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Future Wood and Fibre Sources – Case North Karelia in Eastern Finland

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Information on the potential wood supply is important for the wood industry. In this study, the future development of growing stock, cutting potential and wood properties corresponding to the regional scenario of North Karelian Forest Programme 2006–2010 was analysed. The simulations were performed by employing the Finnish MELA system together with the sample plot and tree data of the 9th Finnish National Forest Inventory (NFI9) as initial data for the simulations. Disc-based models for basic wood density, proportion of latewood and fibre length of Norway spruce and Scots pine in Sweden were calibrated and integrated into the MELA system. The wood properties at breast height of both harvested and standing trees were analysed in different strata (age, site type and cutting method) during the scenario period of 50 years (2002–2052). The average wood properties within the same strata varied only slightly over time. However, the results for different strata differed considerably. In general, wood density, fibre length and proportion of latewood increased, on average, as a function of tree age and along with a decrease in site fertility (excl. wood density and proportion of latewood in harvested Norway spruce in the first case and fibre length in the latter case for both species). For trees less than 80 years, properties in harvested trees were equal to or slightly greater than those of standing trees. The values for clear-cuttings were greater or equal to those of thinnings (excl. wood density and proportion of latewood in Norway spruce). The study demonstrates the value of model-based analyses utilising NFI tree measurements in regions that are considered to be sources of raw material.

Keywords wood density, proportion of latewood, fibre length, national forest inventory, forest scenario analysis

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1 Introduction

Information on the quantity and quality of the potential supply of raw material from current forest resources and those expected in the future is important for the wood industry when strategic decisions are made, e.g. concerning investments in processing mills. Because different types of products (e.g. paper grades) require different properties in raw material, it is important to have information on the potential supply of trees for fulfilling these requirements. To support their decision-making, wood users measure samples from harvested trees and, based on this sampling, calculate average wood properties (e.g. wood density and fibre properties) for different strata (e.g. for pine pulpwood harvested from first thinning). However, statistical averages of particular strata (e.g. age-class or cutting method) apply, in principle, to trees with the same type of management history.

In many countries, in the future an increasing amount of cutting potential will be from thinning. Furthermore, in future decades, trees harvested in clear-cuttings will more often be regenerated artificially and grown in managed forests. Trees harvested from below in thinning have usually been dominated by larger trees; therefore, wood properties differ from the remaining trees of the same age. In addition to competition between trees, site fertility affects the growth rate of trees, and consequently, the properties of the wood. Therefore, the wood of trees of the same age may have different properties, depending on the growing site and management history.

Forest management, such as thinning, is known to accelerate the growth rate of trees left in a stand after thinning due to increasing availability of nutrients, water and light, which also affect the properties of the growing stock in coniferous species such as Norway spruce (*Picea abies* L. Karst.) and Scots pine (*Pinus sylvestris* L.) (e.g. Pape 1999a,b, Ikonen et al. 2008). Moreover, for Norway spruce and Scots pine the dominant and co-dominant trees usually have a higher rate of growth than suppressed trees do. On the other hand, they also have, on average, lower wood density and latewood content, whereas contradictory results exist, e.g. for fibre length (e.g. Pape 1999a,b, Wilhelmsson et al. 2002, Ekenstedt et al. 2003, Ikonen et al. 2008). Thus, the type of thinning (e.g. thinning from below or above) also affects the properties of the growing stock not only those of harvested trees. The properties of trees also differ depending on tree species and phase of rotation, in the latter case the differences being greatest between juvenile and mature wood (e.g. Wilhelmsson et al. 2002, Ekenstedt et al. 2003, Ikonen et al. 2008).

In recent years, several different kinds of models for estimating stem and wood properties have been developed (e.g. Leban et al. 1996, Tian and Cown 1996, Kellomäki et al. 1999, Wilhelmsson et al. 2002, Ekenstedt et al. 2003, Ikonen et al. 2003, Repola 2006, Kantola et al. 2007, Mäkinen et al. 2007, Molteberg and Hoibo 2007, Ikonen et al. 2008). Such models could provide useful tools for analyses of the properties of forest resources on a regional basis also in countries like Finland. This would be the case especially for the Swedish models (Wilhelmsson et al. 2002, Ekenstedt et al. 2003), which predict average properties (e.g. wood density, proportion of latewood and fibre length) for cross-sections of stems at a certain height in Scots pine and Norway spruce based on variables typically measured in forest resource inventories and available in many growth and yield models. In these models, the independent variables, such as average width of the growth ring (number of growth rings and diameters in cross sections) and temperature sum, have been selected to incorporate the effect of cambial age and growth rate (diameter) on wood properties in certain climatic conditions. These Swedish cross-sectional models have previously been used to estimate regional variation in wood properties of forests in Sweden (e.g. Moberg and Wilhelmsson 2003). Furthermore, their suitability for Finnish conditions have also been evaluated previously by Ikonen et al. (2008), who found them to be applicable also to Scots pine and Norway spruce grown in eastern Finland.

Estimates of the current growing stock and future cutting removals have been produced in Finland and elsewhere (see e.g. Nuutinen 2003). This is because in the short- and medium term (i.e. less than 30 years) the potential supply of wood depends mainly on the amount, structure and maturity of existing growing stock and is therefore highly predictable. For example, in Finland the MELA system (Siitonen et al. 1996) has been used since the 1980s for regional and national analyses of growing stock and future cuttings (e.g. Siitonen 1993, Nuutinen et al. 2000, Nuutinen et al. 2006). MELA is a flexible tool for medium-term strategic forestry modelling and analysis, and is based on sample plot and tree measurements of the National Forest Inventory (NFI). However, future wood and fibre resources at a regional level from the standpoint of industrial processes have not yet been estimated anywhere.

In the above context, the objective of this study was to analyse the development of wood and fibre resources as well as cutting potential in terms of different properties (i.e. wood density, proportion of latewood and fibre length) in Scots pine and Norway spruce over the 50-year period in North Karelia, eastern Finland. For this purpose, the models of wood properties developed for Scots pine and Norway spruce in Sweden by Wilhelmsson et al. (2002) and Ekenstedt et al. (2003) were first integrated with the output variables of the MELA system (Siitonen et al. 1996). The models were utilised in the prediction of future wood and fibre resources corresponding to the regional scenario of the North Karelian Forest Programme 2006–2010 (Nuutinen ym. 2005, North Karelian Forest Programme… 2005). The calculations were based on the sample plot and tree data of the 9th Finnish National Forest Inventory (NFI9).

