AUTOMATIC SELECTION, BUCKING CONTROL, AND SORTING OF SAWLOGS SUITABLE FOR APPEARANCE-GRADE SAWNWOOD FOR THE FURNITURE INDUSTRY*

LENNART MOBERG†, JOHAN J. MÖLLER, and JAN SONDELL

The Forestry Research Institute of Sweden,
Uppsala Science Park, SE-751 83 Uppsala, Sweden

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ABSTRACT

A model for automatic bucking of sound-knot sawlogs has been implemented in Timberjack and Ponsse cut-to-length harvesters. It is based on a relationship between diameter at breast height (dbh) and the largest small-end diameter (s.e.d.) of logs to produce sound-knot sawnwood in the centre boards. In order to evaluate the possibilities for using this new functionality of harvesters in practical applications, a series of studies were carried out to identify, buck, and sort logs for a commercial appearance-grade of *Pinus sylvestris* L. (Scots pine) marketed for furniture industries. In an initial calibration study, the lowest in-grade height-level was determined for taper-sawn logs from seven stands of different ages and growth rates in central Sweden. The mean sound-knot quotient (SKQ, calculated as small-end diameter at this threshold limit divided by diameter at breast height) was 0.73 (0.69 for final cutting and 0.78 for thinnings). Using these data, the effects of different parameter settings were simulated to evaluate automatic classification of logs. It was apparent that a restrictive setting (a low sound-knot quotient-level forcing the bucking limit higher up the stem) could lead to a high proportion of correctly classified in-grade logs, but at the cost of missing furniture raw material through incorrect classification of logs as out-of-grade. Three sound-knot quotient-levels (0.64, 0.68, and 0.72) were tested in a practical study to evaluate log sorting in two final cutting stands and for two lumber dimensions (50 × 125 mm and 50 × 150 mm). For each setting and stand, logs with s.e.d. 192–239 mm were automatically selected by the on-board computer, and identified (in-grade, out-of-grade, or butt-log) with the paint-spraying function of the harvester head. The results verified the findings of the simulation study: the proportion of correctly classified logs (success rate) changed considerably with the different settings, and a high success rate also resulted

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† Corresponding author: Lennart.Moberg@skogforsk.se

in a substantial number of out-of-grade logs (as classified by the harvester) containing furniture-grade sawnwood. Finally, a large-scale, industrial trial was performed using SKQ 0.70 and a normal production environment involving several harvesters and a large sawmill. In total, of the 1087 logs classified as in-grade by the harvester computer, 86% fulfilled the furniture grade requirements for sawnwood when converted in the sawmill. Correspondingly, of the 622 non-butt logs classified as out-of grade, 63% did not meet the furniture grade requirements.

Keywords: bucking algorithms; cut-to-length harvesters; wood utilisation; *Pinus sylvestris*.

INTRODUCTION

Background

Cut-to-length harvesters are the predominant logging machines used for both commercial thinning and final felling in Nordic countries (Frumerie 1997). More recently, they have also become widely used in many other parts of the world (Konttinen & Drushka 1997; Godin 2000). A modern harvester is equipped with a felling head which has a saw (for cross-cutting), delimbing knives (for delimbing and diameter measurements), a length recording device, a paint-spraying device (for marking logs sorts), and is supported by an on-board computer for bucking decisions. Most often the computer uses dynamic programming (DP) bucking optimisation algorithm (e.g., Pnevmaticos & Mann 1972; Näsberg 1985) to maximise the value of the logs produced, based on diameter/length measurements and value of log sorts. Sawlogs are often bucked according to a pre-defined length/diameter matrix based on the needs of the receiving mill or a negotiated price-list. The operator can manually identify quality limits and over-ride the suggestion of the computer (Andersson & Sondell 1989). However, the average feeding speed of the harvester head is quick (2–3 m/sec, Nordén *et al.* 2005) putting stress on the operator for a correct decision (Gellerstedt 2002). It is difficult for the operator to judge internal properties of logs other than the most obvious stem damage (such as spike knots, butt-rot, or severe crook), and it is not possible to get similar judgements from the large number of harvester operators involved for a large sawmill.

