# Timber Assortment Recovery Models for Southern Finland

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*Abstract*

Along with the total volume harvested, the recovery of timber assortments defines the suitability of the marked stands for different uses of wood. The recovery of the different assortments impacts, to a great extent, the sale value of the stand for the forest owner as well as on the processing value for the wood buyers. In this paper, models to predict the timber assortment recoveries of Scots pine and Norway spruce in clear-cutting stands in southern Finland are presented concerning the application of different bucking instructions for the targeted timber assortments, and for the allowed log dimensions. The material consisted of empirical data from 124 stands in southern Finland collected from circular sample plots. The timber recoveries, when using different timber assortment combinations, were modelled as separate model chains. The potential predictor variables were required to be easily measurable within the limits of capabilities by the forest owner or by the wood buyer. Stand characteristics used as potential predictor variables included variables depicting site fertility, tree species composition, stand volume, and stem size distribution. Furthermore, concerning the options to cut each assortment, the minimum log lengths and top diameters were used as potential predictor variables describing the bucking instructions applied.

**Key words:** assortment recovery, modelling, bucking simulation

## Introduction

While using cut-to-length harvesting, which is the main logging method in Scandinavia and steadily expanding worldwide, the first processing operation of the wood raw material, that is, bucking of the stem, is carried out immediately after the felling. In bucking, the stems are divided into the timber assortments and desired log dimensions according to bucking instructions. The bucking instructions comprise a variety of possible timber assortments, available log lengths, and dimensions for them. Desired log dimensions are derived from the wood-based products, for example, veneer log lengths are concluded from multiplied widths of the veneers, saw log lengths from the lumber lengths suitable for their customers. Possible top diameters of the logs are dependent on the basic diameters and tapering of the stem, while possible log lengths are controlled by bucking according to demanded log lengths, stem straightness, branchiness, and other technical defects.

Available timber assortments and their unit prices as well as available log lengths and top diameters have a crucial role in the timber assortment and value recoveries from the stand. Used log dimensions effect assortment recoveries (Puumalainen 1998, Malinen et al. 2006, Piira et al. 2007), different prices for different log dimensions might diminish saw log recoveries (Gobakken 2000, Piira et al. 2007), and measurement errors effect bucking outcomes and may result in losses in value recovery (Olsen et al. 1989, Sondell et al. 2002, Marshall et al. 2006).

One of the forest owner's most important objectives when selling timber is to achieve the highest net income possible from the stands to be sold. In practice, this means that if the cut-to-length harvesting method and pricing based on the unit values of different timber assortments are used, timber should be sold to the buyer who cuts the most valuable assortments and pays the best total price for them.

Recently, growing interest has been shown in a new pricing system in Finland and Sweden, which is based on a constant unit price for wood in a stem irrespective of log assortments that may be obtained. This unit price can be determined, for example, according to the average stem size, or by the general quality of the stand, both of which are factors that will affect the sawlog recovery. This "stem pricing system" is easy to understand and straightforward to apply from the forest owner's point of view. However, prior information on the stands is needed in order to calculate the potential value for decision making purposes, that is, to determine how much each timber procurement company is likely to pay for the timber in each stand.

Since the achieved timber assortment and sale value from the stand depend on the bucking instructions, the problem is how to predict the assortment and sale value recovery achieved from bucking made by different companies. Buying bids vary not only according to their unit prices for different timber assortments, but also according to available timber combinations and quality and dimension constraints on them. However, when applying the so-called assortment pricing, where all timber assortments cut from the trees have their own unit prices, the sale value recovery is highly predictable by assessing the predicted assortment recoveries. The timber assortment recovery has a great importance to the wood buyer as well. Assortment recoveries define the buyer's ability to pay for wood and how the logistics should be carried out.

Prediction of timber assortment recovery may be obtained by predicting assortment recovery using stand level variables or predicting stem level characteristics and using bucking simulation for dividing stem volume into assortments. Timber assortment predictions based on stem database and bucking simulations (Deadman and Goulding 1979, Deadman 1991, Ahonen and Mäkelä 1995, Nieuwenhuis 2002, Malinen et al. 2001, Malinen 2003, Malinen et al. 2006) offer more precise predictions than assortment recovery models. However, these methods require quite a detailed stem description and bucking simulators, which are usually not available for forest owners or small wood procurement companies. Thus, these methods are applicable only for organisations, which are capable to build their own stem databases and bucking simulators. By using regression model chains, it is possible to predict diameter distribution, heights and tapering of the stems to compensate the lack of stem database. However, the results have not been encouraging, especially the prediction of tapering of the stems have been problematic (Kuusisto 1997).

Timber assortment recovery regression models (Nyyssönen and Ojansuu 1982, Päivinen 1983, PMP-ohje 1987, Maltamo and Uuttera 1994, Kangas and Maltamo 2002), and non-parametric models (Tommola et al. 1999, Weijo 2000, Malinen et al. 2001) has been widely developed. These assortment recovery models have not considered the technical defects of the stem affecting the assortment recovery, thus, different models predicting reduction in the volumes of timber assortment recovery due to the stem or stand defects have been created (Vähäsaari 1988, Mehtätalo 2002). However, in the models of Vähäsaari and Mehtätalo, the interaction between the defects and bucking instructions has not been considered. Piira et al. (2007) studied the variation in the sawlog recovery, and the sale value of timber stand depending on the bucking instructions, that is, the effects of the changes in the minimum sawlog diameter, different allowable log lengths and the available selection of special timber assortment (poles and small-diameter logs for Scots pine, veneer logs and small-diameter logs for Norway spruce). In the study, the bucking simulator developed was able to consider the pre-measured technical defects of the stems, and the interaction between the stem defects and the bucking instructions were taken into account. However, the variation in the sawlog recovery and sale value was defined as the averages for all stands; thus, the results cannot be used to compare the timber assortment and sale value recoveries in individual stand.

The use of airborne laser scanning (Peuhkurinen et al. 2007, Peuhkurinen et al. 2008, Korhonen et al. 2008) offers interesting prospects, although methodology for species specific prediction of timber assortment recovery demands more detailed data than usually are available. While timber assortment recovery modelling has been the primary focus of interest in Scandinavia, for example, in North America the main focus has been on prediction of the lumber volume (e.g., Zhang and Liu 2006) and lumber value (e.g. Kellogg and Warren 1984, Aubry et al. 1998).

