000) used receiver operating curves as a measure of model accuracy reaching high classification ability in his models.

Øvrum (2008) studied the effects of timber length, forest quality, tree size, and board position on the grade yields of strength classes for spruce, in Norway, using ordinal multinomial regression. He found that strength grade yield, according to Nordic INSTA 142 rules (SFS 2000), decreased toward the top end of the tree and that this was due to the increased relative knot size in the sawn piece; whether the board was inner or outer board, it had no affect on the strength grade yield. Accordingly, positions of the board in a tree, both longitudinally and in the cross section were the most important grade yield predicting variables except for board length. Model accuracy was good when predicting grade probabilities for INSTA 142 grades within a 10-percent margin.

Lyhykäinen et al. (2009) developed models to estimate the timber grade and by-product yield from Scots pine trees using multinomial logistic regression. The study was based on both simulated and empirical stem information. The best combination of explanatory variables included tree diameter at breast height, its logarithmic transformation, and distance from the ground to the first living branch and to the first dead branch. Nordic Timber grade yields among center boards were predicted as a proportion of total merchantable stem volume.

The objective of this study was to study the variation in and predictability of grade distributions for appearance quality and visual strength in sawn timber of Scots pine and Norway spruce from Finland and north-western Russia. The aim was to find out how accurately it would be possible to predict the grade yield from either the outer features of the logs or the properties of sawn timber using binary or multinomial regression modeling, and, in particular, whether any regional differences remained thereafter.

Materials and methods

The Scots pine data consisted of 1,069 logs from three sawmills and their respective domestic wood procurement regions, Lappeenranta for south-eastern Finland, Merikarvia for western Finland, Kajaani for northern Finland, and two regions in north-western Russia; Novgorod representing southern and fertile growing conditions and Vologda representing more continental, colder, and tundra-like growing conditions. The Norway spruce data consisted of 1,162 logs from the saw mills of Kitee for south-eastern Finland, Kyröskoski for western Finland, and Iisalmi for northern Finland.

The geographical origin of spruce was similar to pine except for the Republic of Karelia replacing Novgorod in Russia. The number of logs and the number of sawn pieces in the respective dimension class are shown by species and region in Tables 1 and 2 and the geographic location of the regions in Figure 1.

Table 1. Number of Scots pine and Norway spruce logs by diameter class and number of sawn pieces by respective dimension class, by region

Scots pine						
	Diameter class of the log with bark, min top diameter, mm					
	160	175	210	280	310	
Region	Dimensions of the sawn piece, mm					
	38*100	50*100	50*150	63*200	44*200	Total
South - eastern Finland	22	22	17	44	105	210
Western Finland	22	21	22	42	108	215
Northern Finland	22	22	21	43	108	216
Novgorod, Russia	21	22	23	44	107	217
Vologda, Russia	22	22	21	44	102	211
	109	109	104	217	531	**1,069**

Norway Spruce						
	Diameter class of the log with bark, min top diameter, mm					
	155	170	205	275	305	
Region	Dimensions of the sawn piece, mm					
	38*100	50*100	50*150	63*200	44*200	Total
Eastern Finland	45	44	44	44	44	221
Western Finland	44	44	44	44	44	220
Nortehrn Finland	44	44	44	44	44	220
Vologda, Russia	44	44	44	44	44	220
Eastern Karelia, Russia	44	57	60	60	60	281
	221	223	236	236	236	**1,162**

Figure 1. Approximate sampling areas in Finland and in Russia. W-F representing western Finland, N-F for northern Finland and S-E F for south-eastern Finland

The logs were measured and cut to a length of 4.5 metres after sawing disc specimens from both ends of the log. Mean width of annual rings, proportion of latewood of the ring width, and proportion of heartwood were measured from the discs in the laboratory using binocular microscope equipped with video camera and a sliding table to which the disc was attached. Then the logs were sawn using dimensions described in Tables 1 and 2, and dried to 16-22% moisture content (dry weight basis). Several features were measured from the logs, and sawn pieces were then graded manually by an experienced grader at the Finnish Forest Research Institute (see Table 3).

Visual strength grading was performed according to the Finnish T grading (Lipitsäinen 1994), which is compatible with the EN 338 standard of strength classes and Nordic INSTA 142 grading (SFS 2000, SFS 2003). Here, each grade represents the minimum bending strength (MPa) which is obtained by indirect measurements correlated to bending strength, density, and modulus of elasticity. The visual strength grades used, in this study, were T40, T30, T24, T18, and T10 (reject), which correspond to minimum bending strengths of 40 MPa in descending order to 18 MPa. Appearance grading was performed according to Nordic Timber grading rules, called NT grading (Nordic Timber… 1994), which are used for general sorting of Nordic softwoods. Here, the main grades are A, B, C, and D (reject); grade A may be divided into four sub-grades, however, this precision was omitted in this study.

Statistical analysis and regression models were calculated using SPSS version 16.0 (SPSS 2007). Parametric and non-parametric methods were used to analyze statistically the significant differences between the regions in the measured variables. Due to the categorical nature of the response variables, multinomial regression and binary regression were chosen as methods to conduct the modeling. The grade yields in NT grading were applied for Scots pine only, using the multinomial regression technique, because the appearance grade distribution did not satisfactorily meet the requirements of modeling procedures for spruce.

Binomial regression is a form of regression used when the dependent variable has only two values, often referred to as "success" or "failure". The binomial response Y has a certain "success" probability when the explanatory variable X has a value x. The logistic regression model has a linear form for the logit of this probability (Agresti 1996).

$$LogitP(Y=1) = \pi_{ik} = \ln\left(\frac{P(Y=1)}{1-P(Y=1)}\right) = \alpha+\beta x \quad (1)$$

where *logit P(Y=1)* is the logarithm of the probability that a case falls into category, 1 (success), α is the constant, β is the coefficient of independent variable x

Alternatively, logistic regression can refer directly to the success probability (Agresti 1996).

$$P(Y=1) = \frac{\exp(\alpha+\beta x)}{1+\exp(\alpha+\beta x)} \quad (2)$$

The model produces an intercept and coefficients, which predict the logit odds of being in category 1 using category 0 as a reference category.

Multinomial regression, in turn, is an expansion of logistic regression, and can be used when the response variable has more than two categories, the number of them denoted as J. Each response category is paired with the reference category and interpreted in reference to it so that the multinomial model consists of J-1 logit equations with separate parameters for each (Agresti 1996).

For multinomial regression models, the multicategorical logit model can be expressed as the probability of the categories with some value of x (Fox 1984).

Let π_{ik} denote for the probability that the i[th] case falls into category k.

$$\pi_{ik} = \frac{\exp^{z_{ik}}}{\exp^{z_{i1}} + \exp^{z_{i2}} + ... + \exp^{z_{ik}}}$$

where z_{ik} is the value of the k[th] variable for the i[th] case

$$z_{ik} = b_{k0} + b_{k1}x_{i1} + b_{k2}x_{i2} + .. + b_{kJ}x_{ij}$$

is the general form of linear regression equation, where b_{k0} is the constant, b_{kj} is the coefficient, x_{ij} is the value of the predictive variable

The resulting coefficients of binary and multinomial regressions can also be interpreted as changes in the log odds ratio of an event occurring. Logistic regression applies the maximum likelihood method for calculating the logit coefficients and seeks to maximize the log likelihood function (Agresti 1996).

Choosing the predictive variables used in each regression was performed by likelihood ratio tests (LRT) for model fit and by assessing the significance of likelihood ratio tests for each variable. Model fit was also tested using the deviance goodness-of-fit test for multinomial regression and the Hosmer and Lemeshow test for logistic regression. (Agresti 1996).

Correlations between potential explanatory variables were examined and were at their maximum 0.387 for pine and 0.497 for spruce. The models developed are symbolized with alphabetical letters and explanatory variables with abbreviations in Table 2.

Results

Grade distributions and wood properties by region

Observed T and NT grade distributions of sawn timber are presented by region in Figure 2 for Scots pine and in Figure 3 for Norway spruce. The distributions were typically wider for pine than for spruce, in parallel with the larger variation in the wood and timber properties (see later). Furthermore, the best grades, but also the worst grades, were more common for pine than for spruce, especially in NT grading.

For pine, the best grade was notably more common in western and south-eastern Finland and notably more uncommon in the Russian regions, both in NT grading and T grading. The regional differences were generally reverse in the proportions of the worst grades. However, the worst grade was more common in NT grading in northern Finland and Vologda and less common in south-eastern Finland and Novgorod. The largest proportion occurred in western and south-eastern Finland in grade A and in Novgorod in grade B, but in northern Finland and Vologda in grade D.

