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Forest biomass and sequestered carbon estimation according to main tree components on the forest stand scale

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Abstract

Background and Purpose: *The estimation of forest woody biomass has a significant role in forestry due to several reasons. One of the reasons is that good woody biomass estimation is important for the planning of forest woody assortments production, for main commercial roundwood assortment and for assortments like »waste wood« or »recovered wood« as a potential for electricity (heat) generation (firewood, wood bricks, wood pellets etc.). Economic and political meaning of woody biomass estimation is important to know forest biomass resources in the country and present these facts to international institutions or in treaties as needed. The estimation is also important for strategic planning of the use of renewable energy sources from woody biomass. On the other hand, estimation of the carbon content in forest woody biomass has importance in global climate mitigation policy and processes (Kyoto- and post-Kyoto period). The purpose of this paper is to present methodology applied for estimation of forest woody biomass and its carbon content according to main tree components, on the forest stand scale.*

Material and Methods: *As research area, two representative Croatian forest communities/stands were selected. The one represents flooded lowland pedunculate oak forest of Pokupski Basin, and the other represents mountain fir-beech forest of the Gorski Kotar region. Emphasis in the paper is on the methodology which was developed for the purpose of research. The methods applied in this study consist of: a) dendrometrical measurements on selected forest stands (research sites), b) sampling of main tree components and sample analyses in laboratory, and c) calculation of forest woody biomass and its carbon content according to main tree components.*

Results: *General result of the laboratory analyses of the samples of main tree componets is that the carbon content in biomass was around 50,0% of the dry matter of a component. In line with volume allocation of main tree components are the biomass of tree components and the content of carbon sequestered in these components. Stem had the largest share in total tree biomass while foliage or needle biomass had the smallest share. The shares of main tree components in total biomass of the tree depend on morphology each of tree species.*

Conclusion: *This research was a pilot and pioneering research of forest biomass in Croatian forestry, and it should be continued to acquire better knowledge of relations in forest woody biomass in main forest communities in Croatia.*

INTRODUCTION

Forest woody biomass and its carbon content estimation are significant for several reasons. From the forestry point of view, estimation of forest woody biomass is important for planning its exploitation (production of forest wood assortments). Forest biomass estimation for the scales larger than stand (from management units to all state forests scale) has a strategic and political meaning which is important for knowing the stock of these natural resources, for e.g., the purpose of mandatory annual reports to certain international institutions and treaties (Kyoto Protocol, Intergovernmental Panel on Climate Change (IPCC), etc.), or for strategic planning of the use of renewable energy sources from woody biomass. In Croatia, the forest woody biomass estimation is mainly carried out for scales larger than stand, in a way that aboveground tree biomass is calculated by multiplying merchantable wood volume (from forest inventory) with adequate conversion factor, the so called Biomass Expansion Factor or BEF *(1)*. Most countries which deliver an annual report about changes in stock of carbon sequestered in forest biomass to United Nations Framework Convention of Climate Change (UNFCCC), use BEF values for the purpose of calculation from '*Good Practice Guidance on Land use, Land-use change and forestry*' (GPG LULUCF) manual issued by IPCC *(2)*.

Forest woody biomass estimation for the tree or on the stand scale has so far been a research topic for only a few Croatian researchers, while in western countries such studies have been carried out for already a couple of decades. Vuletić *et al.* *(3)* wrote, among others, about biomass estimation as a part of estimation the total economic value of Croatian forests. Lukić and Kružić *(4)* presented research results of beech (*Fagus sylvatica* L.) biomass for the Pannonian region of Croatia.

A paper by Topić *(5)* is important because it presents localized mathematical models for biomass estimation of Pubescent oak (*Quercus pubescens* Willd.), Evergreen oak (*Quercus ilex* L.) and Hungarian oak (*Quercus frainetto* Ten.) in the Mediterranean region of Croatia. Krpan *et al.* *(6)* conducted the research about biomass of Aleppo pine (*Pinus halepensis* Mill.) that grows in the coastal part of Croatia.

Kajba *et al.* *(7)* carried out a research of applicability of the tree genus *Alnus* L. for biomass production, and biomass production of stemy willows during short rotations *(8)*. The same author later carried out a research of biomass production of white willow (*Salix alba* L.) clones *(9)*.

