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METHODS FOR ACQUISITION OF BIOMASS COMPARTMENTS

Otto Eckmüllner*; Pascal Schedl
Institute of Forest Growth and Yield Research
Department of Forest and Soil Sciences
BOKU-University of Natural Resources and Applied Life Sciences
Peter Jordanstraße 82, A-1190 Vienna, Austria
otto.eckmuellner@boku.ac.at, pascal.schedl@boku.ac.at

Abstract: *The usage of biomass in Austria became more and more important during the last years. Therefore the prediction of the potential of sustainable biomass in forest management is necessary for forest companies. Inventories usually measure magnitudes like the stands age, height of the largest trees and the middle diameter of a stand.*

In the course of some projects it was found that by using these magnitudes it is not possible to make precise predictions about the biomass compartments of a single tree or stand. For a serious prediction of the compartments taper volume (in- and excluding bark), branch and needle biomass it was found that the measurement of four magnitudes (tree species, diameter in breast height, height of the tree and of its crown attempt) are of particular importance.

A rough prediction can give information about the ecological sustainability for a certain stand site of the usage of biomass compartments. For the economic calculation of biomass usage a splitting in merchantable compartments is necessary. The developed model is able to give answers to both questions. Furthermore the efficiency of different inventory designs (in forest inventory and in stand inventory) is compared to demonstrate the most appropriated way to assess data.

1. Introduction

Due to the increasing importance and usage of biomass in Austria a lot of research was done during the last years. Therefore additive to logs of low quality the usage of branches and needles for energy recovery became to an option. Of course its use affects the nutriments cycling of the stand and therefore the ecological effects should not be ignored.

Different functions for the estimation of dry or fresh branch and needle biomass were developed for broadleaved species (Gschwantner and Schadauer, 2006) and coniferous species (Eckmüllner 2006, Ledermann and Neumann 2006). The simplest ones use as dependent variable the diameter in breast height (dbh) for biomass estimation, but as the dimension of the crown and therefore its biomass is also dependent from the crown length, above mentioned authors developed functions with more precise prediction by using additionally height of the tree and crown ratio as variables.

From economic point of view clear cuts supply more or less always a positive contribution margin, but for thinnings this is not always assured. The price for a log depends on the middle diameter, colour of the wood, tree species length, relation of diameter loss and branch diameter. These conditions are arranged in the Austrian timber trading usance (Kooperationsplattform Forst Holz Papier, 2006) for all commercial traded species. Therefore a prediction of the quantity and quality of harvested logs is of importance. An algorithm to translate tree boles into merchantable logs for several Austrian tree species was developed by Eckmüllner et al. (2007), using easily measurable magnitudes, like acquired in inventories, as variables.

2. Material and Methods

2.1 Stand

From our institute data of a stand located in Arnoldstein (Southern Austria) including each trees diameter, height total and of the crown attempt, social rank and terrestrial measured coordinates was chosen for our calculations. The stand measures 1600 square meters including 117 Norway spruces (Picea abies). The spatial distribution of the stands trees in 1993, assumed into five centimetres dbh-classes is given in Figure 1.

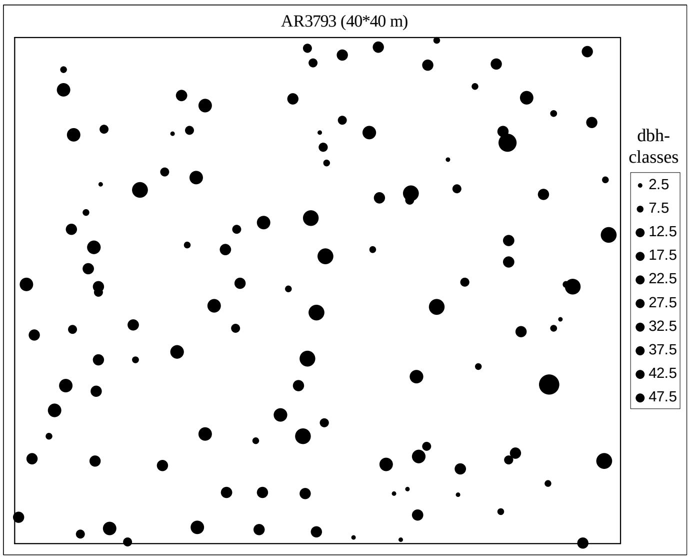

Figure 1: Spatial distribution of the 117 trees of the stand “AR3793” split up into 5 cm dbh-classes

