Value of Complete Information on Red Heartwood Formation in Beech (*Fagus sylvatica*)

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Knoke, T. 2002. Value of complete information on red heartwood formation in beech (*Fagus sylvatica*). Silva Fennica 36(4): 841–851.

Beech (*Fagus sylvatica* L.) is the most important deciduous tree species in Germany. The wood of beech shows normally a bright colour (white beech) as long as no coloured heartwood has been formed. The facultative heartwood formation is induced when oxygen enters central parts of older trees, where dead or at least less vital parenchyma exist. The coloured heartwood is usually called 'red heartwood'. Beech without red heartwood can preferably be found in younger trees which show a high water content even in central parts of the stem. The presence of red heartwood is regarded as a severe reduction of timber quality. Numerous studies have investigated opportunities to derive information on the presence and characteristics of red heartwood of standing beech trees. But until now it has not been tested whether such information could be helpful to improve the economics of beech-silviculture. This paper investigates whether complete information on the heartwood of standing beech could be useful to control the proportion of discoloured timber harvested during one rotation. It is also examined, which kind of information on the heartwood could be used to improve the economic results. To verify this, simulations based on simple algorithms were conducted. The general assumption was made that all information on the heartwood would be available. The results show that information which is restricted on the mere existence of red heartwood is neither suited to significantly reduce the amount of coloured timber nor is it possible to improve economic results based on this information. Only based on information on the recent formation of red heartwood of beech, which is actually still white the amount of discoloured timber can be reduced significantly. Consequently the discounted cash flows can only be substantially improved based on information on an expected formation of recent red heartwood.

Keywords economics of beech, red heartwood, value of information, silvicultural treatment

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Received 11 March 2002 **Accepted** 11 October 2002

1 Introduction

In Germany, beech (*Fagus sylvatica* L.) is the most important deciduous tree species. It covers an area of 1.43 million ha (FMFAF 1990, 1994). In comparison to other hardwood species beech not always forms heartwood (facultative) and if it does so, heartwood develops rather late at a high age (e.g., Sachsse 1991). The phenomenon of facultative heartwood formation is induced by oxygen, which enters central parts of older trees, where dead or at least less vital parenchyma exist. Beech trees without red heartwood (white beech) can be found within a wide range of ages and diameters (Klädtke 2001). The presence of red heartwood devaluates severely the timber quality mainly for aesthetical reasons (Necesany 1969, Voß and Brandl 1991, Höwecke and Mahler 1991, Gfeller 1998, Seeling 1998, Spellmann 1999, Tarp et al. 2000). Due to this substantially higher prices can be achieved for white beech logs rather than for beech with red heartwood.

Consequently, several studies were conducted to assess the economic loss by red heartwood formation in beech (e.g. Seeling 1998, v. Büren 1998). According to Richter (2001), for example, yearly losses of 5.1 million Euros for North Rhine-Westphalia were reported due to this phenomenon. Some scientists do not believe that silvicultural management is able to reduce the amount of red timber (Racz et al. 1961, Wobst 1972, Richter 2001). Others claim that special silvicultural regimes may contribute to minimise the formation of red heartwood (Wilhelm et al. 1999, 2001).

In order to assess the heartwood formation in standing beech trees, numerous studies investigated statistical relations between stem characteristics and site properties and the heartwood attributes (for a detailed overview see Seeling, Becker and Schwarz 1999, Günsche 2000). But so far, it has neither been investigated whether this information actually could improve the beech management, nor has been questioned which kind of heartwood information would be required for an improved beech silviculture. This paper has therefore been focused on the question of whether the amount of red heartwood could be controlled if all the information about the heartwood of the standing trees was available. Thus the information about the heartwood formation would be accessible for evaluation prior to the felling of the trees. A special aspect that was analysed was whether information on future heartwood formation in currently white beech stems was able to improve beech management. In addition it was tested whether or not the financial returns could be improved by using the information gained on the red heartwood to select the trees to be felled.

The following research hypotheses were tested:

H1: ‘Even if the full information on the red heartwood of standing beech was available, it would not be possible to reduce the amount of timber with red heartwood harvested in one rotation.’

H2: ‘Complete information on the red heartwood of standing beech would not lead to improved economic results.’

By investigating the two hypotheses the value of the information on the red heartwood in standing beech was assessed.