The aim of this study was to model the timber assortment recoveries of the stand when the technical quality of the stems is considered and the different bucking instructions are applied. The potential predictor variables were required to be easily measurable variables from a relascope sample plot. By using timber assortment recovery models also forest owners and small and medium-sized wood raw material users would be able to generate practical knowledge which previously has not been available for them, that is, the relationships between the most critical properties of the stand and bucking instructions for the sale value recovery when using assortment pricing method. The models would help in comparing the effect of the different bucking instructions in an individual stand or how to select appropriate stands for the current raw material usage. The effects of requirement for log dimensions and the merchantable special assortments, that is, small-diameter logs of pine and spruce, poles of pine, and veneer logs of spruce, were included in the analyses.

## Material and methods

For the study, the empirical data were collected from 124 stands in southern Finland during the period 2003-2004 (Fig. 1). The data including commercial clear-cutting stands in private and state forests, dominated by Scots pine (*Pinus sylvestris* L.) or Norway spruce (*Picea abies* (L.) Karst.), were collected using measurements on trees from circular sample plots (1-6 plots/stand, each of them 200-300 m2). For each sample plot, geographical location (meridian, latitude, altitude), stand age (age of stump after felling), site fertility class (Cajander 1926), soil type (mineral soil or peatland), and the thickness of the peat layer (measurement to the closest 10 cm) were determined.

**Table 1.** Mean characteristics of the stands in southern Finland. G is a basal area of all species), D25, DGM, and D75 for the diameter of the cumulative basal area diameter distribution trees of 25, 50, and 75 per cent, and H25, HGM, and H75 for the height of the cumulative basal area distribution trees, respectively

| | *Scots pine* | | | *Norway spruce* | | |
|---|---|---|---|---|---|---|
| | min | mean | max | min | mean | max |
| Number of stems per hectare | 63 | 259 | 633 | 75 | 454 | 1025 |
| Stand Age | 59 | 99 | 160 | 59 | 93 | 157 |
| G ($m^2ha^{-1}$) | 10.4 | 25.5 | 39 | 18.0 | 27.4 | 41.3 |
| $D_{25}$ (cm, o.b.) | 20.0 | 26.4 | 34.4 | 13.7 | 22.7 | 32.4 |
| $H_{25}$ (m) | 15.3 | 22.6 | 30.0 | 9.6 | 20.7 | 26.6 |
| $D_GM$ (cm, o.b.) | 23.4 | 29.9 | 39.8 | 16.8 | 27.2 | 39.9 |
| $H_GM$ (m) | 15.4 | 23.0 | 30.3 | 16.2 | 23.1 | 30.2 |
| $D_{75}$ (cm, o.b.) | 25.7 | 33.9 | 50.0 | 19.3 | 31.3 | 44.8 |
| $H_{75}$ (m) | 18.2 | 23.9 | 32.4 | 16.3 | 24.3 | 30.6 |
| Volume ($m^3ha^{-1}$, o.b.) | 55.6 | 161.8 | 355.5 | 40.0 | 217.1 | 480.1 |

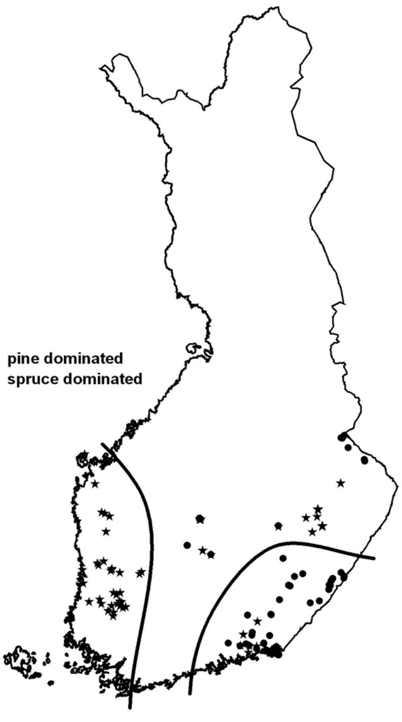



**Figure 1.** Location of the study stands. The sub-data for the butt log analysis for Scots pine was limited to south-eastern and western Finland (bounded regions)

Every tree from each plot was measured for the dimensions (incl. diameter at breast height, height of the tree, heights of the lowest dead and living branch, heights of the thickest dead and living branch) and assessed for the stem quality, with particular attention to estimating visually the occurrence and measuring the effective lengths of the technical defects (e.g., sweep, crooks, branchiness, and scars). From the subset of 61 stands located in south-eastern and western Finland the length of the grade-one butt log, that is, straight and branchless butt log section, were measured as well for a subset of the stands (see Fig. 1). A total of 1,822 Scots pine (*Pinus sylvestris*) and 2,776 Norway spruce (*Picea abies*) stems were measured (Table 1).

The sample trees were bucked with the bucking-to-value simulator developed in the Finnish Forest Research Institute for research purposes. The simulator uses dynamic programming (e.g., Pnevmaticos and Mann 1972, Näsberg 1995) to maximise the value of each individual tree. The used simulator is also capable to consider the technical quality of the stems according to measured technical properties. The bucking instructions were selected to cover the typical range of dimensions of the logs (Table 2). The stems were cut to fixed lengths in 3-dm modules, except pulpwood which was free-cut to lengths between minimum and maximum length, and pine poles which were cut to fixed lengths of 91, 101 and 111 dm. Pine stems that qualified for the poles had to taper less than 27 per cent from 2 to 10 m in height. The unit prices, that is, the price for each timber assortment regardless of the length, top diameter and quality, in the bucking-to-value procedure for sawlog and pulpwood were average stumpage prices in Finnish wood procurement from January to September 2004 in southern and central Finland (Metinfo 2006). Other prices were estimates based on the available information from different wood procurement companies and the expertise of the research group in this study. Standwise, timber assortment recoveries were constructed by summing up the volumes of each log belonging to a certain assortment.

