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Examensarbete i skogsuppskattning och skogsindelning
Handledare: Sören Holm och Tomas Thuresson

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ABSTRACT

In forest management planning it is essential to be able to evaluate standing trees. For this purpose, taper curve functions and ways to estimate quality is needed. This work presents taper curve functions for Common Oak (Quercus robur L.) in Sweden. Data was collected in a two phase inventory, where 100 oaks were measured before and after felling. The data was processed by using ordinary least square regression. Also, quality probabilities for logs along the stems were estimated conditioned a subjectively estimated butt log quality.

Keywords: *forest management planning, forest measurement, quality estimation, Quercus robur, taper curve.*

INTRODUCTION

Good information about our forest resources is essential in forest management planning. An often used system for strategic planning in Sweden is the Forest Management Planning Package (FMPP) described by Jonsson, Jacobsson & Kallur (1993). The overall goal when using FMPP is to achieve a high sustainable economic yield. One strength with the system is that all prognoses are based on high resolution data, objectively inventoried on a single tree level. Today, due to the lack of taper curve functions and quality models, all hardwoods are classified as pulpwood in the FMPP, leading to an underestimation of the economic potential in areas with hardwoods. This is more than apparent when dealing with Common oak (*Quercus robur* L.), for which some assortments are very valuable compared to pulpwood. To make it possible to use the FMPP or other forest management planning systems, also in hardwood forests, it is necessary to find a way to evaluate standing oaks in monetary terms.

To estimate the yield of logs from standing trees, a way to predict size and quality of each log is needed. This can be accomplished by using taper curve functions. Also, ways to estimate the qualities of the logs are needed.

The main application of taper curve functions is estimation of volumes in different parts of a stem for forest valuation purposes. For Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.), taper curve functions are constructed by Edgren & Nylinder (1949). These are based on a model with three logarithmic curves for different parts of the stem. Edgren & Nylinders taper curve functions are used together with assortment estimation models (Johansson & Westerlund, 1985) in the FMPP, to evaluate the timber assortments.

The Common oak stemform has not been extensively studied in Sweden. Hagberg & Matérn (1975) presented volume functions for oak, both for the stem and the branches. Söderberg (1986) constructed form height functions based on circular plot data and tree variables. Taper curve models for oak in Sweden are not developed. However there is an apparent advantage of such models for estimation of timber assortment volumes (Kilkki & Lappi, 1987). Taper curve models combined with quality prediction along the stem makes it possible, within the planning system, to scale the stem into assortments.

The necessity to evaluate standing oaks is obvious. Without a present value on the trees, it is not possible to evaluate and make forecasts of the effects of different treatments in stand. This is equally important in multi-criteria decision-making (Tarp & Helles 1995), when dealing with issues regarding choice of tree species, nature conservation, etc.

The purpose of this study was to construct taper curve models for oak and to discuss ways to estimate the quality on standing oak.

MATERIALS AND METHODS

Reference material

The oak trees in the investigation come from a two phase inventory at the Manor of Östad. Östad is situated in the county of Västergötland (latitude 58.0°, longitude 12.5°). In the first phase a sample of five oak stands, legal for cutting operations, was taken. Within these stands a sample of 355 oak trees was taken. The oaks were cross-calipered and type classified according to the ratio, relative crown height (RCH), between live crown height to the tree height: Type1 - RCH > 1/2; Type 2 - 1/3 < RCH < 1/2; Type 3 - 1/3 < RCH.

