# Internal Knottiness with Respect to Sawing Patterns in *Betula pendula* and *B. pubescens*

**HENRIK HERÄJÄRVI**
*Finnish Forest Research Institute METLA*
*METLA, Joensuu Research Centre*
*P.O. Box 68, FIN-80101 Joensuu, Finland*
*Email: henrik.herajarvi@metla.fi*

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The objective of this study was to examine the internal knottiness structure, and define the possibilities to predict – on the basis of the board's within-stem location – the knottiness grades of boards sawn from mature *Betula pendula* and *B. pubescens*. The differences of the knottiness between the alternative growing conditions and trees representing different crown layers were also studied. The sample trees were sawn into unedged boards with a 25-millimetre green thickness and a 2-metre length. Boards were graded according to the existence of knots into three categories (1: knot-free, 2:only dead knots or both dead and sound knots, 3: only sound knots). Polytomous logistic regression (PLR) models were constructed to predict the grades for the boards based on their location within the stem. Generally, *B. pendula* butt logs from the stump up to six metres, as well as *B. pubescens* butt logs up to four metres contained mainly knot-free boards from a 75-millimetre distance from the pith outwards. At those heights, the inner boards were rather equally distributed between the grades 1, 2 and 3. Sound-knotted boards were, as expected, mainly situated in the small-sized top parts of the stems. At the lower heights, sound-knotted boards were gradually replaced by dead-knotted, and finally, knot free boards. In all growing conditions studied, knot-free and sound-knotted boards were separated in a satisfactory accuracy by the PLR models. Boards with only dead knots or with a mixed knottiness structure were slightly more poorly classified.

**Key words:** *Betula pendula, Betula pubescens*, grading, knottiness, lumber.

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## Introduction

In the biological sense, the terms knot, branch and limb stand for the same thing. Branch is, however, commonly referred to the outside of stem part of the limb, whereas knot means the part inside the stem. As far as wood-product industry is considered, thus, knots are of grater importance. Knots are, in fact, the most common defect affecting the grading of lumber and veneers both in softwood products (cf. Heiskanen 1965, Kärkkäinen 1985, Hakala 1992, Samson 1993, Uusitalo 1994, 1997) and in hardwood products (cf. Meriluoto 1965, Heiskanen 1966, Kärkkäinen 1986, Verkasalo 1997, Kivistö et al. 1999, Luostarinen & Verkasalo 2000). The influence of the knots is twofold. Firstly, they decrease the mechanical strength and stiffness of wood intended for structural uses, such as construction and framing (e.g., Zobel & van Buijtenen 1989, Madsen 1992, Boren 2001). Secondly, knots influence the surface characteristics, i.e., visual appearance of sawn wood or veneer either positively or negatively, depending on the end-use of the product. In structural wood products especially, the existence of a knot is, thus, normally considered a negative feature.

North European birch species, *Betula pendula* and *B. pubescens*, have mostly been utilied in visible uses, for instance, as facing materials on lower-quality wood products, as well as for decorative purposes (e.g., Louna & Valkonen 1995, Luostarinen & Verkasalo 2000, Forbes et al. 2001). Therefore, their appearance is often the dominating factor. In uses such as furniture or floorings, also high mechanical performance is still required.

Sound knots inside the stem are normally physiologically connected with the surrounding wood material and, as long as alive, they grow in diameter along with the growth of the stem. On the other hand, the overgrowing stem wood treats a dead knot as an external object; the new overgrown wood material is not connected with a dead knot anymore. Thus, the stem wood embraces the knot. After pruning the branch, either naturally or artificially, the overgrowing stem wood begins healing-over the stub. The healing-over time depends on the speed of the growth, as well as the size of the stub. Clear wood with a straight grain pattern starts growing on the stub after the healing-over process has finished (e.g., Kärkkäinen 1985, Mäkinen & Colin 1999, Wood handbook 1999).

All branches visible on the surface of the stem, hence, are originated from the pith of the tree. However, an exception is made by the epicormic branches (or sometimes called "water sprouts") caused by resting buds on the surface of the stem and which, therefore, cannot be seen in the inner wood material. Their existence is related to damages in the foliage caused by, for instance, frost or an increased amount of light available in the lower parts of the stem (Heiskanen 1957). Epicormic branches may be a degrading factor for veneers obtained near the surface of the butt-logs. Some hardwoods, such as oak, ash and alder species are especially prone to produce epicormic branches. Older birch trees with poor foliage sometimes grow them, as well.