For spruce, grade B was the dominant NT grade in all regions the proportion being the largest in western Finland and the lowest in south-eastern Finland. However, grade A was also the most common in south-eastern Finland, in addition to Vologda, whereas its proportion was low in western Finland, in addition to the Republic of Karelia. The proportion of grade D was very low in northern Finland. In T grading, the best grade was the most common in Vologda and northern Finland and the least common in south-eastern Finland. The worst grade was the most common in the Republic of Karelia and the least common in northern and western Finland.

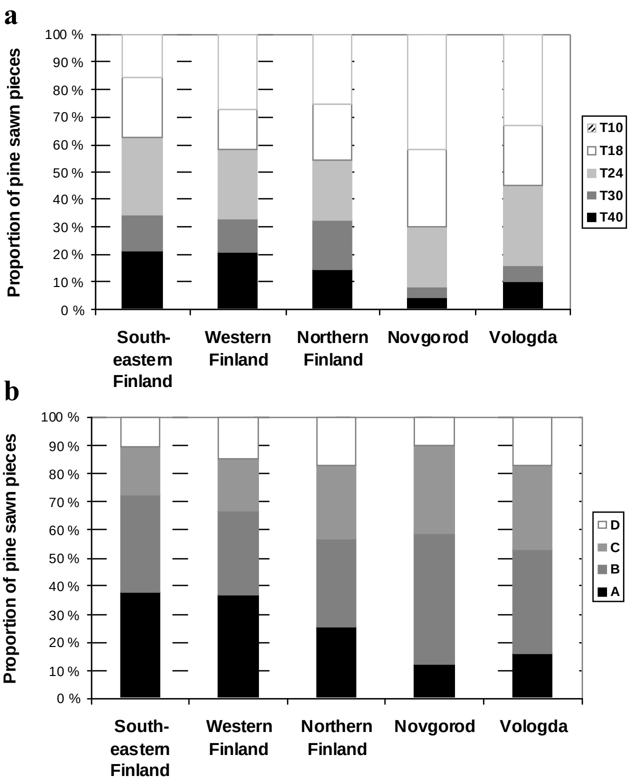

Figure 2. Observed visual strength grade (T grading) distributions left, and appearance quality distributions (NT grading) right for Scots pine by region

Table 2. Symbols of variables and abbreviations used in the text

Models	
A	Multinomial regression model for Scots pine using log properties as explanatory variables predicting visual strength
B	Multinomial regression model for Scots pine using log properties as explanatory variables predicting appearance quality
C	Multinomial regression model for Scots pine using sawn timber properties as explanatory variables predicting visual strength
D	Multinomial regression model for Scots pine using sawn timber properties as explanatory variables predicting appearance quality
E	Binary regression model for visual strength of Scots pine using log properties as explanatory variables where response categories are T40 and T30 vs. other
F	Binary regression model for visual strength of Scots pine using log properties as explanatory variables where response categories are T40,T30 and T24 vs. other
G	Binary regression model for visual strength of Scots pine using sawn timber properties as explanatory variables where response categories are T40 and T30 vs. other
H	Binary regression model for visual strength of Scots pine using sawn timber properties as explanatory variables where response categories are T40, T30 and T24vs. other
I	Multinomial regression model for Norway spruce using log properties as explanatory variables predicting visual strength
J	Multinomial regression model for Norway spruce using sawn timber properties as explanatory variables predicting visual strength
K	Binary regression model for visual strength of Norway spruce using log properties explanatory variables where response categories are T30 and T24 vs. other
L	Binary regression model for visual strength of Norway spruce using sawn timber properties as explanatory variables where response categories are T30 and T24 vs. other
Variables	
LSK	Mean diameter of the largest sound knot on the log or sawn piece (depending on the model), mm
LDK	Mean diameter of the largest dry knot on the log or sawn piece (depending on the model), mm
LK	Mean diameter of the largest knot on the outer face of the sawn piece, mm
SKper1m	Mean number of sound knots on one meter lengths of sawn piece.
DKper1m	Mean number of dry knots on one meter lengths of sawn piece.
SmallKper1m	Mean number of small knots (<8 mm) on one meter lengths of sawn piece.
AnnRing	Mean annual ring width, 1/100 mm
LateW	Proportion of latewood of the annual ring width on the sawn disc, %
HeartW	Proportion of heartwood of the cross section of the sawn disc, %
TopD	Top diameter of the 4,5 m log, mm
ResinP	Mean number of resin pockets on one meter lengths of sawn piece.
S-E F	Region south - eastern Finland (Lappeenranta sawmill)
W-F	Region western - Finland (Merikarvia sawmill)
N-F	Region northern - Finland (Kajaani sawmill)
Nov	Region Novgorod in north - western Russia
Vologda	Region Vologda in north - western Russia
RofK	Region Republic of Karelia in north - western Russia
Log type for pine	
	1 High quality butt log
	2 Lower quality butt log
	3 Upper log
Log type for spruce	
	1 High quality butt log
	2 Normal quality upper log
	3 Lower - quality butt log
	4 Lower - quality upper log

a b

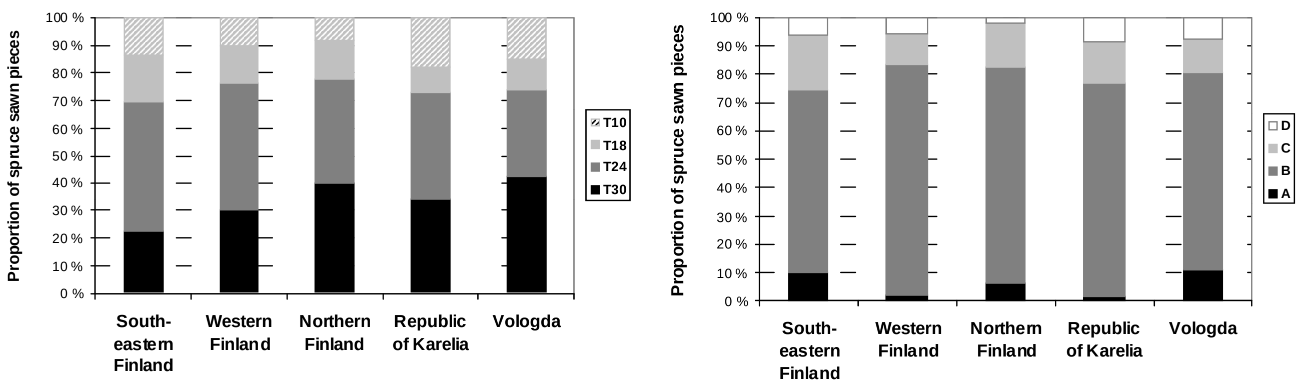

Figure 3. Observed visual strength grade (T grading) distributions left, and appearance quality distributions (NT grading) right for Norway spruce by region

For **pine**, of the potentially important log properties, the diameters of the largest sound and dry or rotten knots were larger in Novgorod compared to the other regions. The sizes of the largest knots were rather homogeneous in the other regions, except for northern Finland where the dry knot was smaller (Table 3). The annual rings were, on average, wider in Russia compared to Finland, and in northern Finland narrower than in the other regions. Also, the proportion of latewood was the largest in northern Finland, and the lowest in Novgorod, but there were no differences between western Finland and Vologda.

All in all, based on external evaluation, the high-quality butt logs were the most common in south-eastern Finland and western Finland and the least common in Novgorod (Fig. 4). In this study, the butt logs covered 63-76% of the data in Finland and 86-92% in Russia.

Of the potentially important sawn timber properties, the largest sound knot was thicker in diameter in Russia compared to Finland. Otherwise, the dry knot was smaller in western and south-eastern Finland compared to the other regions. Sawn from butt logs, the largest dry knot was thicker in diameter in Novgorod, Vologda, and northern Finland in comparison with western and south-eastern Finland. The mean number of sound knots per one meter was larger in Novgorod compared to the other regions. The number of dry knots was larger in northern Finland compared to the other regions, and in western and south-eastern Finland compared to Novgorod and Vologda (Table 3).

For **spruce**, of the potentially important log properties, the largest sound knot was larger in western Finland compared to Vologda and south-eastern Finland. The dry or rotten knot was smaller in northern Finland compared to the other regions, and in south-eastern Finland smaller than in Russia. The annual rings were narrower in northern Finland and Vologda in comparison with the other regions and the widest in south-eastern Finland. Furthermore, the latewood proportion was the largest in south-eastern Finland and smallest in Vologda. On the other hand, the proportion of heartwood was smaller in south-eastern Finland compared to the other regions and smaller in western Finland compared to Russia (Table 4).