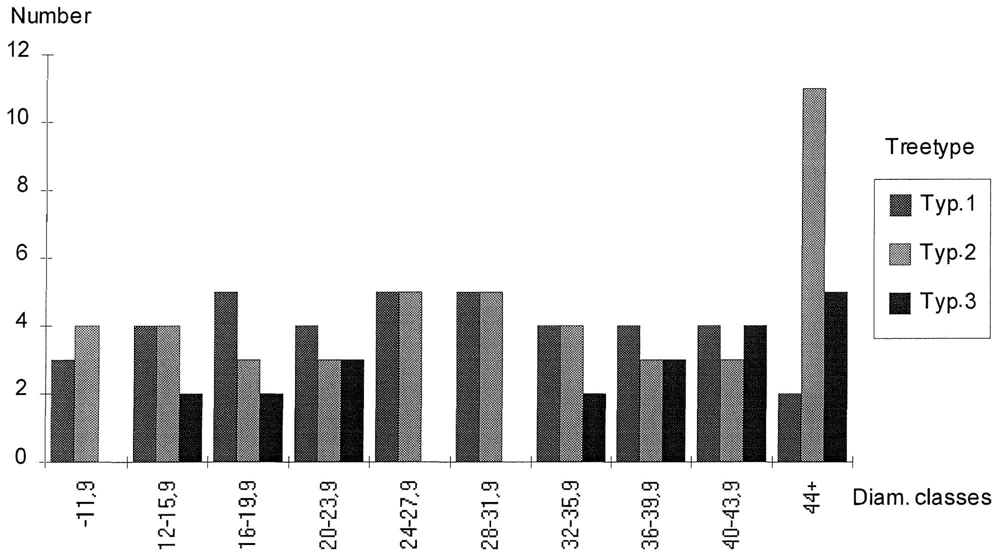

Figure 1. Number of stems per 4 cm diameter class and tree type.

All trees were numbered and marked. In the second phase 106 trees were randomly sampled within strata of diameter classes and types (Figure 1). On standing trees, diameter at breast height outside bark, bark thickness, tree height, live and dead crown height, adventitious branch height, fork height and quality heights were measured. When felled, diameter outside bark and bark thickness (at height 0, 0.5, 1.0, 1.3, 1.5, 2.0, 3.0, 4.0, ... , tree tip), total age, tree length, diameter of first live branch. Also, the assortment yield (number of logs and length, top diameter and quality on each log) were determined on each sample tree. The timber assortment were divided into the traditional qualities: Veneer; A; B; C and sawlogs of standard length. Wood with a top diameter under 15 cm, wood of lower quality, the top parts and branches were classified as fuel chip or traditional fire wood. During the cutting operation 6 of the 106 original sample trees were excluded from the sample because of felling problems or by nature conservation causes.

Choice of taper curve model

Since the material include trees with forks, the relative square diameter (d_i^2 / D_{bh}^2) along the stem was considered a more relevant dependent variable than the diameter along the stem. Here d_i^2 is the squared diameter inside or outside bark at height *i* and D_{bh}^2 is the squared diameter at breast height outside bark. Above fork height d_i^2 was defined as the sum of the squared diameter for each fork stem.

Different regression models were tested, i.e. Max & Burkhart (1976) made taper curve model for, e.g., Willow oak (*Quercus phellos* L.) by using different segmented polynomial equations conditioned to join smoothly. Thomas & Parresol (1991) instead constructed taper curve functions for Willow oak by using a trigonometric model. In our study a simplification of the model described by Max & Burkhart (1976) fitted best. Equation (1) describes the model, which is of the segmented sort, with relative square diameter joins at a_1 and a_2. The first part describes the lower section where the relative height (h_i / H) $\leq a_1$, where h_i is the height i, and H is the entire height of the tree. The second describes the middle section ($a_1 <$ relative height $\leq a_2$) and the last describes the top section (relative height $> a_2$). The following model was used:

$$y_{ij} = b_1(x_{ij} - 1) + b_2(x_{ij}^2 - 1) + b_3(a_1 - x_{ij})^2 L_{ij} + b_4(a_2 - x_{ij})^2 U_{ij} + e_{ij}, \qquad (1)$$

where:

j is tree index,

$y_{ij} = d_{ij}^2 / D_j^2$,

x_{ij} = relative height (h_{ij} / H_j),

$b_1 ... b_4$ = parameters estimated using OLS (ordinary least square),

a_1, a_2 = join point parameters,

L_{ij}	= 1	if	$a_1 - x_{ij} \geq 0$	and
	= 0	if	$a_1 - x_{ij} < 0$,	
U_{ij}	= 1	if	$a_2 - x_{ij} \geq 0$	and
	= 0	if	$a_2 - x_{ij} < 0$,	

e_{ij} are the random deviations with expectation zero.

