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DETERMINATION OF TRANSITION RATES FOR THE ENERGY BIOMASS CALCULATIONS IN SPRUCE STANDS IN LATVIA

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Abstract: *The Baltic Sea region with its forest resources has a big potential in order to achieve EU goals in the use of biomass in heating and energy production. Insufficient knowledge about the potential involved in energy production holds back a sustainable development of bio-energy. There is no calculation methodology worked out up to now for energy production for determination of the available biomass volume. There are no precise data at our disposal about how much wood tree branches and roots contain. According to foreign literature, the mass of branches and roots can reach more than 40% of the total amount of wood.*

The aim of research is to estimate the amount of biomass accumulated and available in Latvia's fir stands, as well as the management possibilities of it. For this aim, it is necessary to calculate the fir stand timber volume, the biomass transition rates and the biomasses of crowns, roots and stubs. There were collected sample-tree data during the field work season. The crown biomass of every sample-tree was dividend in separate fractions and then in green condition weighed.

The crown fractions: 1) large branches (the thin end in average d(l) > 6.0 cm); 2) medium branches 3.0 ≤ d(m) ≤ 6.0 cm; 3) thin branches d(t) < 3.0 cm; 4) needles. The root biomass was dividend in three fractions: 1) large roots (the thin end in average d(l) > 6.0 cm); 2) medium roots with 3.0 ≤ d(m) ≤ 6.0 cm; 3) thin roots with d(t) < 3.0 cm.

After unearthing, the parts of stubs and the roots of every sample-tree were washed in a plastic bath of appropriate dimensions and dried after that. All the fractions were weighed after the processing. The biomass transition rate is a proportion between the biomass of the relevant part of the sample-tree, and the stem volume. When calculating, the transition rates of the crown, stub and root biomass were determined, namely c_C, c_S and c_R, as well as Σc_i. It is easy to perform calculations by means of these transition rates for determination of non-stub fraction biomass amounts in fir stands.

1. Introduction

The Baltic Sea region with its forest resources has a big potential in order to achieve EU goals in the use of biomass in heating and energy production. Insufficient knowledge about the potential involved in energy production holds back a sustainable development of bio-energy. There is no calculation methodology worked out up to now for energy production for determination of the available biomass volume.

There are no precise data at our disposal about how much wood tree the branches and roots contain. According to foreign literature, the mass of branches and roots can reach more than 40% of the total amount of wood.

By the term wood biomass, the mass of tree group of a stand per one square unit is meant (Helms, 1998). For the sake of data comparability in forest ecology it is commonly expressed also as $t \cdot ha^{-1}$. Biomass structure is formed by its separation in stand components (belonging of trees to certain hybrid species, stages) and fractions (stems, branches, needles (leaves), stumps, roots), but in the groups of stands - also by the site quality index and age classes, thickness and other groups of stands. A demand for stem fraction evaluation in volume units has been existing through centuries, usually it is $m^3 \cdot ha^{-1}$. Therefore, many convenient and precise methods of determining the volume of separate tree stems and the stand total volume of tree groups have been developed in forest inventory (Philip, 1994). Then, knowing the wood density values offered by wood science (Уголев, 2001), it is possible to re-calculate the volume into mass units. The situation is radically different in determination of the non-stem fraction biomass, where this methodological solution is not suitable due to the non-fraction volume calculation difficulties.

It is generally known that forests are the main producer of wood among the land ecosystems. The non-stem fraction biomass contains a considerable part of tree stand wood that can reach 40% and more. However, the methodology of determining this part of biomass has been worked out incompletely by now. The relatively small use of the non-stem biomass up to now has not facilitated obtaining of more precise data on this part of tree stand. It is why the information being at the disposal of many countries including Latvia, relating the volume of this forest resource, could be considered as fragmentary. The aim of this work is to fill up the gap by completing the following tasks:

- evaluation of the fir stand total volume;
- determination of the transition rate of non-stem fraction biomass;
- calculation of the biomass of stems, branches, needles, stumps, roots and the total fir stand biomass.

2. Methodology and material

Stem fraction biomass is expressed by formula (1)

$$M_{st} = \varphi \cdot V \tag{1}$$

where M_{st}, φ and V are the stem fraction biomass in t, the wood density rate in $t \cdot m^{-3}$ and the total volume in m^3.

Fir stand total volume of the state level is taken from the forest inventory data of 01.01.05 available at State Forest Service of Ministry of Agriculture (Боровиков and Уголев, 1989). Wood density depends on moisture in wood. In our case, the density of freshly cut wood is aplicable, for fir which is $\varphi = 0.794$, $t \cdot m^{-3}$ (Уголев, 2001).