2.2 Dry needle and branch mass

The estimation of dry needle and branch mass was done using Eckmüllners (2006) function for Norway spruce [1], whereas the coefficients vary in dependence of the calculated magnitude. The variables are dbh, height of the tree (H), crown ratio (CRA, [2]) and a Dummy variable (D) for needle loss (yes = 1; no = 0).

$$\ln(BiomF_{[kg]}) = a_0 + a_1 \cdot D + a_2 \cdot \ln(DBH_{[cm]}) + a_3 \cdot \ln(H_{[m]}) + a_4 \cdot \ln(1 - CRA) \quad (1)$$

The crown ratio is defined as:

$$CRA = \frac{CL_{[m]}}{H_{[m]}} \quad (2)$$

where CL is the crown length.

<u>Example:</u> For a tree with a total height of 25 m, crown attempt at 15 m, dbh of 28 cm and no needle loss the dry branch (dbm) and needle (dnm) mass is calculated following:

$$dbm_{[kg]} = e^{\left(-3,6270 - 0,1784 \cdot 0 + 2,8018 \cdot LN(28) - 0,7826 \cdot LN(25) - 0,3408 \cdot \left(1 - \frac{(25-15)}{25}\right)\right)} = 19,8\,kg$$

$$dnm_{[kg]} = e^{\left(-2,6347 - 0,2708 \cdot 0 + 1,9262 \cdot LN(28) - 0,3124 \cdot LN(25) - 0,3646 \cdot \left(1 - \frac{(25-15)}{25}\right)\right)} = 12,9\,kg$$

2.3 Bole volume

Volume calculation was done by using the taper curves of Eckmüllner et al. (2007) which are the basic information for assortment into merchantable compartments. Following magnitudes are necessary for the calculation of the taper curve: species, diameter in breast height, height of the tree (H) and the crown attempt (CH), altitude (AL) and social rank (as Dummy-variable for social rank “2” or “34”, SR”X”). The model (Figure 2) is composed by two conoids stumps, first from diameter at the stump to dbh and second from dbh to the height of the crown attempt and above to the top the curve is described by a conoid. Thus the two unknown diameters, [3] at the stump (DST) and [4] at the crown attempt (DCR), have to be estimated by use of following equations:

$$DST_{[m]} = a_0 + a_1 \cdot DBH_{[m]} + a_2 \cdot DCR_{[m]} + a_3 \cdot DBH_{[m]} \cdot DCR_{[m]} + a_4 \cdot (CH_{[m]} - 1,3) + a_5 \cdot \frac{(CH_{[m]} - 1,3)}{DBH_{[m]}} + a_6 \cdot \frac{AL_{[m]}}{100} \qquad (3)$$

$$DCR_{[m]} = a_0 + a_1 \cdot DBH_{[m]} + a_2 \cdot (H_{[m]} - 1,3) + a_3 \cdot (CH_{[m]} - 1,3) + a_4 \cdot \frac{(H_{[m]} - 1,3)}{DBH_{[m]}} + a_5 \cdot \frac{(CH_{[m]} - 1,3)}{DBH_{[m]}} + a_6 \cdot \frac{(CH_{[m]} - 1,3)}{(H_{[m]} - 1,3)} + a_7 \cdot \frac{AL_{[m]}}{100} + a_8 \cdot SR2 + a_9 \cdot SR34 \qquad (4)$$