A substantial amount of research has been carried out to predict sound-knot core through recursive use of growth, taper, and crown recession models (e.g., Maguire *et al.* 1991; Houllier *et al.* 1995; Barbour *et al.* 1997; Mäkelä *et al.* 1997; Grace *et al.* 2000; Ikonen *et al.* 2003). These rely on a large number of inter-connected models which it would be computationally inefficient for harvesters to use during real-time measurements. Furthermore, many of these rely on information about past silviculture and/or predictor variables which are simply not available for normal harvesting tracts. In an alternative approach, Øyen & Høibø (1999) and Vestøl & Høibø (2000) using destructive measurements and Moberg (2001) using non-destructive CT-scanning investigated the possibilities of predicting internal knot properties based on external measurements and identified a relationship between the diameter of the sound-knot core (SKC) and tree diameter at breast height. A second-order polynomial equation (similar to the models of Øyen & Høibø (1999) but slightly modified after discussions with manufacturers), which can be used to predict sound-knot core and to control bucking of sawlogs suitable for appearance-grade products, has been adopted in the StandForD standard used in Europe to manage on-board bucking computers (Anon. 2005). In the StanForD standard, the information flow from and to modern harvesters is described. It also deals with how to control production according to a price-matrix, length/diameter distribution table, quality restrictions, and other parameters used in bucking optimisation. In StanForD, the method of saving the production data is also described. All cut-to-length harvester manufacturers in Europe use this standard. This function relies on existing measurement technology, and was implemented by Timberjack in 2001 (Sondell *et al.* 2002) and, more recently, by Ponsse (J. Korhonen pers. comm.).

Potential Benefits of Bucking and Log-sorting for End-product Properties

A number of sensory devices such as X-ray (Oja *et al.* 2004), acoustic (Ross *et al.* 1997), or laser-based 3D-scanners (Lundgren 2000; Jäppinen & Beauregard 2000) have been developed to measure (directly or indirectly) internal log properties at sawmills for the purpose of sorting before conversion. Waller (2002) evaluated improvements in sorting strategies at a sawmill using laser-based, 3D-scanner technology by comparing the possibilities of pre-sorting sawlogs for differentiated sawing patterns with the aim of producing either appearance grade (sound-knots), high-grade millwork (small knots), or low-grade Japanese construction lumber. Using scanning technology the value recovery increased by nearly 4–10% through a better match between sawlogs and end-product.

With the cut-to-length system, the length-diameter distribution of logs is fixed in the logging operations, and log sorting at the sawmill is primarily to apply different sawing patterns within the same diameter class in order to improve the match between dimension and grade (Waller 2002; Oja *et al.* 2004). Therefore, if there is a need to differentiate the length distribution for a specific market or product group, end-product requirements need to be identified during the harvesting operation, but the advanced measurement devices used in sawmills are generally too expensive or not rugged enough for use in the harvesting environment. In New Zealand (Murphy 2003) and North America (Marshall & Murphy 2004), the economic potential for introducing scanning technology for improved stem diameter and quality determination at harvesting, with the ultimate goal of increasing value recovery through the bucking operation, has been studied. Murphy (2003) reported that net value recovery could hypothetically increase by 7% for *Pinus radiata* D. Don using automated scanning in comparison with conventional measurement technology. In a similar study, Marshall & Murphy (2004) identified a 6% net value recovery increase for *Pinus ponderosa* Lawson & C.Lawson and 8% for *Pseudotsuga menziesii* (Mirb.) Franco (Douglas fir).

Different scanning technologies used for log measurements in sawmills were compared by Nordmark (2005) for potential bucking and/or sorting applications in terms of gross value (no costs considered) and volume recovery. Nordmark (2005) found that, in comparison with conventional measurements, the increased value recovery from added information about knot properties with X-ray scanning was 10% when applied in bucking, 3.4% in log sorting, and 14.1% in combination; the corresponding increases in volume recovery were 2.6%, 0.8%, and 3.9% respectively.

The studies of Waller (2002), Murphy (2003), Marshall & Murphy (2004), and Nordmark (2005) jointly indicate that there should be an economic incentive for companies to differentiate sawlogs with respect to inherent properties before sawing: Waller (2002) showed increases in value recovery when pre-sorting logs for appearance and Japanese construction grades; the other three studies specifically addressed the benefits of product differentiation during the bucking operation.

The use of models for automatic bucking of sound-knot sawlogs in harvesters provides an additional benefit for the harvester operators who don't need to judge quality manually; they get more time to concentrate on other decisions. Furthermore, the same basis for bucking can be applied for several harvesters, regardless of the light conditions.