2 Material and Methods

The value of information was also studied by Kao (1984). He used the following definition (p. 926): ‘The value of information is the difference between what you can get with the information already held and what you could get if you were to know with certainty the outcome prior to making the decision (...). Perfect information concerns the elimination of all uncertainty, i.e., information leads to a known outcome, and provides an upper bound on the value of information in a particular decision.’ Following this definition all uncertainty was discarded in the present investigation.

Methodologically, this paper was based on the simulation of different management strategies using simple algorithms. The simulations were carried out under the main assumption that information on the presence (yes/no) and the extent of red heartwood was available for standing trees. Furthermore, one strategy was simulated, which utilised information on the future formation of heartwood in beech, which is actually still white. Hence the management strategies described below integrated the heartwood information in different ways. A random choice option was chosen as a reference strategy, which did not make use of the heartwood information. The value of heartwood information was defined as the difference of the discounted cash flows between management strategies, which were based on the heartwood information and the random choice option.

2.1 Management Strategies

In order to focus on the efficiency of heartwood information, it was basically assumed that the amount of timber to be felled was already determined (for example by the forest management plan). The assumptions made regarding the felling volumes at different stand ages are given in Table 1.

At an age of 118 years the simulation stopped, as several management concepts for beech were based on a rotation of about 120 years (for example Altherr 1971). The quality structure as well as the felling value of the final crops was analysed. Until this age the following management strategies were simulated:

A) Strategy 'red stem'. At first trees, which show the largest red heartwood diameters were felled. High quality trees were left in the stand, i.e., white beech and stems with merely small red heartwood diameters remained.

B) Strategy 'white stem'. In contrast to strategy A. at first white beech or stems, which exhibit small red heartwood diameters were harvested. Low quality stems remained in the stand.

C) Strategy 'quality conservation'. This strategy utilises information on the dynamics of future heartwood formation in actually white beech in the next ten years (see chapter 2.3). Preferably white beech, which would form new heartwood in the next ten years, is cut.

Superficially it seems easy to say that strategy C. must be the best management option. However, it is a well-known fact that the proportion of trees with red heartwood increases with increasing diameter at breast height (dbh) (e.g., Becker et al. 1989, Frank 1996, Frommhold 2001, Kotar 1994, Mahler and Höwecke 1991, Palmer 1994, and Racz et al. 1961). A strategy like the 'quality conservation', which aims at harvesting trees before they form red heartwood, will merely result in the production of small diameter trees. As the monetary value of a beech tree is closely related to its diameter (e.g. Holm 1974, v. Büren 1998) the 'quality conservation' may also show a poor economic performance.

D) Strategy 'random choice'. The random choice option served as a reference. It represented the mean of three repetitions. Trees to be felled were randomly selected.

Table 1. Assumptions regarding the volumes to be cut at different stand ages.

Stand age (years)	Amount of volume to be cut (in cubic meters solid measure inside bark)
58	47
68	59
78	71
88	59
98	47
108	35

2.2 Model Stand

2.2.1 Start Condition

In order to construct a model stand data from sample plots in an existing 58-year-old stand of the Forest, located at Landshut (lower Bavaria), belonging to the Ludwig-Maximilians-University Munich, was used. An overview of the data of the model stand, which comprised an area of 1.15 ha, is given in Table 2. After the felling of 50 stems almost no trees with red heartwood were found. Consequently also the standing trees were assumed to be white.

2.2.2 Diameter Increment and Volume Estimation

In Central Europe, several growth models based on fundamental principles published by Ek and Monserud (1979) are available to predict stand growth. The assumptions on the future heartwood formation and the increase of existing red heartwood were based on diameter development of the stems (explanation below). Therefore, under

Table 2. Basic data on the model stand.

	Overall	Per ha
Average age	58	
Minimum	58	
Maximum	78	
Stem number	394	342
Basal area (m^2)	27.51	23.92
Diameter at breast height (cm)		
Arithmetic mean	28.6	
Basal area mean diameter	29.8	
Minimum	9.8	
Maximum	69.5	
Standing volume (cubic meters solid measure inside bark)	327	284

the assumption that information is complete the future diameter development had to be known prior to the simulation in order to carry out the management strategies. In the case of the growth model available (i.e., SILVA, Kahn and Pretzsch 1997), however, the diameter development could only be obtained after the simulation. Because of this the growth model was not used. In fact a simple approach, which was mainly based on yield tables for beech, was utilised (for a detailed description see Knoke 2002).