Different wood procurement scenarios, that is, combinations of available timber assortments, were modelled as model chains. Timber assortments were divided into two groups, sawable timber volume and

**Table 2.** Unit price, and minimum top diameters and lengths of logs for different timber assortments applied in the bucking simulations. Available log lengths were defined in 3-dm modules, except for pine poles (10-dm modules) and pulpwood (cut free into the lengths between the minimum and maximum)

| Assortment | Unit price (€/$m^3$) | Min. top diameter (cm) | Log lengths (dm) |
|---|---|---|---|
| Pine saw logs | 46 | 14, 15, 16 | 31-61 |
| Pine butt logs (grade one) | 50 | 18, 20, 22 | 31-61 |
| Pine poles (transmission poles) | 48, 50, 52 | 17 | 91-111 |
| Conventional small-diameter logs of pine | 20 | 10, 12 | 31-52 |
| Short small-diameter pine saw logs of pine | 15 | 9 | 25-34 |
| Pine pulpwood | 12 | 5-8 | 27-55 |
| Spruce saw logs | 45 | 15, 16, 17 | 31-61 |
| Spruce veneer logs | 47 | 22 | 52 |
| Conventional small-diameter logs of spruce | 28 | 10, 12 | 31-52 |
| Spruce pulpwood | 20 | 6-9 | 27-55 |

small-diameter log recovery. The sawable timber volume was further divided if the bucking comprises special assortments, which were included in the sawable timber volume in addition to conventional saw logs. Small-diameter log recovery was not included in the sawable timber volume due to the smaller log top diameter, and it was modelled separately. In the first step in the model chains, the proportion of the recovery of sawable timber from the total volume was modelled, that is, the recovery of timber assortments the minimum diameter of which was equal or exceeded the minimum diameter of the saw logs (saw logs, butt logs, and poles for pine, and saw logs and veneer logs for spruce). In the second step, the proportions of different special timber assortments, if existed, within sawable timber were modelled. The third step was to model the proportion of the small-diameter logs from the total volume. By using model chains it was assured that the proportion of saw logs and special timber assortments did not exceed the total proportion of the sawable timber volume. In this study, the proportion of pulpwood or energy biomass from the stem volume was not modelled due to the fairly constant share of from the total volume in the clear-cutting stands and the negligible relevance to the sale value of the stand. (e.g., Piira et al. 2006).

For pine, five regression model chains for predicting timber assortment recoveries, according to a harvested assortment combination, were created: 1) saw logs, 2) saw logs and small-diameter logs, 3) saw logs and butt logs, 4) saw logs and poles, and 5) saw logs, butt logs, and small-diameter logs. Model chains, where butt logs were considered, were modelled by using a subset of data where necessary butt log quality information was recorded (Fig. 1). For Norway spruce, four regression model chains were created: 1) saw logs, 2) saw logs and small-diameter logs, 3) saw logs and veneer logs, 4) saw logs, veneer logs, and small-diameter logs.

The potential predictor variables were required to be easily measurable variables from a relascope sample plot within the limits of capabilities by the forest owner or by the wood buyer. Selected variables included variables depicting the growing site; stem size distribution, external stem quality, and bucking instructions (Table 3). Stem size distribution was depicted by using rank order statistic based variables (Mehtätalo 2005) of diameters and heights of cumulative basal area diameter distribution of tree of 25%, 50% and 75%. The selection of these trees is relatively easy from a relascope sample plot as cumulative basal area diameter distribution of tree of 25% is a tree which has 25% of trees smaller than it is. Furthermore, 50% tree (DGM) is a median tree and 75% tree is a tree which is ranked according to diameter of breast height and is located in a place 75% from a distribution of diameter at breast height.

**Table 3.** The independent and dependent variables used in the Scots pine and Norway spruce models

| *Variable* | *Explanation* |
|---|---|
| OMT | dummy variable for site fertility of *Oxalis-Myrtillus* mineral soil or corresponding peatland type |
| MT | dummy variable for site fertility of *Myrtillus* mineral soil or corresponding peatland type |
| *Nc* | north coordinate in the Finnish uniform coordinate system |
| *Ec* | east coordinate in the Finnish uniform coordinate system |
| *Pl* | dummy variable for a stand on peatlands |
| *Age* | stand age (years) |
| *G* | basal area of all species ($m^2ha^{-1}$) |
| $D_{25}$ | the diameter of the cumulative basal area diameter distribution tree of 25 per cent |
| $D_{gM}$ | the diameter of the cumulative basal area diameter distribution tree of 50 per cent |
| $D_{75}$ | the diameter of the cumulative basal area diameter distribution tree of 75 per cent |
| $H_{25}$ | the height of the cumulative basal area diameter distribution tree of 25 per cent |
| $H_{gM}$ | the height of the cumulative basal area diameter distribution tree of 50 per cent |
| $H_{75}$ | the height of the cumulative basal area diameter distribution tree of 75 per cent |
| LQ | dummy variable for a low-quality stand due to any defect (proportion of trees containing any defect affecting bucking is over 30% |
| $LQ_b$ | dummy variable for a low-quality stand owing to the excessive branchiness (proportion of trees having branch defects affecting bucking is over 35%) |
| $LQ_s$ | dummy variable for a low-quality stand owing to the occurrence of sweeps and/or curvature (proportion of trees having sweeps and/or curvature affecting bucking is over 40%) |
| *Tdb* | height (m) of the thickest dead branch (basal-area weighted average) |
| *Hdb* | height (m) of the dead branch section (basal-area weighted average) |
| $D_{min}$ | minimum top diameter of logs (cm) |
| $L_{min}$ | minimum length of logs (dm) |
| $D_{blmin}$ | minimum top diameter of butt logs (cm) |
| $D_{sdmin}$ | minimum top diameter of small-diameter logs (cm) |
| SL% | proportion of the sawable timber volume from the total roundwood volume |
| BL% | proportion of the butt log volume of the sawable timber volume |
| P% | proportion of the pole volume of the sawable timber volume |
| V% | proportion of the veneer log volume from the sawable timber volume |
| *SDL%* | proportion of the small-diameter log volume of the total roundwood volume |

Stem quality affects considerably the assortment recovery and variables depicting stand quality were needed. However, measurements of quality variables are usually considered laborious and, therefore, more general quality variables were chosen. Basal area weighted averages for height of the dead branch section and height of the thickest dead branch section can be estimated according to basal area median tree. In addition to these continuous variables, dummy variables for low-quality due to sweeps and/or curvature and low-quality due to excessive branchiness were added for pine, as well as dummy variables for low-quality due to any defect for spruce. The boundary between good and low quality was defined subjectively according to the expertise of the research group.

Nevertheless, the decision whether the stand is considered as a low-quality stand according to dummy variables can be estimated by sample plots.