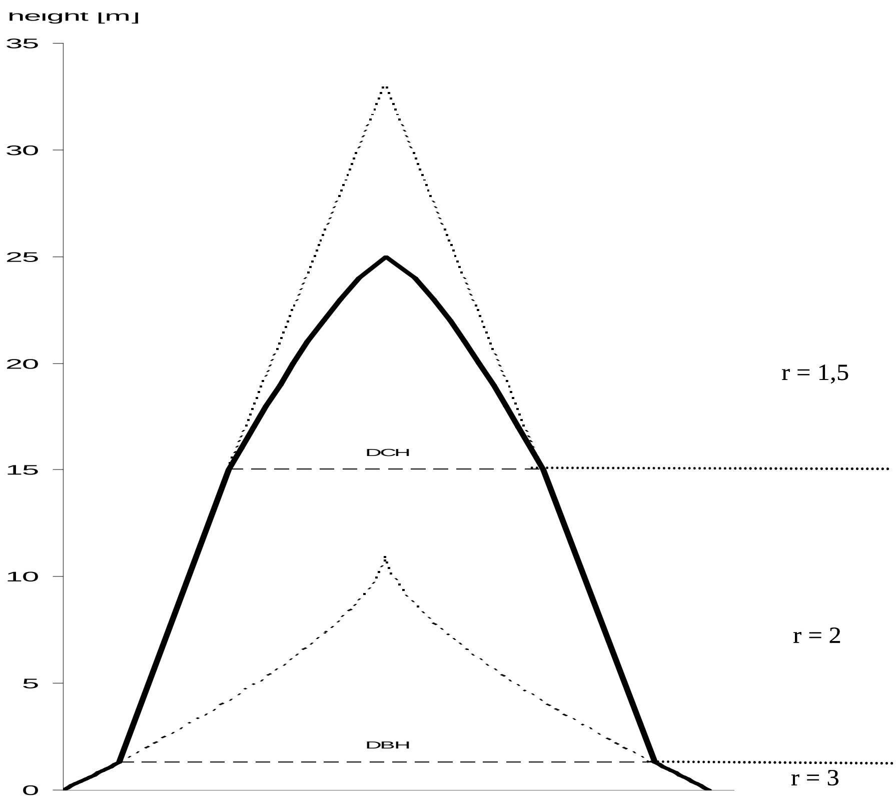

Figure 2: Model of the used taper curves for coniferous species, including the form factors (r) for each conoid or rather stump. The dotted lines represent the further gradient of the two cutted conoids.

Example: The taper volume of our sample tree located in a stand with an altitude of 400 m, social rank of 1 is calculated:

1. Diameter at the crown attempt

$$DCR_{[m]} = 0{,}101044 + 0{,}489653 \cdot 0{,}28 + 0{,}007389 \cdot 26{,}7 - 0{,}010630 \cdot 13{,}7 - 0{,}001225 \cdot \frac{26{,}7}{0{,}28} + 0{,}002045 \cdot \frac{13{,}7}{0{,}28} - 0{,}164197 \cdot \frac{13{,}7}{26{,}7} - 0{,}000233 \cdot \frac{400}{100} - 0{,}001814 \cdot 0 - 0{,}002668 \cdot 0 = \underline{0{,}168}\, m$$

2. Diameter of the stump

$$DST_{[m]} = 0{,}01470 + 1{,}26441 \cdot 0{,}28 + 0{,}07796 \cdot 0{,}168 - 0{,}18760 \cdot 0{,}28 \cdot 0{,}168 + 0{,}00152 \cdot 13{,}7 - 0{,}00024 \cdot \frac{13{,}7}{0{,}28} - 0{,}00174 \cdot \frac{400}{100} = \underline{0{,}375}\, m$$

3. Volume of the three conoids or rather stumps:

$$V_{[m^3]} = \frac{\Pi}{4} \cdot \left(\left(\frac{0{,}375^2 + \sqrt[3]{0{,}375^4 \cdot 0{,}28^2} + \sqrt[3]{0{,}375^2 \cdot 0{,}28^4} + 0{,}28^2}{3+1} \right) \cdot (1{,}3 - 25 \cdot 0{,}00726) + \left(\frac{0{,}28^2 + 0{,}28 \cdot 0{,}168 + 0{,}168^2}{2+1} \right) \cdot 13{,}7 \right) + 10 \cdot \frac{0{,}168^2 \cdot \Pi}{4} \cdot \frac{1}{2{,}5} = \underline{0{,}735}\, m^3$$

The mean stump-percentage of the total tree height for Norway spruce (Picea abies) in this equation is 0.728 %.

