Influence of cambium age and growth rate on heartwood formation in Scots pine originating from drained peatlands

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Summary

Heartwood formation of Scots pine (*Pinus sylvestris* L.) is usually modelled by assuming cambium age as an independent variable. The aim of this study was to analyse how well cambium age and growth rate explain heartwood formation of Scots pines grown on drained peatlands. Furthermore, two earlier models (rules) between cambium age and heartwood age were tested. According to the results, cambium age and stem diameter accounted for 66% of the variation in heartwood proportion. Generally, the heartwood age rules worked quite well. However, the rules gave clear underestimates at stump height in old and slow-grown trees.

Key index words: *Pinus sylvestris*, cambium age, growth rate, heartwood formation

Introduction

Scots pine (*Pinus sylvestris* L.) is a tree species in which – during the maturing process – a clear heartwood formation is initiated. In southern Finland, heartwood formation begins at the age of 20–40 years (Lappi-Seppälä, 1952; Uusitalo, 2004). Generally, heartwood formation is a consequence of dying of parenchyma cells (e.g. Panshin and de Zeeuw, 1980). Thus, heartwood is formed by dead xylem, while conducting of liquids takes place only in the living and active part of xylem, sapwood. In Scots pine, dry heartwood also differs from sapwood by its brownish-red colour. This colour comes from the accumulation of extractives to the heartwood making it toxic against fungi (e.g. Venäläinen *et al.*, 2002). According to the standard EN 350-2 (European Committee for Standardisation, 1994), Scots pine heartwood is classified as slightly or moderately durable and sapwood as non-durable against wood-destroying fungi.

Natural durability of Scots pine heartwood was not actively considered for a long time after the introduction of wood impregnation with toxic substances such as Copper-Cromium-Arsenic preservatives (CCA). Interest towards natural durability of wood revived in the 1990s when alternative ways to protect wood were sought. Today, the use of super effective preservatives is prohibited in the European level because of health and environmental reasons. As a consequence of ecological awareness, wood products manufactured of Scots pine heartwood have achieved brand indicating natural durability.

In the Nordic countries, over 95% of wood for forest industry is harvested with modern harvesters. Accurate online measurements of heartwood content in harsh forest conditions are, however, out of reach. Pre-grading of stems according to their heartwood proportion would make the forest-wood chain more forward-looking. Without the possibility of direct measurement, heartwood models are needed. Since heartwood area in a stem increases when a tree matures, cambium age is the most evident variable to explain heartwood formation. In Uusitalo's study (2004) regarding Scots pine on mineral soil sites in southern Finland, cambium age (A_c) accounted for 92.8% of the variation in heartwood age (A_h):

$$A_h = -13.660 + 0.659 A_c$$

Another heartwood age rule was introduced by Gjerdrum (2003). In this nonlinear model for Scandinavian Scots pine, cambium age accounted for 93% of the variation in heartwood age:

$$A_h = (A_c^{0.5} - 3)^2$$

Although growth rate is not included into these models, it has been reported to affect heartwood formation. According to Kärkkäinen (1972), the effect of growth rate on heartwood formation should be divided into two parts. The heartwood proportion is lower in fast-grown trees than slow-grown trees of the same size but is higher in fast-grown trees than slow-grown trees of the same age.

Great variations in growth rate are typical for Scots pines grown on drained peatlands. Narrow annual year rings formed before drainage is followed by improved growth – wide year rings – after drainage (Rikala, 2003). In Uusitalo's data (2004), heartwood age increased annually by two thirds of a year ring (transition rate) after it had been initiated. How well this trend is manifested in trees with ultimate growth rate variations, is unclear.

The aim of this study was to examine how well cambium age and growth rate explain the variation in heartwood proportion of Scots pine grown on drained peatlands. Heartwood age models introduced by Gjerdrum (2003) and Uusitalo (2004) were tested to evaluate their suitability for Scots pines grown on drained peatlands where extreme growth rate variations within stems are typical.

Material and methods

Study material was collected from 10 permanent sample plots on drained peatlands dominated by Scots pine. The sites were located in southern Finland in a region between 60–62°N and 24–26°E. All trees in the sample plots were measured for dbh (diameter at breast height, i.e. at a height of 1.3 m above the ground level). Trees to be felled on the plot were chosen randomly from the dbh distribution, however, by weighting those diameter classes with highest number of observations. The sampling procedure is presented in detail in Rikala (2003). Each felled tree was cut into lengths according to the quality requirements for saw logs. A disc roughly 3 cm thick was sawn from the butt end of each log and from the top end of the top log. In pulpwood section, discs were taken at the intervals of 2 m to a diameter of 7 cm. Each disc was measured for annual ring widths and heartwood diameter.

Heartwood age was traced by adding the widths of annual rings together until the radius of heartwood 'circle' was reached. The heartwood age was calculated as an average from two measurement lines. The final material consisted of 618 sample discs taken from 91 pine stems. Some average characteristics of the study stands are presented in Table 1.

Linear regression models were fitted into the data. Firstly, variation in heartwood proportion (percentage of the cross-section area) was explained by cambium age as an independent variable. Secondly, stem diameter over bark as a new variable was added to the model.

Results

Cambium age alone accounted for 61.8% of the variation in heartwood proportion determined from the cross-section area. By adding diameter over bark to the model, the coefficient of determination (R^2) increased to 66.5%. Thus, one third of the variation could not be explained by cambium age and stem diameter (growth rate).

Heartwood age rules introduced by Gjerdrum (2003) and Uusitalo (2004) were tested with the present data. Figs. 1 and 2 show how well measured heartwood ages correspond with the calculated ones. The straight line represents the perfect fit. The observations follow the line quite well to the heartwood age of 40 years in Gjerdrum's rule and that of 50 years in Uusitalo's rule. Beyond these

Table 1. Study stands and some average characteristics of the sample trees.