All in all, high quality butt logs were the most common in the Republic of Karelia and the least common in south-eastern Finland. However, of the butt logs, the percentage of high quality butt logs was the largest in south-eastern Finland and the smallest in northern Finland. In the data, the butt logs covered 41-61% by region, the percentage being the largest in northern Finland and the Republic of Karelia, and the smallest in south-eastern Finland. Of the upper logs, the normal-quality covered 84-89% in Finland and 80% in Russia (Fig. 4).

Table 3. Means and standard deviations (in parenthesis), or medians and 25- and 75 percentiles of selected log and sawn timber properties for Scots pine. Appearance of a variable denotes the percentage of individual logs or sawn pieces where the variable is present. See Table 2 for abbreviations

Scots pine	South-eastern Finland	Western Finland	Northern Finland	Novgorod	Vologda
LSK on the log, mm	37.25 (11.24)	42.32 (11.86)	41.91 (11.81)	48.35 (10.61)	41.65 (11.29)
Appearance of LSK. %	28,1	23,1	20,3	21,2	9,7
LDK on the log, mm	28.35 (9.59)	27.16 (10.2)	25.67 (10.04)	35.76 (12.85)	31.14 (10.44)
Appearance of LDK. %	62.9	71.4	81.1	87.6	78.3
AnnRing, 1/100 mm	169.25 (45.51)	162.56 (40.00)	140.76 (32.14)	186.60 (45.02)	192.09 (54.54)
LateW, %	30.28 (3.87)	26.00 (3.26)	36.98 (4.22)	24.77 (3.22)	27.29 (6.16)
HeartW, %	59.84 (9.02)	64.85 (10.07)	61.45 (8.68)	70.44 (7.05)	67.68 (7.27)
SK, mm	35.76 (16.79)	33.45 (15.94)	35.03 (17.23)	44.47 (21.36)	42.14 (16.41)
Appearance of SK. %	70	67.6	78.3	82.7	76.2
DK, mm	18	17	21	26	23
25 percentile	13	11	14	17	13
75 percentile	27	25	34	37	36
LK, mm	28	27	32	40.5	39
25 percentile	19	17	21	32	25
75 percentile	42	40	46	54	50
SmallKper1m, Nr	0.556	0.667	1	0.333	0.444
25 percentile	0.11	0.33	0.33	0.11	0.11
75 percentile	1	1.222	1.667	0.667	0.778
SKper1m, Nr	2.21 (1.27)	2.26 (1.45)	2.59 (1.20)	2.70 (1.16)	2.31 (1.15)
DKper1m, Nr	1.42 (0.841)	1.5 (0.742)	1.92 (0.927)	1.1 (0.77)	1.06 (0.70)

Of the potentially important sawn timber properties, there were no differences in the diameter of the largest knots on the outer faces. However, the number of sound knots per meter was larger in south-eastern Finland and smaller in the Vologda region compared to the other regions. There appeared more dry knots per one meter in sawn pieces from northern Finland and less in sawn pieces from south-eastern Finland in comparison with Vologda. However, there were more knots smaller than 5 mm in sawn pieces from Vologda compared to the other regions. Resin pockets were more common in sawn pieces from northern Finland compared to the other regions (Table 4).

Factors in the models for grade distributions

For **Scots pine**, in multinomial and binary regressions analyses on the visual strength grade and appearance grade yield based on the log properties, the largest dry knot had the greatest contribution to the model. Log type was another important predictor influencing toward better grades when the sawn piece was sawn from the butt log compared to the upper log, in general. When the

Table 4. Means and standard deviations (in parenthesis), or medians and 25- and 75 percentiles of selected log and sawn timber properties for Norway spruce. Appearance of a variable denotes the percentage of individual logs or sawn pieces where the variable is present. See Table 2 for abbreviations

Norway spruce	South-eastern Finland	Western Finland	Northern Finland	Republic of Karelia	Vologda
LSK on the log, mm	25.51 (7.07)	30.27 (7.48)	27.84 (8.08)	28.07 (8.42)	26.09 (7.84)
Appearance of LSK. %	79	80.2	86	57.2	49
LDK on the log, mm	17.22 (5.72)	18.49 (5.67)	14.61 (4.45)	19.22 (6.00)	20.35 (7.61)
Appearance of LDK. %	90	9806	98.1	97.8	97.6
AnnRing, 1/100 mm	229.73 (63.77)	204.92 (64.71)	145.02 (57.34)	178.06 (59.12)	149.2 (53.71)
LateW, %	29.35 (5.00)	25.98 (5.66)	24.19 (2.86)	23.6 (4.44)	22.33 (2.86)
HeartW, %	66.16 (6.99)	68.24 (6.83)	69.2 (8.1)	70.74 (9.5)	72.22 (15.3)
SK, mm	26.65 (10.63)	26.81(14.3)	24.01 (13.4)	23.86 (16.51)	23.41 (14.73)
Appearance of SK. %	95.8	93.5	90.6	89.8	82.6
DK, mm	14.78 (10.04)	15.52 (8.14)	17.03 (8.25)	15.92 (11.87)	17.28 (11.62)
Appearance of DK. %	84.8	94	97.6	95.4	94
LK, mm	28.29 (9.33)	28.69 (12.61)	26.62 (11.61)	26.81 (13.96)	27.44 (13.16)
SmallKper1m, Nr	3.83 (2.18)	3.77 (2.24)	4.15 (2.41)	3.93 (2.04)	3.06 (2.06)
SKper1m, Nr	4.32 (2.64)	3.79 (2.27)	3.73 (2.6)	3.85 (2.55)	3.17 (2.04)
Appearance of SK	91	93.5	90.6	89.8	82.6
DKper1m, Nr	2.11 (1.75)	2.13 (1.43)	2.8 (1.62)	2.4 (1.67)	2.56 (1.78)
Appearance of DK	84.4	94	97.6	95.4	94
ResinP, Nr	0.222	0.222	0.222	0.222	0.222
25 percentile	0	0	0	0	0
75 percentile	0.444	0.667	0.667	0.444	0.667
Appearance of ResinP	51	54.5	67	60	53

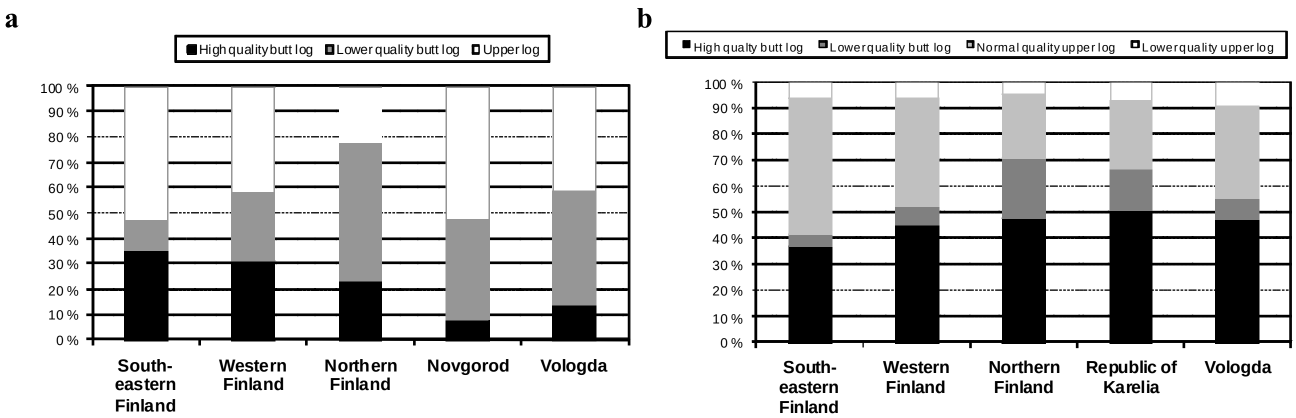

Figure 4. Log grade distributions of Scots pine left, and Norway spruce right by region

region was concerned, the log origin from Novgorod seemed to increase the probability of a lower grade when compared to Vologda, and the log origin from Finland decreased the probability, in general. The increasing diameter of the largest dry or rotten knot and sound knot increased probability toward a lower grade, while an increase in the latewood proportion had an opposite effect. All regions did not appear to be significant predictors in all analyses (Tables 5-6).

When grade yields were predicted using sawn timber properties as predictors, the diameter of the largest knot, number of knots per one meter, and the dimensions of the sawn piece related to log diameter contributed the most to the analysis. When the diameter of the largest knot and number of sound knots per one meter increased, the probability toward a lower grade grew, while the number of dry knots influenced toward a higher grade. The effects of the dimensions of the sawn piece were somewhat varying; pieces of 63*200 mm sawn from 275-304 mm logs using 2 EXLOG setup generally seemed to have a lower probability toward a lower grade than the pieces of 44*200 mm sawn from over 305 mm logs using 4 EXLOG setup. This could be probably due to the fact that the sawn piece can be either the first or the second piece from the core while in dimension 63*200 only two pieces are sawn from both sides of the core (Tables 7-8).