2.4 Assortment

As the trade of merchantable saw wood in Austria is done using the rounded middle diameter without bark of each log, this diameter was estimated in dependence if the searched diameter was located beneath (Ba%benCA) [5] or upon (Ba%upCA) [6] the crown attempt:

$$Ba\%benCA = a_0 + a_1 \cdot DBH_{[m]} + a_2 \cdot (H_{[m]} - 1{,}3) + a_3 \cdot \frac{AL_{[m]}}{100} + a_4 \cdot CH\% + a_5 \cdot (CH_{[m]} - 1{,}3) + a_6 \cdot (H_{[m]} - 1{,}3) \cdot DBH_{[m]} + a_7 \cdot (CH_{[m]} - 1{,}3) \cdot DBH_{[m]} + a_8 \cdot SR2 + a_9 \cdot SR34 \quad (5)$$

$$Ba\%upCA = a_0 + a_1 \cdot Ba\%benCA + a_2 \cdot CH\% + a_3 \cdot DBH_{[m]} + a_4 \cdot \frac{AL_{[m]}}{100} + a_5 \cdot (CH_m - 1{,}3) + a_6 \cdot DBH_{[m]} \cdot Ba\%benCA \quad (6)$$

Example: If the middle diameter in bark for a certain log is 20 cm and located beneath the crown attempt the diameter without bark is calculated with equation [5]:

$$Ba\%benCA = 0{,}09105 - 0{,}0991 \cdot 0{,}28 - 0{,}000659 \cdot 23{,}7 + 0{,}000864 \cdot \frac{400}{100} + 0{,}0 \cdot \frac{13{,}7}{23{,}7} - 0{,}000172 \cdot 13{,}7 + 0{,}001454 \cdot 23{,}7 \cdot 0{,}28 + 0{,}0 \cdot 13{,}7 \cdot 0{,}28 + 0{,}002059 \cdot 0 + 0{,}005043 \cdot 0 = \underline{0{,}0903} = \underline{9{,}03\%}$$

If the searched diameter is located upon or at the crown attempt, then equation [6] is used:

$$Ba\%upCA = 0{,}0034 + 0{,}08191 \cdot 0{,}0903 + 0{,}0254 \cdot \frac{13{,}7}{23{,}7} + 0{,}04 \cdot DBH_{[m]} + 0{,}0 \cdot \frac{400}{100} + 0{,}0 \cdot 13{,}7 + 0{,}0 \cdot 0{,}28 \cdot 0{,}0903 = \underline{0{,}1032} = \underline{10{,}32\%}$$

Translation into merchantable logs (Figure 3) was done with the same but simplified algorithm from Eckmüllner et al. (2007). Each tree of a dataset is split into 4.06 meter segments if it has minimum diameter without bark for saw wood log, if the minima in length and diameter are not given it is sorted as industrial wood in segments up from two to six meters length.