Objectives

The objective of the present study was to evaluate the possibility of using a new functionality of harvesters in practical logging operations to automatically identify sawlogs containing sound-knots suitable for appearance-grade sawnwood. This was carried out in collaboration with Sveaskog AB and Setra Group AB (Sweden's largest forest-owning and sawmilling companies, respectively), whose goal was to differentiate higher-value furniture sawnwood for primarily Danish and German markets, needing a normal length distribution (34–55 dm), from lower-value sawnwood for Japanese construction markets, requiring a different length distribution (41 dm). The study was divided into four sub-projects, namely: (a) initial calibration of the function to a commercial appearance-grade for Scots pine aimed at furniture industries; (b) simulation of the effect of different parameter settings of the function; (c) a practical test to evaluate sensitivity to different settings; (d) a large-scale industrial trial using one setting and a normal production environment involving several harvesters and a large sawmill (250 000 m^3/annum capacity).

METHODS AND MATERIALS

A commercial Scots pine appearance grade marketed for the furniture industry was selected by the member sawmill company (Setra Group AB). The quality requirements were that at least 60% of the knots were to be sound and evenly distributed. Maximum allowable sound-knot size was quite liberal (50 mm), and generally not restrictive. Loose knots, within the frequency allowance, were not to be grouped and had a maximum size restriction of 25 mm. Lumber that did not meet the furniture grade was graded according to a Swedish visual grading standard (Anon. 1982) into grades U/S, V, and VI. According to the standard, grade U/S has the harshest restrictions on knot size and type (sound or loose), and grade VI has the most liberal restrictions. Sound (intergrown) knots are the part of branch wood, inside a stem, attached to living branches, whereas loose (encased) knots are attached to dead branches (Panshin & de Zeeuw 1980). Wane restrictions, although not judged to be harsh, were excluded from the study since it was felt they were more the result of the diameter interval of logs chosen for the sawing pattern. Likewise, drying defects were not considered.

A. Calibration Study

An initial study (A) was carried out with member companies to calibrate the function to the chosen grade; a total of 150 logs were chosen from seven stands (*see* Table 1) of different age and growth rates in central Sweden — three stands were commercial thinnings and four were final fellings. Two logs (one above and one below the lowest live branch) were collected from each stem. The logs were taper-sawn (a slab of 20 mm was removed parallel to the stem surface) at a small sawmill so that the grade-quality manager (from Setra Group AB) could ascertain the lowest in-grade height-level for each tree. This level represented the small-end of the lowest possible log meeting the grade requirements, assuming a cylindrical sound-knot core. Below this level, there would be too many loose (encased) knots on the sap-wood side of centre boards. The relationship between the diameter at this level (*SKC*) and tree diameter at breast height was analysed in terms of the following function implemented in harvesters:

$$SKC/DBH = a + b\ DBH + c\ DBH^2 \qquad \text{(Eq. 1)}$$

B. Simulation Study

In Study B, the results from the calibration study were used to evaluate the sensitivity of the function to three different sound-knot quotient-settings using the APTAN-simulation system (Arlinger *et al.* 2002). This system uses the same DP-optimisation algorithm (including the sound-knot function) as European cut-to-length harvesters, and can predict the expected conversion of stems into sawlogs and pulpwood. The results were analysed in terms of accuracy in sorting (percentage

TABLE 1–Data from the stands used in the studies (stands A1–A3 were thinnings; the others were final fellings).

Study	Stand	Number of samples*	Site index† (m)	Dbh_{mean} (cm)	Age_{mean} (years)	$Height_{mean}$ (m)
A. Calibration, and	A1	13	26	28.0	53	20.2
B. Simulation study	A2	5	25	24.4	55	19.5
	A3	12	25	29.2	68	21.9
	A4	12	23	30.0	88	20.8
	A5	12	20	30.4	107	20.0
	A6	12	25	33.3	127	26.3
	A7	12	14	30.2	176	18.0
	Sum	78				
	Mean		22.6	29.4	96	21.0
C. Practical test	C1	517	26	29.8	90	23.5
	C2	316	19	29.5	103	17.0
	Sum	833				
	Mean		23	29.7	96	20.2
D. Industrial validation	D1	620	‡	‡	90	‡
	D2	300	23	28.8	105	20.2
	D3	440	‡	‡	110	‡
	D4	291	23	27.0	125	20.7
	D5	58	26	31.2	130	22.5
	Sum	1709				
	Mean		23.2	28.2	105	20.6

* In the calibration study, several logs were sampled from each tree; in the other studies, the sample numbers represent logs.

† Defined as dominant height at 100 years.

‡ Data were automatically collected by the harvester, but accidentally lost for stands D1 and D3.

of correctly classified in-grade logs) and grade recovery (percentage of available sound-knot volume identified at each sound-knot quotient-value) within the sawlog at s.e.d. 192–239 mm.

