HEARTWOOD AND EXTRACTIVE CONTENT OF SCOTS PINE IN SOUTHERN FINLAND: MODELS TO APPLY AT HARVEST

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ABSTRACT

The biggest obstacle to better utilization of Scots pine heartwood lumber is the difficulty of separating heartwood in the sawing process. The aim of this study was to analyze the variation in heartwood proportion and extractive content of Scots pine in southern Finland, and to develop a model that could be employed at harvest to predict heartwood taper. In accordance with many previous investigations, the number of rings in heartwood at any tree height is under the control of time and is thus best predicted by cambium age. The results suggest that the heartwood starts to form when the cambium age is roughly 20 years and increases by two-thirds of a year ring annually after it has been initiated. In order to apply this model in practice, we need accurate estimates of the cambium age and the radial growth rate as well. A comprehensive model is presented that enables prediction of heartwood taper for mature Scots pines while handling the tree at harvest if the tree age is known. The results suggest a mean error of roughly 2 cm in predicting the heartwood diameter by using the equations developed.

Keywords: Cambium age, heartwood, radial growth rate.

INTRODUCTION

The durability of Scots pine (*Pinus sylvestris*) heartwood far exceeds that of other Finnish commercial timbers. This valuable property has been historically utilized in house construction and various kinds of outside woodwork (Löyttyniemi 1986). In the old days, log cabins were constructed only from logs obtained from 120–140-year-old trees (Blomqvist 1879). Unfortunately, increased exploitation of the forest and increasing use of chemical preservation have meant that the good properties of pine heartwood have been neglected in Finland. While the use of preservative-treated lumber has been expanded, there are a growing number of lumber buyers who are concerned over the ecological risks it involves. This partly explains the popularity of heat-treated wood in Finnish markets recently.

Obviously, there would be general interest among lumber buyers, window manufacturers, and outdoor woodwork (playgrounds, garden houses, outdoor furniture) manufacturers in buying pine heartwood if it were available (Grönlund et al. 1979). The biggest obstacle to better utilization of such lumber is the difficulty of separating heartwood in the sawing process. The boundary between sapwood and heartwood in fresh timber is not clearly perceptible. Since the amount of heartwood varies markedly among the top diameter classes, the logs should be re-graded by their heartwood proportion in order to separate pure heartwood lumber in the sawing process (Kellomäki 1981).

Although the top diameter of logs has been a rather poor predictor of pine heartwood proportion, this does not mean that it is difficult to predict (Kärkkäinen 1972; Kellomäki 1981). Since heartwood is formed through the aging and death of parenchyma cells, the heartwood proportion is best predicted by the age of the tree or when the heartwood proportion at a certain height is concerned with the cambium age. Pine heartwood starts to form at the age of 20. . .40 years in southern Finland, and its proportion seems to increase linearly after it has been initiated (Lappi-Seppälä 1952, Uusvaara 1974). In addition to age, the growth rate of the tree or crown size has

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been observed to affect the heartwood proportion in many species (Ojansuu and Maltamo 1995). Suppressed trees tend to have a higher heartwood proportion than dominant trees in even-aged Scots pine stands (Lappi-Seppälä 1952; Ojansuu and Maltamo 1995). Similar results have also been found with other pine species (Carrodus 1972; Hillis and Ditchburne 1974). Logically, a slow growth rate inevitably increases the heartwood proportion by increasing the age of trees of a certain diameter or by decreasing the diameter of trees of a certain age.

In many investigations special attention has been paid to analyzing the variation in heartwood proportion at different proportional tree heights. The heartwood proportion of Scots pine has been observed to be highest at the relative height of 20–30% in individual trees and then to start to decrease rapidly towards the top of the tree (Lappi-Seppälä 1952; Uusvaara 1974). This can be partly explained by the increasing growth rate in diameter after self-pruning at the bottom of the tree, which decreases the heartwood proportion. There are no conclusive findings that the diameter of heartwood would decrease in any section from stump height to the top of the tree. However, it is well known that the boundary between sapwood and heartwood does not follow a particular ring either at different heights in the tree or in the same cross-section.