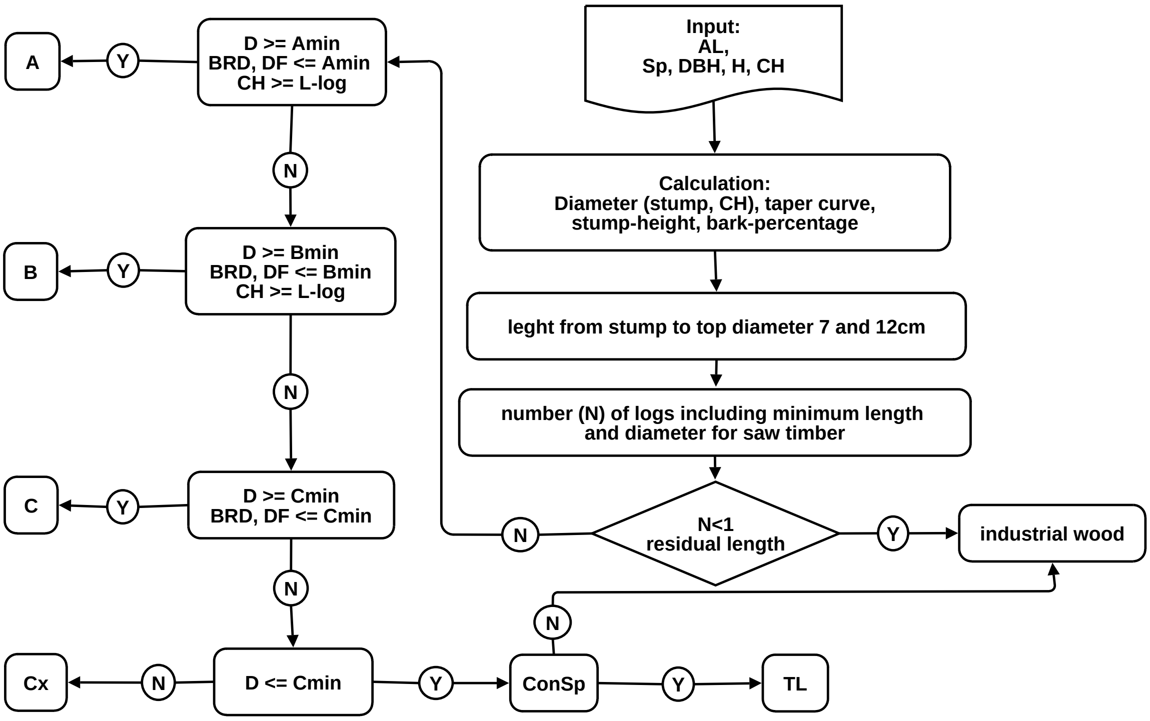

Figure 3: Flowchart of the assortments algorithm, whereas the input variables are altitude (AL), species (Sp), diameter in breast height (DBH), height (H) and crown attempt height (CH). Quality relevant criteria are middle diameter of the stump (D), maximum branch diameter at the crown attempt (BRD) and diameter fall (DF) for each log. The log qualities from well to poor are A, B, C, Cx and TL (thin log).

2.5 Quality prediction

For each tree its representing mean quality of merchantable log volume (MLV) was calculated by following equation [7] which provides a quality-digit, in this case set as medium:

$$MLV_{[m^3/m^3]} = a_0 + a_1 \cdot DBH_{[m]} + a_2 \cdot \sqrt{DBH_{[m]}} + a_3 \cdot \ln(DBH_{[m]}) + a_4 \cdot CRA + a_5 \cdot \frac{H_{[m]}}{DBH_{[m]}} + a_6 \cdot H_{[m]} + a_7 \cdot CH_{[m]} \quad (7)$$

This function was developed by the assortment of 4067 generated Norway spruces including a dbh distribution from 10 to 60 centimetres. The goal in present study was to find out witch tree(s) represents best the quality distribution of the total stand, so that the out coming volume can be multiplied with the total number of trees of the stand.The calculated quality digit represents the log in solid cubic meter of solid wood of the diameter class from 25 to 30 cm divided by the volume of the living tree.

Example: The merchantable log volume (medium quality) of our sample tree is therefore calculated following:

$$MLV_{[m^3/m^3]} = -15{,}6147 - 16{,}3852 \cdot 0{,}28 + 31{,}2163 \cdot \sqrt{0{,}28} - 3{,}27868 \cdot \ln(0{,}28) + 0{,}0 \cdot \frac{(25-15)}{25} * 100 - 0{,}001608 \cdot \frac{25}{0{,}28} + 0{,}009394 \cdot 25 + 0{,}000875 \cdot 15 = \underline{0{,}594}$$

2.6 Samples

For calculation of the estimations precision of the biomass compartments angle count samples and plots with fixed radius using different basal area factors (4, 5 and 12) and radii (8, 5.1 and 4.2 m) were done. The sampled trees of the different plots are given in Figure 4.