Max & Burkhart estimated both the join points (a_1, a_2) and the parameters (b_1, b_2, b_3 and b_4) through regression. In this study different join points (a_1, a_2) were tested and for each of these combination of join points the parameters (b_1, b_2, b_3 and b_4) were estimated through OLS-regression (ordinary least square). Criteria used for the final decision of (a_1, a_2) was the estimated standard deviation about regression and visual inspection of residual plots. The parameters were estimated separately for the three tree types and for all types together.

From the plot in Figure 3 it was obvious that the butt swell influenced the stem form up to approximately 10 % of the tree height. Because of that values ranging from 0.06 up to 0.18 were tested for a_1. For the second inflection point (a_2), values from 0.3 up to 0.8 were tested.

Quality estimation

The total yield of saw timber (veneer, A, B, C) from the 100 sample trees was 189 logs. The timber assortment distribution of volume and value is shown in Fig. 2. All quality estimations, both on the standing trees and on the felled trees, were made by a professional buyer of oak timber. Due to quality defects inside the stem, i.e. ring shake, rot included sap wood and tension wood, the quality on the butt log can be overestimated, when quality is classified on standing tree. Inversely, false signs of probable inner defects can lead to an underestimation of the quality.

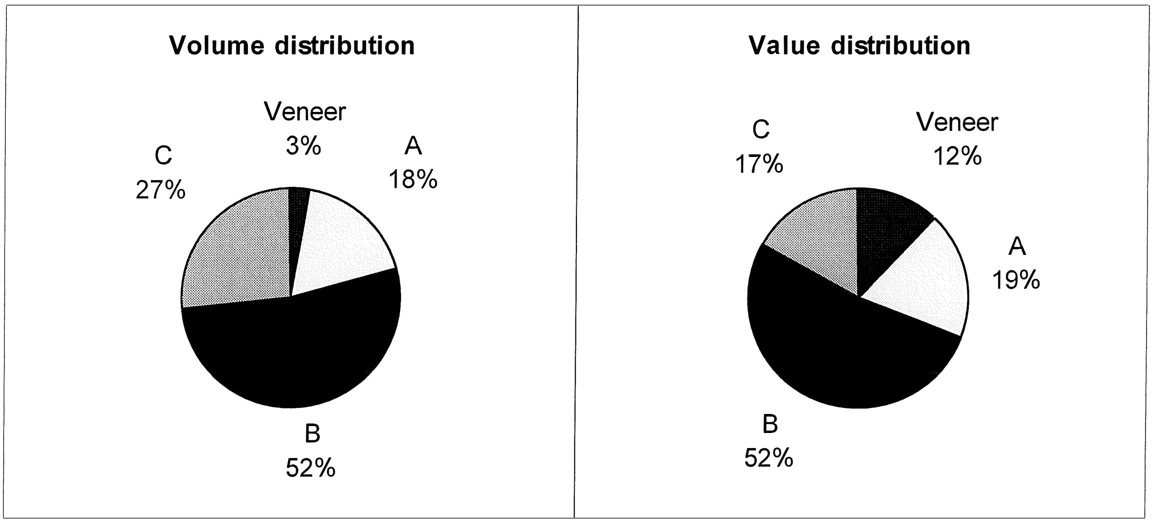

Figure 2. The timber volumes (left) and the timber values (right) distributed among assortment grade.

The quality estimation of the butt log on the standing tree was compared with the outcome from the felled tree. The probability $P(TQ_{bl} | EQ_{bl})$ of the true quality TQ_{bl}, of the butt log, the second, third, fourth and fifth, conditioned on the field judged quality EQ_{bl}, was estimated. The estimations were made for two groups, trees with breast height diameter smaller or equal to 30 cm and trees with breast height diameter bigger than 30 cm.

RESULTS

Taper curve functions

The three stem form types gave statistically significant different taper curve functions (Table 1). Type 1 trees (see the material and method section) have a better stem form, i.e., with a gentle taper. Logically the functions for these trees have a slower taper then the functions for trees belonging to type 2 or 3 (Fig. 3). In Fig. 3 it is also shown that the function for tree type 3 has an extra rapid taper. Functions were estimated for outside and inside bark for five material groups as there was a significant difference between, e.g., the tree types 1, 2 and 3. A general function for the tree types together were constructed as a function to be used if tree type for some reason are not decided. Also functions that separate type 1 plus 2 from type 3 (Table 1) were estimated. The reason for this was that oaks of type 3 are easy to recognize and separate by ocular inspection from tree type 1 and 2 and this separation by material will give better predictions then the general function. The function for type 1 and 2 has a slower taper (Fig. 4) then the general function which, as the general function also contain tree type 3. The multiple correlation coefficient (R^2) were for all functions > 0.985 and the p-levels < 0.001 for all functions and parameters. An obvious bias at the top of the tree were observed for all functions presented (Fig. 5).