Freist (1962, p. 40) used yield table data to develop a formula, which projects the diameter development of the mean stem depending on the stands density. Freist's formula was utilised to estimate the diameter increment level for the model stand (formula 1).

$$\lg(i_{\mathrm{dmean}}) = \frac{\lg(N) + 0.098 \cdot \mathrm{BA} - 6.581}{0.125 \cdot \mathrm{BA} - 6.250} \tag{1}$$

where

$\lg(i_{\mathrm{dmean}})$ = decade logarithm of the basal area mean tree diameter increment in mm

N = stem number per ha

BA = basal area per ha in m^2

The individual tree diameter increment was then estimated by a formula derived from annual ring analyses for 154 beech stems (formula 2, R^2: 0.43, MSE: ± 1.49 mm).

$$i_d = 2.098 - 0.053 \cdot \mathrm{dbh} + 14.891 \cdot \frac{\mathrm{dbh}}{\mathrm{age}} \tag{2}$$

where

i_d = individual tree diameter increment in mm

dbh = diameter at breast height in cm

age = age in years

The individual tree diameter increment was adjusted to the stands density by the factor k, which was computed by the relation of the basal area mean stem diameter increment according to formula 1 and formula 2 (formula 3):

$$k = \frac{i_{\mathrm{dmean}(1)}}{i_{d(2)}} \tag{3}$$

As an example the resulting diameter increments for the 'random choice' option are described in Table 3.

For the purpose of estimating the volume of the beech trees formula 4 was used:

$$v = -0.202 + 0.000714 \cdot \mathrm{dbh}^2 + 0.00128 \cdot \mathrm{age} + 0.00000627 \cdot \mathrm{age} \cdot \mathrm{dbh}^2 \tag{4}$$

Table 3. Estimated diameter increments for the 'random choice' option.

Age (years)	Diameter increment (mm/yr)			Parameters of the resulting diameter-increment-curves $i_d = b_0 + b_1 \cdot \mathrm{dbh}$	
	Minimum	Mean	Maximum	b_0	b_1
More than 58–68	0.19	0.36	0.66	0.9650	0.0937
More than 68–78	0.21	0.38	0.67	1.0700	0.0847
More than 78–88	0.24	0.40	0.70	1.1959	0.0786
More than 88–98	0.25	0.41	0.70	1.2798	0.0709
More than 98–108	0.26	0.42	0.69	1.3637	0.0643
More than 108–118	0.26	0.41	0.67	1.4057	0.0569

where

v = individual tree gross volume in cubic meter solid measure inside bark

dbh = diameter at breast height in cm

age = age in years

The parameters of formula 4 were estimated using the volumes of 2991 beech trees measured by means of the continuous forest inventory of the Bavarian State Forest Administration.

2.3 Assumptions Regarding the New Heartwood Formation

Starting the simulations on a comparatively young stand, which consisted of only white beech stems it was important to predict the formation of new red heartwood. For this purpose assumptions were based on a study by Knoke and Schulz Wenderoth (2001). Table 4 contains the assumed probabilities with which new heartwood formation will take place within a period of ten years.

Table 4. Assumed probabilities for the formation of new red heartwood within ten years.

dbh-class (cm)	Probability with which a red heartwood is formed within 10 years
Up to 30	0.04
30.1–40	0.16
40.1–50	0.31
50.1–60	0.45
60.1–70	0.65
70.1–80	1.00
80.1–90	1.00
Greater than 90	1.00

Based on the probabilities reported in Table 4, trees which will form new heartwood within ten years were randomly selected among the white beech trees. Once red heartwood has been formed the diameter of the colouration may extend as the diameter of the stem increases. Although this is not necessarily the case and further research is needed it was assumed that the red heartwood diameter extends when the stem diameter grows. Also based on the study of Knoke and Schulz Wenderoth (2001) it was presumed that the relative heartwood diameter (i.e., absolute heartwood diameter divided by the stems diameter) rises 0.7 percent points when the dbh of the stem increases by 1 cm.

2.4 Monetary Value of the Harvested Trees

Apart from measures like the dbh, the branchiness, and the length of the butt log, the stumpage prices, which can be achieved for beech timber, depend also on its heartwood characteristics. In order to use the heartwood attributes as independent variables, which determine the stumpage price, four heartwood classes were distinguished. Subsequently a theoretical quality grading was done, which was solely based on the heartwood characteristics. The timber was quality graded in classes from A decreasing in quality to D:

Class A: no red heartwood at the felling cut.

Class B: heartwood diameter up to 30 % of the stump diameter.

Class C: heartwood diameter more than 30 % but not more than 50 % of the stump diameter.

Class D: heartwood diameter more than 50 % of the stump diameter.