C. Practical Test

In order to substantiate these results in a practical application for actual lumber converted in a conventional sawmill, three *SKQ* settings (0.64, 0.68 and 0.72) as well as butt logs in two stands (*see* Table 1), and for two dimensions of sawnwood (50 × 125 mm and 50 × 150 mm) were tested (Study C). For each setting and stand, logs with s.e.d. 192–239 mm were automatically selected by the on-board computer, and identified (in-grade, out-of-grade, or butt log) with the paint-spraying function of the harvester head. In this study, in-grade logs was a term used to describe those logs for which the harvester, at a particular setting, predicted that the centre boards would meet the furniture grade requirements at the sawmill. Likewise, out-of-grade logs were predicted at a harvester setting to not contain furniture grade lumber. In total, 562 logs were transported to a large sawmill, and separated at the log sorting station according the colour scheme. Each pile was sorted by stand origin, sawing pattern, and quality as classified by the harvester.

D. Industrial Validation

After discussions with the member companies, a suitable function setting was chosen (*SKQ*=0.70) for a large-scale industrial trial (Study D) to achieve a good balance between sorting accuracy and grade recovery. Several harvesters were used in six different final-felling stands (*see* Table 1). The harvesters used the automatic paint-colouring function to classify the logs as in Study C. A different sample size was obtained from each stand since the number of logs was dependent on the size of the harvesting tract and the number of logs in the small-end diameter interval used for the sawing pattern. The logs from each stand were kept separate, and sorted into in- or out-of-grade piles according to the colour. Each pile was subsequently converted to lumber during ordinary production conditions, and graded by the same quality manager who did the calibration study.

RESULTS

A. Calibration study

Through the initial calibration study, the lowest limit along the stem where the small-end diameter of an in-grade sawlog could be bucked was identified. The relationship between this small-end diameter and tree diameter at breast height has been illustrated in Fig. 1, whereby the sound-knot quotient was given by the slope of the solid line (representing predicted values). The relationship was adequately described by a straight line: the higher order parameters (*b* and *c*) of Eq. 1 were non-significant.

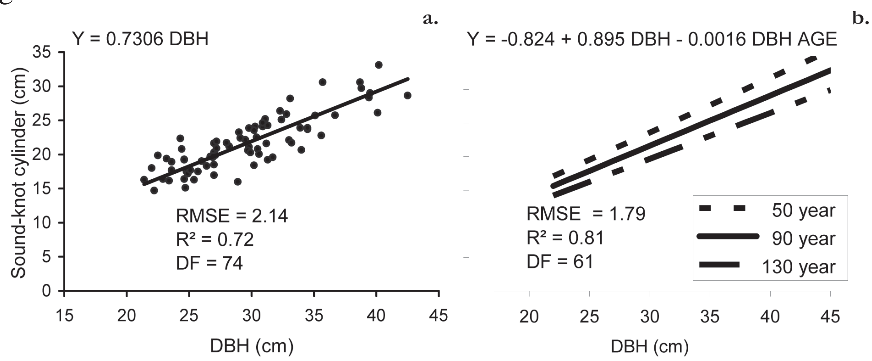

FIG. 1–Diameter of sound-knot cylinder (SKC) as a function of diameter at breast height (a) and AGE (b, with predicted values for three different levels of AGE).

Although attempts to introduce additional tree- and stand-level predictors did not improve model fit, there were some ambiguous results with respect to stand age. Stand A7 was extremely old and had a low growth rate, but had a similar sound-knot quotient to the thinning stands. When data from this stand were removed from the analysis, stand age was also highly significant. The effect of three arbitrary levels of age, when Stand A7 was excluded, is given in Fig. 1b.

B. Simulation Study

Since only parameter *a* of Eq. 1 was found to be significant in Study A, the other parameters were dropped. Parameter *a* then became an estimate of mean sound-knot quotient. Using the data from Study A and the bucking simulation facility of APTAN, the effects of different levels of sound-knot quotient on sorting accuracy and grade recovery could be compared. With a low sound-knot quotient, the quality limit for in-grade logs (as classified by the harvester) was forced relatively high up the stem, and provided a high proportion of correctly classified logs (Fig. 2). However, a substantial volume of appearance grade lumber was missed. With a higher, more liberal, sound-knot quotient-threshold the classification accuracy was reduced, but more of the available appearance grade sawnwood was identified.