Since the goal of growing trees is usually to maximise the quantity and quality of saw or veneer timber, where the knot-free grades are the most valuable, young trees are sometimes artificially pruned in order to produce as much knot-free butt-log as possible. For instance, Uusvaara (1993) showed that the percentage of the best grades in artificially pruned Scots pine butt-logs was 57, whereas, non-pruned logs provided the best grades with only 22% from the entire lumber volume. Concerning birch trees intended for veneer, plywood or sawn wood production, artificial pruning undoubtedly increases the value of the stem at least as much as is the case with Scots pine. Birch is, nevertheless, highly susceptible for discolouration, especially when living branches of over 20 millimetres in diameter are pruned. Moreover, pruning methods and correct timing have a significant influence on the successful healing-over process, as well as on the resistance to the decaying fungi (cf. Blomqvist 1879, Heiskanen 1958, Zobel & van Buijtenen 1989, Verkasalo & Rintala 1998).

In addition to artificial pruning, tree branchiness can be controlled by tree breeding, i.e., improving the genetic material. Furthermore, silvicultural practices, such as between tree spacing and correctly scheduled thinnings influence the number, growth, suppress, dying and self-pruning of branches (cf. Zobel & van Buijtenen 1989, Mäkinen 1999).

Principally, when hardwoods have been utilized by the wood-product industries, the aim has been to obtain as much knot-free – or to some extent sound-knotted – products as possible. Dead knots are mainly degrading factors. Holes in facing veneers caused by loosened dead knots must be repaired by a patch or, alternatively, veneers with dead knots must be sorted for the inner layers of plywood. Hardwood lumber with dead knots is typically used in hidden structures of furniture or in low-value products, such as packaging materials (Luostarinen & Verkasalo 2000).

Kärkkäinen (1986) modelled the internal knottiness structure of birch on the basis of the development of the dead branch height and the living crown height at different age of trees. The models were based on the biological development, whereas the natural variability was not taken into consideration. Therefore, no attention could be paid on the fact that the external crown layers, not to mention the internal knottiness structure of birch species are not as straightforward as the crown layers of many softwood species are. Heräjärvi (2001) showed that in birch, small dry and rotten branches are common not only below the living crown, but also in it, between the larger living branches. It is obvious that this influences also the internal knottiness structure of birch stems.

Much work has been devoted in order to develop simulation programs for hardwood lumber grading according to appearance (cf. Hallock & Galiger 1971, Klinkhachorn et al. 1988, Samson 1993, Steele et al. 1994). However, softwoods have been of even more interest, especially in the Nordic countries (cf. Björklund 1997, Björklund & Petersson 1999, Lundgren 2000), where more than 90% of the sawn wood production consists of softwoods. Uusitalo (1994) defined two generic methods for using logistic regression for studying the lumber grade distributions within a tree stem. Firstly, he stated that at least in theory, the lumber grade should be a proper outcome for a polytomous logistic regression model. Secondly, he suggested that either polytomous or binary logistic regression should be a proper tool for predicting the number of boards representing a certain grade within one saw log. He also successfully applied the latter method for Scots pine (Uusitalo 1997).

Considering *Betula pendula* and *B. pubescens*, the studies of Kärkkäinen (1986) are the only articles published on the structure of the internal knottiness. No applications are presented for the practical needs, such as for studying the distributions of different lumber grades or for determining the optimal sawing patterns for processing birch logs. This is, undoubtedly, affected by the fact that compared to sawing softwoods, sawing birch has traditionally played a minor role in the Nordic countries. The increasing economical importance of birch as sawn wood completed with the limited availability of high-quality birch logs has raised an interest in improving the efficiency of birch utilization in all countries near the Baltic Sea region.

The objective of this article was to study the internal knottiness structure of mature *Betula pendula* and *B. pubescens* by theoretical modelling of the knottiness structure of 2-metre long and 25-millimetre thick boards on the basis of their location within birch stem. A similar modelling method has not been introduced earlier for this purpose. The results are intended, in particular, for facilitating the selection of sawing patterns for birch saw logs.