For the calculation of non-stem fraction biomass, the transition rates c_i have been used. The transition rate is i-proportion of that fraction biomass M_i and the total volume V, which is expressed by $t \cdot m^{-3}$. Therefore, multiplication of the rate c_i with stem volume or the total stand volume is biomass of the relevant tree or part of the stand, expressed in mass units. Values of c_i for Latvia's conditions have been unknown so far. Therefore, we have determined them empirically by the sample tree method, separating biomass in the fractions of branches, needles, stumps and roots. Volume of the sample tree stems v has been calculated by formula (2) (Forest Sector in Latvia, 2005):

$$v = \psi \cdot h^{\alpha} d^{\beta \lg h + \varphi} \tag{2}$$

Where v, d and h are the stem volume in m^3, the breast-height diameter in cm and the height in m. Ψ, α, β and φ are the stem capacity rates for fir: $\Psi = 2.3106 \cdot 10^{-4}$; $\alpha = 0.78193$; $\beta = 0.34175$; $\varphi = 1.18811$.

Branch fraction includes also the green and the dry branches. After sorting, all the branches were packed and weighed by using the movable hanging scele KERN HCB 100K200 with weighing possibility range from 0.2 up to 100.0 kg. The green branches were weighed together with needles. The diference between this total mass and the needles' mass is the green branches' mass.

Needle mass was determined indirectly by using the sample branch method. 5 sample branches were cut from each sample tree, which have been weighed before, and for the purpose of the control – also after de-needling. Needles of the sample branches were weighed by using the scale KERN MH 5K5 with digit value 5 g. When selecting the sample branches, the condition strictly observed was the branches should have been cut from the upside of the cut-down tree, on the line that was parallel to the tree growing line. Attachment places of the sample branches: attachment place of the first branch is in the distance of 0.2l from the beginning of the first green branch (l = crown length in m); place of the second branch – in the distance of 0.2l from the top bud; place of the third branch – exactly in the middle of the crown; place of the forth branch – midpoint between the first and the third branch; place of the fifth branch - midpoint between the third and the second branch. Needle mass of the whole crown was calculated proportionally to the total mass of green branches by using the total mass of non-needled sample trees and the needles masses of these branches.

Unearthing of roots is technically the most complicated stage of research execution. It demands long and careful work in order to minimize amount of roots left in soil. Fir has a superficial and large roots system which extends the crown projection boundaries far away. A complete unearthing of roots system is not efficient due to the considerable time and labour consuming. A high probability is that a small part of the minor roots would be left in soil. Roots of the sample trees were unearthed by tracking them individually.

Stem consists of the superficial part and the part in earth. By the last one, the monolithic part, undifferentiated in separate roots, is meant. After unearthing, the part of stem and the roots previously being in earth of every sample tree were carefully washed in a plastic bath of appropriate size, then dried and weighed.

For mathematical processing of the empiric material the graphical and analytical methods were used (State Forest Service Riga, 2005) by taking opportunities of the computer program MS Excel (Liepa, 1996).

The material of sample trees have been collected in spruce stands (Oxalidosa, Myrtyllosa-Polytrichosa and Myrtyllosa mel) thus representing the most common fir growing condition types. It should be emphasized that no diferences have been noticed during the whole season of field works.

The total number of sample trees – 21, so in different growing conditions – 7. This number results from a conclusion that at least 7 corelogram points are needed for a quantitative description of biomass grouping specifics of various size trees of one stand in a form of regression equation, and these points are more or less evenly distributed in the definition area empirically represented by the argument.

Location area of sample trees – regions of Dobele, Jelgava and Bauska and the middle part of Latvia. Site quality index of stands - I^a, I and II, thickness – 0.6 – 0.8, age – middle age, maturity stands and adult tree stands, and hybrid and layering – various. Trees of the first and the second layer as well as trees of different G. Craft classes are represented by the sample trees. The foreign authors' research and our previous researches in Latvia show that the total tree biomass and its fractional separation is determined mainly by the tree breast-height diameter. So the selection of sample trees in each stand has been carried out in the interval $d_{min} \leq d_j \leq d_{max}$, trying to represent the I, II and III G. Craft classes (utmost in proportions 2:3:2). The conclusion on dependence of the tree biomass volume on the breast-height diameter has been used also in order to check the quality of field works (Figure 1).