The quantity of extractives and their composition vary markedly in vary parts of the tree. In pines, the heartwood typically contains more extractives than the sapwood. Moreover, not only may the composition of the extractives in different parts of the tree differ, but the extractives in different tissues in those zones may also differ (Hillis 1987). The extractives in the resin canals have markedly different compositions from those of the nearby parenchyma cells. In pines, oleoresin, synthesized by the epithelial cells surrounding the resin canals, is the dominant resin type. Monoterpenoids and especially resin acids (diterpenoids) are dominant and the most important oleoresin constituents commercially. The resin acid fractions in pine sapwood and heartwood may vary from each other the amounts being higher in the heartwood (Hemingway and Hillis 1970)

Quantitative determination of extractives in wood is carried out by standardized methods after extraction with organic solvents such as acetone. For identification of individual extractive components, gas-liquid chromatographic methods in combination with mass spectrometry are required. These methods being rather laborious, studies investigating the amounts of various extractive components are restricted mostly to a couple of trees (Pensar 1967, Lloyd 1978). On the other hand, studies concentrating on the total extractive content are typically restricted to certain parts of trees (Campbell et al. 1990) or the average amount of extractive in the whole tree. In the work on the geographical variation in average Scots pine (*Pinus sylvestris*) pulpwood properties in Finland, Hakkila (1968) found a slight increase towards the north in the acetone extractive content of wood. The aim of the present study was to analyze the variation in heartwood proportion and extractive content of Scots pine in southern Finland, and to develop models that could be employed at harvest to predict heartwood taper.

MATERIALS AND METHODS

The study material, from five Scots pine *(Pinus sylvestris)* stands located close to the Koskisen Oy sawmill in southern Finland, was collected in 1998. Roughly 10 systematically chosen trees were selected as samples (See Tables 1 and 2). These trees were measured for diameter at breast height, tree height, crown height and dead branch height. The sample trees were felled manually by an experienced feller applying general instructions for bucking. After felling, logs were measured for diameters from the top and from the butt, diameters every one meter from the butt of the log and log length. A disk roughly 2 cm thick was cut off the lower end of each log. The disks were immediately transported in plastic

TABLE 1. *Study stands.*

Stand no.	Location	Forest type	Cutting method	Average age *years*	Area *ha*	Mean Dbh *cm*	Mean tree height *m*	Sample trees N	Sample disks N
1	Renko	MT	Seeding felling	125	1	27.9	24.2	19	83
2	Renko	MT	Clear cut	135	0.7	27.1	24.5	9	38
3	Renko	MT	Clear cut	85	0.7	28.8	24.5	11	47
4	Hausjärvi	VT	Rem. of seed trees	130	2.5	32.0	24.0	10	42
5	Hollola	VT	Clear cut	125	0.8	30.2	22.3	10	39
Sum								59	249

bags to a freezer at the University of Joensuu until laboratory analysis could be performed. The total study material comprises 59 sample trees and 249 sample disks.

The sample disks were measured for the number of annual rings and corresponding distance in 10-year segments from pith to bark. A random line from pith to bark was drawn, and the boundary between heartwood and sapwood within this line was determined without any color reaction reagents since a short period of storage turns the surface of Scots pine heartwood dark making the boundary clearly perceptible. The distance from the pith to this boundary and the corresponding number of rings were measured. Two adjoining specimens of roughly 2 × 2 × 2 cm each from both sides of the random line and from four different zones of the disk (eight altogether), were separated for determination of the extractive content and basic density. The two adjoining specimens were demarcated from the following zones of the disk: outermost sapwood—specimens next to the cambiun; inner sapwood—specimens next to the boundary between heartwood and sapwood; outer heartwood—specimens next to the boundary between heartwood and sapwood; inner heartwood—specimens next to the pith. The center point of each specimen (cub) was determined and the distance from the pith to that point and the corresponding number of rings were measured.