According to binary regression analysis, the increase of the annual ring width and latewood proportion influenced toward higher grades. Instead, when the proportion of heartwood increased the probability toward lower classes grew. When the region appeared significant, the log origin from Vologda seemed to increase the probability toward lower grades, in general (Table 9).

For **Norway spruce,** there appeared more significant predictors for the visual strength grade distributions compared to Scots pine. Moreover, no significant predictor emerged to contribute to the model more clearly than the others**.** Regarding log properties, lower quality upper logs had a higher probability toward lower grades than other logs. The increase of diameter of the largest sound and dry or rotten knot had a similar effect. There also occurred a weak increase in the probability toward a lower grade, as the annual ring width and the top diameter increased. Region was not a significant predictor in multinomial regressions in all paired models, according to the Wald tests. However, they indicated a higher probability of grade T18 in south-eastern Finland and northern-Finland than in Vologda (Tables 10 and 12).

Several predictors appeared significant when sawn timber properties were used as independent variables in multinomial and binary regression analyses. The diameter of the largest sound knot, followed by the dimension of the sawn piece, came forth to contribute the most to the grade distributions. The number

Table 5. Model A: Parameters for multinomial regression models for Scots pine where visual strength grades are predicted from log properties. See Table 2 for abbreviations

Model A					
T10/T40	**B**	**S.E.**	**Wald**	**d.f**	**Sig.**
Intercept	-1,585	0,462	11,762	1	0,001
LSK	0,031	0,015	4,424	1	0,035
LDK	0,161	0,013	151,346	1	0,000
Region					
S-E F	-1,342	0,353	14,449	1	0,000
W-F	-0,727	0,326	4,969	1	0,026
N-F	-0,716	0,335	4,584	1	0,032
Nov	0,687	0,404	2,898	1	0,089
Vologda	Reference category				
Log type					
Log 1	0,600	0,434	1,917	1	0,166
Log 2	-0,822	0,369	4,971	1	0,026
Log 3	Reference category				
T18/T40					
Intercept	0,164	0,439	0,140	1	0,708
LSK	0,230	0,015	2,430	1	0,119
LDK	0,108	0,013	72,424	1	0,000
Region					
S-E F	-0,690	0,354	3,799	1	0,051
W-F	-0,989	0,351	7,936	1	0,005
N-F	-0,374	0,35	1,142	1	0,285
Nov	0,924	0,412	5,023	1	0,025
Vologda	Reference category				
Log type					
Log 1	-2,699	0,498	29,382	1	0,000
Log 2	-1,552	0,365	18,075	1	0,000
Log 3	Reference category				
T24/T40					
Intercept	1,338	0,397	11,353	1	0,001
LSK	0,001	0,015	0,002	1	0,960
LDK	0,069	0,012	34,005	1	0,000
Region					
S-E F	-0,513	0,312	2,708	1	0,100
W-F	-0,713	0,305	5,456	1	0,019
N-F	-0,564	0,316	3,184	1	0,569
Nov	0,543	0,389	1,943	1	0,163
Vologda	Reference category				
Log type					
Log 1	-1,807	0,373	23,507	1	0,000
Log 2	-1,212	0,351	11,933	1	0,001
Log 3	Reference category				
T30/T40					
Intercept	-0,136	0,483	0,079	1	0,778
LSK	0,011	0,017	0,43	1	0,512
LDK	0,011	0,013	0,724	1	0,395
Region					
S-E F	0,49	0,387	1,605	1	0,205
W-F	0,328	0,328	0,736	1	0,391
N-F	0,804	0,378	4,518	1	0,034
Nov	0,346	0,512	0,458	1	0,499
Vologda	Reference category				
Log type					
Log 1	-1,277	0,408	8,901	1	0,003
Log 2	-0,125	0,407	0,095	1	0,758
Log 3	Reference category				

Table 6. Model B: Parameters for multinomial regression models for Scots pine where appearance grades are predicted from log properties. See Table 2 for abbreviations

Model B					
A/B	B	S.E.	Wald	d.f	Sig.
Intercept	0,978	0,771	1,607	1	0,205
LDK	0,048	0,009	26,750	1	0,000
TopD	0,007	0,002	13,209	1	0,000
LateW	-0,073	0,022	10,910	1	0,001
Region					
S-E F	-0,771	0,291	7,000	1	0,008
W-F	-1,170	0,278	17,659	1	0,000
N-F	0,353	0,334	1,117	1	0,291
Nov	0,118	0,312	0,144	1	0,705
Vologda	Reference category				
Log type					
Log 1	-0,980	0,370	7,010	1	0,008
Log 2	-1,009	0,263	14,723	1	0,000
Log 3	Reference category				
A/C					
Intercept	-1,74	0,869	4,01	1	0,045
LDK	0,059	0,01	34,895	1	0,000
TopD	0,016	0,002	56,822	1	0,000
LateW	-0,079	0,025	10,279	1	0,001
Region					
S-E F	-0,924	0,338	7,467	1	0,006
W-F	-1,471	0,311	22,397	1	0,000
N-F	0,481	0,370	1,687	1	0,194
Nov	-0,054	0,334	0,026	1	0,871
Vologda	Reference category				
Log type					
Log 1	-1,621	0,416	15,221	1	0,000
Log 2	-1,316	0,284	21,517	1	0,000
Log 3	Reference category				
A/D					
Intercept	-1,894	0,970	3,585	1	0,058
LDK	0,092	0,012	57,750	1	0,000
TopD	0,009	0,002	12,874	1	0,000
LateW	-0,084	0,027	9,256	1	0,002
Region					
S-E F	-0,777	0,375	4,290	1	0,038
W-F	-1,022	0,335	9,338	1	0,002
N-F	0,547	0,408	1,799	1	0,180
Nov	-0,795	0,387	4,214	1	0,040
Vologda	Reference category				
Log type					
Log 1	0,540	0,505	1,144	1	0,285
Log 2	-0,237	0,323	0,538	1	0,463
Log 3	Reference category				

Table 7. Model C: Parameters for multinomial regression models for Scots pine where visual strength grades are predicted from sawn timber properties. See Table 2 for abbreviations

Model C					
T10/T40	B	S.E.	Wald	d.f	Sig.
Intercept	-4,143	1,078	14,768	1	0,000
SKper1m	1,674	0,123	184,620	1	0,000
DKper1m	-0,489	0,146	11,268	1	0,001
LateW	-0,143	0,019	56,254	1	0,000
HeartW	0,113	0,014	69,267	1	0,000
Dimensions of sawn piece					
38*100	-0,607	0,501	1,464	1	0,226
50*100	-0,622	0,493	1,594	1	0,207
50*150	-1,480	0,416	12,677	1	0,000
63*200	-1,985	0,277	51,470	1	0,000
44*200	Reference category				
T18/T40					
Intercept	-4,921	1,091	20,346	1	0,000
SKper1m	1,571	0,125	157,569	1	0,000
DKper1m	-0,582	0,151	14,958	1	0,000
LateW	-0,106	1,019	30,494	1	0,000
HeartW	0.104	0.014	58.833	1	0.000
Dimensions of sawn piece					
38*100	0,167	0,501	0,111	1	0,739
50*100	0,530	0,481	1,215	1	0,270
50*150	-0,677	0,413	2,694	1	0,101
63*200	-1,405	0,283	24,661	1	0,000
44*200	Reference category				
T24/T40					
Intercept	-4,931	1,011	23,787	1	0,000
SKper1m	1,214	0,119	103,243	1	0,000
DKper1m	-0,006	0,137	0,002	1	0,966
LateW	-0,09	0,018	25,804	1	0,000
HeartW	0,098	0,013	58,607	1	0,000
Dimensions of sawn piece					
38*100	0,763	0,486	2,466	1	0,116
50*100	0,938	0,464	4,078	1	0,043
50*150	0,191	0,377	0,258	1	0,611
63*200	-1,042	0,262	15,758	1	0,000
44*200	Reference category				
T30/T40					
Intercept	-4,6	1,102	17,413	1	0,000
SKper1m	0,701	0,132	28,059	1	0,000
DKper1m	0,628	0,152	17,064	1	0,000
LateW	-0,034	0,02	2,997	1	0,083
HeartW	0,046	0,014	11,061	1	0,001
Dimensions of sawn piece					
38*100	0,755	0,564	1,791	1	0,181
50*100	1,421	0,493	8,289	1	0,004
50*150	0,761	0,414	3,368	1	0,066
63*200	-0,038	0,289	0,017	1	0,896
44*200	Reference category				

of sound knots per one meter, in general, increased the probability toward a lower grade. On the other hand, the number of knots smaller than 5 mm indicated a better strength grade in multinomial regression analysis because the dry knots were then smaller. Sawn timber dimensions of 50*150 and 63*200 seemed to have a lower probability toward a lower grade compared to the reference dimension 44*200. Annual ring width, latewood proportion, or the diameter of the largest dry knot did not appear to be strong predictors. Region had no significance except for the higher probability of T10 versus T30 in the Republic of Karelia, and T18 and T24 versus T30 in south-eastern Finland, both compared to Vologda (Tables 11-12).