Table 1. ***Estimated regression coefficients for estimation of the dependent variable relative square diameter ($y_i=d_i^2 / D^2$) as functions of the independent variables: relative height ($x_i=h_i/H$) and the indicator variables for butt swell (L_i) and upper inflection point (U_i). The functions I to V are for diameter inside bark and the functions VI to X for diameter outside bark. In all cases the R^2 > 0.985 and the p-level < 0.001 (both for the functions and the parameters). The SE is the estimated standard deviation about regression. The numbers of observed trees for the three types are 40 (type 1), 40 (type 2) and 20 (type 3).***

Basic model. $E(y_i) = b_1(x_i - 1) + b_2(x_i^2 - 1) + b_3(a_1 - x_i)^2 L_i + b_4(a_2 - x_i)^2 U_i$

Function	Treetype	b_1	b_2	b_3	b_4	a_1	a_2	SE
I	**General**	-2.1720	0.9478	32.5357	-1.5574	0.1000	0.5000	0.0622
II	**1, 2**	-3.1228	1.4934	32.9818	-1.8695	0.1000	0.6500	0.0512
III	**1**	-3.5364	1.6874	34.4280	-2.0571	0.1000	0.7000	0.0329
IV	**2**	-2.8751	1.3856	32.1409	-1.8167	0.1000	0.6000	0.0371
V	**3**	-2.2947	1.1081	28.5266	-2.2097	0.1000	0.4000	0.0288
VI	**General**	-2.6029	1.1064	38.7758	-2.0180	0.1000	0.5000	0.0730
VII	**1, 2**	-3.8437	1.8196	39.4981	-2.4365	0.1000	0.6500	0.0594
VIII	**1**	-4.3152	2.0355	41.6413	-2.6467	0.1000	0.7000	0.0370
IX	**2**	-3.5680	1.7047	38.3558	-2.3962	0.1000	0.6000	0.0443
X	**3**	-2.7555	1.3063	32.6002	-2.7734	0.1000	0.4000	0.0338

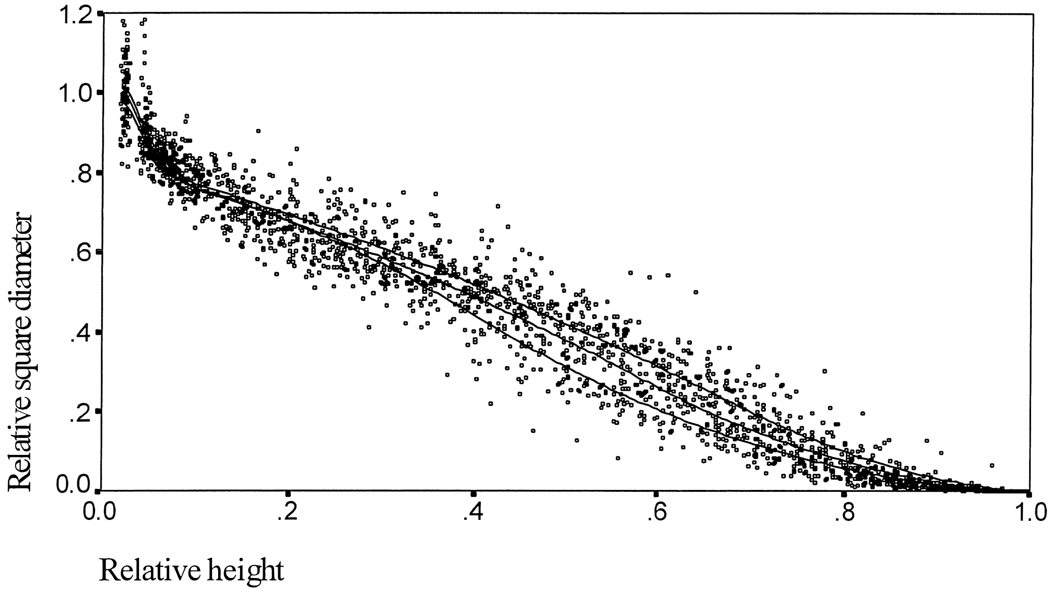

Figure 3. **The taper curve functions for the three oak types plotted together. The upper curve represents function III, the middle function IV and the lower function V. The plots are observations from the sample trees.**