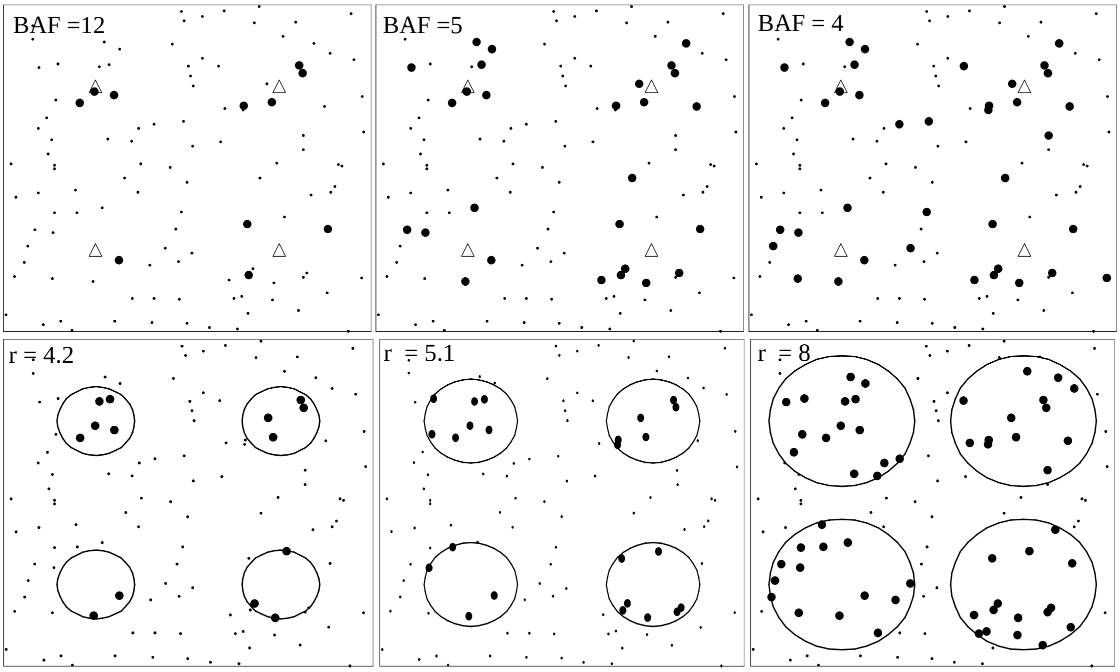

Figure 4: The sampled trees of the stand market as fat dots for the different basal area factors (BAF), for the angle count samples whereas there canter is a triangle, and radii (r) for the plots with fixed radius, the resulting circle is drawn in.

3. Results

It was our main interest which sample method had the higher precision in relation to the measured stems. Therefore we compared angle count samples and plots with fixed radii having exactly the same number of trees. As we expected the angle count samples, because their selection probability is proportional to size, were more precise in all compared sample sizes in total volume as well as in the single biomass compartments (Table 1).

The time needed for the four samples with basal area factor 4 was 81 minutes for the 37 trees. If there is only one tree per plot in the sample the measurement time would be only 11 percent, for three trees 27 percent of the total time.

Table 1: Comparison coefficients of variation for the two sample methods, including the same number of trees (N) per plot, calculated per hectare for taper volume (V), dry needle and branch mass (Dnm, dbm) and the merchantable log volume excluding bark in regard to quality (QmV)

			N	*V* [m³]	*dbm* [kg]	*dnm* [kg]	*QmV* [m³]
		4	37	2.8%	3.3%	2.2%	2.5%
angle count sample	***BAF=***	5	27	7.3%	12.6%	9.9%	8.0%
		12	11	23.2%	23.0%	22.2%	22.1%
		6.51	37	8.7%	13.5%	8.6%	10.4%
plot with fixed radius	***r** [m] =*	5.50	27	7.7%	8.4%	7.6%	9.5%
		3.90	11	41.6%	39.3%	38.4%	43.0%

Finally we plotted the time for measurement against the precision (coefficient of variation) of the predicted biomass compartments. As to see in Figure 5 the angle count sample is predominant in all compartments in relation to the plot with fixed radius.