Estimation of carbon content in forest woody biomass is important with regard to Greenhouse effect mitigation, and regarding mandatory reporting about carbon dioxide (CO_2) emissions and removals in forestry sector for countries which signed the Kyoto treaty. Herbs, primarily wooden perennials that in their growth process use photosynthesis absorb CO_2 from the air and in such a manner sequestrate carbon in biomass, decreasing the concentration of this quantitatively most significant greenhouse gas (GHG) in the air. For this reason, forest stands are called Carbon pools or Carbon sinks. The carbon sequestration function of forests has been well researched during the last 20 years, and forest ecosystems, depending on their capacity, have been found to be the biggest carbon sinks among all other terrestrial ecosystems.

A couple of papers regarding carbon sequestration in forest biomass have appeared in Croatian scientific literature recently. Marjanović *et al*. *(10)* gave an overview of carbon cycling dynamics, CO_2 sinking in the stand and emission from forest stand at a daily, weekly and seasonal basis for young pedunculate oak (*Quercus robur* L.) stand in Pokupski Basin. Balenović *et al*. *(11)* presented initial quantitative indicators of soil respiration dynamics for the 2008 spring-summer period. In the paper from Paladinić *et al*. *(12)*, results are presented about estimation of the quantity of carbon sequestered in tree biomass of young lowland pedunculate oak forest according to two different climate scenarios (with and without extreme drought period).

The main goal of this research is to present custom methodology of estimanting forest biomass and the quantity of sequestered carbon according to main tree components of two sylviculturally different forest stands in Croatia, in order relate this methodology to practical issues in forestry sector.

MATERIALS AND METHODS

Major part of the research was carried out in 2008 as a component of a comprehensive research for the purpose preparing E. Paladinić dissertation »Estimation of ability of forest stands to sequestrate carbon in the context of Kyoto protocol implementation« *(13)*.

For the purpose of the research, two forest stands were chosen, each representing one of the two basic sylvicultural systems in Croatia (even-aged and uneven-aged) and typical forest community of a wider geographical area in which it grows. As representatives, pedunculate oak forests and fir-beech forests were chosen. In Croatia, there are 215 683 ha of pedunculate oak forest, which makes 8.0% of all forests and forest land area in the country. Fir-beech forests cover 196 658 ha of Croatia, which is 7.3% of all forests and forest land area in the country.

Criteria for selection of research site were first of all existence of permanent sample plots in selected forest stands and measurements carried out on sample plots in last few years. The first research site was located in flooded lowland pedunculate oak forest (*Genisto elatae – Quercetum roboris* Ht. 1938) of Pokupski Basin and belongs to forest management unit 'Jastrebarski lugovi'. Because it is inside forest compartment No 37, working name for the site is 'Jastrebarski lugovi, f.c. 37'. The center of research site was at 45° 37' 16'' latitude north and 15° 41' 24'' longitude east. The altitude ranged from about 109 to 112 m a.s.l. The mean annual temperature (during last 25 years) was 10.4 °C and annual rainfall about 734–1174 mm. In the year when measurements were carried out (2008), the oak stand was 38 years old. Main structural

TABLE 1

Main structural elements of the research site 'Jastrebarski lugovi, f.c. 37' in 2008.

Tree species	Mean tree diameter cm	Number of trees N ha^{-1}	Stem basal area m^2 ha^{-1}	Merchantable wood volume m^3 ha^{-1}	Wood volume ratio %
Pedunculate Oak	17.27	440.1	10.30	99.7	48.82
Hornbeam	11.93	526.2	5.88	45.4	22.22
Narrow-leaved Ash	13.15	220.1	2.99	22.0	10.78
Black Alder	14.29	264.1	4.24	32.8	16.05
Other Hardwoods	10.46	72.7	0.62	3.6	2.13
Total		1.523.2	24.03	203.5	100.00

elements of the stand/forest compartment are presented in Table 1. The stand is even-aged and managed on the principles of sustainable forest management, belonging to the 2nd yield class. By regular thinning carried out in 2007, 6.88% of pedunculate oak growing stock, 25.42% of narrow-leaved ash, 9.49% of hornbeam, 9.05% of black alder, and 1.1% of other hardwoods were removed from stand.