To obtained linear relationship between independent and independent variables, the variables D25 for pine and DgM for spruce were transformed by the natural logarithms. The models were built using stepwise regression, with P = 0.05 for entry and P = 0.1 for retention. For the correction of non-constant variance and non-normality of error terms, a logarithmic transformation was carried out for the proportion of the sawable timber volume from the roundwood volume and the proportion of the small-diameter log volume of the total roundwood volume. Due to these transformations, a bias correction was needed when using models. For obtaining unbiased model predictions, half of the estimate for the error variance of the model was added to the model prediction before its back-transformation into the antilogarithmic scale (Baskerville 1972).

Timber assortment recoveries are mainly dependent on average stem size of the stand and technical quality of the stems. To find out how the developed models perform in different stands depending on the average stem size and quality indicators the original modelling data were divided into subgroups. Scots pine data were classified into five classes based on the soil fertility and average stem volume of the stand and Norway spruce data were classified into six classes based on the technical quality and average stem volume of the stands (Table 4). The reliabilities of the timber assortment recoveries were investigated using root mean square error (RMSE):

**Table 4.** Data classification for model validation. OMT is for site fertility of *Oxalis-Myrtillus* type, MT is for site fertility of *Myrtillus* type, VT is for site fertility of *Calluna* type and VT is for site fertility of *Vaccinium* type, according to Cajander (1926). A_vol is the average stem volume of stand and defect % depicts the proportion of trees containing any defect affecting bucking

| | Scots pine | Norway spruce |
|---|---|---|
| Class 1 | OMT, MT<br>A_vol < 0,6 $m^3$ | A_vol < 0,40 $m^3$<br>defect% < 30 |
| Class 2 | OMT, MT<br>0,6 $m^3$ ≤ A_vol ≤ 0,75 $m^3$ | A_vol < 0,40 $m^3$<br>defect% ≥ 30 |
| Class 3 | OMT, MT<br>A_vol > 0,75 $m^3$ | 0,40 $m^3$ ≤ A_vol ≤ 0,55 $m^3$<br>defect% < 30 |
| Class 4 | VT, CT<br>A_vol < 0,55 $m^3$ | 0,40 $m^3$ ≤ A_vol ≤ 0,55 $m^3$<br>defect% ≥ 30 |
| Class 5 | VT, CT<br>A_vol ≥ 0,55 $m^3$ | A_vol > 0,55 $m^3$<br>defect% < 30 |
| Class 6 | | A_vol > 0,55 $m^3$<br>defect% ≥ 30 |

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}} \quad (1)$$

where $n$ is the number of the bucking outcomes, $y_i$ is a bucking simulation based value and $\hat{y}_i$ is a model predicted value for the variable $y$ in bucking outcome $i$. The estimation biases were calculated as

$$bias = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{n} \quad (2)$$

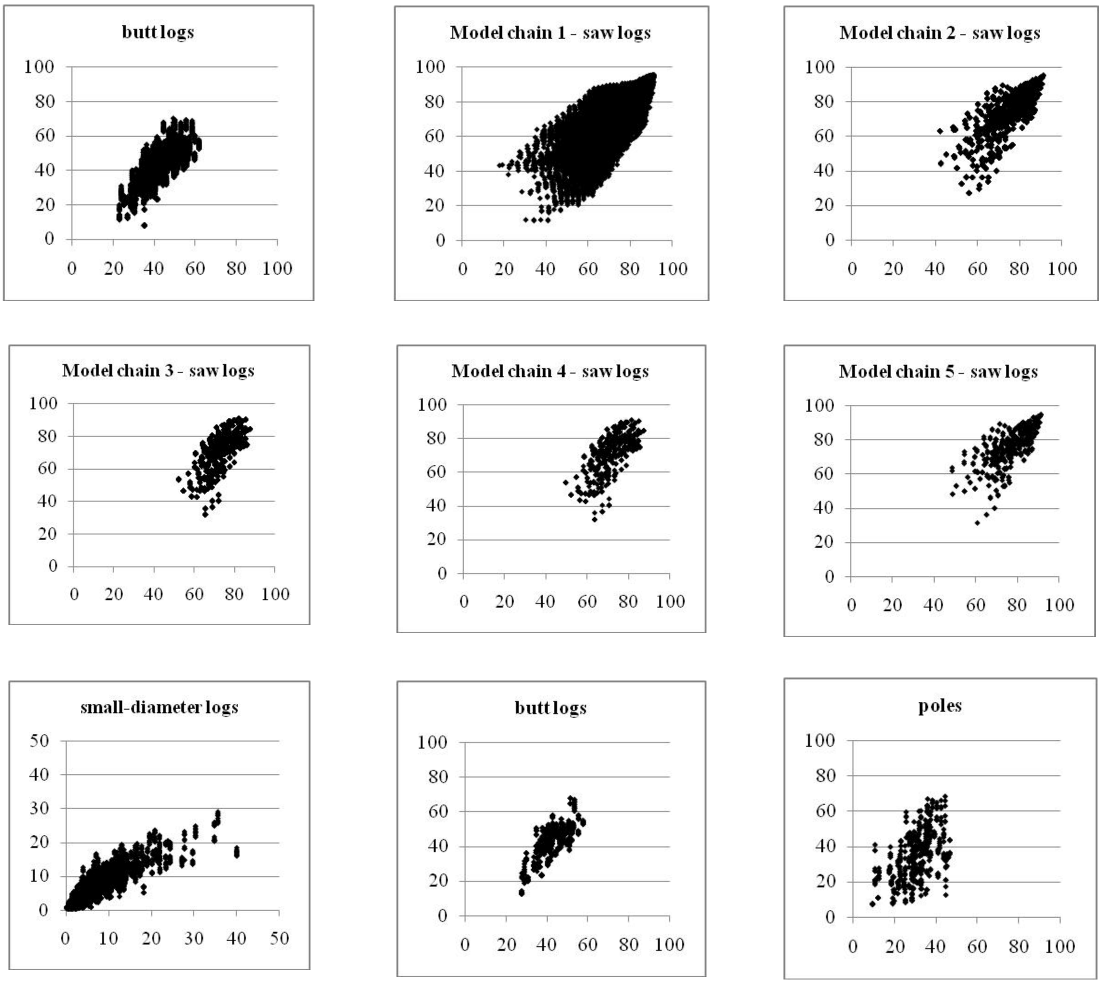
## Results

The timber assortment recovery of Scots pine was greatly dependent on the technical quality of the stems which impairs the performance of the models (Table 5, Fig 2). The prediction of timber assortment recoveries was least accurate when grade-one butt logs were bucked separately. This problem reflected also on the prediction of small-sized timber recovery. The performance of the pole recovery models was found weak.