## Materials and methods

The material consisted of 261 mature (age: 68-108 years) birch trees selected from 20 randomly chosen stands in southern, central and eastern Finland. *B. pendula* stands were, on average, slightly older compared to the *B. pubescens* stands. This is analogous to the natural difference between the biological life-cycles of the two species. All stands were located on mineral soils or peatlands representing average or good fertility. Heräjärvi (2001) presented the key characteristics of the sample stands and measurement methods in more detail. The stands were required to meet the normal silvicultural status according to the Finnish practice and no exceptional treatments, such as artificial pruning or birch bark peeling were allowed. Stands were categorised into six strata in the following manner:

| | |
|---|---|
| Stratum 1 | Pure *Betula pendula* stands on mineral soils (3 stands, mean age for birch 86 years, mean diameter at breast height (dbh) for birch 250 mm) |
| Stratum 2 | Mixed stands of conifers and *B. pendula* on mineral soils (4 stands, 81 years, 264 mm) |
| Stratum 3 | Pure *B. pubescens* stands on mineral soils (3 stands, 72 years, 234 mm) |
| Stratum 4 | Mixed stands of conifers and *B. pubescens* on mineral soils (4 stands, 75 years, 237 mm) |
| Stratum 5 | Pure *B. pubescens* stands on drained peatlands (3 stands, 74 years, 210 mm) |
| Stratum 6 | Mixed stands of conifers and *B. pubescens* on drained peatlands (3 stands, 79 years, 208 mm) |

Only trees having a dbh of more than 140 millimetres were regarded as potential sample trees. In addition, at least one sawable log was to be obtained from each applicable sample tree. On average, 13 trees per stand were sampled using stratified random sampling. The basis for the stratification was that a representative dbh series from 140 millimetres upwards was wanted. The competitive status (dominant, co-dominant), dbh, crown limits, as well as characteristics of the technical quality of each sample tree were assessed before felling.

After felling and delimbing, the sample trees were crosscut into logs with lengths of two or four metres. Each log was coded using a felt-tip pen, thus, enabling its identification and location in the stem afterwards. In addition, an arrow was drawn at the top end of each log so that during sawing, all the logs from one tree could be positioned in respect to the other logs obtained from the same tree. Logs having a top-diameter of 120 millimetres or more were transported to a sawmill.

The logs were sawn pith-centrally without edging into the green thickness of 25 millimetres using a circular saw. In practice, each trunk from the base up to the height where the diameter was approximately 120 millimetres was, hence, systematically divided into two- or four-metre long and 25-millimetre thick sections. Immediately after sawing, the boards obtained were coded according to their origin and location in the log. The four-metre boards were handled as two two-metre boards. Altogether 10,251 two-metre-long sections were obtained.

Type (sound, dead), size and number of knots were measured from each board. Knots were measured in perpendicular to the grain direction; therefore, measuring diagonally cut knots did not necessarily reflect their true size. Only knots having a diameter of more than 5 millimetres were considered when the boards were graded into the following, non industry-based, categories:

| | |
|---|---|
| Grade 1 (Knot-free) | at most 1 knot (diameter ≥ 5 mm) / 2 m, smaller knots allowed |
| Grade 2 (Dead-knotted or mixed) | at least 2 dead knots (diameter ≥ 5 mm) / 2 m, irrespectively of the other knots |
| Grade 3 (Sound-knotted) | others |

In this study, sound knot did not necessarily stand for a living knot, but one having at least 50% of its circumference tightly connected with the surrounding wood. Dead knot, on the other hand, could be either dry or rotten. Epicormic branches were not included into the analyses due to their unsystematic existence and exceptional structure.

The differences in the knottiness grades between the study groups, i.e., strata and crown layers, were studied firstly using the nonparametric Mann-Whitney

U –test. Secondly, the odds for falling into a given grade by the knottiness, was modelled for each board based on its known location (relative distance from the pith, % of the top radius of the log: X1; relative distance from the stump, % of the height of the tree: X2), by using the Polytomous Logistic Regression (PLR). According to Hosmer & Lemeshow (1989), PLR can be used when the test subjects are to be classified into more than two groups according to the values of the predictor variables. This type of regression is similar to the binary logistic regression, but it is often more applicable since the dependent variable is not restricted into two categories.

While the logistic regression is applied to classify the data into two or more subsets, it is necessary the subsets to be of approximately the same size. If one subset is exceptionally small in number of observations in comparison to the others, the model will probably fail in classification into that subset. As seen in Table 1, grade 3 has clearly larger number of boards compared to grades 1 and 2. In this case, however, the difference between the group sizes was not considered counterproductive, since all three grades still had thousands of observations. The total number of boards accepted into the analyses was 10,050, while 201 boards were excluded from the analyses because of their highly divergent knottiness characteristics, obviously caused by an error either in the coding or in the measuring.