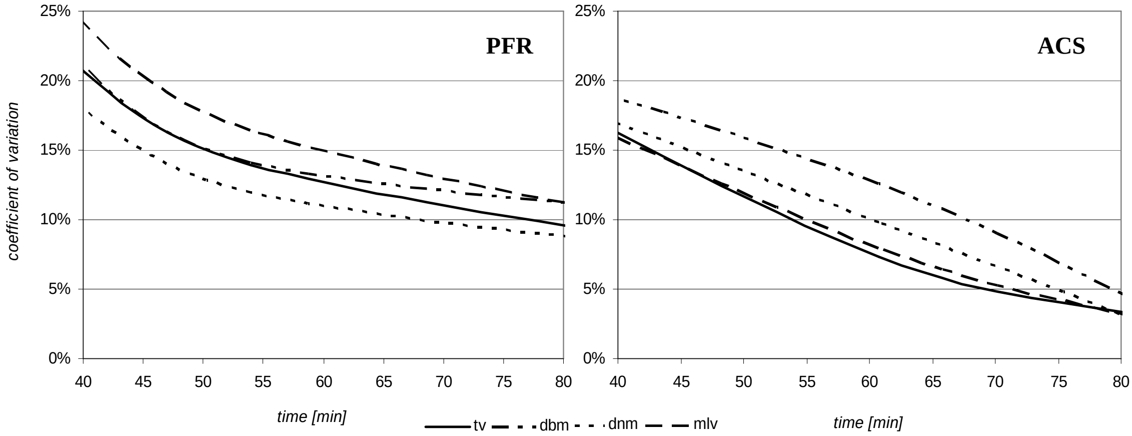

Figure 5: Coefficients of variation for precision of the taper volume (tv), dry needle mass(dnm) and dry branch mass (dbm) and merchantable log volume (mlv) plotted against the time for measuring of the sample, on the left for a plot with fixed radius (PFR) and the right for an angle count sample (ACS).

The merchantable log volume was estimated first by stem of mean basal area and secondly by the median stem of the basal area distribution, whereas best fit was given by second one. For approximations with higher precision additionally stems of the 10th and 90th percentile were taken into the calculations and their out coming compartments weighted. Best fits were found for angle count samples, but for plots with fixed radii the compartments estimation was still worse, independently by the combinations of selected stems and their weighting (Tabel 2).

The correction factor “Y” is the relation between real versus estimated basal area (stem of median basal area). In our case it was possible to calculate it for both sample methods, because all stems of the stand were known. But in inventories this is only practicable for angle count samples, because the basal area is known and unbiased from measurement.

Table 2: The different representing stems (mean (mn) and median (md) basal area, 10th (10p) and 90th (90p) percentile of basal area distribution) including (Y) or not the correction factor (cf) and used weighting on the left and the deviation from the real magnitudes in percent for the biomass compartments (dry needle (dnm) and branch (dbm), merchantable log volume (mlv)) on the right.

The compartments representing stem(s) and its (their) weighting					sample method					
					ACS			PFR		
mn	md	90p	10p	cf	dnm	dbm	mlv	dnm	dbm	mlv
1.0					-21%	-9%	-11%	-22%	-10%	-12%
	1.0				-2%	-2%	8%	45%	44%	60%
	0.8	0.2			-1%	-2%	12%	55%	52%	75%
	0.7	0.2	0.1		0%	2%	2%	42%	40%	59%
	0.8	0.2		Y	-3%	-4%	10%	15%	13%	32%
	0.7	0.2	0.1	Y	-2%	0%	0%	7%	6%	21%

4. Conclusions

As for economic decisions the prediction of contribution margin of thinning is of main interest for forest companies, this study shows clearly that angle count samples, in relation to plots with fixed radii, estimate the all biomass compartments more precisely for a given time of measurement. The assortments output provides information about quantity and quality of harvested wood and therefore a much better prediction-level of the contribution margin. Furthermore the used magnitudes (variables) for the calculations are easily and quickly measurable.

It is also shown that the often used stem of mean basal area for representation of merchantable volume is not the best estimator; much better prediction is given by the stem of median basal area or in combination with it the 10^{th} and 90^{th} percentile of the basal area distribution, by using different weightings.

From ecologic point of view estimation about the possible nutriments loss for soils through whole tree system harvesting can be done.

5. References

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