2 Materials and Methods

2.1 Outline of the MELA System

The MELA system has two main components: a stand simulator and an optimisation package (Fig. 1). This system was developed for conditions where most stands have, at any time point, more than one option for management operations and individual forest owners are free to choose between these options. Therefore, a stand simulator automatically generates feasible alternative management schedules (over time) for management units, such as forest stands or sample plots representing the stands, and for each management schedule calculates hundreds of variables. The scenario (simulation) period is also divided into sub-periods, for which, both at the beginning and end of each sub-period, so-called state variables are calculated to describe standing trees and their environmental conditions within the stand. In the middle of each sub-period, so-called change variables describing management activities (e.g. harvested trees, costs and incomes) are calculated. Diameter and age at breast height as well as total tree height are recorded for all standing and harvested trees. All these variables can be included into an optimisation package for calculation of regional scenarios. The optimization package seeks a combination of management schedules that corresponds to the values given as scenario assumptions concerning management and development of forest resources at the regional level. All the state and change variables are available for reporting the scenario at the regional, management unit and tree level.

During the simulation, whenever there are options for stand management, a new branch is generated to track the changes caused by various events, which consist of natural processes (e.g. in-growth, growth and mortality of trees) and management activities defined by the built-in basic event routines (e.g. artificial regeneration with the selection of tree species, clearing of regeneration area, soil preparation, tending of young stands and cuttings). The event parameter of the MELA model enables a set of optional events to be defined for each analysis within the built-in event routines and their arguments. The feasibility of management activities can be

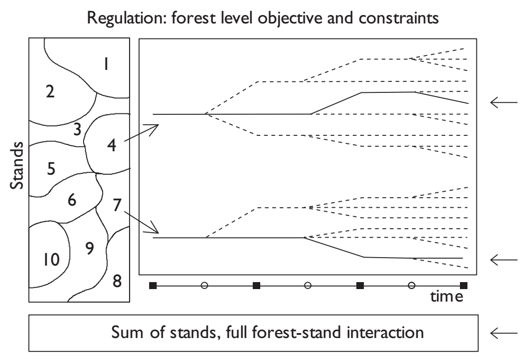

Fig. 1. The principle on which the MELA system is based (Siitonen et al. 1996).

defined, for example, by management categories. In the model, the development of growing stock is predicted for the sample trees of the sample plots in five-year time steps by using a set of individual-tree models based on empirical studies (Hynynen et al. 2002). For optimisation, the MELA system utilises a JLP (LP) software package designed especially for management planning systems based on integrated simulation and optimisation (Lappi 1992).

2.2 Incorporation of the Swedish Models for Wood Properties into the MELA System

In this study, the empirical Swedish disc-based models presented for basic density and proportion of latewood by Wilhelmsson et al. (2002) and corresponding models presented for fibre length by Ekenstedt et al. (2003) for Scots pine and Norway spruce (see Appendix 1) were adopted for predicting average properties at breast height for each sample tree. These Swedish models are based on stand and plot data with large geographical variation in Sweden, including both young and old stands from high- to low-fertility sites and sample trees representing large, medium and small diameter classes (see Wilhelmsson et al. 2002, Ekenstedt et al. 2003, Ikonen et al. 2008).

These models were slightly modified for our work based on previous work by Ikonen et al. (2008), in which the results by these Swedish disc-based models were compared to the corresponding results given by the Finnish ring-based empirical models based on various datasets collected in eastern Finland for Norway spruce and Scots pine. The slight modification of these disc-based models was necessary, because the measurement methodology and definitions of wood density (i.e. basic density versus air dry density), proportion of latewood and fibre length (weighting of length) differed in the Swedish disc- and Finnish ring-based models (see details in Ikonen et al. 2008). Thus, to make the Swedish models more comparable to the Finnish models and also to consider also climatic and site differences, the results given by the Swedish disc-based models used in our work were multiplied by the following species-specific constants given by Ikonen et al. (2008): 0.85 for proportion of latewood, 1.08 for basic density and 1.25 for fibre length (length weighted) in Scots pine, and 0.94 for proportion of latewood, 1.09 for basic density and 1.05 for fibre length in Norway spruce. The wood properties of broadleaf species were excluded from our analysis since no suitable models were available for them.

2.3 Layout for the Case Study

2.3.1 Description of the Study Region

A region in eastern Finland covered by the Forestry Centre of North Karelia was chosen for this study (Fig. 2). The total area of forest and scrub land in that region is 1.54 mill. ha. The input data were based on inventory sample plots for forest and scrub land from the 9th National Forest Inventory (NFI9) carried out in 2000 (Korhonen et al. 2001). According to the inventory, the total standing volume was 157 mill. m^3 and the average standing volume was 102 m^3 ha^{-1} (Korhonen et

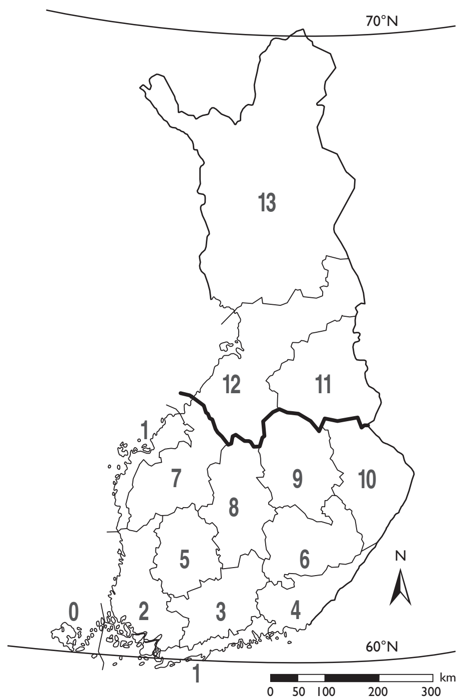

Fig. 2. Map showing the regions of the Forestry Centres in Finland (North Karelia = 10).

al. 2001). The proportion of Scots pine was 51%, Norway spruce 30% and broadleaved species 19% of the total standing volume. The annual volume increment was 7.2 mill. m^3 per year (4.7 m^3 $ha^{-1}a^{-1}$), of which Scots pine made up 47%, Norway spruce 28% and broadleaved species 25%. A total of 32% of the forest and scrub land, 26% of the volume and 26% of the increment were on peatland (Korhonen et al. 2001). In North Karelia, most of the forestry land is owned by non-industrial (54 %) or industrial (20 %) private forest owners (North Karelian Forest Programme… 2005).