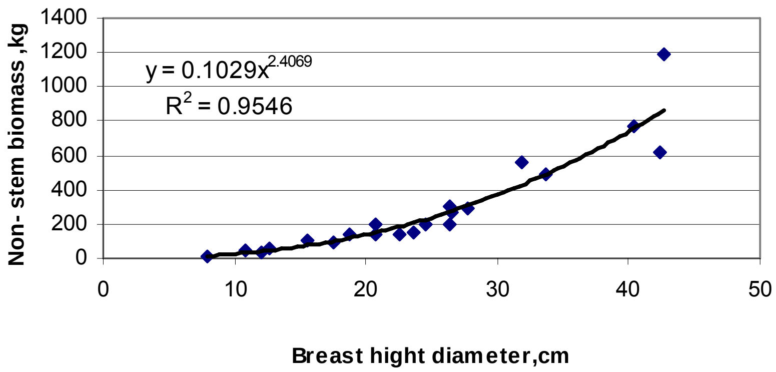

Figure 1: The quality control for non-stem biomass data collection.

As the empiric points excluding two of them, are grouping densily along the adjustment curve, it may be considered that the data of sample trees have been collected strictly observing the methodological rules. Separation of the chosen sample trees and the evaluation data are shown in Table 1:

Table 1: The characteristic of sample trees

No.	d, cm	h. m	Branches without needles, kg			Needles, kg	Stumps, kg	Roots, kg
			total	green	dry			
1	20.7	18.6	52.1	50.1	2.0	63.7	22.0	61.6
2	26.4	27.5	62.9	62.4	0.5	94.4	48.2	96.4
3	31.8	27.7	51.4	34.4	17.0	161.9	91.6	255.7
4	40.4	25.1	221.5	213.1	8.4	84.5	91.4	371.8
5	23.6	20.6	35.7	29.7	6.0	39.4	33.6	48.1
6	20.7	16.1	17.5	11.1	6.4	49.1	24.2	53.4
7	26.4	21.8	50.5	38.9	11.6	46.5	29.0	72.8
8	26.5	19.9	87.0	82.6	4.4	78.7	30.0	73.0
9	12.1	11.1	8.7	8.1	0.6	8.0	4.2	11.2
10	42.4	31.3	179.6	150.6	29.0	56.8	117.4	269.6
11	27.7	20.1	94.8	87.4	7.4	70.4	35.4	87.6
12	12.7	13.9	14.3	13.0	1.3	15.9	8.0	24.2
13	18.8	13.0	35.3	32.5	2.8	30.4	17.2	59.4
14	15.6	14.7	23.8	21.8	2.0	30.9	14.0	38.5
15	33.7	22.2	240.2	220.6	19.6	65.9	59.8	129.6
16	42.7	24.7	438.2	424.7	13.5	261.4	117.8	378.4
17	24.5	23.5	59.5	55.9	3.6	52.6	29.2	58.0
18	17.5	17.5	22.5	19.1	3.4	14.0	10.6	42.0
19	8.0	19.2	4.3	3.1	1.2	1.7	1.6	3.6
20	22.6	17.8	43.1	39.0	4.1	33.9	39.5	28.0
21	10.8	9.6	4.7	4.5	0.2	25.7	3.5	9.2

It follows out of the Table that the breast-height diameter of the sample trees is represented in the interval of d_{min} = 8.0 cm and d_{max}= 42.7 cm, height – h_{min} = 9. 6 m and h_{max} = 31.3 m.

3. Results and discussion

The transition rate values of branches, needles, stumps, roots (c_Z, c_{Sk}, C_C, C_S) and the total non-stem biomass (ΣC_i) are shown in Table 2.

Table 2: Biomass expansion factors

No.	v, m^3	Factors				
		c_Z	c_{Sk}	c_C	c_S	Σc_i
1	0.30964	0.16826	0.20572	0.07105	0.19894	0.64398
2	0.75419	0.08340	0.12517	0.06391	0.12782	0.40030
3	1.04073	0.04939	0.15556	0.08801	0.24569	0.53866
4	1.36497	0.16227	0.06191	0.06696	0.27239	0.56353
5	0.43522	0.08203	0.09053	0.07720	0.11052	0.36028
6	0.25921	0.06751	0.18942	0.09336	0.20601	0.55631
7	0.56181	0.08989	0.08277	0.05162	0.12958	0.35385
8	0.50358	0.17276	0.15628	0.05957	0.14496	0.53358
9	0.07151	0.12166	0.11187	0.05873	0.15662	0.44888
10	2.01177	0.09035	0.02857	0.04682	0.13401	0.31361
11	0.54827	0.17291	0.12840	0.06457	0.15978	0.52566
12	0.10002	0.14297	0.15896	0.07998	0.24195	0.62386
13	0.17126	0.20612	0.17751	0.10043	0.34685	0.83091
14	0.14792	0.16090	0.20890	0.09465	0.26028	0.72472
15	0.85972	0.27939	0.07665	0.06956	0.15075	0.57635
16	1.44796	0.29910	0.17842	0.08136	0.26133	0.81622
17	0.54601	0.10897	0.09634	0.05348	0.10623	0.36501
18	0.21908	0.10270	0.06390	0.04838	0.19171	0.40669
19	0.06858	0.06270	0.02479	0.02333	0.05249	0.16331
20	0.33802	0.12751	0.10029	0.11686	0.08283	0.42748
21	0.05088	0.09238	0.50514	0.06879	0.18083	0.84714
$\bar{c}_i$		**0.13539**	**0.13939**	**0.07041**	**0.17912**	**0.52478**