Performance of the models for grade distributions

For **Scots pine**, the overall classification ability of the multinomial regression models for individual sawn pieces was 40-50%. For visual strength grading, the highest and lowest strength classes were classified with the best performance with the correct prediction

Table 8. Model D: Parameters for multinomial regression models for Scots pine where appearance grades are predicted from sawn timber properties. See Table 2 for abbreviations

Model D					
A/B	B	S.E.	Wald	d.f	Sig.
Intercept	0,113	0,371	0,093	1	0,761
DKper1m	0,070	0,124	0,322	1	0,570
LK	0,018	0,005	15,435	1	0,000
Dimensions of sawn piece					
38*100	0,526	0,338	2,418	1	0,120
50*100	-0,530	0,301	3,107	1	0,078
50*150	0,549	0,384	2,051	1	0,152
63*200	-0,080	0,211	0,142	1	0,706
44*200	Reference category				
Region					
S-E Fin	-0,874	0,278	9,861	1	0,002
W-F	-1,072	0,295	13,173	1	0,000
N-F	-0,634	0,311	4,160	1	0,041
Nov	0,127	0,316	0,161	1	0,688
Vologda	Reference category				
A/C					
Intercept	0,294	0,388	0,572	1	0,450
DKper1m	0,178	0,133	1,794	1	0,180
LK	0,014	0,005	8,196	1	0,004
Dimensions					
38*100	0,026	0,382	0,004	1	0,947
50*100	-2,029	0,484	17,560	1	0,000
50*150	0,438	0,405	1,173	1	0,279
63*200	-0,343	0,226	2,292	1	0,130
44*200	Reference category				
Region					
S-E Fin	-1,526	0,305	25,017	1	0,000
W-F	-1,561	0,316	24,318	1	0,000
N-F	-0,883	0,323	7,457	1	0,006
Nov	0,001	0,325	0,000	1	0,998
Vologda	Reference category				
A/D					
Intercept	0,347	0,424	0,669	1	0,413
DKper1m	-0,234	0,156	2,261	1	0,133
LK	0,016	0,005	8,908	1	0,003
Dimensions					
38*100	-0,584	0,444	1,725	1	0,189
50*100	-2,172	0,534	16,559	1	0,000
50*150	-0,653	0,536	1,485	1	0,223
63*200	-0,978	0,282	11,989	1	0,001
44*200	Reference category				
Region					
S-E Fin	-1,215	0,349	12,098	1	0,001
W-F	-0,827	0,342	5,863	1	0,015
N-F	-0,368	0,363	1,030	1	0,310
Nov	-0,542	0,388	1,957	1	0,162
Vologda	Reference category				

of 62-63%, while for the other classes only 13-46% of the predictions were correct. There appeared no major difference in the accuracy whether the log properties or sawn timber properties were used as predictors. For appearance grading, the two best classes (A and B) were classified correctly for 51-69% of the sawn pieces while only 3-41% for the other two lower classes were classified correctly (Table 13).

Table 9. Parameters of binary regression models for Scots pine. Model E denotes combined strength grades T40 and T30 against lower classes predicted from log properties and model F denotes combined T40, T30, and T24 grades, respectively. Model G denotes combined T40 and T30 grades against lower classes predicted from sawn timber properties and model H denotes combines T40, T30, and T24, respectively. See Table 2 for abbreviations

Model E	B	S.E.	Wald	df	Sig
Intercept	-3,1	0,753	16,966	1	0,000
LDK	-0,093	0,010	84,926	1	0,000
LateW	0,079	0,024	11,192	1	0,001
Log type			14,634	2	0,001
1	0,729	0,315	5,366	1	0,210
2	1,049	0,274	14,608	1	0,000
3	Reference category				
Region			27,393	4	0,000
S-E Fin	0,963	0,316	9,286	1	0,002
W-F	1,115	0,296	14,185	1	0,000
N-F	0,288	0,345	0,697	1	0,404
Nov	-0,307	0,365	0,704	1	0,401
Vologda	Reference category				
Model F	**B**	**S.E.**	**Wald**	**df**	**Sig**
Intercept	1,306	0,860	2,306	1	0,129
LSK	-0,24	0,006	17,82	1	0,000
LDK	-0,700	0,006	133,756	1	0,000
LateW	0,056	0,190	8.260	1	0,004
HeartW	-0,019	0,009	4,092	1	0,043
Region			9,788	4	0,440
S-E Fin	0,346	0,276	1,569	1	0,210
W-F	0,349	0,239	2,145	1	0,143
N-F	-0,347	0,299	1,345	1	0,246
Nov	-0,156	0,242	0,418	1	0,518
Vologda	Reference category				
Model G	**B**	**S.E.**	**Wald**	**df**	**Sig**
Intercept	5,843	1,488	15,427	1	0,000
SKper1m	-0,512	0,120	18,322	1	0,000
DKper1m	0,407	0,151	7,294	1	0,007
AnnRing	-0,009	0,003	7,140	1	0,008
LateW	0,062	0,02	9,818	1	0,002
HeartW	-0,066	0,014	21,265	1	0,000
LK	-0,106	0,012	74,733	1	0,000
Dimensions of sawn piece			36,291	4	0,000
38*100	-1,343	0,505	7,078	1	0,008
50*100	-0,808	0,453	3,179	1	0,075
50*150	0,312	0,412	0,572	1	0,449
63*200	1,111	0,281	15,69	1	0,000
44*200	Reference category				
Model H	**B**	**S.E.**	**Wald**	**df**	**Sig**
Intercept	3,52	1,163	9,158	1	0,002
SKper1m	-0,441	0,082	28,845	1	0,000
DKper1m	0,306	0,116	6,952	1	0,008
AnnRing	-0,005	0,002	4,626	1	0,031
LateW	0,039	0,15	6,828	1	0,009
HeartW	-0,028	0,011	7,152	1	0,007
LK	-0,049	0,007	57,426	1	0,000
Dimensions of sawn piece			29,081	4	0,000
38*100	0,016	0,331	0,002	1	0,962
50*100	0,294	0,323	0,831	1	0,362
50*150	1,104	0,311	12,642	1	0,000
63*200	0,938	0,221	18,033	1	0,000
44*200	Reference category				

Table 10. Model I: Parameters for multinomial regression models for Norway spruce where visual strength grades are predicted from log properties. See Table 2 for abbreviations

Model I	B	S.E.	Wald	df	Sig
T10/T30					
Intercept	-3.166	0,961	10,860	1	0,001
LSK	0,006	0,008	0,584	1	0,445
LDK	0,065	0,015	17.788	1	0,000
AnnRing	0,009	0,002	22.025	1	0,000
LateW	0,009	0,021	0,172	1	0,678
TopD	0,004	0,002	3.044	1	0,081
Log type					
1	-1.829	0,437	17.545	1	0,000
2	-1.446	0,436	10.998	1	0,001
3	-1.233	0,480	6.598	1	0,010
4	Reference category				
Region					
S-E Fin	-0,010	0,407	0,001	1	0,981
W-F	-0,543	0,368	2.177	1	0,140
N-F	-0,229	0,366	0,386	1	0,534
RofK	0,181	0,277	0,426	1	0,514
Vologda	Reference category				
T18/T30					
Intercept	-3.814	1,110	11.808	1	0,001
LSK	0,048	0,009	26.788	1	0,000
LDK	0,08	0,017	23.018	1	0,000
AnnRing	0,009	0,002	24,700	1	0,000
LateW	-0,096	0,025	14.887	1	0,000
TopD	0,006	0,002	5.691	1	0,017
Log type					
1	-1.639	0,465	12.408	1	0,000
2	-0,572	0,444	1,660	1	0,198
3	-1.422	0,527	7.281	1	0,007
4	Reference category				
Region					
S-E Fin	1.102	0,429	6,590	1	0,010
W-F	0,091	0,384	0,056	1	0,813
N-F	0,646	0,386	2.795	1	0,095
RofK	-0,114	0,347	0,109	1	0,742
Vologda	Reference category				
T24/T30					
Intercept	-0,429	0,713	0,362	1	0,547
LSK	0,021	0,006	12.352	1	0,000
LDK	0,053	0,012	19	1	0,000
AnnRing	0,008	0,001	30.473	1	0,000
LateW	-0,015	0,015	1.055	1	0,304
TopD	-0,003	0,001	5,46	1	0,019
Log type					
1	-0,991	0,391	6.425	1	0,011
2	-0,149	0,388	0,148	1	0,700
3	-0,945	0,431	4.811	1	0,028
4	Reference category				
Region					
S-E Fin	0,488	0,304	2,58	1	0,108
W-F	0,147	0,265	0,307	1	0,580
N-F	0,457	0,255	3.203	1	0,074
RofK	0,349	0,224	2.428	1	0,119
Vologda	Reference category				