In the sawable timber recovery model for Norway spruce, the R2 values were considerably higher than for Scots pine and the model predicted saw log recovery well, especially for stands with high saw log percentage (Table 6, Fig. 3). The prediction of the proportion of veneer logs from sawable timber recovery and the prediction of the proportion of small-sized timber volume from total volume were as significant due to the fact, that overall defects do not play as note-

**Table 5.** Regression model chains for timber assortment recoveries of Scots pine: Model chain 1: saw logs; Model chain 2: saw logs and small-diameter logs; Model chain 3: saw logs and grade-one butt logs; Model chain 4: saw logs, grade-one butt logs and small-diameter logs; Model chain 5: saw logs and poles

| | Model chain 1 | Model chain 2 | Model chain 3 | Model chain 4 | Model chain 5 |
|---|---|---|---|---|---|
| The proportion of the sawable timber volume from the total roundwood volume | | | | | |
| n | 28637 | 6353 | 4914 | 871 | 557 |
| Dependent var. | ln(100- SL%) | ln(100- SL%) | ln(100- SL%) | ln(100- SL%) | ln(100- SL%) |
| Constant | 10.902 | 11.763 | 3.646 | 3.666 | 12.475 |
| $LQ_b$ | 0.324 | 0.349 | | | 0.357 |
| $LQ_s$ | 0.282 | 0.291 | 0.333 | 0.331 | 0.285 |
| $\ln(D_{25})$ | -1.522 | -1.710 | -0.467 | -0.473 | -1.687 |
| Nc | $-7.77 \cdot 10^{-7}$ | $-8.50 \cdot 10^{-7}$ | | | $-8.62 \cdot 10^{-7}$ |
| Pl | 0.149 | 0.179 | | | 0.164 |
| Tdb | -0.024 | -0.024 | -0.020 | -0.020 | -0.024 |
| Hdb | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 |
| $D_{min}$ | 0.107 | 0.115 | 0.106 | 0.106 | 0.118 |
| $L_{min}$ | 0.019 | 0.020 | | | |
| OMT | | | 0.371 | 0.369 | |
| MT | | | 0.132 | 0.131 | |
| $H_{75}$ | | | -0.032 | -0.032 | |
| $S_{ee}$ | 0.30 | 0.31 | 0.32 | 0.32 | 0.32 |
| $R^2$ | 0.63 | 0.63 | 0.44 | 0.44 | 0.61 |
| The proportion of the special timber assortment volume from the sawable timber volume | | | | | |
| Dependent var. | | | BL% | BL% | P% |
| Constant | | | -63.651 | -119.682 | -74.295 |
| Ec | | | $1.92 \cdot 10^{-5}$ | $1.99 \cdot 10^{-5}$ | |
| G | | | -0.405 | -0.348 | |
| Age | | | 0.108 | 0.106 | |
| $LQ_b$ | | | 6.759 | 7.875 | |
| $D_{blmin}$ | | | -2.769 | | |
| $LQ_s$ | | | | | -10.206 |
| $D_{75}$ | | | | | -1.431 |
| Tdb | | | | | 1.334 |
| $\ln(D_{25})$ | | | 28.120 | 27.195 | 43.373 |
| $S_{ee}$ | | | 7.40 | 6.53 | 12.52 |
| $R^2$ | | | 0.55 | 0.54 | 0.34 |
| The proportion of the special timber assortment volume from the total roundwood volume | | | | | |
| Dependent var. | | ln(SDL%+0.5) | | ln(SDL%+0.5) | |
| Constant | | 10.826 | | 1.974 | |
| $\ln(D_{25})$ | | -4.688 | | -3.100 | |
| $D_{sdmin}$ | | -0.264 | | 0.150 | |
| $D_{min}$ | | 0.590 | | 0.512 | |
| $LQ_b$ | | | | -0.258 | |
| $S_{ee}$ | | 0.49 | | 0.94 | |
| $R^2$ | | 0.72 | | 0.32 | |



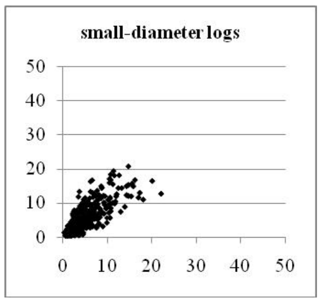




**Figure 2.** Predicted recoveries (%) versus bucking simulation based recoveries (%) of timber assortments for Scots pine. Model chains were: 1: saw logs; 2: saw logs and small-diameter logs; 3: saw logs and grade-one butt logs; 4: saw logs, grade-one butt logs and small-diameter logs; 5: saw logs and poles

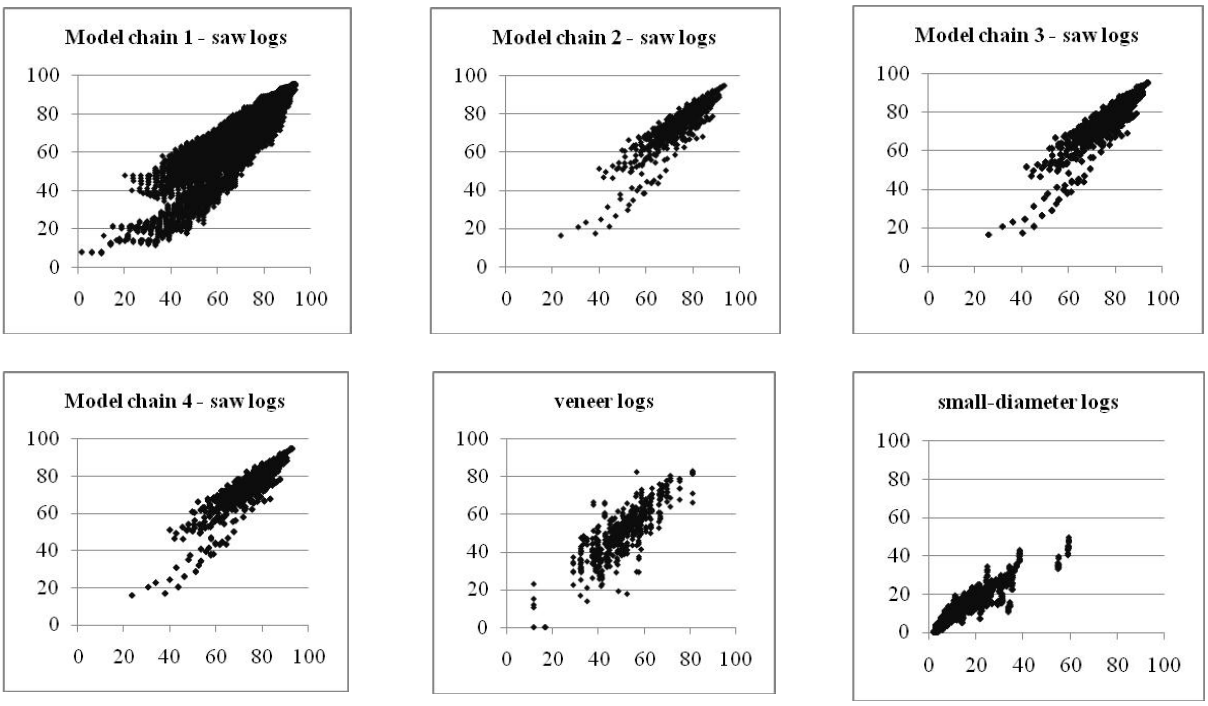
worthy a role in the variation of assortment recovery as for pine.