North Karelia is dominated by Scots pine forests; the proportion of pine-dominated forests on forest and scrub land is 64%. The proportion of forests less than 40 years old, most of which are Scots pine forests, is 45% of the total forest land. The forests in this region are actively managed. During the 10-year period before the inventory, the clear-cutting area was 103 400 ha, natural regeneration (with seed trees of Scots pine, birch (*Betula pendula* and *Betula pubescens*) and aspen (*Populus tremula*) and shelterwoods of Norway spruce) made up 41 100 ha and thinning 195 700 ha (Korhonen et al. 2001).

2.3.2 Simulations of Forest Management Activities

For each NFI sample plot, the tree data were converted to MELA sample-tree variables and the sample plot data to MELA sample-plot variables (see Siitonen et al. 1996). For the simulation, a number of management units were created (Nuutinen et al. 2000) and classified into three forest management categories: 1) no restrictions on management activities, 2) restrictions on management activities, but limited activities permitted, 3) no activities permitted. In the first category, where and when feasible according to silvicultural recommendations, all typical forest management measures (artificial regeneration, clearing of regeneration area, soil preparation, tending of young stands, different types and intensities of thinning, clear-cuttings, regeneration using seed trees or shelterwoods, supplementary ditching) were simulated as options. In the second category, clear-cuttings with subsequent artificial regeneration measures were not simulated. In the third category, no activities were simulated. Of the total area of forest and scrub land (1.54 mill. ha), 4.5% had restrictions on activities and on 2.6% no activities were permitted (Nuutinen and Hirvelä 2001).

The forest management activities were simulated for the first two management categories according to previous silvicultural recommendations given for private forest owners in Finland (see Yrjölä 2002), following the restrictions of the management categories. For example, thinning rules were based on dominant height and number of trees (first thinning) or on basal area (other thinnings). The rotation period was determined by the mean diameter at breast height and/or stand age. The rules were given separately for each tree species and site type.

Regeneration options included clear-cutting followed by planting or sowing, and natural regeneration with seed trees of Scots pine and birch or shelterwood of Norway spruce. For Scots pine, natural regeneration was simulated on less-fertile sites (*Vaccinium* type, VT, and drier) and for Norway spruce and birch on medium-fertile (*Myrtillus* type, MT) or fertile (*Oxalis Myrtillus* type, OMT, and better) sites. Planting was simulated for Scots pine on medium-fertile and less-fertile sites, and for birch and Norway spruce on medium-fertile and fertile sites. Sowing for Scots pine was simulated for less-fertile sites (*Vaccinium* type, VT, and drier). The wood prices and costs of silvicultural and forest improvement work were based on the deflated (year 2003) average realised prices and costs during the 10-year period 1994–2003.

The analysis of future wood and fibre resources was based on a regional scenario of maximum sustainable cutting removal (Nuutinen et al. 2005), which was also the basis for the North Karelian Forest Programme 2006–2010 (North Karelian Forest Programme… 2005). In the optimisation the objective function was to maximise net present value from timber production by using a 4% interest rate (Nuutinen et al. 2005). The optimisation was constrained by the non-decreasing flow of wood, saw logs and net income over a 50-year period and net present value after the 50-year period greater than or equal to the beginning. The scenarios and sustainability constraints were based on the 50-year simulations. Simulations were carried out for all management categories; but in the reporting of the results, the area where no activities were permitted was excluded. The results presented in this study cover only the area in timber production.

2.4 Calculation of Wood Properties

After simulations over the 50-year period had been carried out, the wood properties were examined for standing trees in the years 2002, 2022 and 2042 and for harvested trees in 2007, 2027, and 2047 for stands dominated either by Norway spruce or Scots pine. First, the disc-based models for wood properties were applied at breast height separately for each sample tree growing on forest land with unditched mineral soil. However, only the trees in young thinning stands, advanced thinning stands and mature stands were included; trees smaller than 5 cm at breast height were excluded from the analyses. Thereafter, average values were calculated for different strata of interest such as standing and harvested trees in tree age classes (0-40, 41-81 and 81- years) and two site types (MT and VT for Scots pine and OMT and MT for Norway spruce). Other strata included cutting methods (first thinning, other thinning, seed-tree cuttings/shelterwood cuttings and clear-cuttings) for the harvested trees.

3 Results

3.1 Changes in Growing Stock and Annual Removal over the Simulation Period

For the first simulation sub-period (2002–2011), the maximum sustainable annual removal was 5.2 mill. m^3, of which 48% was Scots pine, 34% Norway spruce and 18% broadleaved species. During the next two decades (2012–2031), the maximum sustainable annual removal reached 6.2 mill. m^3. The proportion of tree species in the removal remained stable throughout the decades, but the proportion of thinnings increased from 27% to 45%. If fellings were implemented corresponding to the maximum sustainable annual removal, the growing stock increased to 163 mill. m^3 in 2032 (109 m^3ha^{-1}). The proportion of Scots pine gradually increased from 50% up to 58%. Correspondingly, the proportion of broadleaved species decreased during the 30-year period. Furthermore, in the future, in North Karelia trees harvested in clear cuttings will more often be grown in managed forests and an increasing amount of cutting potential will be from stands of thinning age.

3.2 Predicted Wood and Fibre Properties at Breast Height of the Standing and Harvested Trees

3.2.1 Differences between Age Classes

In Scots pine, the average wood density increased as a function of age both in standing (Fig. 3, A) and in harvested (Fig. 3, B) trees, in both cases being, on average, 11% higher in the oldest age class compared to the youngest one over the simulation period of 50 years. In age classes below 80 years, the average wood density of harvested trees was slightly greater than (1%) or equal to that of standing trees. However, in the above-80-years age class, in harvested trees it was somewhat lower (only about 1%) than that of standing trees.