The classification ability of the binary regression models was determined using the probability of 0.5 as a cut-off value. The joined visual strength grades of two or three best classes could be predicted moder-

Table 11. Model J: Parameters for multinomial regression models for Norway spruce where visual strength grades are predicted from sawn timber properties. See Table 2 for abbreviations

Model J	B	S.E.	Wald	df	Sig
T10/T30					
Intercept	-2.772	0,700	15,68	1	0,000
SmallKperM	-0,394	0,056	49.787	1	0,000
LSK	0,085	0,01	69.159	1	0,000
LDK	0,033	0,009	13.919	1	0,000
AnnRing	0,004	0,002	4.571	1	0,033
LateW	-0,011	0,021	0,291	1	0,590
SKper1m	0,254	0,057	19.784	1	0,000
Dimensions					
38*100	0,612	0,412	2.204	1	0,138
50*100	-0,542	0,368	2.164	1	0,141
50*150	-0,339	0,320	1.124	1	0,289
63*200	-2.786	0,317	77.259	1	0,000
44*200	Reference category				
Region					
S-E Fin	0,149	0,393	0,144	1	0,704
W-F	-0,231	0,343	0,454	1	0,500
N-F	-0,25	0,32	0,613	1	0,434
RofK	0,666	0,292	0,5178	1	0,023
Vologda	Reference category				
T30/T18					
Intercept	-1.136	0,784	2.103	1	0,015
SmallKperM	-0,259	0,053	23.698	1	0,000
LSK	0,113	0,010	122.014	1	0,000
LDK	-0,022	0,013	2.831	1	0,092
AnnRing	0,006	0,002	9.164	1	0,002
LateW	-0,104	0,024	19.328	1	0,000
SKper1m	0,172	0,057	9.213	1	0,002
Dimensions					
38*100	0,080	0,461	0,030	1	0,863
50*100	-0,781	0,385	4.114	1	0,043
50*150	-2.025	0,537	14.213	1	0,000
63*200	-3.259	0,357	83.176	1	0,000
44*200	Reference category				
Region					
S-E Fin	1.184	0,395	8.959	1	0,003
W-F	0,446	0,343	1.693	1	0,193
N-F	0,493	0,321	2,36	1	0,124
RofK	0,182	0,335	0,295	1	0,587
Vologda	Reference category				
T30/T24					
Intercept	-1.507	0,544	7.682	1	0,006
SmallKperM	-0,236	0,039	36.244	1	0,000
LSK	0,073	0,008	75.153	1	0,000
LDK	0,001	0,009	0,011	1	0,917
AnnRing	0,004	0,002	5.088	1	0,024
LateW	-0,016	0,015	1.083	1	0,298
SKper1m	0,246	0,046	28,52	1	0,000
Dimensions					
38*100	1.277	0,294	18.803	1	0,000
50*100	0,017	0,247	0,005	1	0,945
50*150	-0,549	0,251	4.783	1	0,029
63*200	-1.891	0,203	86.974	1	0,000
44*200	Reference category				
Region					
S-E Fin	0,675	0,301	5.027	1	0,025
W-F	0,407	0,256	2.524	1	0,112
N-F	0,331	0,231	2.057	1	0,152
RofK	0,287	0,24	1.432	1	0,231
Vologda	Reference category				

Table 12. Parameters of binary regression models for Norway spruce. Model K denotes combined strength grades T30 and T24 against lower classes predicted from log properties and model L denotes combined T30 and T24 grades predicted from sawn timber properties, respectively. See Table 2 for abbreviations

Model K	B	S.E.	Wald	df	Sig
Intercept	2,984	0,664	20,183	1	0,000
LDK	-0,039	0,011	13,210	1	0,000
AnnRing	-0,004	0,001	12,489	1	0,000
LateW	0,023	0,014	2,611	1	0,106
TopD	-0,007	0,002	19,110	1	0,000
Log type			24,096	3	0,000
1	1,273	0,269	22,412	1	0,000
2	0,900	0,269	11,205	1	0,001
3	0,782	0,313	6,222	1	0,013
4	Reference category				
Model L					
Intercept	1,18	0,436	7,319	1	0,007
LSK	-0,05	0,007	54,105	1	0,000
LateW	0,034	0,015	5,031	1	0,025
ResinP	-0,233	0,105	4,952	1	0,026
Dimensions of sawn piece			50,715	4	0,000
38*100	0,714	0,306	5,438	1	0,020
50*100	0,642	0,287	5,019	1	0,025
50*150	0,631	0,296	4,533	1	0,033
63*200	1,8	0,267	45,4	1	0,000
44*200	Reference category				

ately well using both log and sawn timber properties as predictors; then, overall 75% of sawn pieces were classified correctly (Table 13).

For **Norway spruce**, the overall classification ability of the multinomial regression models for visual strength grades was 52-58%. The two best classes (T30 and T24) were predicted correctly for 62-73% of individual sawn pieces while the two lower classes for only 5-26% of sawn pieces. The classification ability of the multinomial models was weaker for spruce than for pine, although the overall classification ability was satisfactory (over 76%). Then, most of the sawn pieces in the two weakest strength classes were predicted incorrectly into the two best strength classes, thus, including most of the sawn pieces (Table 14).

In the binary regression models, the improvement in the classification ability is expressed as the difference in the classification ability to the final model from the model where all sawn pieces were classified in the modal class. This improvement was 8-28% for pine, but less than 5% for spruce. This indicated a weaker predicting ability for spruce when using selected predictive variables that can be measured or evaluated in the morphology of logs or sawn pieces.

The accuracy of the multinomial regression models is presented for pine in Table 15 as the absolute difference between the observed category distribution (%) and the predicted mean response category probability (%) for both visual strength class models and appearance quality class models. For spruce, the accuracy for the visual strength class models by response grade is presented in Table 16, respectively.

Table 13. Classification ability based on the percentage of correctly classified sawn pieces in each grade and Nagelkerke's R^2 for Scots pine models in visual strength grading (T grades) and appearance grading (NT grades)

Multinomial regression models							
T grading	**T40**	**T30**	**T24**	**T18**	**T10**	**Overall**	**Nagelkerke**
Model A. T grading with log properties.	62,3	13,4	46,2	28,3	63,6	46,3	0,485
Model C. T grading with sawn timber properties	62,2	14,7	41,1	22,8	62,2	43,7	0,437
NT grading	**A**	**B**	**C**	**D**		**Overall**	**Nagelkerke**
Model B. NT grading with log properties.	69,9	57,7	41	12,8		50,1	0,319
Model D. NT grading with sawn timber properties.	53,5	51	33	3		39,9	0,158

Binary regression models	T40 or T30	T40, T30 or T24	Others	…	Overall	Nagelkerke
Model E. T grading,T40 or T30 with log properties	60.2	....	91.2	…	83.5	0.49
Model F. T grading, T40, T30 or T24 with log properties	...	73.8	78.3	…	76.1	0.415
Model G. T grading, T40 or T30 with sawn timber properties	70.2	…	93.1	…	87.4	0.623
Model H. T grading, T40, T30 or T24 with sawn timber properties	…	77.2	78	…	77.6	0.451

Table 14. Classification ability based on the percentage of correctly classified sawn pieces and Nagelkerke's R^2 for Norway spruce models in visual strength grading (T grading)

Multinomial regression models	T30	T24	T18	T10	Overall	Nagelkerke
Model I. T grading with log properties	62.3	71.3	13,1	5,2	52.1	0.29
Model J. T grading with sawn timber properties	72.6	73.6	25,9	11,2	58.5	0.463