Scots pine recovery models performed better on the stands where the average stem size was greater and where soil fertility was lower (Table 7). However, the stand properties were related to average sawable timber recovery. The models gave underestimates for sawable timber recovery in classes where soil fertility was high and average stem size less than 0,6 m$^3$ or more than 0.75 m$^3$, and in class 4, where soil fertility was low and average stem size was less than 0.55 m$^3$. The recovery models for special assortments performed fairly equally in all classes, except pole recovery models which gave clear underestimates in the classes where site fertility was high and average stem size was less than 0.75 m$^3$, and in class 5, where site fertility was low and average stem size was more than 0.55 m$^3$.

The timber assortment recovery models for Norway spruce performed better on stands where the average stem size was higher and where the quality of the stems was better (Table 8), except in the case of veneer log proportion from sawable timber recovery in classes 1 and 2, where the average stem size was lower than 0.40 m$^3$.

**Table 6.** Regression models for timber assortment recoveries of Norway spruce. Model chain 1: saw logs; Model chain 2: saw logs and veneer logs; Model chain 3: saw logs and small- diameter logs, Model chain 4: saw logs, veneer logs and small-diameter logs

| | Model chain 1 | Model chain 2 | Model chain 3 | Model chain 4 |
|---|---|---|---|---|
| The proportion of the sawable timber volume from the total roundwood volume | | | | |
| n | 27300 | 546 | 6554 | 3276 |
| Dependent var. | ln(100- SL%) | ln(100- SL%) | ln(100- SL%) | ln(100- SL%) |
| Constant | 4.439 | 4.159 | 4.338 | 4.284 |
| $D_{25}$ | -0.071 | -0.074 | -0.075 | -0.071 |
| $\ln(D_{gM})$ | -0.797 | -0.753 | -0.771 | 0.755 |
| $D_{min}$ | 0.146 | 0.151 | 0.150 | 0.144 |
| $L_{min}$ | 0.015 | 0.017 | 0.014 | 0.016 |
| LQ | 0.237 | 0.251 | 0.251 | 0.239 |
| $S_{ee}$ | 0.20 | 0.20 | 0.20 | 0.19 |
| $R^2$ | 0.81 | 0.81 | 0.81 | 0.81 |
| The proportion of the special timber assortment volume from the sawable timber volume | | | | |
| Dependent var. | | V% | | V% |
| Constant | | -198.493 | | -212.593 |
| $\ln(D_{gM})$ | | 68.362 | | 74.155 |
| $H_{75}$ | | 0.961 | | 0.879 |
| $S_{ee}$ | | 7.96 | | 7.71 |
| $R^2$ | | 0.69 | | 0.72 |
| The proportion of the special timber assortment volume from the total volume | | | | |
| Dependent var. | | | ln(SDL%+0.5) | ln(SDL%+0.5) |
| Constant | | | -1.964 | -1.050 |
| $SL\%^3$ | | | $-1.36*10^{-6}$ | $-1.07*10^{-6}$ |
| $D_{gM}$ | | | -0.075 | -0.069 |
| $D_{min}$ | | | 0.427 | 0.357 |
| $S_{ee}$ | | | 0.30 | 0.23 |
| $R^2$ | | | 0.82 | 0.84 |



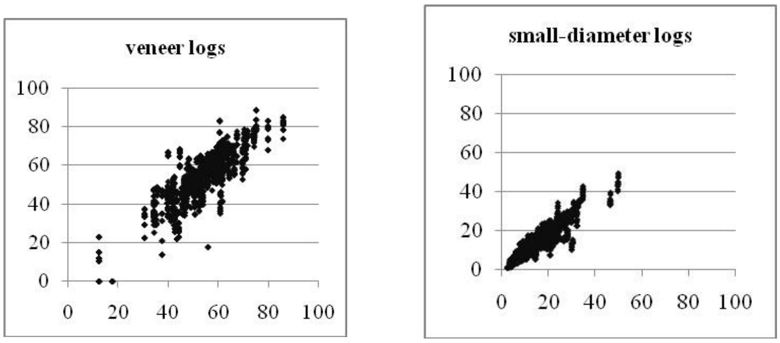




**Figure 3.** Predicted recoveries (%) versus bucking simulation based recoveries (%) of timber assortment for Norway spruce. Model chains were: 1: saw logs; 2: saw logs and veneer logs; 3: saw logs and small-diameter logs, 4: saw logs, veneer logs and small-diameter logs