The goodness-of-fit of the PLR models were studied by the deviance chi-square –test, which in principle, corresponds to the residual sum of squares in the linear regression model. The significance of individual variables was tested using the Wald –test statistics obtained by comparing the maximum likelihood estimate of the slope parameter to the estimate of its standard error. Roughly, when the value of Wald statistics exceeds the value of 2, the variable is considered significant (Hosmer & Lemeshow 1989). Odds ratios, being presented for the PLR models as well, approximate how much more likely or unlikely it is for the outcome to be present in the given group than in the reference group.

## Results

Tested by the Mann-Whitney test, the lumber grade distributions between the dominant and the co-dominant trees did not differ significantly (Z: -0.167, p: 0.868). This was rather unexpected since, externally, the relative size of the living crown of the co-dominant trees is usually clearly smaller and more suppressed than the crown of the dominant trees.

Since the total lumber grade distributions were examined (without taking into account the effect of the location parameters), it appeared that strata 1 and 2 had similar distributions, whereas, stratum 3 was different from any other stratum by having a larger percentage of sound-knotted boards and a smaller percentage of knot-free boards. Strata 4, 5 and 6 were fairly similar to each other in the overall lumber grade distributions (Table 1, Figure 1). Circa one third of the boards belong to each of the three grades. Thus, the overall distributions in the two strata with *Betula pendula* trees were similar to each other, whereas the four strata with *B. pubescens* trees had more variation

**Table 1.** Number of measured two-metre boards by grade and stratum. Strata: 1: pure *Betula pendula* stands on mineral soils; 2: mixed stands of conifers and *B. pendula* on mineral soils; 3: pure *B. pubescens* stands on mineral soils; 4: mixed stands of conifers and *B. pubescens* on mineral soils; 5: pure *B. pubescens* stands on drained peatlands; 6: mixed stands of conifers and *B. pubescens* on drained peatlands. Grades: 1: knot-free; 2: dead-knotted or mixed; 3: sound-knotted

| Stratum | Grade | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | *Total* |
| | Number of boards | | | |
| 1 | 554 | 639 | 1,001 | *2,194* |
| 2 | 605 | 669 | 1,157 | *2,431* |
| 3 | 338 | 416 | 826 | *1,580* |
| 4 | 467 | 563 | 754 | *1,784* |
| 5 | 315 | 437 | 581 | *1,333* |
| 6 | 195 | 185 | 348 | *728* |
| *Total* | *2,474* | *2,909* | *4,667* | *10,050* |

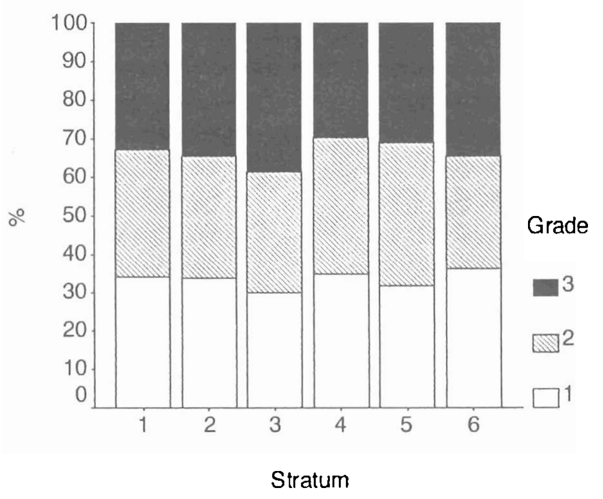

**Figure 1.** Lumber grade distributions within the six strata. For description of strata and grades, see: Table 1

between the knottiness grade distributions. The two birch species differed from each other only slightly.

Once the location parameters were taken into account, the between strata differences in the lumber grade distributions became more apparent. Figure 2 presents the distributions of grades according to the location parameters and strata, calculated on the basis of the observed data. Due to the stem tapering, both volumetrically and numerically most of the actual lumber recovery was situated in the lower parts of the stem. The diagrams in Figure 2 are generalisations, since the size variations of trees within one stratum were not considered. Thus, for instance, the vertical location of ten metres stood for the relative height of between 46% and 60%, while different-sized trees were examined. The absolute scale location parameters were used in Figure 2, instead of the relative values seen in the actual models (Tables 2 and 3), since the absolute scale was more easily visualised.