Binary regression models	T30 or T24	Others			Overall	Nagelkerke
Model K. T grading, T30 or T24 with log properties	96.6	18,3	…	…	76.2	0.142
Model L. T grading, T30 or T24 with sawn timber properties	93.8	31,1	…	…	76.9	0.239

Table 15. Observed and predicted grade distributions and misclassification percent in multinomial regression models of Scots pine in visual strength grading (T grading) and appearance grading (NT grading)

Model A. T grading with log properties					
	T40	**T30**	**T24**	**T18**	**T10**
Observed category distribution, %	14,2	10,3	25,2	21,5	28,8
Mean predicted category distribution, %	18,2	3,9	28,7	13,5	35,8
Error, %	4	-6,4	3,5	-8	7
Model B. NT grading with log properties					
	A	**B**	**C**	**D**	
Observed category distribution, %	25,4	36	24,5	14,1	
Mean predicted category distribution, %	30,5	41,8	23,7	4	
Error, %	5,1	5,8	-0,8	-10,1	
Model C. T grading with sawn timber properties					
	T40	**T30**	**T24**	**T18**	**T10**
Observed category distribution, %	14,2	10,3	25,2	21,5	28,8
Mean predicted category distribution, %	19,3	4,5	24,5	11,6	40,1
Error, %	5,1	-5,8	0,7	-9,9	11,3
Model D. NT grading with sawn timber properties					
	A	**B**	**C**	**D**	
Observed category distribution, %	25,4	36	24,5	14,1	
Mean predicted category distribution, %	31,2	43,9	23,2	1,8	
Error, %	5,8	7,9	-1,3	-12,3	

Table 16. Observed and predicted grade distributions and misclassification percent in multinomial regression models of Norway spruce in visual strength grading (T grading)

Model I. T grading with log properties				
	T30	**T24**	**T18**	**T10**
Observed category distribution, %	34	40.1	12,6	13,3
Mean predicted category distribution, %	38.2	56.1	3,5	2,2
Error, %	4,2	16	-9.1	-11.1
Model J. T grading with sawn timber properties				
	T30	**T24**	**T18**	**T10**
Observed category distribution, %	34	40.1	12,6	13,3
Mean predicted category distribution, %	36.2	53	7,1	3,5
Error, %	2,2	12,9	-5.2	-9.8

The accuracy of the binary regression models is illustrated in Table 17. as figure representing the area under the receiver operating characteristic curves (ROC). The area under the ROC curve ("c") represents the probability that the probability of a randomly chosen "success" exceeds the probability of a randomly chosen "failure". In a ROC curve, the sensitivity is plotted against 1 - specificity. Sensitivity is the probability that a "success" is correctly classified and 1 – sensitivity is the false negative rate, respectively. Specificity is the probability that a "failure" is correctly classified and 1 – specificity is the false positive rate (Fawcett 2006).

Discussion and conclusions

The empirical materials of the study were obtained through commercial wood procurement operations, which limited the possibility for objective sampling and regional representability for the characteristics of the timber stands. The even sampling per selected log

Table 17. Areas under the ROC-curves for accuracy of Scots pine and Norway spruce models according to binary regression analysis. Model E: log properties used as predictors for visual strength grades T40 and T30 vs. other grades; model F: log properties used as predictors for visual strength grades T40, T30, and T24 vs. other grades; model G: sawn timber properties used as predictors for visual strength grades T40 and T30 vs. other grades; model H: sawn timber properties used as predictors for visual strength grades T40, T30, and T24 vs. other grades. Model K: log properties of Norway spruce used as predictors for visual strength grades T30 and T24 vs. other grades; model L: sawn timber properties of Norway spruce used as predictors for visual strength grades T30 and T24 vs. other grades

	Area under the ROC-curve	Std. Error[a]	Asymp. Sig.[b]
Models for Scots pine			
E	0,883	0,011	0,000
F	0,831	0,013	0,000
G	0,929	0,008	0,000
H	0,850	0,012	0,000
Models for Norway spruce			
K	0,697	0,018	0,000
L	0,770	0,017	0,000

[a] Under the non-parametric assumption
[b] Null hypothesis: True area =0,5

diameter classes does not fully correspond with the diameter distribution at the saw mills, where logs of smaller diameter are typically more frequent than large-diameter logs. The proportion of butt logs was 10-20 percentage points higher for pine and 5 percentage points higher for spruce than in the large log measurement data in Finland (e.g., Rikkonen 1987). The difference was obviously parallel in north-western Russia, despite the often smaller outtake percentage of logs in commercial harvesting operations (e.g., Karvinen et al. 2006).

The different sawing setup of log diameter classes resulted in different sawn timber dimensions, which could hamper the comparison of grading results between the sub-samples. However, the approximately similar number of sawn pieces per log diameter class in each region, except for the larger log sample of spruce from the Republic of Karelia, compensated this drawback and contributed positively to the analysis of variation in and the establishment of prediction models for the grade distributions of sawn timber.

Certain geographical differences in timber quality appeared between the regions of the study. It can be assumed that most of the variation is due to the different growing conditions, but forestry practices may also impact timber quality and, therefore, the yields in both appearance and visual strength grading. The origin of the Finnish logs could be traced back to individual stands marked for cutting; instead, there was no information available on the stand properties in the Russian data, for example, on stand density or site fertility. It can be assumed that thinnings did not belong to the forest management history in the regions where the Russian logs were cut. Again, log bucking was not probably optimized for length and quality in Russia, which might lead to more inefficient utilization of tree quality than in Finland with highly developed bucking control in mechanized cutting (Karvinen et al. 2005).

In fertile growing conditions, as in Novgorod, Scots pine commonly develops logs and sawn timber with large knots and wider annual rings compared to colder regions and slower growth. Logs from the Vologda region produced better strength grade yield in sawn timber than those from the Novgorod region, but worse than those from Finland. Sawn timber from the Russian regions suffered from large and frequent knots. In Finland, pine sawn timber from northern Finland had, unexpectedly, a worse appearance grade distribution than the timber from more southern regions in Finland compared to Heiskanen (1977), for example. Northern Finnish pine suffered especially from large and frequent dry knots in our data.

Otherwise, the appearance grade distributions seemed relatively usual for Finnish pine sawn timber compared to, for example, a study by Virtanen (2005) presenting the following proportions of the total production at the sawmills in 1997; u/s (A) 20%, V (B) 30%, VI (C) 21%, unsorted 12%, schaalboards 13%, and sound-knotted 4%. Wall et al. (2005) reported even better NT grade distributions for pine sawn timber from first and second thinning when the value yield was optimized in log bucking and only the center yield was sawn as in this study. Instead, Hemmilä and Sipi (2004) observed much worse distributions for pine sawn timber from first-thinning logs with commercial length of three-decimeter modules length than in this study.

Jouhiaho and Uusitalo (2001) reported, in a similar study, as high proportions of grade A as 50-61% for center yield in the first thinnings on the different soils with the reference of 53% in final fellings when logs were bucked to commercial lengths and center yield was considered.

In her study, Lindgren (1997) achieved the following proportions for the center yield of south-western Finnish pine: A 18%, B 39%, C 33%, p and D 10%. Rikala (2003) reported very high proportions of good quality sawn timber from selected pine stands on drained peatlands in southern Finland; A 29%, B 38%, C 28%, p and D 5%.

No published statistics and few studies are available on the visual strength grade distributions of sawn timber. Lindgren (1997) observed slightly better distributions for pine sawn timber from south-western Finland than in this study, with the exception of somewhat smaller proportion of T40. Rikala (2003) showed roughly parallel results to this study, with, however, a lower percentage of T30 and a higher percentage of T24. Hanhijärvi et al. (2005) reported a high percentage of good-quality timber when INSTA 142 grading was modified with the account of specific density limits in each grade; C40 30%, C30 18%, C18 45%, p and lower 7%.

For Norway spruce, the differences between the regions in grade distributions of this study were much less pronounced compared to Scots pine. There was no difference in the maximum knot diameter on the outer face of the sawn piece, but grade-determining differences existed in annual ring width, latewood proportion, and the number of sound and dry knots in sawn timber. Due to the relative homogeneity of spruce timber and the small variation in timber properties between the regions, it can be said that when acquiring spruce logs or sawn timber, the geographical region is less important compared to pine, except the northernmost region (e.g., Hudson 1967, Heiskanen 1968).

Since spruce timber is more homogenous compared to pine when knots are concerned, timber from northern Finland and the Vologda region is generally graded better compared to other regions because of the smaller annual ring width which leads to higher density (Kollman and Cōté 1968, Bodig and Jayne 1982). On the other hand, the risk of other defects decreasing the grade increases when trees grow in non-favorable growth conditions and the age required for the logging size increases. One can also expect less high quality sawn timber and more intermediate grades when spruce is compared to pine, especially in appearance grading, but also less low quality sawn timber, especially in visual strength grading.