The amount of acetone-soluble extractives in wood based on dry weight was determined by the following procedure. The fresh weight of specimens was measured and then dried at +60°C overnight to ensure a homogenous result in grinding. The dry weight was determined after drying some of the wood samples at 103°C for 48 h. The samples were then cut into pieces of matchstick size and homogenized into a fine powder. About 1,000 mg of the wood powder was extracted with acetone in the Soxtec apparatus. Times were fixed at 90 minutes for boiling and 30 minutes for rinsing. Recent comparative laboratory studies have proved that no significant differences can be found between the standard Soxhlet and the modern Soxtec apparatus. Basic density was determined by applying the standard methods. Each specimen was measured for its dimen-

TABLE 2. *The amount of acetone solube extractives in Scots pine by the distance of specimens above the stump height and from the pith. Based on 598 specimens from 37 trees.*

	Inner heartwood			Outer heartwood		Inner sapwood		Outermost sapwood	
Sample disk number	Mean height above stump m	Extractives %	Mean distance from the pith mm	Extractives %	Mean distance from the pith mm	Extractives %	Mean distance from the pith mm	Extractives %	Mean distance from the pith mm
1	0	14.1	11	12.1	77	6.5	97	5.3	175
2	5.0	4.9	11	4.1	62	4.5	81	5.5	115
3	9.9	5.4	11	4.4	54	5.3	72	6.2	100
4	14.2	5.5	11	5.1	34	5.0	48	5.9	78
5	17.8	6.6	16	—	—	5.6	39	6.2	83

sions, mass, and volume both in fresh and absolutely dry conditions. The volume was measured by the water displacement method.

RESULTS

Heartwood taper

Since comprehensive models that predict the heartwood taper directly by certain stem characteristics easily lead to illogical results, the heartwood taper was constructed using several independent models. The set of models to be presented here follows the nature of the phenomenon more logically and enables us to replace a single model with a better one if such a model is available.

In accordance with many previous investigations, the number of rings in the heartwood of any tree height is under the control of time and is thus best predicted by cambium age. Parallel to the findings of Gjerderum (1999) with Scots pine, other factors such as tree height or crown height seem to be without influence. Gjerderum described the rings in heartwood by a nonlinear ‘‘heartwood age square root law,’’

$$A_h = (\sqrt{A_g} - 3.0)^2$$

where A_h = number of rings in heartwood and A_g = cambium age. With the current data, no reason was found to create a nonlinear equation, but heartwood age and cambium age seem to have rather a linear relation after a certain stage of life. The number of rings in heartwood (A_h) is thus best predicted by the following linear model:

$$A_h = -13.660 + 0.659A_g \qquad R^2 = 92.8,$$

$$n = 249 \text{ observations from 59 sample trees.} \qquad (1)$$

According to this model, the heartwood starts to form at the age of 20–21 and increases by circa two-thirds of a year ring annually after it has been initiated (Fig. 1).

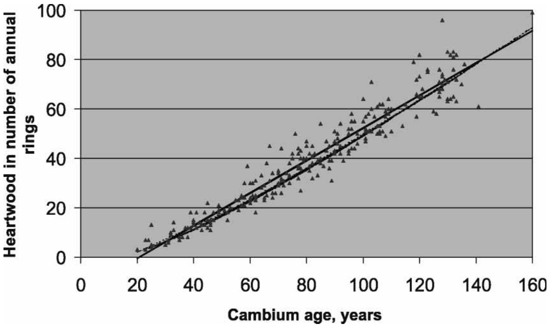

FIG. 1. The relation between cambium age and heartwood in number of annual rings. Black solid line describe model 1, Black dot line describe Gjerderums (1999) model.

In order to apply model 1 in practice, we need to know the cambium age at different heights. The set of models to be presented here is based on the idea that modern harvesters receive accurate tree taper values while delimbering that can be applied to heartwood taper prediction. Consider h_i, where $h_i = R$ and $h_i > 0$, is the height of the tree (meters) for any observation from the butt to the end of the tree the harvester head is delimbering and d_i is the corresponding diameter outside the bark (mm). Provided that tree age at stump height (A) can be given from other sources (e.g., historical records), the cambium age (A_g) for upper parts of the stem ($h_i > 4$ m) can be predicted by the following model

$$A = 19.0 - 3.24h_i + 0.119d_i + 0.510A$$

$$R^2 = 89.7, \qquad n = 188. \qquad (2)$$

The model suggests that for any d_i, when $h_i > 4$ m, cambium age decreases roughly 3 years as height increases by 1 m.