The other research site was in mountain fir-beech forest (*Abieti-Fagetum illyricum* Ht.) of the Gorski Kotar region and belongs to forest management unit 'Delnice', forest compartment No 60. Hence the working name for the site was 'Delnice, f.c. 60'. The center of research site was at 45° 23' 13'' latitude north and 14° 45' 45'' longitude east. The altitude ranged from about 690 to 720 m a.s.l. The mean annual temperature (during last ten years) was 8.1 °C and an annual rainfall about 1510–2332 mm. Main structural elements of the stand/forest compartment are presented in Table 2. The stand is uneven-aged and managed on the principles of sustainable forest management. Regular selective logging was carried out in 2001 when 21.27% of common beech growing stock, 10.27% of silver fir and 11.36% of other hardwoods were removed from the stand.

Methods applied in this research consisted of: a) dendrometrical measurements on selected forest stands (research sites), b) sampling of main tree components and sample analyses in laboratory, and c) calculation of forest woody biomass and its carbon content according to main tree components. All three methods, constituting one comprehensive methodology adapted for the achievement of research goal, were chosen because of possible practical usage in forestry and financially not too demanding (except laboratory analyses).

Dendrometrical measurement of research sites

Research site or stand measurements were carried out in order to calculate basic structural stand elements from collected field data, in units per hectare of area, which is a base for further biomass component calculation.

Measurements on the research site 'Jastrebarski lugovi, f.c. 37' were carried out on 26 permanent experimental plots in early spring 2008. Experimental plots were placed in rectangular web 100×100 m. The area of each plot had circular shape and in line with stand age occupied 0.0201 ha (radius 8.0 m). Field works were composed of permanent marking of trees on plots and detailed measurements of all trees on plot with the diameter at Brest-height (DBH) higher than 5 cm. DBH of trees were measured by callipers with millimetric accuracy in three directions (east-west, north-south, and direction according to plot center). Tree heights and stem heights were measured by ultrasound hypsometer Vertex III (Haglöf). Position of each tree in relation to plot center was recorded by measuring distance from centre and tree azimuth. In the second phase of measurement, dendrometric bands were installed on trees of selected plots *(14)*. On these bands, electronic movable scale was used to measure periodic (weekly) increments in the circumference with accuracy to a tenth of a millimeter, during

TABLE 2

Main structural elements of the research site 'Delnice, f.c. 60' – autumn 2001.

Tree species	Number of trees	Stem basal area	Growing stock divided in diameter classes				Growing stock ratio	Mean annual increment
			5–30 cm	31–50 cm	Above 51 cm	Total		
	N ha^{-1}	m^2 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}	%	m^3 ha^{-1}
Silver Fir	118	29.69	9.50	50.65	436.82	496.97	82.98	2.923
Common Beech	312	7.71	50.34	19.81	0.00	70.15	11.71	2.874
Mountain Maple	31	2.66	6.39	25.38	0.00	31.77	5.30	0.510
Total	461	40.06	66.23	95.83	436.82	598.88	100.00	6.307

vegetation period. From these data, annual volume stem increments per tree species were subsequently calculated.

Measurements on the research site 'Delnice, f.c. 60' were carried out on October 2001 on Croatian Forest Research Institute Jastrebarsko permanent experimental plot, size 100×100 m. The plot was measured according to methodology by Dubravac and Novotny *(15)*. The following values were measured on the plot: DBH > 5 cm, tree height, stem height for trees on subplot 60×60 m, and stem cores taken from a certain number of trees. Tree heights were measured using Blume-Leiss hypsometer with 0.5 m accuracy, and stem cores were taken by Pressler borer.

Sampling of tree components

Sampling of main tree components of different tree species was carried out for laboratory analyses, primarily to get an estimation of average carbon content in dry matter of these tree components. The obtained carbon content was used for comparing with generally accepted value used in methodology for calculation of GHG emissions from Land Use, Land Use Change and Forestry sector according to IPCC guidelines *(2)*.

From the aspect of this research, it is essential to collect the following material: discs from stem and branches (Figure 1), and foliage and needle samples. On the research site 'Jastrebarski lugovi, f.c. 37' the trees marked for thinning were selected for sampling procedure in a way that four the most represented tree species in growing stock were selected, each species with four of trees in three diameter classes (from beginning, middle and the end of diameter distribution of trees). In total, 16 trees were selected which were felled by forest workers. Several discs (2–3 cm thick) were collected from each tree (one from stem, 1.30 m high from the ground level, and a few from branches). Foliage samples were taken from the crowns of felled trees.