The appearance grade distributions of Finnish spruce sawn timber were somewhat worse for the proportion of grade A, but much better for the proportion of grade B than by Virtanen (2005), who reported the proportions of u/s (A) 11%, V (B) 15%, VI (C) 17%, unsorted 41%, and schaalboards 16%. Lindgren (1997) presented, for southern Finnish spruce, the proportions of A 21%, B 41%, C 25%, D 13% and for northern Finnish spruce of A 27%, B 40%, C 25%, and D 8%, respectively. Verkasalo *et al.* (2002) reported as high proportions of grade A in the center yield as 75-84% in bulk sawing operation and 45% in specializing sawing operation based on simulations; however, only dimensions, knots, wane, and compression wood were considered in the sorting of sawn timber. Rikala (2003) observed, in parallel, high-quality spruce in southern Finnish peatlands: A 57%, B 22%, C 17%, and D 4%.

In visual strength grading, Lindgren (1997) reported also a yield of T40 for spruce sawn timber both in southern and northern Finland (less than 10%), but a lower yield for T30. Rikala (2003) showed exceptionally high percentages of the best grades, nearly 20% for T40 and 30% for T30. Hanhijärvi *et al.* (2005) arrived at, again, high percentages when INSTA 142 grading, modified as described before, was applied: C40 17%, C30 22%, C18 57%, and lower 4%.

The number and size of knots are the most important predictive variables when grade yield is modeled from sawn timber properties (see also Heiskanen 1955, Hemmilä and Sipi 2004, Hanhijärvi and Ranta-Maunus 2008). The type of the log (vertical position) is an important independent variable in predicting grade yield from log properties, as it combines the directions of influence of many predictive factors. Log type was also found to be an important predictor of log quality for spruce by, e.g., Kärkkäinen 1980 and Verkasalo et al. (2002). The effect of log procurement region remains at a lower significance compared to knots and log type in determining the grade yield. Generally, there are more significant explanatory variables for spruce, partly demonstrating the small variations in timber properties, which affect the ability of the models to separate the grades.

In comparison with other studies predicting grade yield, the accuracy of the models was weaker in this study. Ųvrum (2008) predicted the INSTA 142 strength grade distribution and NT grade distribution for Norway spruce within a ten-percent margin. In this study, the strength grade probability error was 16% at the maximum when predicting grade distribution from log properties, the mean being 10%. When predicting the visual strength grade from sawn timber properties, the error was smaller, the maximum error and mean being 13.0% and 7.5%. Lyhykäinen et al. (2009) reached, for Scots pine, the mean absolute errors of 8.8-9.5% for grades A and B, and less than 2% for combined C and D grades. In this study, the mean absolute errors in grade probability varied between 5.5% and 6.8%. The between-study differences in the prediction accuracy are most probably due to the differences in the number and quality of explanatory variables. It should be noted that no interaction variables were used in the models of this study due to the fact that the interactions were largely insignificant in the data.

The weaker classification ability of the models for Norway spruce sawn pieces of lower visual strength grades was partly due to the fact that the most common defects decreasing the grade were not individual knots in the low end of grade distribution, but rather other properties such as knot sum, and new shoot formation from a branch, which occur rarely, but the occurrence of which downgrade the grade fatally. These factors were not included in the models as predictive variables, thus, the models placed such sawn pieces into better grades. The most common reasons for downgrading are for both Scots pine and Norway spruce edge knots, which were excluded from the model (see also Kärkkäinen 1980, Øvrum 2008).

The main problem in the visual strength grading is the low correlations between the grading parameters and measured strength characteristics (Lindgren 1997, Jäppinen 2000, Hanhijärvi et al. 2005). Knots alone are a weak predictor of strength, but combined with other properties, such as modulus of elasticity or density, the predictive power increases. Lindgren (1997) found that knots alone can explain less than 30% of the variation in bending strength for Norway spruce. Different knot parameters combined explain more, up to 50% of the variation for Scots pine, and combined with annual ring width up to the level of 42-57% (Lindgren 1997, Hanhijärvi et al. 2005). It should be noted that the INSTA 142 grades explain, according to Hanhijärvi et al. (2005), only 22% and 55% of the variation in bending strength for spruce and pine, respectively.

Concerning manual work, human variation in objectivity, and the inability to look inside the sawn pieces lead to the need for large risk tolerance in visual grading. Thus, the efficient utilization of the strength characteristics of sawn timber demands more exact strength grading. This probably leads to further investigation of machine stress rating (MSR) using predictors more strongly correlated with strength, although, at present, these methods are already at an advanced level.

This study brought up some new information on the quality of sawn timber and logs from Russia and mostly confirmed earlier results and perceptions concerning differences in timber properties between the sub-regions in Finland and between Scots pine and Norway spruce. Log and sawn timber properties proved satisfactory as predictors of appearance grades and visual strength grades when the response categories were dichotomous. This proved a promising approach, especially for Scots pine, for example, 76-87% of individual sawn pieces were then classified correctly in visual strength grading. This showed that the grading methods can be seriously considered based also on the sufficiency of the accuracy in practical grading.

The results of the study can be applied in the planning of log procurement and sawn timber purchase from the regions concerned when either appearance grade or structural grade is emphasized, considering the before-mentioned uncertainty in the representative ability of the data. Moreover, the results provide basic information for the development of wood sorting, either based on log properties or sawn timber properties. The data will be used in a parallel study where the regional differences in density, modulus of elasticity, and bending strength are analyzed, the predictive log and sawn timber properties are identified, and models established for the estimation of these structural properties of sawn timber.

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ФАКТОРЫ, ВЛИЯЮЩИЕ НА РАСПРЕДЕЛЕНИЕ ПО КЛАССАМ КАЧЕСТВА И ПРОЧНОСТИ СОРТИМЕНТОВ СОСНЫ ОБЫКНОВЕННОЙ И ЕЛИ ЕВРОПЕЙСКОЙ ПРИ ВИЗУАЛЬНОЙ ОЦЕНКЕ И МОДЕЛИРОВАНИИ В ФИНЛЯНДИИ И НА СЕВЕРО-ЗАПАДЕ РОССИИ

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Резюме

С целью выявления колебания и прогнозируемости распределения по классам качества были исследованы образцы сортиментов и пиленых заготовок сосны обыкновенной (*Pinus sylvestris*) и ели европейской (*Picea abies*) из трех регионов Финляндии и двух регионов Северо-запада России. Замерялись характеристики сортиментов и пиленых фрагментов, и проводился статистический анализ, в частности, различий по географическим регионам.

Образцы древесины визуально классифицировались по качеству внешнего вида и прочности по скандинавским правилам классов NT и T (Применение правил INSTA 142 в Финляндии) соответственно. Ставилась цель определить, насколько точно возможно прогнозировать выход сортимента по классам качества на базе характеристик сортиментов и пиловочника с помощью бинарного или многочленного регрессивного моделирования и, в частности, сохраняются ли при этом региональные различия.

Тип сортимента (часть ствола, из которого заготовлено бревно и визуальная оценка) был самым важным отдельным фактором для обеих пород при прогнозировании класса с использованием характеристик сортимента в качестве предикторов. При использовании характеристик пиленых образцов в качестве предикторов, самыми существенными независимыми переменными были характеристики, связанные с сучками. Географическое положение не выступало основным фактором при прогнозировании выхода древесины определенного класса при обоих подходах, но оно было более очевидным для сосны обыкновенной, нежели чем для ели европейской.

Для прогнозирования распределения по классам качества и прочности при визуальной оценке применялись многочленные регрессионные модели. С их помощью удалось правильно прогнозировать 40-50% класса NT и 44 — 59% класса T по отдельным пиленым образцам. Для определения классов визуальной прочности применялись бинарные регрессионные модели; учитывались две соответствующие категории, например, два наивысших класса и два низших. Данные модели оказались самыми точными, и они дали правильный прогноз 76 — 83% выхода по двум классам, и модели по прогнозированию классов сосны обыкновенной работали лучше, чем модели по ели европейской.

Между регионами проявились серьезные различия по нескольким характеристикам сортиментов и пиленых образцов. В целом, выход классов по качеству был ниже по Новгородской и Вологодской областям, чем по Финляндии. По ели европейской региональные различия характеристик сортиментов пиловочника были намного меньше, чем по сосне обыкновенной.

Ключевые слова: *Pinus sylvestris, Picea abies*, пиломатериалы, классификация по внешнему виду, классификация по визуальной прочности, выход по классам, Финляндия, Россия