In general, the fibre length of Scots pine trees also increased as a function of tree age (Fig. 3, A and B), being about 30% longer in the oldest age class compared to the youngest one. Over the 50-year period, a slight decrease in average fibre length was found in the 0-to 40-years age class of standing trees, and in the over-80-years age class of harvested trees (3% decrease in both). In the 41-to 80-years age class, the fibres were, on average, longest at the beginning of the simulation period both in standing and in harvested trees (3.2 mm). In the age classes below 80 years, fibres were also only slightly longer (2–3%), on average, in the harvested trees compared to the standing trees. In the above-80-years age class, however, they were somewhat (only 1%) longer than those of harvested trees.

In Scots pine, the proportion of latewood also increased as a function of age. This increase was more distinct in standing trees than in harvested trees. Moreover, compared to the youngest age

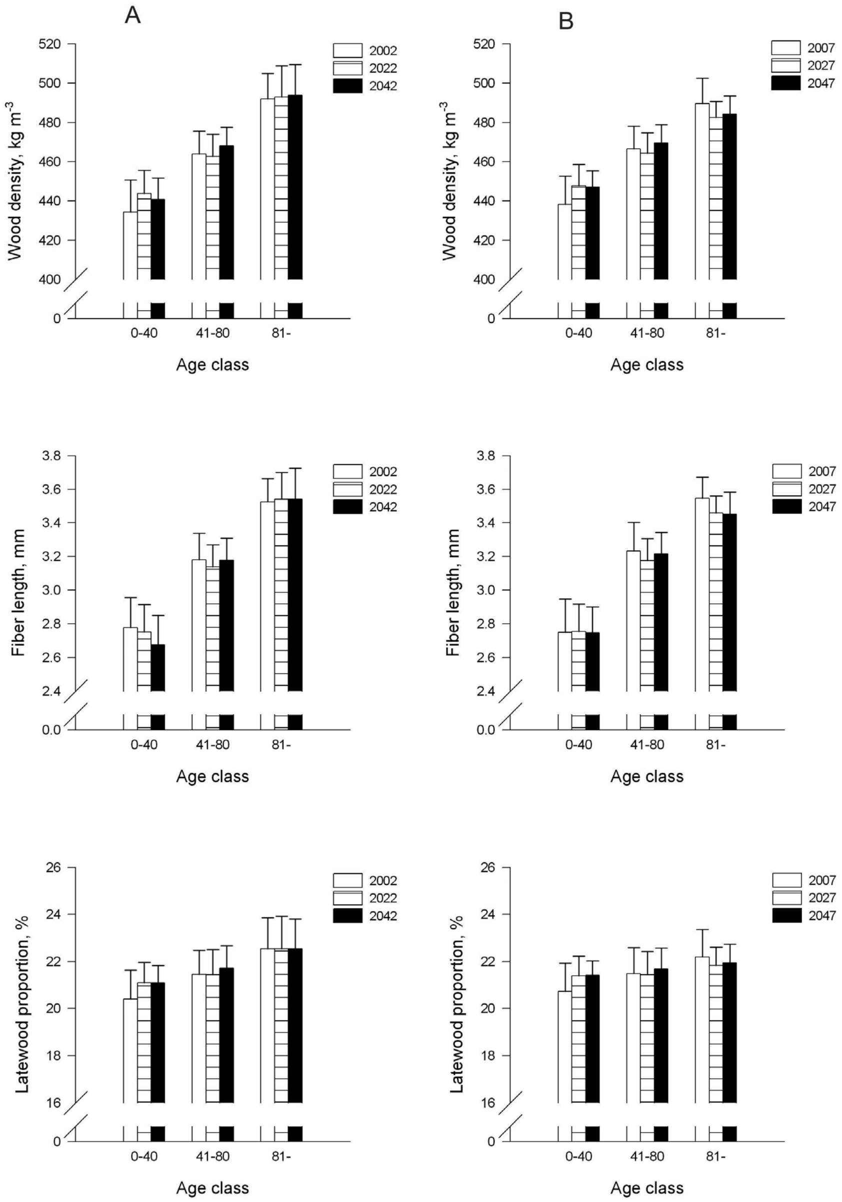

Fig. 3. Wood properties of standing (A) and harvested Scots pine trees (B) of different age classes.

class, the proportion of latewood in the oldest age class was 10% higher for standing trees and 5% higher for harvested trees. In standing trees, the change in proportion of latewood over the 50-year period was smallest in the above-80-years age class (Fig. 3, A). In harvested trees, which were over 80 years old, the proportion of latewood was also only slightly (about 2%) smaller than in standing trees. In the 41-to 80-years age class, the average proportion of latewood was equal to that of standing trees, but in the youngest age class it was higher.

In the standing Norway spruce trees, the average wood density increased only slightly as a function