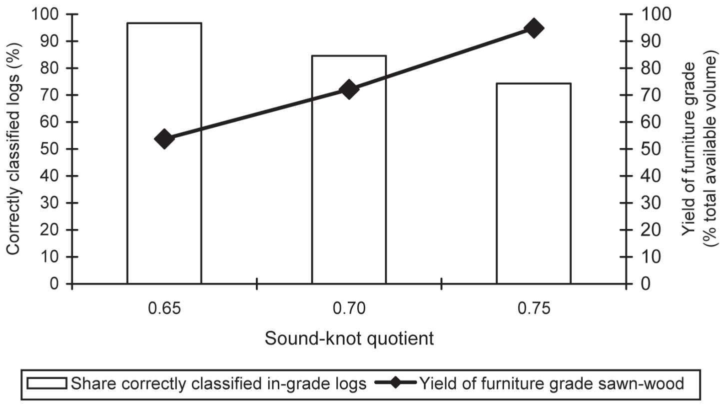

FIG. 2–Percentage correctly classified in-grade logs and recovery of sound-knot boards at three levels of sound-knot quotient (0.65, 0.70 and 0.75; butt logs were excluded).

C. Practical Test

Logs from two stands (C1 and C2) were automatically bucked, sorted, and delivered to a sawmill in a first practical test using several different settings of the sound-knot function in harvesters. The results from this study have been presented for two lumber dimensions: 50 × 125 mm (Fig. 3 and 4) and 50 × 150 mm (Fig. 5 and 6). For each stand and dimension, the logs were grouped according to the function setting, and whether they were judged by the harvester to be in-grade, out-of-grade, or butt logs. Each such group of logs was then sawn separately, and graded at the sawmill.

Over 90% of the in-grade logs for 50 × 125 mm lumber were correctly classified at SKQ 0.64 and 0.68 (Fig. 3). At SKQ 0.72 for the younger stand (C1), this was reduced to about 80%. For the out-of-grade logs in the same stand, about 30–40% of the logs fulfilled appearance grade requirements when converted to lumber. However, in the older stand (C2), about 90% of the out-of-grade logs still contained appearance grade lumber; it appears that in this stand nearly all non-butt logs fulfilled the lumber grade requirements. Butt logs contained little or no appearance grade lumber, although most of the high-value U/S-grade lumber was found amongst these logs.

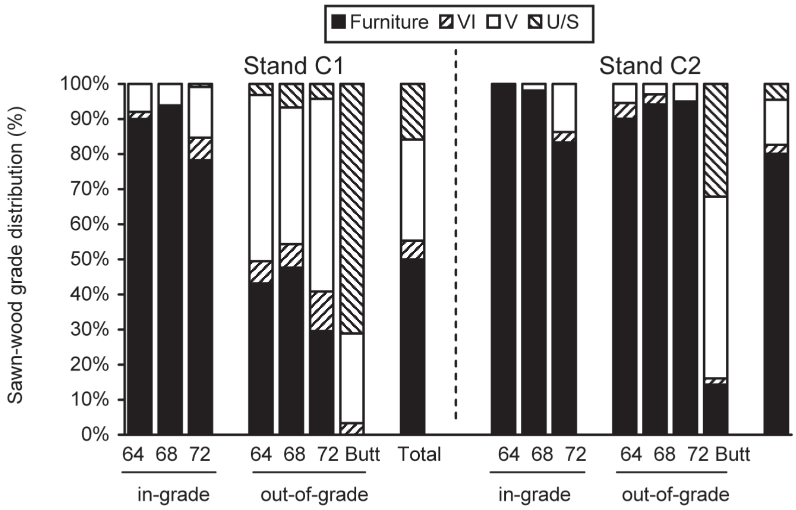

FIG. 3–Distribution of 50 × 125 mm lumber grade of the logs classified as in- and out-of-grade by the harvesters at three levels of sound-knot quotient (multiplied by 100 due to space limitations), as well as butt logs, and for two different stands. The weighted total grade distribution for each stand has also been given.

At 0.64 SKQ for stand C1 and 50 × 125 mm lumber, although a high degree of correct in-grade classification was obtained (Fig. 3), only 20% of the available appearance grade lumber was identified by the harvester (Fig. 4). This grade recovery rate increased to 80% at 0.72 SKQ, thus showing the same general pattern as was found in the simulation study (Fig. 2). Although slightly different grade recovery rates were evident in stand C2, a similar pattern was again apparent (Fig. 4). For the 50 × 150 mm lumber (Fig. 5 and 6), the trend was the same showing that a low sound-knot quotient-level gave a high degree of correct in-grade classification but a low percentage of identified appearance-grade lumber.