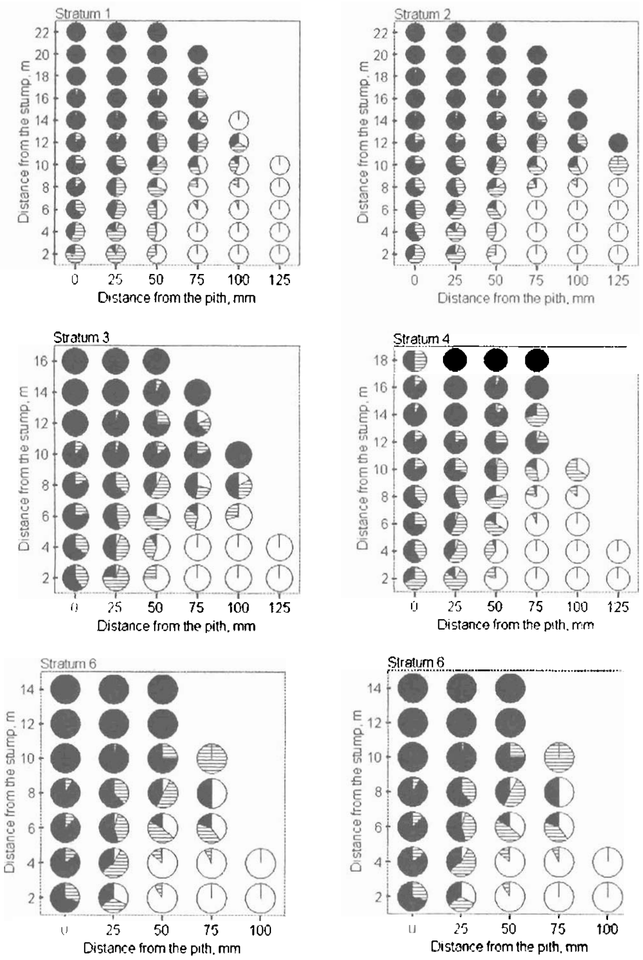

**Figure 2.** Falling of boards obtained from different within-tree locations into separate knottiness grades. Slices represent percentages of separate grades in a large sample. White: grade 1, lineation: grade 2, black: grade 3. For description of strata and grades, see: Table 1

**Table 2.** Polytomous logistic regression models predicting the odds for a board of falling into the grades 1, 2 or 3 (Grade 3 = reference group) in strata 1, 2 and 3. For description of strata and grades, see: Table 1

| Stratum | Grade | Estimated |  |  |  |
|---|---|---|---|---|---|
|  |  | Variable | Coefficient (S.E.) | Wald | Odds ratio (95% CI) |
| 1 | 1 | Constant | -0.325 (0.276) | 1.385 |  |
|  |  | X1 | 0.164** (0.008) | 443.852 | 1.178 (1.160; 1.196) |
|  |  | X2 | -0.258** (0.011) | 543.056 | 0.772 (0.756; 0.789) |
|  | 2 | Constant | 2.347** (0.165) | 201.856 |  |
|  |  | X1 | 0.077** (0.007) | 115.194 | 1.080 (1.065; 1.095) |
|  |  | X2 | -0.114** (0.006) | 410.023 | 0.892 (0.883; 0.902) |
| Correctly classified: grade 1: 83.2%, grade 2: 55.9%, grade 3: 83.2%, overall: 75.3%. |  |  |  |  |  |
| Model fit: |  |  |  |  |  |
| Deviance Chi-square | 1602.241 |  |  |  |  |
| Df | 2660 |  |  |  |  |
| P | 1.000 |  |  |  |  |
| 2 | 1 | Constant | -0.244 (0.260) | 0.882 |  |
|  |  | X1 | 0.164** (0.008) | 419.519 | 1.178 (1.159; 1.196) |
|  |  | X2 | -0.276** (0.012) | 521.856 | 0.759 (0.741; 0.777) |
|  | 2 | Constant | 2.027** (0.149) | 184.685 |  |
|  |  | X1 | 0.028** (0.003) | 81.531 | 1.028 (1.022; 1.035) |
|  |  | X2 | -0.096** (0.005) | 410.639 | 0.908 (0.900; 0.917) |
| Correctly classified: grade 1: 86.4%, grade 2: 49.3%, grade 3: 84.2%, overall: 75.2%. |  |  |  |  |  |
| Model fit: |  |  |  |  |  |
| Deviance Chi-square | 1703.181 |  |  |  |  |
| Df | 2816 |  |  |  |  |
| P | 1.000 |  |  |  |  |
| 3 | 1 | Constant | -1.030** (0.327) | 9.915 |  |
|  |  | X1 | 0.153** (0.009) | 280.330 | 1.166 (1.145; 1.187) |
|  |  | X2 | -0.270** (0.015) | 309.706 | 0.763 (0.740; 0.786) |
|  | 2 | Constant | 1.325** (0.169) | 61.199 |  |
|  |  | X1 | 0.031** (0.004) | 71.758 | 1.032 (1.024; 1.039) |
|  |  | X2 | -0.093** (0.006) | 247.011 | 0.911 (0.901; 0.922) |
| Correctly classified: grade 1: 83.1%, grade 2: 44.7%, grade 3: 83.9%, overall: 73.4%. |  |  |  |  |  |
| Model fit: |  |  |  |  |  |
| Deviance Chi-square | 1265.362 |  |  |  |  |
| Df | 1876 |  |  |  |  |
| P | 1.000 |  |  |  |  |