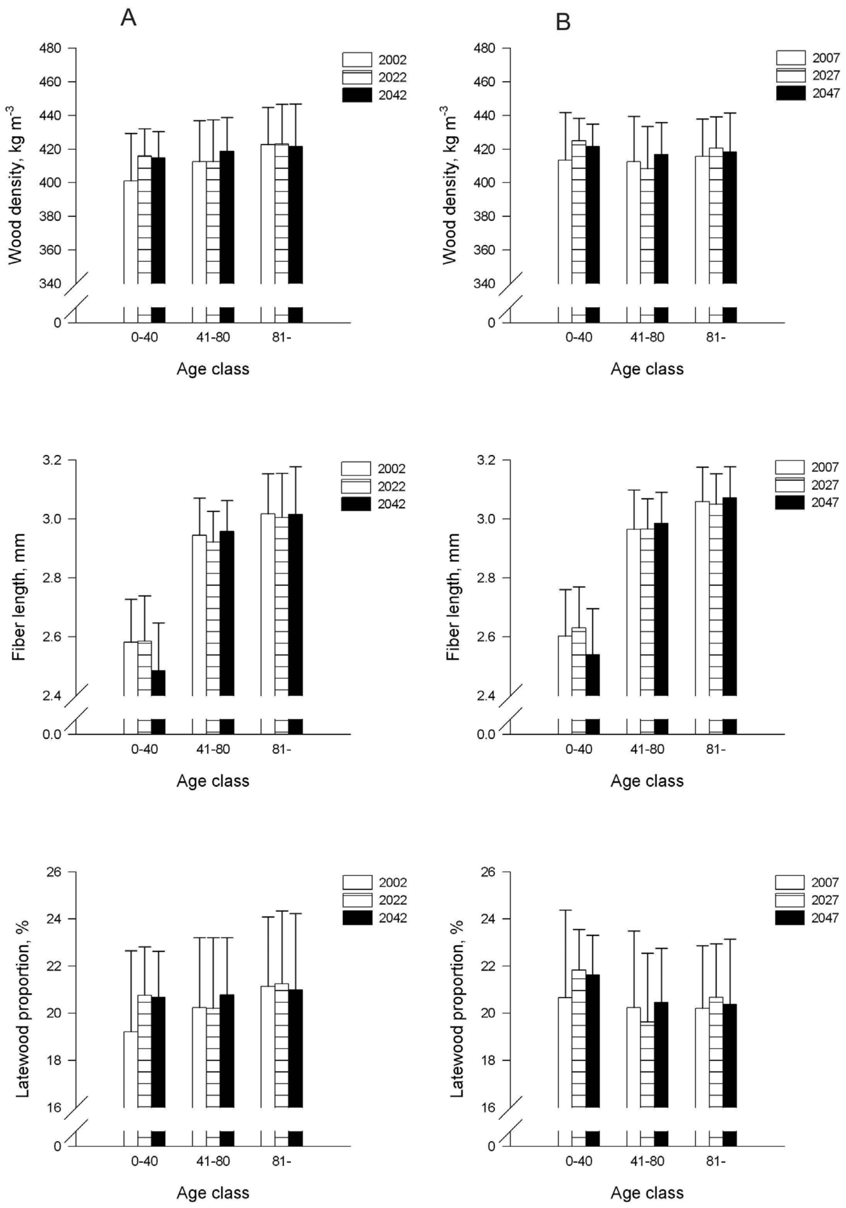

Fig. 4. Wood properties of standing (A) and harvested Norway spruce trees (B) of different age classes.

of age (Fig. 4, A); i.e. compared to the youngest age class, in the 40-to 80-years and over-80-years age classes the difference was only 1–2% (Fig. 4, A). On the contrary, in the harvested trees, in older age classes the average wood density was 2% lower than in the youngest one. In Norway spruce, the average wood densities of harvested trees were equal to those of standing trees, with the exception of the youngest age class, in which wood density was 2% higher in harvested trees.

Similarly to Scots pine, both in the standing and harvested Norway spruce trees the average fibre length increased as a function of age (Fig. 4, A and B); and on average, 15% longer fibres

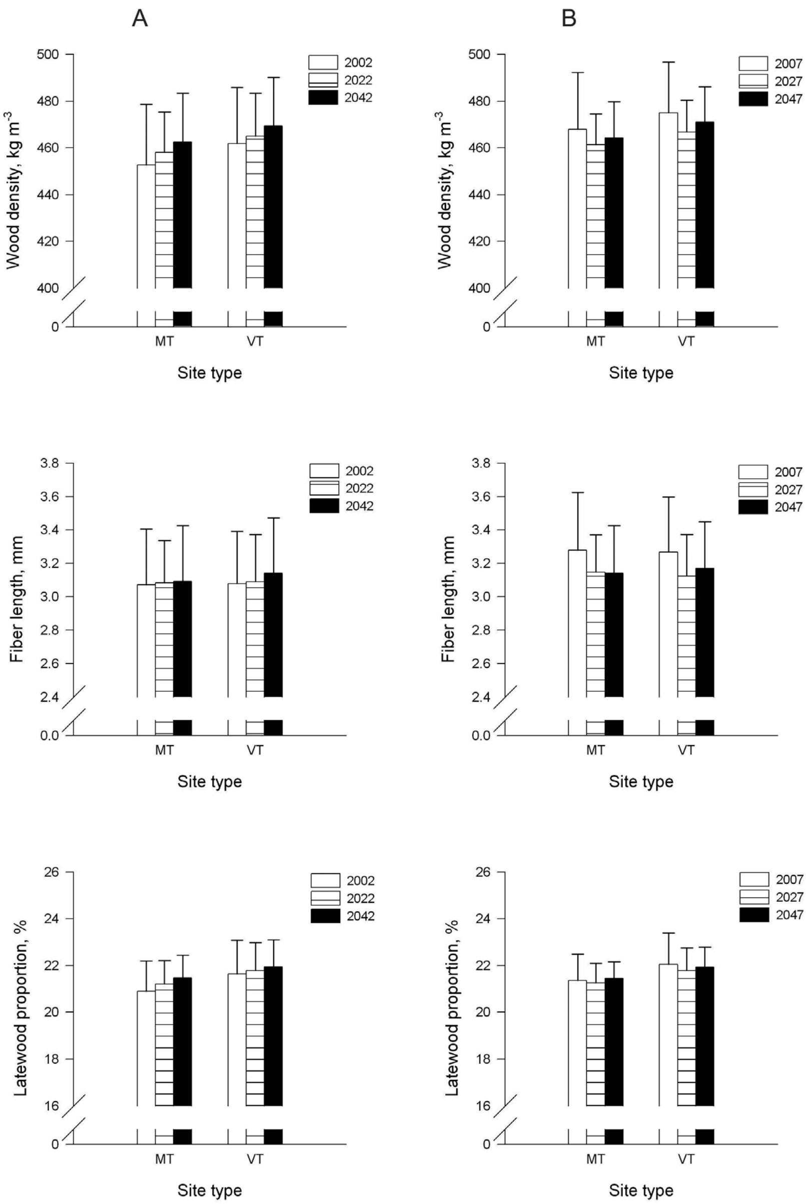

Fig. 5. Wood properties of standing (A) and harvested Scots pine trees (B) on different site types (MT = *Myrtillus* type, VT = *Vaccinium* type).

were found in the oldest trees than in the youngest ones. In the youngest age class, the fibres were, on average, 2.6 mm long both in standing and in harvested trees during the first two ten-year sub-periods; but a slight decrease (2%) was observed in fibre length in the last 10-year sub-period in both standing and harvested trees.