Usually, the red heartwood on the top diameter of the log is used to assess the content of red heartwood. This study was, however, based on the analysis of actually achieved stumpage prices for 175 beech stems (see Knoke 2002). For these stems price differences could be well predicted using the red heartwood diameter at the stump, the dbh, and the butt log length. The price analysis resulted in the following general formula, which estimates the gross value for one solid cubic meter of beech timber (formula 5):

$$\mathrm{GValue} = \frac{b_0 + b_1 \cdot \mathrm{dbh}^2 + b_2 \cdot \mathrm{bl}}{b_3 + b_4 \cdot \mathrm{dbh}^2} \tag{5}$$

where

GValue = gross value in Euro per solid cubic meter

dbh = diameter at breast height in cm

bl = butt log length in meters

As Table 5 shows the parameter b_1 in formula 5 is different for each quality class.

The logging expense was calculated according to formula 6:

Table 5. Parameters for formula 5.

Parameter	b_0	b_1				b_2	b_3	b_4
		Class A	Class B	Class C	Class D			
	–225.20	+0.148866	+0.116288	+0.094900	+0.048714	+19.43	–0.00232	+0.001692

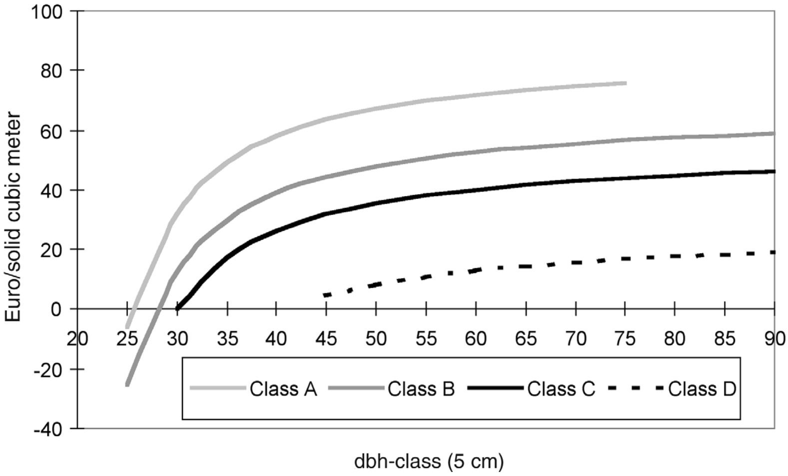

Fig. 1. Net value of one cubic meter beech timber depending on heartwood characteristics and stem dbh.

$$\text{LogExp} = \frac{-23.05 - 1.28 \cdot \text{dbh} + 1.45 \cdot \text{dbh} \cdot \text{cb}^{0.2}}{-0.00232 + 0.001692 \cdot \text{dbh}^2} \qquad (6)$$

where
LogExp = logging expense in Euro per solid cubic meter
dbh = diameter at breast height in cm
cb = crown base in meters

Fig. 1 represents an example for the resulting net value per solid cubic meter for the different heartwood classes.

3 Results

3.1 Quality Structure of the Timber Amount

The total growth performance of the strategies ranged between 853 (‘white stem’) and 904 m^3/ha (‘quality conservation’). The simulated growth performance is well comparable to data reported by Kramer (1988) for beech long time experimental areas. Even with all the information none of the strategies avoided the formation of red coloured timber totally. Also the final crops of the strategies ‘red stem’ and ‘quality conservation’ showed a substantial amount of coloured timber (Table 6). The felling volumes of the thinning interventions were obviously too small to cut all trees in time, before they formed new heartwood. However, timber of the poor quality classes C and D was not present in the 118-year-old stands and it did not occur with the thinning interventions. This finding agrees well with the paper by Fleder (1987) who pointed out that red heartwood does not to a large extent play a role on stands aging 120 years.

The final crops comprised of about 50 % of the timber without red heartwood in the cases of the ‘red stem’ and ‘quality conservation’ strategies

Table 6. Timber quality structure of the thinning interventions and the 118-year-old stands.

Strategy	Timber volume (in cubic meter inside bark, portion in parenthesis)			Basal area mean diameter (cm)	Total growth performance (in solid cubic meter)
	Quality class A	Quality class B	Total		
			Thinning-timber		
'Red stem'	53 (17 %)	262 (83 %)	315	40.5	
'White stem'	280 (89 %)	35 (11 %)	315	34.1	
'Quality conservation'	311 (100 %)	0 (0 %)	311	40.3	
'Random choice'	207 (67 %)	102 (33 %)	309	36.4	
			118-year-old final crops		
'Red stem'	271 (46 %)	318 (54 %)	589	48.6	904
'White stem'	0 (0 %)	538 (100 %)	538	61.7	853
'Quality conservation'	324 (54 %)	280 (46 %)	604	49.0	915
'Random choice'	110 (19 %)	457 (81 %)	567	54.4	876

while the option 'white stem' led to 100 % timber with colouration. The 'random choice' option exhibited merely 19 % without red heartwood of the standing volume at age 118.