X1: relative distance from the pith, percent of the top radius of the log.
X2: relative distance from the stump, percent of the height of the tree.
**=Significant at 1% level, *=significant at 5% level.

Generally, *B. pendula* butt logs from the stump up to six metres, as well as *B. pubescens* butt logs up to four metres contained mainly knot-free boards from a 75-millimetre distance from the pith outwards. At those heights, the inner boards were rather equally distributed between the grades 1, 2 and 3. Sound-knotted (grade 3) boards were mainly situated in the small-sized top parts of the stems, and were gradually replaced by dead-knotted boards and finally knot free boards at the lower heights.

The location parameters were the only significant predictors for the lumber grade. Adding other explanatory variables, such as the basal area of the stand, age of the tree, height of the living crown or dbh to the location parameters, improved the efficiency of the models only slightly. The PLR models predicting the falling of boards into separate knottiness grades are presented in Tables 3 and 4. According to the deviance tests, the models fit to the data. Depending on the stratum in question, the overall percentage of

**Table 3.** Polytomous logistic regression models predicting the odds for a board of falling into the grades 1, 2 or 3 (Grade 3 = reference group) in strata 4, 5 and 6. For description of strata and grades, see: Table 1

| Stratum | Grade | Estimated | | | |
|---|---|---|---|---|---|
| | | Variable | Coefficient (S.E.) | Wald | Odds ratio (95% CI) |
| 4 | 1 | Constant | -0.846** (0.312) | 7.346 | |
| | | X1 | 0.155** (0.009) | 321.457 | 1.168 (1.148; 1.188) |
| | | X2 | -0.261** (0.013) | 382.405 | 0.770 (0.750; 0.791) |
| | 2 | Constant | 1.970** (0.168) | 136.732 | |
| | | X1 | 0.019** (0.003) | 38.008 | 1.020 (1.013; 1.026) |
| | | X2 | -0.085** (0.005) | 268.023 | 0.918 (0.909; 0.928) |
| Correctly classified: grade 1: 86.5%, grade 2: 52.8%, grade 3: 77.3%, overall: 72.0% | | | | | |
| Model fit: | | | | | |
| Deviance Chi-square | 1443.968 | | | | |
| Df | 2102 | | | | |
| P | 1.000 | | | | |
| 5 | 1 | Constant | -1.168** (0.376) | 9.658 | |
| | | X1 | 0.161** (0.010) | 270.460 | 1.175 (1.152; 1.197) |
| | | X2 | -0.269** (0.016) | 294.806 | 0.764 (0.741; 0.788) |
| | 2 | Constant | 1.732** (0.193) | 80.684 | |
| | | X1 | 0.035** (0.004) | 90.061 | 1.035 (1.028; 1.043) |
| | | X2 | -0.094** (0.006) | 217.829 | 0.911 (0.899; 0.922) |
| Correctly classified: grade 1: 79.7%, grade 2: 56.5%, grade 3: 77.3%, overall: 71.0% | | | | | |
| Model fit: | | | | | |
| Deviance Chi-square | 1066.722 | | | | |
| Df | 1578 | | | | |
| P | 1.000 | | | | |
| 6 | 1 | Constant | -1.006* (0.415) | 5.884 | |
| | | X1 | 0.148** (0.012) | 147.866 | 1.159 (1.132; 1.187) |
| | | X2 | -0.229** (0.018) | 155.312 | 0.795 (0.767; 0.825) |
| | 2 | Constant | 0.333 (0.242) | 1.892 | |
| | | X1 | 0.040** (0.005) | 57.628 | 1.041 (1.030; 1.051) |
| | | X2 | -0.067** (0.008) | 68.576 | 0.936 (0.921; 0.950) |
| Correctly classified: grade 1: 83.6%, grade 2: 33.0%, grade 3: 83.9%, overall: 70.9% | | | | | |
| Model fit: | | | | | |
| Deviance Chi-square | 618.347 | | | | |
| Df | 886 | | | | |
| P | 1.000 | | | | |

X1: relative distance from the pith, percent of the top radius of the log.
X2: relative distance from the stump, percent of the height of the tree.
**=Significant at 1% level, *=significant at 5% level.

correctly classified boards varied between 70.9 and 75.3. At its lowest, however, no more than 33% of the grade 2 boards were sorted out by the PLR, whereas the percentages of correctly classified boards representing grades 1 and 3 were typically close to 80.