In the standing Norway spruce trees, the proportions of latewood increased as a function of age; and, on average, 5% smaller proportions of latewood were observed in the youngest trees than in the oldest trees (Fig. 4, A). On the contrary, in harvested trees, the largest proportions of latewood were found in the 0-to 40-years

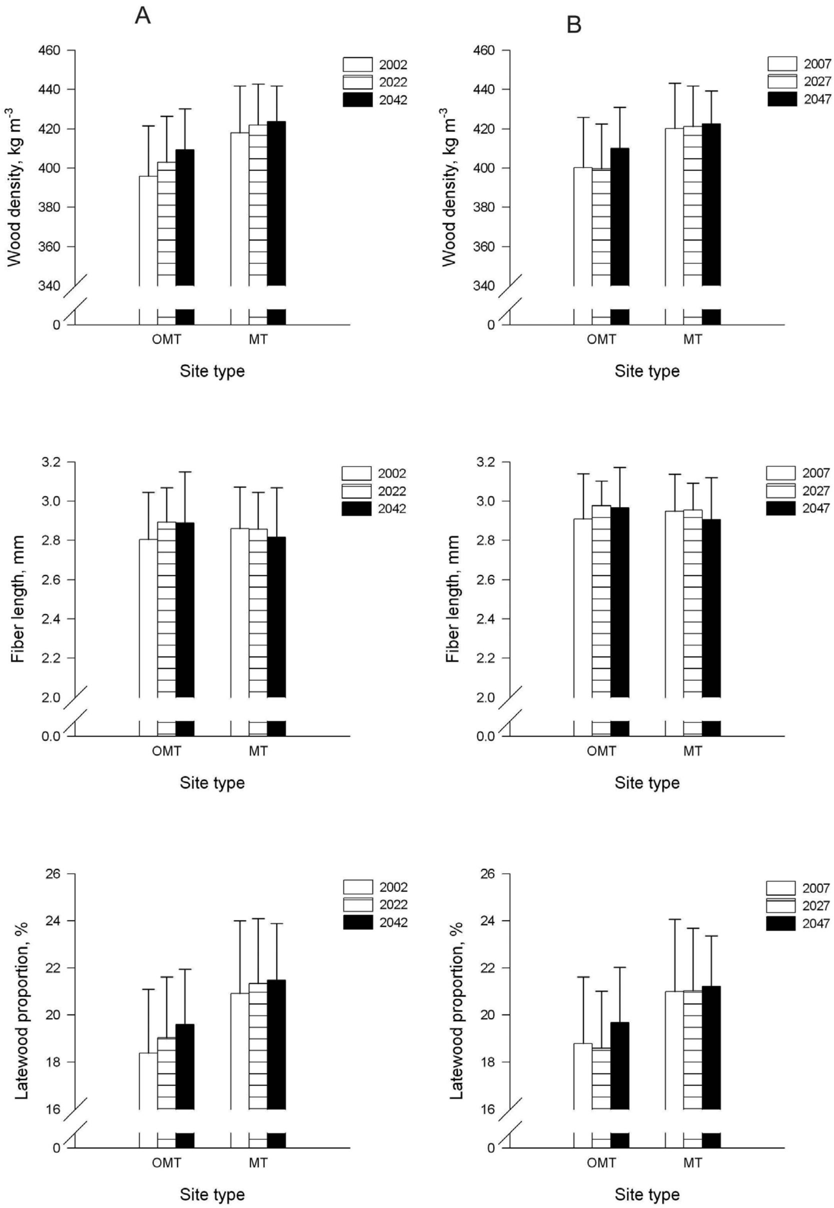

Fig. 6. Wood properties of the standing (A) and harvested Norway spruce trees (B) on different site types (OMT = *Oxalis Myrtillus* type, MT = *Myrtillus* type).

age class of (21%) and the proportions were the same (20%), on average, in the other age classes (Fig. 4, B). Only in the youngest age-class the proportion of latewood was higher in harvested trees (5%).

3.2.2 Differences between Site Types

The wood density was, on average, only slightly (2%) higher when site fertility decreased (from MT to VT) both in the standing and in harvested