It is obvious that the cutting of trees before heartwood was formed ('quality conservation') on the one hand generated comparatively small sized final crop stems. In contrast to the 'white stem' and 'random choice' strategies, 'quality conservation' yielded a basal area mean diameter of only 49.0 cm. On the other hand the mean diameter of the stems felled during the thinning interventions was comparatively high. The 'quality conservation' showed the largest volume increment. Due to the higher risk under which large trees form heartwood these stems were preferably cut. Large trees generally show comparatively poor volume growth percents. Therefore is appears logical that the 'quality conservation' strategy produced the highest volume increment under the assumption of equal felling volumes for all strategies during the thinning interventions.

Summarily it can be said that only the strategy 'quality conservation' led to a significantly higher amount of white beech timber when compared to the 'random choice' option. 'Quality conservation' produced 635 m^3 white beech timber (i.e. about 70 % of the total growth performance), while the 'red stem' strategy merely yielded 324 m^3 white beech timber. Consequently the 'red stem' strategy was only as good as the random 'choice option', which produced 317 m^3 white beech timber. Evaluating the timber-quality-structure the 'white stem' strategy was the worst performer, resulting in only 280 m^3 of white beech timber.

3.2 Financial Return

In the previous chapter it was shown that the strategy, which produced a good quality timber, yielded relatively small sized stems when regarding the final crops. This fact may diminish the felling value of the final crops. It now seemed interesting to analyse the income derived from the thinning interventions and the felling value of the final crops (Table 7).

During the first intervention on the 58-year-old stand only white stems existed. The selection of stems to be harvested at this age was done at random not only for the 'random choice' option but also for the 'red stem' and 'white stem' strategies. Because of this no difference between the management strategies could be realised at an age of 58.

Measured by the income of the 'random choice' option a substantial positive difference in the total income was only achieved by the 'quality conservation', which yielded a surplus of 15 %. However, the evaluation of the financial return cannot be conducted without the integration of

Table 7. Net income from the thinning interventions and felling values of the final crops of the considered strategies in Euro/ha.

Stand age (years)	Management strategies			
	'Red stem'	'White stem'	'Quality conservation'	'Random choice'
58	1.898	1.898	2.328	1.916
68	2.327	2.425	3.285	2.640
78	3.065	3.287	4.196	3.271
88	2.799	2.867	3.554	2.755
98	2.034	2.554	2.908	2.416
108	1.850	1.641	2.016	1.745
118	32.908	29.268	34.597	31.054
Total	46.881	43.940	52.884	45.797
Portion of the thinning in %	30	33	35	32
Total net income in Euro/ha/yr	397	372	448	388
In % of the 'random choice' option	102	96	115	100

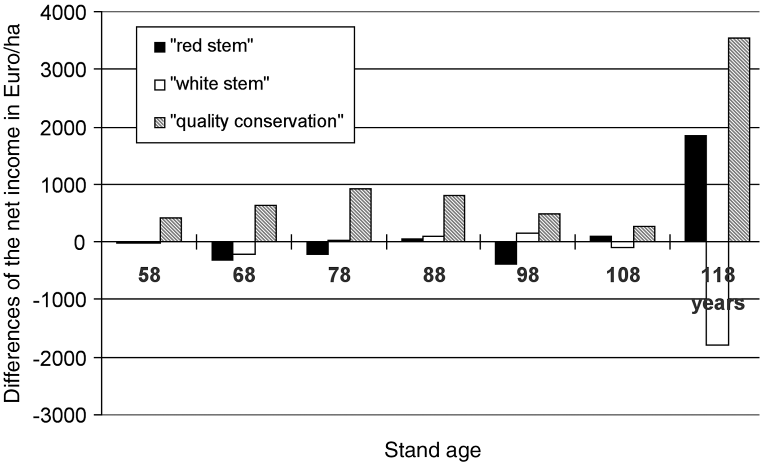

Fig. 2. Differences between the income and the felling value of the final crops if the management strategies and the 'random choice' option were compared.

the time preference. In order to take into consideration the time structure in which the income occurred, the discounted cash flows of the income differences between the management strategies and the 'random choice' option were analysed. The differences of the cash flows are depicted in Fig. 2.