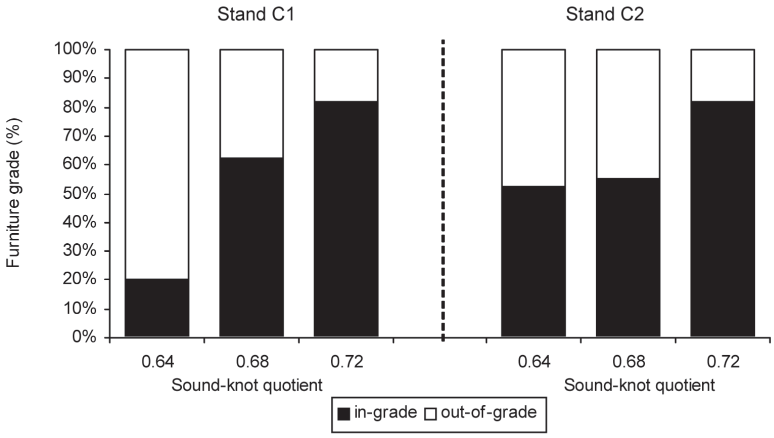

FIG. 4–Distribution of total available furniture grade sawnwood (50 × 125 mm) by harvester classification (in- or out-of-grade) at three levels of sound-knot quotient for two different stands.

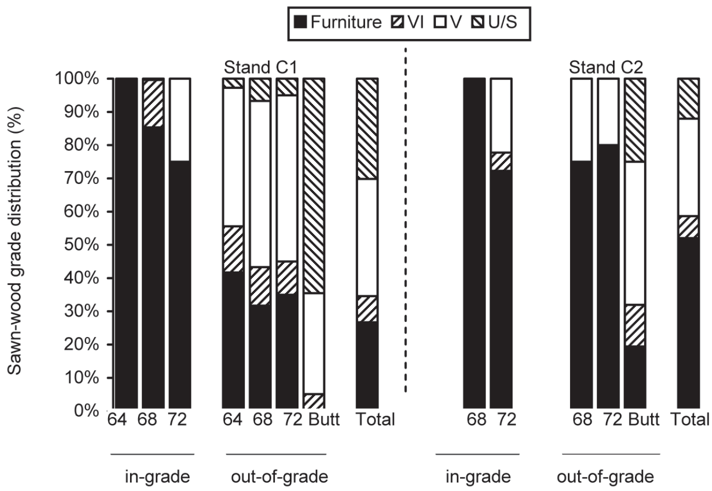

FIG. 5–Distribution of 50 × 150 mm lumber grade of the logs classified as in- and out-of-grade by the harvesters at three levels of sound-knot quotient (multiplied by 100 due to space limitations), as well as butt logs, and for two different stands. The weighted total grade distribution for each stand has also been given.

D. Industrial Validation

Using 0.70 SKQ and 50 × 125 mm lumber throughout, automatic selection, bucking, and sorting of sawlogs with respect to grade quality was replicated for five ordinary final-felling stands. Of the in-grade sawlogs, 86% were correctly classified by the harvesters, whereas 37% of the out-of-grade sawlogs contained appearance

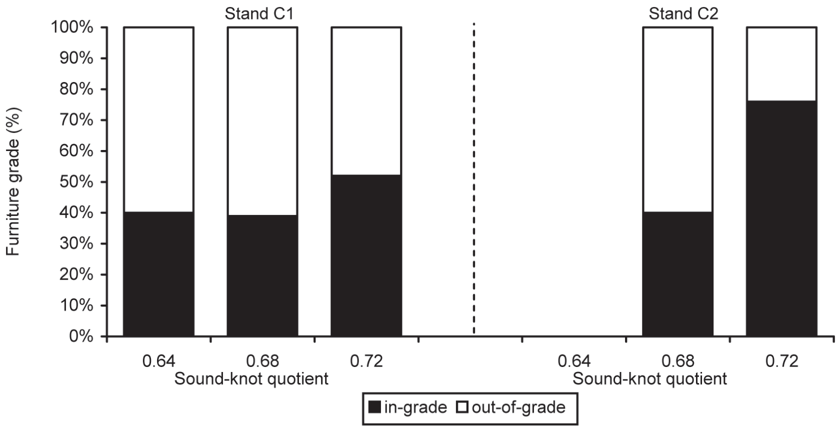

FIG. 6–Distribution of total available furniture grade sawnwood (50 × 150 mm) by harvester classification (in- or out-of-grade) at three levels of sound-knot quotient for two different stands.

grade lumber (Fig. 7). In comparison with Study C, there were slight differences among stands (especially among the out-of-grade sawlogs). There was a slight tendency for younger stands to have a higher proportion of correctly classified in-grade logs (Fig. 7); this was most apparent for the youngest stand (D1) in comparison with the others. The identified yield of appearance-grade lumber was about 80% of the available volume with little variation among stands (Fig. 8).