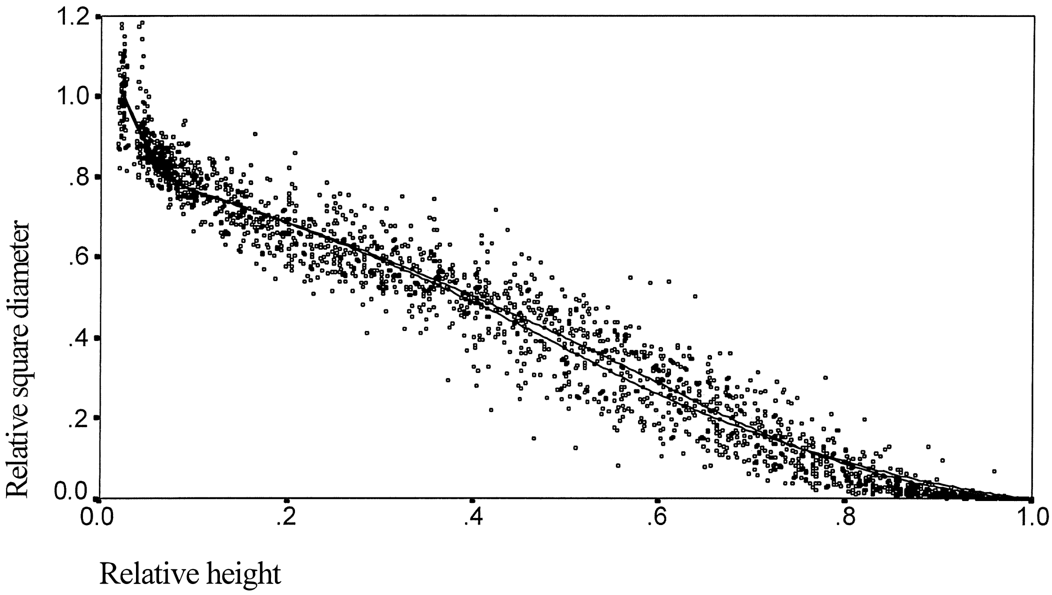

Figure 4. **The general taper curve function (I) and the joint function (II) plotted together. The plots are observations from the sample trees.**