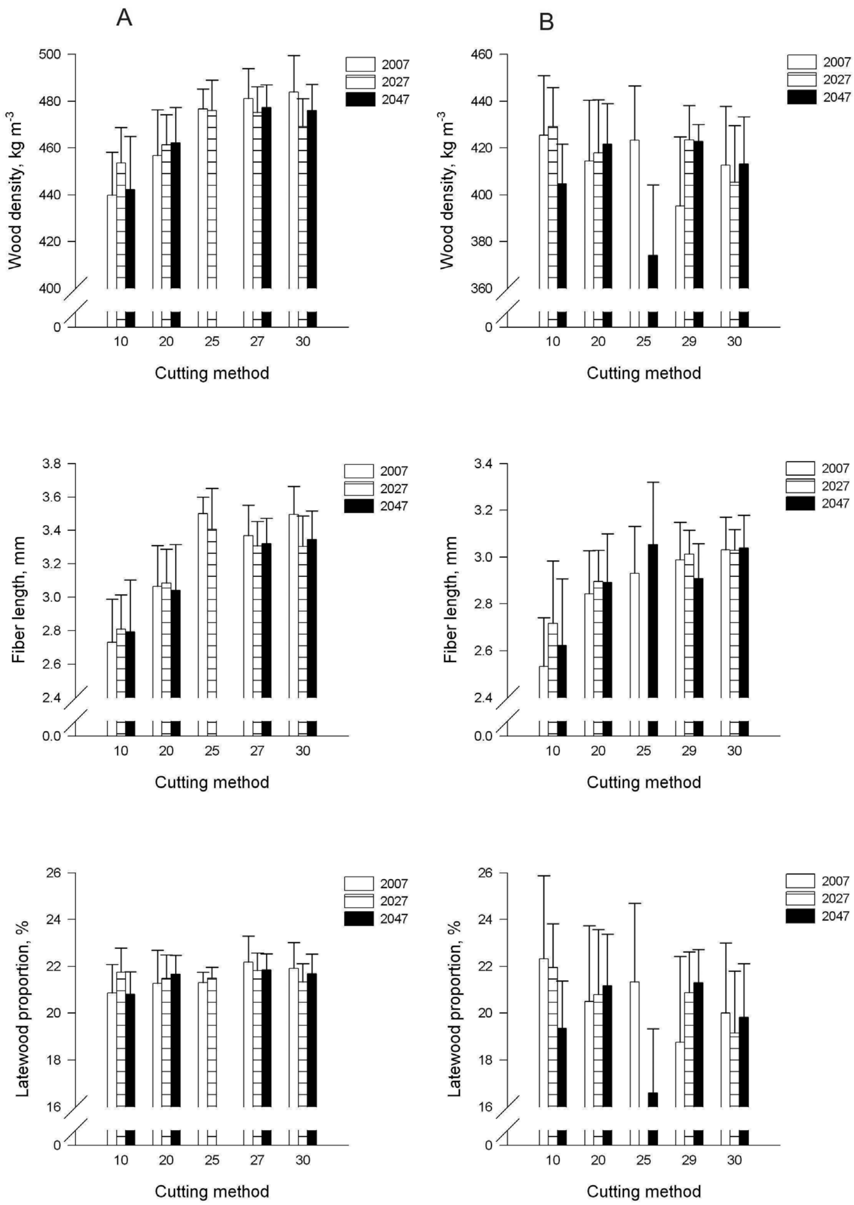

Fig. 7. Wood properties of the harvested Scots pine (A) and Norway spruce trees (B) in different cutting methods. Legends: 10 = (first) thinning, 20 = basal area (other) thinning, 25 = over-story removal, 27 = seed tree cutting (pine), 29 = shelterwood cutting (spruce), and 30 = clear-cutting.

Scots pine trees (Fig. 5, A and B). However, no change was observed in average wood density either in standing trees (1%) or in harvested trees over the 50-year period. This was also the case for fibre length in standing Scots pine trees. However, in harvested Scots pine the longest fibres (3.3 mm) were found at the beginning of the simulation period regardless of site type (Fig. 5, A and B). The proportion of latewood also increased slightly (2%) with lower site fertility in both standing and harvested Scots pine trees (Fig. 5, A and B), and also over the 50-year period for the standing trees.

In standing Norway spruce trees, when site fertility decreased (from OMT to MT) the average wood density was 5% higher (Fig. 6, A). On the most fertile site type (OMT) it was, on average, about 400 kg m^{-3} and on the medium fertile site (MT) 420 kg m^{-3} over the simulation period. Also in harvested Norway spruce trees, average wood density was higher (5%) on the medium-fertile site type (MT) compared to the most fertile one (OMT) (Fig. 6, B). In the 50-year simulation period, in both standing and harvested trees, wood density was, on average, 2% higher (OMT) or almost the same (MT) at the end of the period compared to its beginning.

For standing or harvested Norway spruce trees the average fibre length was not affected (decrease < 1%) by site fertility or simulation sub-period (Fig. 6, A and B). In both standing and harvested Norway spruce trees the proportion of latewood was considerably higher (10%) with lower site fertility (Fig. 6, A and B). Except for harvested trees, it also increased over the simulation period (3%) from the most fertile site type (OMT). Over the simulation period the average proportion of latewood on the most fertile site type (OMT) was 19 % and on the medium-fertile site type (MT) 21 %.

3.2.3 Differences between Cutting Methods

In the year 2007, the average wood density of Scots pine was 9% higher in the clear-cuttings than in the first thinnings (Fig. 7 A). In 2027, the highest wood densities, on average, were found in over-story removals, which class was absent in 2047. In the year 2047, the highest values for the wood density were observed in seed-tree cuttings and clear-cuttings (Fig. 7, A). For Norway spruce, the densest wood (425 kg m^{-3}) was found in the first thinnings in the year 2007 as well as in 2027 (Fig. 7 B). In the other thinnings, for both Norway spruce and Scots pine the wood density increased over the simulation period. For Norway spruce, the average wood density was about 5% lower in the clear cuttings, compared to the first thinnings or other thinnings (Fig. 7, B).

In Scots pine trees, the longest fibres, on average, were found in over-story removals and in clear-cutting in the year 2007. The fibre length in the seed-tree cutting was, on average, the same as in the clear-cuttings, whereas the shortest fibres, 2.8 mm, were found in the first thinnings (Fig. 7, A). On average, fibres were 21% longer in the clear-cutting compared to the first thinning. Similarly, in Norway spruce, during the whole simulation period the fibres were about 15% and 5% shorter in the first thinnings and the other thinnings, respectively, compared to the fibres in the clear-cuttings (Fig. 7, B).

With all cutting methods the proportions of latewood in Scots pine were 21–22 %, while in Norway spruce it varied considerably, 16–22 % (Fig. 7, A). For Norway spruce, the largest proportions, on average, were observed in the first thinnings and other thinnings; but in 2047 in the first thinnings, the proportion of latewood was 19 %, which was lower than in the clear-cuttings, for which the average proportion was about the same over the 50-year simulation period (Fig. 7, B).

4 Discussion and Conclusions

In general, wood density, fibre length and proportion of latewood, which reflected the breast height values, increased both in Scots pine and Norway spruce, on average, as a function of tree age and along with a decrease in site fertility (excl. wood density and proportion of latewood in harvested Norway spruce in the first case and fibre length in the latter case for both species). In detail, average wood density increased both in standing and in harvested Scots pine and Norway spruce trees, on average, by 5% and 2%, respectively, as the site fertility decreased, which is in agreement with earlier studies (e.g. Mäkinen at al. 2002). During the simulation period, the average variation in proportion of latewood was consistently 2% for Scots pine and 10% for Norway spruce.

According to the results, wood density and proportion of latewood in harvested Scots pine and Norway spruce trees were, on average, slightly higher than or equal to and the fibres longer than or equal to those for standing trees less than 80 years old. This is in accordance with earlier results concerning the trees harvested from below in thinning; the trees have been dominated by larger trees, and therefore their wood properties differ from the remaining trees of the same age (e.g. Larson 1963, Kozlowski 1971, Tasissa and Burkhart 1997, Pape 1999a,b, Peltola et al. 2007). Accordingly, Pape (1999a,b) for example, found that removal of trees from the understory decreased the basic density of a Norway spruce stand. Our results are also in agreement with the results of Peltola et al. (2007) where suppressed Scots pine trees in the first thinning from below had grown less in diameter and had higher wood density and proportion of latewood than the dominant and co-dominant trees did.

However, contrary to younger trees, the difference between harvested and standing trees was more distinct in older Scots pine and Norway spruce trees. In older trees, the values for different wood properties were also, on average, smaller in harvested trees than in standing trees, excluding fibre length in Norway spruce. These results indicate that in the oldest age-classes the harvested trees may have grown faster than the remaining trees. This is partly due to the profitability requirement and constraints set for the scenario (Nuutinen et al. 2005); the stands are cut and trees removed only when and if cutting helps to meet the requirements.