**Table 7.** Summary of model validation for Scots pine. The number of observations (n) refers to bucking outcomes from the stands with different bucking instructions

| | | Model chain 1 | Model chain 2 | Model chain 3 | Model chain 4 | Model chain 5 |
|---|---|---|---|---|---|---|
| Class 1 | n | 6128 | 1408 | 1107 | 201 | 114 |
| SL% | Mean / bias | 65.23 / -1.63 | 66.80 / -2.05 | 67.14 / -2.02 | 66.51 / -2.47 | 71.40 / -0.07 |
| | RMSE | 12.02 | 12.17 | 10.30 | 10.61 | 10.37 |
| BL% or P% | Mean / bias | | | 39.10 / 0.27 | 38.20 /-0.83 | 33.07 / 3.81 |
| | RMSE | | | 8.17 | 7.12 | 13.04 |
| SDL% | Mean / bias | | 8.64 / -0.27 | | 7.56 / 2.52 | |
| | RMSE | | 2.72 | | 4.29 | |
| Class 2 | n | 4898 | 1117 | 891 | 162 | 93 |
| SL% | Mean / bias | 72.14 /-0.79 | 73.89 / 0.48 | 71.90 / -1.06 | 71.96 -1.03 | 77.96 / 2.01 |
| | RMSE | 8.65 | 8.14 | 7.85 | 7.70 | 7.09 |
| BL% or P% | Mean / bias | | | 42.93 /0.85 | 44.42 /1.55 | 41.35 /9.03 |
| | RMSE | | | 7.16 | 7.26 | 15.50 |
| SDL% | Mean / bias | | 4.99 / -0.78 | | 4.81 / 0.87 | |
| | RMSE | | 2.23 | | 2.36 | |
| Class 3 | n | 9388 | 1902 | 1539 | 256 | 193 |
| SL% | Mean / bias | 74.31 / -2.88 | 76.70 / -2.62 | 76.44 / -0.99 | 76.46 / -1.04 | 78.34 / -2.32 |
| | RMSE | 7.97 | 7.61 | 6.83 | 6.72 | 6.98 |
| BL% or P% | Mean / bias | | | 49.49 / 0.53 | 49.77 /-0.15 | 30.52 / -0.15 |
| | RMSE | | | 7.80 | 6.78 | 9.25 |
| SDL% | Mean / bias | | 2.94 / -0.74 | | 2.54 / -0.12 | |
| | RMSE | | 1.57 | | 1.44 | |
| Class 4 | n | 3653 | 862 | 729 | 135 | 66 |
| SL% | Mean / bias | 64.03 / -3.44 | 65.56 / -3.60 | 64.99 / -3.98 | 64.68 / -4.29 | 70.28 /-2.35 |
| | RMSE | 9.34 | 9.27 | 11.85 | 12.06 | 21.65 |
| BL% or P% | Mean / bias | | | 37.62 / -0.56 | 37.51 / -0.77 | 24.49 / -1.69 |
| | RMSE | | | 6.04 | 5.22 | 12.03 |
| SDL% | Mean / bias | | 10.54 / -1.40 | | 9.60 / 2.71 | |
| | RMSE | | 4.33 | | 4.33 | |
| Class 5 | n | 4570 | 1064 | 648 | 117 | 91 |
| SL% | Mean / bias | 76.85 / 0.31 | 78.84 / 0.16 | 78.97 / 1.78 | 78.79 / 1.68 | 80.06 / 0.32 |
| | RMSE | 5.16 | 4.62 | 6.33 | 6.33 | 4.28 |
| BL% or P% | Mean / bias | | | 43.21 / -1.11 | 44.72 / -0.09 | 41.93 / 9.57 |
| | RMSE | | | 5.27 | 4.44 | 15.19 |
| SDL% | Mean / bias | | 5.46 /- 0.30 | | 5.13 / 1.13 | |
| | RMSE | | 1.86 | | 2.59 | |

**Table 8.** Summary of model validation for Norway spruce. The number of observations (n) refers to bucking outcomes from the stands with different bucking instructions

| | | Model chain 1 | Model chain 2 | Model chain 3 | Model chain 4 |
|---|---|---|---|---|---|
| Class 1 | n | 4800 | 96 | 1152 | 576 |
| SL% | Mean / bias | 60.52 / -1.64 | 62.25 / -1.80 | 62.17 / -2.98 | 61.82 / -1.53 |
| | RMSE | 7.76 | 7.54 | 7.94 | 7.39 |
| V% | Mean / bias | | 38.61 /-1.89 | | 40.73 / 1.76 |
| | RMSE | | 11.16 | | 11.04 |
| SDL% | Mean / bias | | | 18.31 / -0.60 | 18.58 / 0.18 |
| | RMSE | | | 4.77 | 3.78 |
| Class 2 | n | 3000 | 60 | 720 | 360 |
| SL% | Mean / bias | 55.88 /-1.99 | 57.50 /-1.92 | 57.38 / -3.40 | 57.16 / -1.81 |
| | RMSE | 9.75 | 9.75 | 10.12 | 9.67 |
| V% | Mean / bias | | 37.88 / -2.29 | | 39.57 / -3.15 |
| | RMSE | | 9.34 | | 9.31 |
| SDL% | Mean / bias | | | 15.24 /-2.76 | 15.28 /-2.26 |
| | RMSE | | | 5.94 | 5.08 |
| Class 3 | n | 3900 | 78 | 936 | 468 |
| SL% | Mean / bias | 75.06 / -1.81 | 76.56 / -1.60 | 76.57 / -2.44 | 75.97 / -1.44 |
| | RMSE | 4.17 | 3.77 | 4.068 | 3.70 |
| V% | Mean / bias | | 50.89 / -0.59 | | 54.84 / 0.31 |
| | RMSE | | 5.73 | | 5.53 |
| SDL% | Mean / bias | | | 10.61 /-0.06 | 11.18 / -0.06 |
| | RMSE | | | 1.93 | 1.87 |
| Class 4 | n | 6000 | 120 | 1440 | 720 |
| SL% | Mean / bias | 69.91 / 0.80 | 71.31 /-0.90 | 71.38 / -0.16 | 70.83 / 1.03 |
| | RMSE | 5.82 | 5.69 | 5.47 | 5.69 |
| V% | Mean / bias | | 49.02 / -0.65 | | 51.94 / -0.66 |
| | RMSE | | 7.05 | | 6.59 |
| SDL% | Mean / bias | | | 11.48 / -0.68 | 12.03 / -0.61 |
| | RMSE | | | 2.42 | 2.12 |
| Class 5 | n | 4200 | 84 | 1008 | 504 |
| SL% | Mean / bias | 84.11 / 1.36 | 85.34 / 1.58 | 85.43 / 0.96 | 84.71 / 1.63 |
| | RMSE | 3.32 | 2.93 | 2.57 | 2.90 |
| V% | Mean / bias | | 62.48 / 2.26 | | 66.39 / 2.53 |
| | RMSE | | 7.64 | | 7.01 |
| SDL% | Mean / bias | | | 6.70 / -0.11 | 7.50 / -0.24 |
| | RMSE | | | 1.64 | 1.53 |
| Class 6 | n | 5400 | 108 | 1298 | 648 |
| SL% | Mean / bias | 76.71 / -0.36 | 78.04 / -0.11 | 78.17 / -0.91 | 77.54 / 0.04 |
| | RMSE | 4.73 | 4.38 | 4.42 | 4.39 |
| V% | Mean / bias | | 57.03 / -1.04 | | 60.15 / -1.28 |
| | RMSE | | 5.89 | | 5.95 |
| SDL% | Mean / bias | | | 7.34 / -1.45 | 7.98 / -1.57 |
| | RMSE | | | 2.08 | 2.05 |