In order to predict the heartwood taper, we need to know not only the number of rings in the heartwood, but also how fast the diameter of the tree has increased up to this stage of life. Let g_r be the cumulative radial growth rate (mm/years) for any height h_i, diameter d_i and number of year rings from the pith y_r, where $y_r = N$ and $0 < yr < A_g$. Surprisingly, crown height was not found to be a significant predictor, although it has been observed to relate to stem tapering (e.g., Lindström 1996). The cumulative radial growth rate (g_r, mm/

years) can then be predicted by the following model:

$$g_r = 9.24 + 1.65y_r - 0.00373y_r^2 - 0.805A_g + 0.304d_i - 0.548h_i \qquad R^2 = 0.923, \quad n = 12.8. \tag{3}$$

The heartwood taper can now be calculated for any height h_i and corresponding diameter d_i with models 1, 2 and 3, provided that the age of the tree is known. We can first estimate cambium age (A_g) with model 2, then substitute (A_g) in model 1 to estimate the number of rings in the heartwood A_h and finally substitute A_h for y_r and A_g in model 3. The radius (mm) of the heartwood (R_h) at any height can then be derived using the equation

$$\begin{aligned} R_h = {} & -7.94 - 1.476h_i + 0.338d_i + 0.146A \\ & + 0.0125h_id_i + 0.00535h_iA \\ & - 0.000196d_iA - 0.0171h_i^2 \\ & - 0.0000229d_i^2 - 0.000421A^2, \end{aligned} \tag{4}$$

when $0 < A < 160$ (years), $0 < d_i < 340$ (mm) and $4 < h_i < 20$ (m).

The residual analysis suggests that model 4 slightly overestimates heartwood radius with small diameter values and correspondingly underestimates heartwood radius with big diameter values. On the other hand, this model gives only slightly biased results (+1,5 mm). The root mean square error (RMSE) for heartwood radius with the current data is 10.7 mm, which means roughly 2 cm in diameter.

Extractive content

The total amount of acetone-soluble extractives varies markedly both in the axial and radial direction (Table 2). The volume of extractives is highest in heartwood at stump height. Inner heartwood may be regarded as having slightly higher concentrations than outer heartwood while inner sapwood has slightly lower concentrations than the outermost sapwood. Overall the variation seems to be quite small in the upper parts of the stem and there seem to be quite small differences between heartwood and sapwood. This need not have any influence on natural resistance since heartwood is known to have differential extractive composition, lower moisture content, and lower permeability. The way the study material was collected made it rather difficult to estimate how fast extractive concentrations decrease from stump height to the upper parts of the stem. This would be interesting to know, since higher extractive content may be presumed to have better natural resistance to decay. Because of weak correlation and the shortages in the study material, no competent model for predicting the quantity of extractives could be created.

DISCUSSION

The study material was rather small and was located within 3 muncipalities in southern Finland. Since the disks were cut from the lower end of commercial logs of 4 to 5.5 m in length, the material did not contain any observations between the stump height and 4 meters above the stump. Compared to Gjerderum's study (1999), this material did not contain very old trees, which are especially interesting in exploitation of pine heartwood.

The relation between cambium age and heartwood age is very strong and is in accordance with the earlier findings (e.g., Gjerderum 1999). The applicability of Eq. 1 may thus be regarded as rather good in southern Finland. Equations 2 and 3 may be replaced by more sophisticated local models if these meet the practical needs. In the future there will be growing interest in developing cambium age models, since it seems to be an important factor in predicting both heartwood proportion and fiber length.

In this study, a set of models is presented that allows us to predict heartwood taper for any pine tree while handling the tree at harvesting if the age of the tree is known. In the Nordic countries roughly 90% of the total cutting volume is now carried out by modern single-grip harvesters equipped with automatic log measuring and bucking control systems. The harvester head first fells the tree and after feeding the head forward for 2 . . . 3 meters, it automatically makes the first prediction of tree taper. The value and demand table parameters controlling the bucking may be adjusted to enable separation of special ‘‘heartwood logs’’ while logging. The results suggest a mean error of roughly 2 cm in predicting the heartwood diameter using these equations. This may be considered quite tolerable in the sawing process if a sufficient boundary is left while separating heartwood for a special item. The final applicability of the models proposed may be judged after they have been tested by independent data.

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