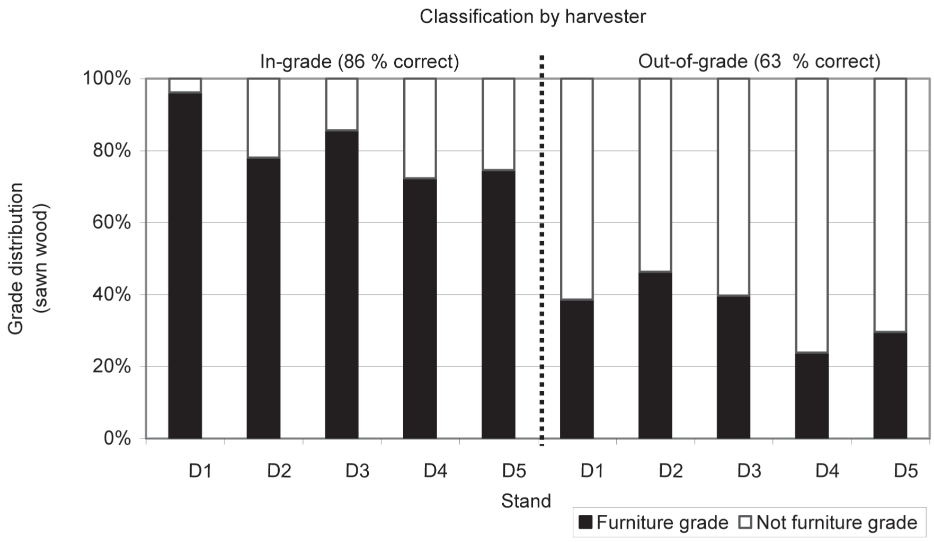

FIG. 7–Distribution of in- and out-of-grade logs (as classified by the harvesters) in terms of graded sawnwood quality. Sorted by age from youngest (Stand D1, 90 years) to oldest (Stand D5, 130 years).

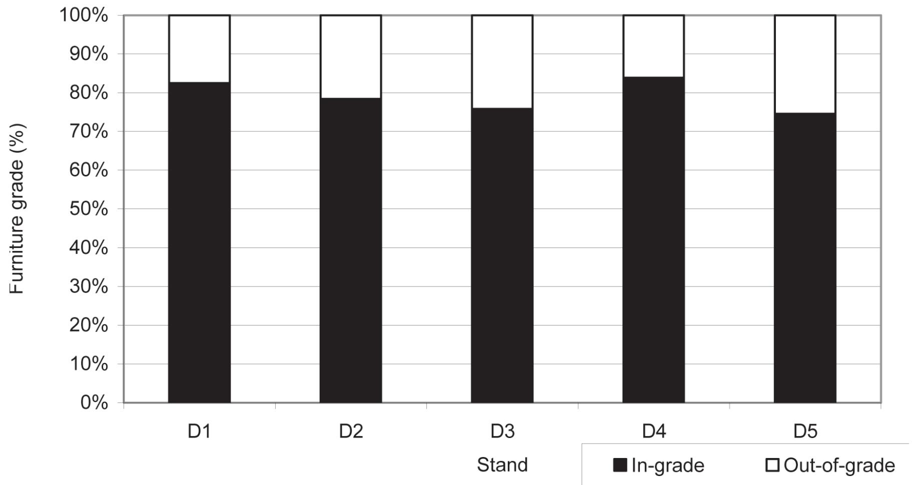

FIG. 8–Distribution of total available furniture grade sawnwood (50 × 125 mm) by harvester classification (in- or out-of-grade) at sound-knot quotient of 0.70 for five different stands.

DISCUSSION

When assessing the limits of the sound-knot core or live crown in terms of lumber grade recovery of appearance grade products, there will always be a need to consider the specific grade requirements of products. In the present study, there was tolerance for up to 40% loose knots, but these had much stricter size limits than sound knots, and could not be grouped together. The size limit for the latter were very liberal, but they had to be evenly distributed, which virtually precluded appearance grade lumber in butt logs. These specific grade requirements make it difficult to compare the absolute levels of sound-knot core or sound-knot quotient with other studies.