## Discussion and conclusion

The aim of the study was to model the timber assortment recoveries of the stand when using the different bucking instructions. The ultimate goal was to provide practical knowledge and construct models to predict the recovery of different assortments for their more extensive identification, harvesting, and utilisation.

The study stands were located in three sub-regions in southern Finland, consisting of final- felling stands dominated by pine and spruce. The data included a large variety of timber stands typical of private and state forests; thus, the predictions can be generalised with a relatively good validity for mature stands. However, broadleaf dominated clear-cuttings or thinning stands were not included in the study. In southern Finland, 87 per cent of the forest land area is dominated by pine and spruce (Finnish Statistical Yearbook of Forestry 2005), and approximately 70 per cent of commercial timber is harvested from final fellings (Metinfo 2006). Moreover, all potential predictors of unit sale value of timber assortment recoveries were not necessarily recorded for the stand and trees, when the focus was on easily measurable variables that could be applicable in practical pre-measurement of timber stands.

The models were capable to predict the saw log recovery well, especially in the stands with high saw log percentage. Studies of non-parametric estimation methods (Tommola et al. 1999, Malinen et al. 2001, Malinen 2003) have reported RMSE values from 4 to 26 for sawlog ratios of pine and spruce stands. However, the most accurate results presented in these studies were calculated without the effect of stem defects on saw log recovery. In Finland, the saw log recovery is usually assessed by using the current data collection method, inventory by compartments, which is based on visual assessments, and some supportive ground measurements. Haara and Korhonen (2004) reported a standard error of ~40 per cent in the sawlog volume estimates obtained with the inventory by compartments.

In the recovery models of spruce, the coefficients of determinations were considerably higher than in those of pine, for which the stem defects were more frequent and variable in severity, which made the prediction more complicated. Thus, the technical, external quality of the stems was an important factor in the prediction of the timber assortment recoveries for pine, but less important for spruce. Branch defects were definitely the most important predictors related to the technical quality for pine, whereas sweep and other stem curvature were important for both species.

The prediction of the recovery of pine poles proved to be difficult, which was partly due to the fact that there are no general requirements for their quality. Actually, the constraints for maximum tapering and minimum and module diameters were the only requirements that could be set on the assortment in the simulation, whilst the true marking of poles is subjective in each stand in commercial cuttings. However, the recovery of poles was the highest in the stands where the stem quality was good, tapering was moderate, and the average stem size above average, but not the largest possible.

Measurements made in the forest always include measurement error. Measurements made by untrained forest owners or SME wood procurement company employees are most obviously more prone to include measurement error. The effect of error is the most severe when measurements are systematically biased. These timber assortment recovery models are especially sensitive for dummy variables depicting the quality of the stand. The problem is not critical when the stand clearly belongs in to the group of high quality or low quality, but problems arise when it is difficult to decide whether the proportion of stems containing certain defects is over the percentage limit or not.

The timber assortment recovery models were constructed by using data which included the measured data and different simulated data on the stems. As always, these kinds of models are suitable in the stands within the range of the critical properties of the study data, and the models do not necessarily give realistic estimates in other kinds of stands. The models are applicable within the range of the modelling data for stand and tree properties, and in even-aged stands of Scots pine or Norway spruce, clearly dominated by either species.

When using these models in the prediction of the assortment recoveries in individual stands, the possibility for errors has to be kept in mind. The results of bucking can be sub-optimal within the given bucking instructions since the working mode, skills, and bucking decisions of harvester operators crucially affect the recovery of different assortments in logging in practice, but this could not be considered in the study. It would be interesting to compare developed models with the actual bucking results, but due to factors affecting the actual assortment recovery, the data should include representative sample of different stand types, harvester operators and wood buyers, and this kind of vast data is very difficult to achieve.

Although it would be desirable to develop models capable to predict exact assortment recoveries based on the stand characteristics, assortments to be bucked, quality and dimension constraints of the logs, the task would be unrealistic (Mehtätalo 2002). The variation in the characteristics of the stands and in the bucking instructions is vast, thus, the method would scarcely be applicable. However, for a timber procurement enterprise and forest owner, it would be beneficial to know what kinds of stands are prone to great variation in the volume of different assortments and in the value recovery due to the bucking to be applied.

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## МОДЕЛИ ПОЛУЧЕНИЯ СОРТИМЕНТОВ В ЮЖНОЙ ФИНЛЯНДИИ

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*Резюме*

Помимо общего заготавливаемого объема, пригодность отмеченных древостоев для различных типов использования древесины определяется выходом сортиментов. Получение разных сортиментов оказывает очень значительное влияние на продажную стоимость древостоя для лесовладельца, а также на стоимость переработки для покупателей древесины. В данной работе представлены модели прогнозирования выхода сортиментов сосны обыкновенной и ели европейской при сплошных рубках в Южной Финляндии в контексте использования разных инструкций раскряжевки на запланированные сортименты и разрешенные параметры бревен. Материал основан на эмпирических данных по 124-ем древостоям Южной Финляндии, собранных с пробных площадок. По отдельным модельным цепочкам моделировался выход древесины при использовании разных комбинаций сортиментов. Потенциальные переменные прогнозирования должны были быть легко измеримы в пределах возможностей лесовладельцев или покупателей древесины. Характеристики древостоев, использованные в качестве потенциальных переменных прогнозирования, включали переменные по плодородию объектов, породному составу, объему древостоя и распределению стволов по объему. Более того, в качестве потенциальных переменных прогнозирования при описании инструкций по раскряжевке использовались параметры минимальных и максимальных размеров сортиментов.

**Ключевые слова**: получение сортиментов, моделирование, моделирование раскряжевки