The knot-free boards (grade 1), as well as the sound-knotted boards (grade 3) were satisfactorily separated from the boards representing grade 2 by the PLR. Grades 2 and 3, however, mixed in the middle sections of the stem. This was due to the unsystematic distribution of dead knots within the externally dead-knotted (i.e., above the knot-free base and below the living crown) stem section of birch. Grades 2 and 3 were, thus, clearly overlapping within the mid-parts of the trunk. Figure 3 illustrates the observed knottiness grade distribution in stratum 1, based on which it is understandable that the models partly failed in classifying between the grades 2 and 3.

Next, an example is given in order to illustrate the interpretation of the results of the PLR models. The deviance chi-square test statistics indicate that the models fit to the data, as they are less than their respective degrees of freedom (cf. Hosmer & Lemeshow 1989). Bearing in mind that grade 3 was determined to be a reference group grades 1 and 2 are to be compared to it. In stratum 1, we have the X1 variable with an estimated coefficient of 0.164, Wald statistics of 443.852 and odds ratio of 1.178. Wald statistics determine, in practice, the significance of an individual variable, showing in this case, high significance. Odds ratio of 1.178 indicates that an increment of one unit (=percent) in predictor variable X1 increases the odds of obtaining the grade 1 board by 17.8% compared to the reference group, grade 3. Similarly, in the case of a negative coefficient X2 with the odds ratio value of 0.772, compared to the reference group, the odds of obtaining the grade 1 board decreases by 26.8% (1.00-0.772=0.268), as the value of X2 increases by 1%.

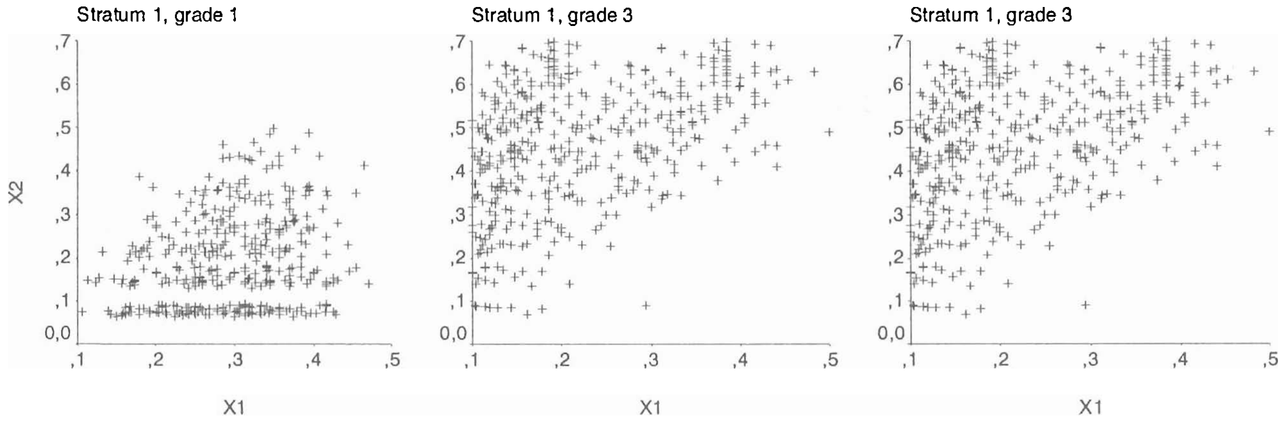

**Figure 3.** Distribution of knottiness grades 1, 2 and 3 in stratum 1 according to the location parameters X1 (relative distance from the pith, % of the top radius of the log) and X2 (relative distance from the stump, % of the height of the tree). For description of strata and grades, see: Table 1