The sums of the discounted cash flows depend heavily on the interest rates applied (Fig. 3).

However, from the point of view of the deciding parties, it seems important that regardless of the interest rate the management strategy 'quality conservation' yielded the largest discounted cash flow.

The differences of the discounted cash flows, which were computed using the 'random choice' option as a reference can be interpreted as the value of the full heartwood information. This view point clarifies that only the information on new heartwood formation in white beech, which

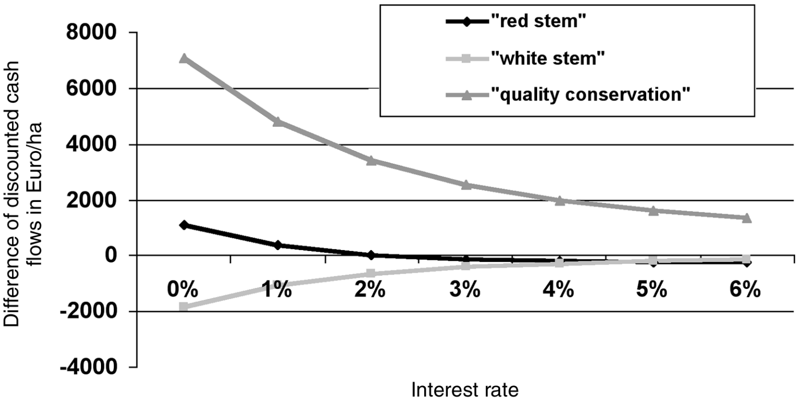

Fig. 3. Differences between the discounted cash flows when comparing the management strategies and the 'random choice' option.

is utilised from the 'quality conservation' strategy, has a potential value. The selection of the trees to be cut merely based on the current heartwood condition – as in the 'red stem' and 'white stem' strategies – does not yield a substantial economic advantage.

4 Discussion

At the beginning of this paper it was asked whether or not the amount of red coloured timber could be controlled if the heartwood information would be available prior to the felling. The financial advantage by using the heartwood information was to be investigated, and a statement should be made on which information could really improve the beech management from an economic point of view. The first hypothesis to be tested can be discussed as follows:

H1: 'Even if the full information on the red heartwood of standing beech was available, it would not be possible to reduce the amount of timber with red heartwood harvested in one rotation.'

While only information on the current heartwood condition was utilised to select the trees to be cut (strategies 'red stem' and 'white stem'), the amount of red coloured timber could not significantly be reduced. Only if it was known which of the currently white stems would in near future form new red heartwood, could the amount of white beech timber notably be raised.

H2: 'Complete information on the red heartwood of standing beech would not lead to improved economic results.'

Consistent to the results achieved regarding H1 the economic results were only improved when the dynamic information on the new formation of red heartwood in white beech was applied. The strategy 'quality conservation' yielded the best results though it produced rather small-sized timber.

Sensitivity analysis, which changed the assumptions regarding the diameter increment and the probability with which new heartwood was formed did not alter the results significantly (Knoke 2002).

It can therefore be concluded that if the beech management should be supported by heartwood information at all, only dynamic information on new heartwood formation and heartwood development would seem to be efficient. Therefore, future research on the red heartwood of beech has to be designed in such a way that this information will be provided.

The mobilisation of such information for standing beech timber poses of course a methodological problem. Once the stem has been felled it cannot be investigated regarding its heartwood formation at a later stage. The non-destructive measurement methods for beech-heartwood are actually not yet far enough developed to be used in providing information on the heartwood formation (v. Büren 1998, Weihs et al. 1999, Gruber 2000). However, artificial time series analysis may be used to derive transition probabilities for white beech stems, which quantify the probability with which stems will form new red heartwood. Möhring (1986) and Dieter (1997), for example, used a similar technique to integrate the windblow-risk in an economic evaluation. By relating the transition probabilities to stem properties like dbh, age, fork (yes/no), and the number of dead branches, stems with high transition probabilities could be identified and cut.

Acknowledgements

The author wishes to thank Prof. Dr. Moog for motivating the study, Dr. M. Weber and Mr. Schmerbeck for critical comments, and Mrs. Edith Lubitz as well as Mr. Seung-Jin So for language revision. Prof. Dr. Dr. h.c. Becker has given valuable comments. The study has been funded by the Deutsche Forschungsgemeinschaft.

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