However, a number of studies have evaluated the possibility of predicting the sound-knot core using diameter at breast height as a predictor variable. For *Picea abies* (L.) H.Karst. (Norway spruce) in Sweden, for example, Moberg (2001) reported a relationship between sound-knot length and diameter, with diameter at breast height as the only tree- or stand-level predictor even though total age varied between 51 and 152 years. In two combined Norway spruce progeny/spacing trials (28 years of age) in France, the variation of sound-knot length among trees and treatments was almost completely explained by diameter at breast height, with a small additional effect of initial stand density, and no effect of progeny (Vestøl & Colin 1998). For Norway spruce in Norway, Øyen & Høibø (1999) described the vertical development of sound-knot length as cylindrical above the first 10% of tree height, and similarly found that most of the between-tree and between-stand variation was explained by diameter at breast height (range 14.4–44.1 cm; R^2=0.631), but there were some improvements in model fit when AGE (range 58–169 years; R^2=0.670) and also height to the lowest live whorl (R^2=0.720) were added.

The present study was limited to using the sound-knot quotient function (Eq. 1) (Anon. 2005), already implemented in harvesters, which uses diameter at breast height as the only predictor variable. However, the effect of other tree- and stand-level predictors on parameter estimates was evaluated in the calibration study (Study A) (Fig. 1). Diameter at breast height alone accounted for a large part of the variation of sound-knot core (Fig. 1a), but the effect of stand age was ambiguous. When the extremely old Stand A7 (age 176 years) was disregarded, the initial calibration study indicated that trees from younger stands had a higher sound-knot quotient (Fig. 1b) and, therefore, that appearance grade lumber could be obtained nearer breast height. Also, Study D gave a higher yield of sound-knot wood from the youngest stand, corroborating that AGE could improve the model, as was also found for Norway spruce by Øyen & Høibø (1999).

When the oldest stand in Study A was included (A7), a test with diameter at breast height and average stand height improved the model fit, whereas AGE was non-significant. But, tree height only marginally improved the model when it was tested with all stands. However, for practical use in harvesters, diameter at breast height in combination with the stand height would probably be easier to use than age because the harvester continuously measures log length and it is possible to estimate stand mean tree length. Age must be measured before harvesting and would add extra work for the operators.

The extent of sound-knot wood is ultimately the effect of live-crown recession in combination with development of stem diameter growth. At poorer sites, it would be expected that height growth is reduced. The competition for light would be less, especially in combination with low stand densities, and in comparison with better sites the result would be longer live crowns. Old trees grown under these conditions would exhibit cylindrical stem shapes (i.e., small taper) below the live crown (Larson 1963), and it would then be expected that they would have a high sound-knot quotient. Stands A7 and C2 both came from very poor to poor sites, and had short stems. Unfortunately, neither stand density nor live crown height were recorded, but these factors are likely related to the deviating results with respect to the AGE. In future studies, stands should also be sampled to represent variation in stand density, as well as age and site quality. Although it is a difficult variable to record in practical logging, height to the live crown should also be recorded.

CONCLUSIONS AND FUTURE DEVELOPMENT

A function relating diameter at breast height to a quality limit along the stem, for identifying logs containing appearance-grade sawnwood, was calibrated against a commercial furniture grade. The sensitivity of function settings was first evaluated using bucking simulation software, and then tested in two stands using different settings for two lumber dimensions. These showed that the proportion of correctly classified logs (success rate) changed considerably with the different settings, and a high success rate also resulted in a substantial amount of out-of-grade logs (as classified by the harvester) containing furniture-grade sawnwood. Finally, a large-scale, industrial trial was performed using one setting and a normal production environment involving several harvesters and a large sawmill. In total, of the 1087 logs classified as in-grade by the harvester computer, 86% fulfilled the furniture grade requirements of sawnwood when converted in the sawmill. Correspondingly, of the 622 non-butt logs classified as out-of grade, 63% did not meet the furniture grade requirements. The harvesters were able to identify about 80% of the total available furniture grade sawnwood.

However, the study was based on only a single commercial lumber grade, one species, and a limited geographical area. The same principles should be applicable to other appearance grade products with similar quality requirements, such as panelling or floorboards. This would probably require calibration to the actual grade requirements of the product in combination with simulation studies to evaluate a suitable trade-off between grading accuracy and grade recovery. For example, Stora Enso Forest Products has calibrated the function according to other appearance-grade sawnwood products, and successfully started to use this new functionality in normal production for both Scots pine (Ala Sawmill with a total capacity of 360 000 m^3 sawnwood, M. Alm pers. comm.) and Norway spruce (Gruvön Sawmill with the same capacity, A. Norling pers. comm.). Test and calibration of the function have also recently been done in Norway.

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