## Discussion and conclusions

The knottiness structure between the two birch species and between the growing conditions showed considerable differences. Generally, in pure *B. pubescens* stands (stratum 3), the percentage of the knot-free boards was slightly smaller and the percentage of the sound-knotted boards slightly larger in comparison to the other strata studied. The differences between the grade distributions of *B. pendula* grown in pure birch stands and in mixed stands of conifers and birch were actually smaller than what could be expected. According to the literature, the density of the stand, as well as the competitive position of an individual tree, inevitably influences its knottiness properties (cf. Merkel 1967, Kellomäki & Tuimala 1981, Kellomäki 1984, Hägg 1988, 1990, Lämsä et al. 1990, Kellomäki et al. 1992, Niemistö 1995, Niemistö et al. 1997). In this study, however, this effect was not observed, while the range of the stand densities was fairly small (cf. Heräjärvi 2001). Moreover, the location parameters as predictors for the lumber grades were so dominating that they faded out the less significant predictors, such as stand density, dbh and heights of the crown limits. The *B. pendula* stands were, on average, slightly older than the *B. pubescens* stands; this might have influenced the comparisons of the knottiness distributions between the two species. However, the between-species variation was not of key importance in this study.

It appeared that the location of especially dead, i.e., dry and rotten knots within birch stems is difficult to model with the methodology chosen. During the sampling and analyses of the materials it was noticed that even large, externally dry or even rotten branches turned into sound knots quite soon after they were investigated further inside the stem.

Concerning the methodological framework of this study, polytomous logistic regression was found suitable for predicting the odds of obtaining knot-free and sound-knotted lumber from birch trees. One possible source of bias related to this kind of modelling is the correlation between the within-tree and within-stand measurements. Such correlation was not observed in this study, which might be due to the natural variability of knottiness characteristics even within one, uniformly treated stand. The mixed knottiness structure in the mid sections of the stems still prevented the models from being able to separate grades 2 and 3 from each other with the accuracy wanted. This was partly affected by the grading practice where fairly long, two-metre boards were classified into one grade as a whole. It is obvious that the shorter the boards are, the better is the accuracy of the models. Undoubtedly, this would be true also in the case of thinner boards.

A similar modelling method has not been introduced earlier for predicting the lumber grade distributions. This method would probably be more applicable to softwoods with the monopodial growing regime (cf. Zobel & van Buijtenen 1989, Kellomäki & al. 1992), which generally results into straighter stem form. From the point of view of the practical applicability, the challenge in this kind of modelling is that the location of the log within the tree should be known in order to select the optimum sawing patterns. Excluding the easily recognisable butt logs, such information is not available in the current sawmills. Nevertheless, a coding or measuring method of some kind, based on the log taper, for instance, would obviously be possible for detecting the logs original vertical location in the stem (cf. Blomqvist & Nylinder 1988, Jäppinen & Nylinder 1997, Lemieux et al. 2000, Lundgren 2000). This question was not approached within the framework of this article.

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# ИССЛЕДОВАНИЕ ХАРАКТЕРИСТИК ВНУТРЕННЕЙ СУЧКОВАТОСТИ БЕРЁЗЫ (*B. PENDULA* И *B. PUBESCENS*) ПРИ УСТАВКИ ПИЛЫ

**Х. Херяйарви**

*Резюме*

Целью данного исследования является: изучение структуры внутренней сучковатости деревьев, и рассмотрение определения степени сучковатости досок, получаемых при распиливании спелой березы (*Betula pendula и B. pubescens*), на основе расположения доски внутри ствола. Для достижения поставленной цели были изучены различия в сучковатости деревьев в разных условиях произрастания, а также рассмотрены деревья образующие разные ярусы в древостое. Учетные деревья были распилены на необрезные доски с толщиной свежей древесины 25 миллиметров, и высотой 2 метра. Доски были отсортированы в зависимости от сучковатости на три группы (1: без сучков, 2: только сухие сучки или и сухие, и здоровые сучки, 3: только здоровые сучки). Модели политомической логистической регрессии (ПЛР) были разработаны для определения степени сучковатости досок. В процессе разработке ПЛР было установлено: большинство комлевых бревен березы бородавчатой (*B. pendula*) с комля до высоты 6 метров, так как комлевые бревна березы пушистой (*B. pubescens*) с комля до высоты 4 метра содержат в основном бессучковые доски (75 миллиметров от сердцевины наружу). В этих высотах внутренние доски довольно ровно разделились на степени 1, 2 и 3. Доски со здоровыми сучками, находятся в основном в маломерной верхней части ствола. На более низких высотах доски со здоровыми сучками постепенно превращаются в доски с сухими сучками и под конец в бессучковые доски. В моделях ПЛР на всех исследованных условиях произрастания бессучковые доски, и доски со здоровыми сучками значительно отличались друг от друга. Доски только с сухими сучками или со смешанной структурой сучковатости были немного хуже классифицированы.

**Ключевые слова:** *Betula pendula*, *Betula pubescens*, классификация, сучковатость, пиломатериал