The average properties of wood were affected by cutting method (and thus, also partly by age) quite consistently in Scots pine compared to those of Norway spruce. In Scots pine, trees from clear-cuttings had, on average, 9% and 4% higher wood densities compared to those from the first thinning and other thinnings. Similarly, fibre lengths were, on average, 21% and 11% longer in trees from clear-cuttings and other thinnings compared to trees from first thinning, but there were only slight changes in proportion of latewood. In Norway spruce, however, there was an average decrease of 5% and 14%, respectively, in wood density and proportion of latewood in trees from first thinning compared to trees from clear-cutting. Fibres were 15% longer in Norway spruce in clear-cuttings compared to the trees in first thinning. This is probably due to the dominance of Scots pine trees in forests of North Karelia and to the fact that Norway spruce trees often grow in a mixture with Scots pine and broadleaved species, thus having more variation in growth and also in wood properties.

According to the results, the average wood properties within the same strata may also change over time because the development of growing stock (remaining trees) is affected by past management. However, the relative differences in wood properties between time periods were not higher than 4% within different strata, and the effect was found to be either positive or negative. Thus, the differences between different strata can be considered to be much greater and to have greater importance.

In practice, there are some uncertainties related to the scenario approach and simulation models applied here. For example, the decisions about cuttings and silvicultural operations are strongly dependent on wood markets, which are facing drastic changes due to globalisation of the forest industry. Therefore, the utilisation of cutting possibilities, the cutting methods applied, and consequent development of forest resources may differ considerably between time periods and from the scenario assumed in the Forest Programme. In addition, in the future average wood properties of standing trees will also be affected by tree selection in thinning operations, as was also found in this study. Related to this, in 2006, forest owners in Finland were given more options to apply thinning operations in the new recommendations for forest management (Hyvän… 2006), which will also affect development of wood and fibre resources of stands in the future. In addition to changes in forest management, changes in climate are expected. Climate change will affect growth and, consequently, wood properties (see e.g. Kilpeläinen et al. 2005) and may call for adaptation of forest management practices (see e.g. Nuutinen et al. 2006, Garcia-Gonzales et al. 2007). However, our study deals mainly with already existing trees, and therefore the effects of climate change were considered to have only minor effects on growth and wood properties during the 50-year period.

In this study, diameter and age at breast height were used as measured indicators of the average width of growth ring; but in the initial data, tree age is estimated. In particular, the estimation of age for trees dominated by larger trees is difficult and leads to uncertainty in the predictions. Furthermore, in tree species such as Scots pine and Norway spruce, wood properties are known to vary in different parts of the stem. For example, in Norway spruce the wood density first increases to some degree from the stem base upwards and the decreases again towards the tree top, whereas in Scots pine it tends to decrease from the stem base to the top of the tree (Ikonen et al. 2008). Consequently, the average values of stems may differ to some degree from those estimated at breast height in this study.

In conclusion, this study is the first attempt to analyse how the average properties of wood within specific strata may change in addition to growing stock and annual removals in the future in a forest region when a certain management scenario is assumed. The results for different strata differed considerably and give insights for the allocation of trees to various end-use purposes according to their properties, which will affect further possibilities to process the raw material and the outcome in wood industries. This study demonstrates the value of model-based analyses utilising NFI tree measurements as input data for estimation of future growing stock, cutting potential and wood properties in regions considered to be a source of raw material for wood industries. Because relatively small changes in the potential supply of wood and fibre resources at the regional level may be important for forest industry, attention should be paid to selection of relevant scenarios for the region in question.

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Appendix 1.

The disc-based models used for Scots pine and Norway spruce are presented below (see Wilhelmsson et al. 2002 for models 4, 5, 7 and 8; and Ekenstedt et al. 2003 for models 6 and 9):

Scots pine:

$$\text{Latewood\%} = 91.7 - 31.7 \cdot \ln\left(0.5 \cdot dh / ch\right) - 224.9 \cdot \frac{1}{0.5 \cdot dh / ch + 2} + 2.09 \cdot e^{\left(dh/dbh\right)^7} + 0.00517 \cdot \text{TSum} \tag{4}$$

$$\text{Basic wood density} = 364.4 - 17.578 \cdot \left(0.5 \cdot dh / ch\right) - 0.6070 \cdot \ln\left(cbh\right)^3 + 0.4172 \cdot \ln\left(cbh\right)^3 \cdot e^{\left(dh/dbh\right)^7} + 0.0578 \cdot \text{TSum} \tag{5}$$

$$\text{Fibre length} = -1.21 + 0.69 \cdot \ln\left(ch\right) + 0.33 \cdot \ln\left(0.5 \cdot dh / ch\right) + 0.65 \cdot \left(1 - e^{\left(-\text{RelHeight}/0.13\right)}\right) + 0.00043 \cdot \text{TSum} \tag{6}$$

Fibres < 0.4 mm excluded

Norway spruce:

$$\text{Latewood\%} = 6.1 - 9.183 \cdot \ln\left(dh\right) + 28.885 \cdot \ln\left(ch\right)^{0.5} + 0.005911 \cdot \text{TSum} \tag{7}$$

$$\text{Basic wood density} = 304.3 + 10.4437 \cdot \ln\left(ch\right)^{0.5} - 444.13 \cdot \frac{dh^{1.5}}{ch \cdot \text{TSum}} + 0.2957 \cdot \frac{\text{TSum}}{0.5 \cdot dh / ch + 2.3} \tag{8}$$

$$\text{Fibre length} = 3.06 - 2.20 \cdot e^{\left(-ch/29.35\right)} - 1.55 \cdot e^{\left(-0.5 \cdot dh/ch/0.74\right)} - 0.70 \cdot e^{\left(-\text{RelHeight}/0.14\right)} + 0.00056 \cdot \text{TSum} \tag{9}$$

Fibres < 0.4 mm excluded

where *dh* is diameter (under bark) at height *h* (mm), *ch* is number of annual rings at height *h*, *cbh* is number of annual rings at breast height, *dbh* is diameter (under bark) at breast height (mm), Tsum is temperature sum, and RelHeight is relative disc height (disc height / total tree height). In addition, $0.5 \cdot dh / ch$ is the average growth-ring width in the cross-section.