Stand	Location	Site type [1)]	Drainage year	Mean tree age years	Mean dbh cm	Mean tree height m
1	Ruotsinkylä	Ptkg	1929	82	29.1	24.7
2	Ruotsinkylä	Ptkg	1929	81	25.2	22.3
3	Vesijako	Ptkg	1914	80	24.9	22.2
4	Ruotsinkylä	Ptkg	1926	144	27.1	22.0
5	Hyytiälä	Ptkg	1955	116	22.2	18.5
6	Hyytiälä	Vatkg	1915	101	21.1	18.0
7	Hyytiälä	Vatkg	1915	110	22.3	18.5
8	Hyytiälä	Vatkg	1915	102	22.5	19.3
9	Hyytiälä	Vatkg	1914	162	22.7	17.0
10	Hyytiälä	Vatkg	1923	118	25.6	16.8

[1)] Old drainage area: Ptkg refers to *Vaccinium vitis-idaea* type and Vatkg refers to Dwarf-shrub type (see Laine 1989)

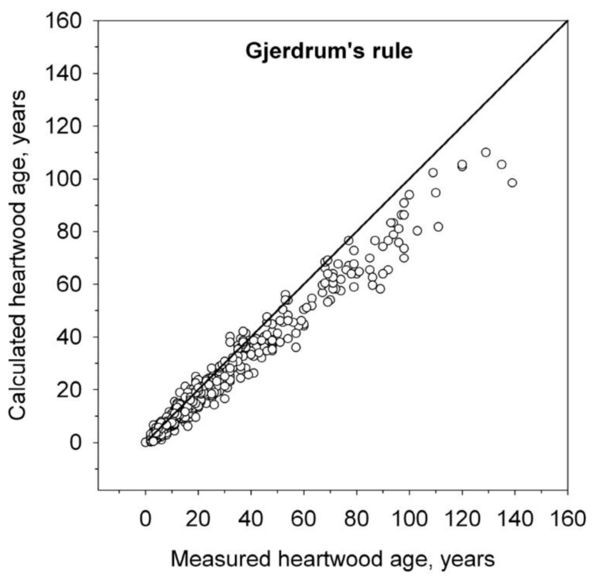

Figure 1. Relationship between measured heartwood age in this study and calculated heartwood age according to Gjerdrum's rule (2003).

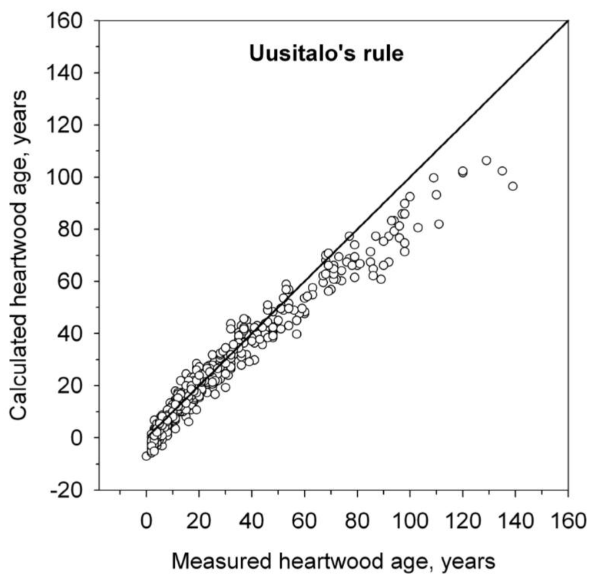

Figure 2. Relationship between measured heartwood age in this study and calculated heartwood age according to Uusitalo's rule (2004).

points, the heartwood ages are underestimated. Uusitalo's rule gives negative estimates for heartwood age when cambium age is under 21 years (Fig. 2).

Discussion

Models constructed are always dependent on the characteristics of the data and their applicability should be tested by independent material. Uusitalo's (2004) data represented typical mature Scots pine stands on mineral soil sites in southern Finland with an average stand age from 85 to 135 years whereas Gjerdrum's (2003) material covered a wide range of Scandinavian Scots pines up to 300 years of age. In this study, the tree age ranged from 66 to 182 years. Thus, tree age alone should not be the explanation for the underestimates of heartwood age observed in this study. Unfortunately, it was not possible to figure out the transition rate of heartwood within a certain period in the past. However, it seems obvious that the transition rate is high in very narrow rings, i.e., in rings formed before drainage. This is supported by the observations that the samples with the lowest growth rates before drainage gave the greatest underestimates in the heartwood age. In practice, this means that the applicability of the rules is weakest at the stump height. More comprehensive measurements should be carried out to test this hypothesis.

Both heartwood age rules have a point under which they do not give logical values. In Gjerdrum's and Uusitalo's rules this point is 9 and 21 years (cambium age), respectively. According to the observations in this study, heartwood formation may start in the upper parts of the stem already when the cambium age is 10 years meaning that Uusitalo's rule is not applicable in these cases. However, from the point of view of utilization of heartwood for industrial purposes this is totally irrelevant.

It may be concluded that the tested heartwood age rules work quite well in most Scots pine stands. In some cases connected to extremely slow growth, however, the rules seem to underrate the heartwood age. It has to be emphasized that in order to apply heartwood age models in practice, estimates of the cambium age and the radial growth rate are required. Further models for estimating the heartwood content in pine logs are presented in Uusitalo (2004). As long as operational means to be used in the field for direct measurement of heartwood content prior to tree bucking are lacking, models for better utilization of heartwood are needed.

Acknowledgements

Mikko Havimo and Juhani Päivänen are greatly acknowledged for their comments on the manuscript.

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