The transition rates sum ΣC_i of the sample trees biomass fraction and the breast-height diameter (Figure 2) are mutually independent features (this refers also to the rates of particular fractions). Dispersion of the empiric points in corelogram is relatively wide. It is explained by the dendrometric, phytocenotic and edaphic variety characteristic to the sample group of sample trees which was chosen on purpose in order to represent Latvia's fir stands as much appropriate as possible. A conclusion following out of the Fig 2 allows using the mean values of transition rates in the non-stem biomass calculation of stands and its groups, which considerably simplifies evaluation of the biomass of stands, because only one initial parameter – total volume of the relevant stand or the group of stands - is needed to determine the total biomass or the biomass of its particular fractions.

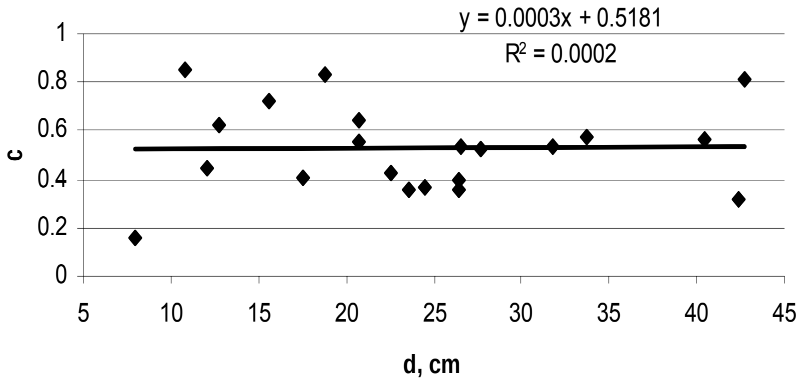

Figure 2: Correlation between an expansion factors sum and stem diameter

Biomass calculation of fir stands in Latvia according to site quality index classes is shown in Table 3.

Table 3: The volume and biomass of spruce forests in Latvia

Site quality index.	Volume m^3	*Biomass*, $mlj.t$					
		stems	branches	needles	stumps	roots	total
I[a]	8562380	6.799	1.159	1.194	0.603	1.534	11.289
I	43219922	34.317	5.852	6.024	3.043	7.742	56.978
II	29359041	23.311	3.975	4.092	2.067	5.259	38.704
III	6274406	4.982	0.849	0.875	0.442	1.124	8.272
IV	1309380	1.040	0.177	0.183	0.092	0.235	1.727
V	87333	0.069	0.012	0.012	0.006	0.016	0.115
V[a]	7835	0.006	0.001	0.001	0.001	0.001	0.010
Total	88820297	70.524	12.025	12.381	6.254	15.911	117.095
%		60.2	10.3	10.6	5.3	13.6	100.0

The total biomass volume in Latvia is 117.095 million t, from which 70.524 million t or 60.2% is the stem fraction part, and 46.571 million t or 39.8% - non-stem fraction part. As the total area of fir stands in Latvia is 515322.2 ha (Уголев, 2001), so 227,2 t of biomass per 1 ha in average have been accumulated. The branches contain 10.3%, needles -10.6%, stems – 5.3% and roots 13.6% of the total biomass volume (Table 3), which is a potential reserve of the economic use of forest resources.

Currently, more easily accessible biomass parts – branches and needles, which make 20.9%, - are being involved in producing woodchip in Latvia. The performed research allows planning the biomass volume potential for energy obtaining. So it is possible to determine the potentially usable biomass volume for obtaining of energy by planning of logging and determining the cutable wood amount in a spruce stand.

4. Conclusions

The transition rate c_i values for spruce non-stem biomass fraction (branches, needles, stumps, roots) and the volume correlation between the relevant fraction biomass and stem volume (mean value ± standard error) have been calculated: branches c_Z = 0.13539±0.01453; needles c_{Sk} = 0.13939±0.02185; stems c_C = 0.07095±0.00451; roots c_S = 0.17905±0.01577; non-stem fractions altogether ΣC_i = 0.52478±0.03945.

The total biomass volume of Latvia's fir stands are 117.095 million t, from which 70.524 million t or 60.2% is the stem fraction part, and 46.571 million t or 39.8% - non-stem fraction part. The branches contain 10.3%, needles -10.6%, stumps – 5.3% and roots 13.6% of the total biomass volume.

The performed research allows planning the biomass volume potential for obtaining of energy.

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