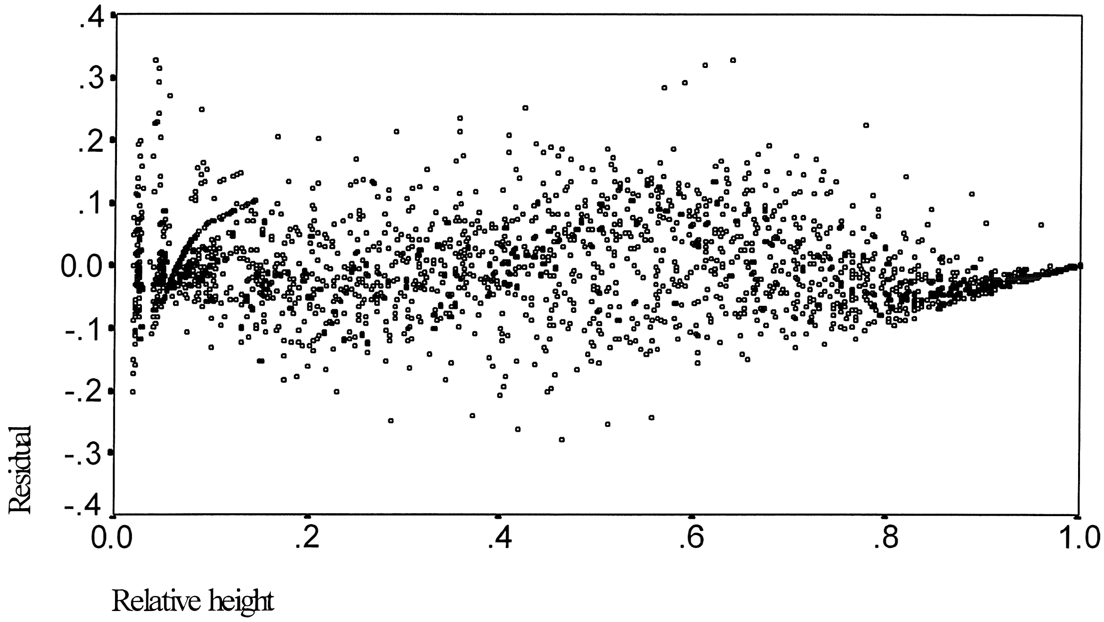

Figure 5. The residual plot for the general function (I).

Quality estimations

Possible timber ”log height” rarely exceeded half the tree height. This is partly explained by the fact that the possible log heights were correlated to the crown height. The quality in the crown was bad and it was not possible to get timber logs from this part of the stem. The number of timber logs basically did not depend on ”log height”. A low crown height leads to a fast taper which optimally gives shorter timber logs and the other way around for trees with a high crown height.

One way to implement qualities on standing trees, in a forest management planning system as the FMPP, is to allocate qualities along the stem based on sample tree butt logs as suggested by Johansson & Westerlund (1985). The probability of the i:th log true quality within the tree conditioned the butt log quality, is presented in Table 2.

Table 2 *The probabilities for the true quality of the i:th log along the tree, conditioned by the subjective occular quality estimation on the first (but) log. V is Veneer, A is second best class, B is third- and C is fourth best class. SL is Sawlogs of standard length and FW is fire wood. The probabilities are divided into trees with breast height diameter outside bark ≤ 30 cm, and trees with bhd outside bark > 30 cm.*

Subjective		True quality of the i :th log																				
Occular		1						2					3				4				5	
Estimation		V	A	B	C	SL	FW	A	B	C	SL	FW	B	C	SL	FW	B	C	SL	FW	C	FW
BHD	V	0.67	0.33	0.00	0.00	0.00	0.00	0.16	0.69	0.15	0.00	0.00	0.54	0.38	0.00	0.08	0.13	0.33	0.00	0.54	0.17	0.83
outs.	A	0.00	0.77	0.23	0.00	0.00	0.00	0.12	0.73	0.15	0.00	0.00	0.50	0.42	0.00	0.08	0.13	0.34	0.02	0.51	0.14	0.86
bark	B	0.00	0.33	0.67	0.00	0.00	0.00	0.05	0.81	0.14	0.00	0.00	0.41	0.51	0.00	0.08	0.13	0.34	0.06	0.47	0.08	0.92
>30	C	0.00	0.00	0.00	0.67	0.00	0.33	0.00	0.00	0.77	0.00	0.23	0.00	0.25	0.00	0.75	0.00	0.10	0.00	0.90	0.00	1.00
BHD	A	0.00	0.77	0.23	0.00	0.00	0.00	0.00	0.19	0.15	0.44	0.22	0.15	0.00	0.56	0.29	0.00	0.00	0.03	0.97	0.00	1.00
outs.	B	0.00	0.33	0.67	0.00	0.00	0.00	0.00	0.16	0.07	0.51	0.26	0.07	0.00	0.48	0.45	0.00	0.00	0.09	0.91	0.00	1.00
bark	C	0.00	0.00	0.00	0.67	0.00	0.33	0.00	0.00	0.19	0.00	0.81	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	1.00
≤30	SL	0.00	0.00	0.13	0.00	0.60	0.27	0.00	0.02	0.00	0.51	0.47	0.00	0.00	0.27	0.73	0.00	0.00	0.07	0.93	0.00	1.00

DISCUSSION

This is a pilot study of limited extent. The oaks originate from one local, the Manor of Östad and the number of oaks were 100. This infer that the results, the taper functions and the probabilities for different qualities could not uncritically be used at other places in Sweden. Especially the quality predictions are local since tree quality varies much depending on silviculture, climate and other environmental factors specific to local (Almgren & others, 1986). Concerning the taper curve functions I think that the individual tree parameters are much more important than the environmental parameters for determination of the taper and stem form of oak. Oaks with a certain diameter, a certain height and a certain crown limit are bound to have a certain taper, which I think is only little dependent on local parameters such as height above see or climate. Oaks of varying stem form were used in this investigation and they were with minor exception, supposed to represent, all different stem form types of oaks in Sweden. This fact, indicates a possible use of the functions even on other locals.

The definition of difference between the three oaktypes are principally depending on crown height. However it was not significant to use crown height as independent variable. It was an obvious correlation between the parameter a_2 (relative height) and the crown height. Therefore it was tested to let a_2 be a function of crown height. This model approach was abandoned since significance could not be found. The value of a_2 was estimated and became logically higher for tree type with better form than for tree type with inferior form. The solution was to let a_2 be fixed per tree type. The variation in a_1 gave very small differences in R^2 and SE (estimated standard deviation around the function) but instead its location influenced the taper function for (relative height < a_1) very much. For ($a_1 < 0.1$) the butt swell was overestimated and for ($a_1 > 0.1$) the butt swell was underestimated. From that, a_1 was determined to be fixed at 0.1.

When constructing the functions the different observations along the stem were used as they were independent of each other. This is not the most efficient way but was although determined to be used. Breast height diameters outside bark and tree heights are the independent variables in function I and VI (Table 1). Oaks of type three are easy to separate from type one and two (see the definition) and thus it is also possible to use the function V and X for oak type three and the joint functions II and VII for other oaks. It is important that the variables are objective and easy to measure at the inventory and therefore either the general function I (VI) or the function II (VII) combined with function V (X) are useful. It is easier to make the division into one aggregated group consisting of tree type one and two and one group with tree type three. The general function for all tree types could be applied when for some reason, division into tree type is not made. The functions makes an assortment estimation possible.

In this investigation, the wood above fork height, is classified as fire wood. The belittling depended on bad quality such as crooks and thick branches. Supposing this to be general, most oak buyers classify wood over fork height as branch wood which infers that the oak wood volume over fork height can be calculated as one assortment - fire wood. The volume of the branches can also be included in this assortment, specially if the intent is to make fuel ship. The conclusion from this is that the taper curve functions should be used to estimate the volume of the more valuable parts of the stem, i.e., the stem under fork height combined with a volume function for the rest of the stem and the branches. The volume functions for oak, described by Hagberg & Matérn (1975), can be used for this purpose.

Quality estimation on standing oaks is difficult. Due to inner defects that not are visual from the outside, the quality of the butt log is generally overestimated (see Table 2). Examples of inner defects that cause reduction of the quality class and that are not normally visual are ring shake and decay. The occurrence of these defects are probably as already mentioned, local or regional due to e.g. the climate situation, soil and other environmental factors. For Östad, probabilities for true quality on different log (x) conditioned on estimated quality on butt log ($P(Q_{xl} \mid EQ_{bl})$), have been worked out (Table 2). For other places, this relation has to be reinvestigated.

Due to the difficulties to estimate quality heights on a standing tree, the qualities on the other logs of tree are assumed to be related to the estimated quality on the butt log. The height limit for bucking logs (log height) was mainly dependent on the fork height and if there was no fork, the crown limited the log height. Above fork height the stem is often crooked and within the crown the branches are quite thick which leads to quality belittling. The possible log height was therefore correlated with the crown height and fork height, low crown height or fork height led to low log height. Over this height the quality was so bad that the wood only could be used as fire wood.

The trees with high crown height had also better stem form which in general infered to longer logs. In this investigation, it was therefore found that the number of logs were independent of the possible log length. The conclusion was that it should be possible to describe the quality of a given log with probabilities conditioned on the estimated quality on the butt log $P\ (Q_{xl} \mid EQ_{bl})$.

Future work in this area could be to include that larger material that was collected from several places in southern Sweden during the first part of this century and contains about 2 500 oaks. The volume functions that Hagberg & Matérn (1975) constructed are based on this material. Taper curve functions for Common oak that would be useful for all places within the oak distribution area in Sweden could by that be obtained.

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