Figure 1. *Sampling of Silver Fir trees (wood discs) on research site Delnice, f.c. 60, April 2008.*

Tree component sampling on the research site 'Delnice, f.c. 60' was carried out in the same way as on the previous site. Stem, branch and needle samples were taken from felled silver fir (*Abies alba* L.), common beech (*Fagus sylvatica* L.) and mountain maple (*Acer pseudoplatanus* L.) trees in a way that one tree of each species was selected from the first (10 cm ≤ DBH≤50 cm) and from the second diameter class (31 cm ≤ DBH ≤50 cm), in total 6 trees.

After all the samples were collected, they were transported to laboratory of Croatian Forest Research Institute Jastrebarsko. Masses of fresh discs, foliage and needle samples were weighed. Also, fresh volume of wooden discs was determined by measuring several diameters and heights for each. After that, all samples were dried at 105 °C for 48 hours to get absolute dry condition (0% humidity) and afterwards were weighed *(16)*. Mass of absolutely dried stem and branch samples and fresh volume was used for calculating specific wood density, and the obtained values were compared with values from domestic literature *(17)*. In the next step, subsamples were taken from wooden discs (20–30 g of sawdust per sample) and from foliage/needle samples for analyzing the carbon content of dry matter by using standard method on CNS 2000 elemental analyzer *(18, 19)*.

Calculation of biomass quantity and carbon content for the main components of living trees

The basis for biomass calculation of the main tree components are well known structural elements of stand – number of trees, Stem Basal Area (SBA) and merchantable wood volume expressed in area units. Hence, dendrometric calculation of field data was carried out first by using software MS Excel© as a type of database with algorithms for calculation. Results of data processing for trees with DBH > 5 cm are structural stand elements presented according to experimental plots, tree species and in total. The next step is calculation of biomass quantity and carbon content for the main tree components (stem, branches, foliage/needles and roots).

Biomass of merchantable wood and roots

Biomass of merchantable wood has been obtained by multiplying merchantable wood volume (including bark) with basic wood density (dry matter per fresh volume). Basic wood density data of different tree species were taken from domestic literature *(17)* after comparing with obtained results which were consistent to those from the literature. An example of merchantable wood biomass calculation for pedunculate oak:

Biomass of merchantable wood (Oak)
= merchantable wood volume × basic wood density
= 86.77 m^3/ha × 0.62 t/m^3 = 53.79 t/ha

Total aboveground trees biomass is calculated by multiplying biomass of merchantable wood with adequate conversion factor, the so called Biomass Expansion Factor (BEF). BEF's are approved numbers which 'expand' tree biomass, in this case merchantable biomass into aboveground tree biomass *(1)*. The research did not involve the development of local BEF's because of the complexity of such research. Also, there is no Croatian study about local BEF's at the moment. Therefore dimensionless BEF's from 'Good Practice Guidance on Land use, Land-use change and forestry' manual *(2)* were used for aboveground biomass calculation. However, various biomass factors are highly dependent on local conditions *(20)*, and it must be noted that biomass factors can be defined in many ways, so that partially because of that many factors and terms are used in research. Neither the application of biomass factors nor the reporting is consistent in either the scientific literature or the greenhouse gas inventory reports of countries obligated by UNFCCC and Kyoto Protocol *(1)*.

Countries which signed the Kyoto Protocol in the meantime use methodology from 'Good Practice Guidance on Land use, Land-use change and forestry' manual *(2)* in order to prepare mandatory annual reports about complete inventory of anthropogenic emissions/removals of GHG to UNFCCC. In the manual there is a list of dimensionless BEF's which are used in this research.

Total aboveground trees biomass (Oak)
= Merchantable wood biomass × BEF_{Oak}
= 53.79 t/ha ×1.35 = 72.62 t/ha

Estimation of root biomass was obtained by multiplying aboveground tree biomass with adequate conversion factor, the so called Root-to-shoot ratio (R/S). As BEF's, R/S ratios were used from the same manual.

Root biomass (Oak)
= Total aboveground trees biomass × R/S_{Oak}
= 72.62 t/ha × 0.35 = 25.42 t/ha

Calculation procedure is uniform for all tree species, and it was carried out primarily to obtain tree root biomass estimation. Table 3 presents the variables and parameters used for aboveground and tree root biomass calculation.

Branch Biomass

The estimation of branch biomass for research site 'Jastrebarski lugovi, f.c. 37' was obtained by using formulas for branch biomass of broadleaved tree species in Austria *(21)*. Formulas (1) and (2) were used, depending on the number of the variables recorded for a single tree. Entering adequate coefficients and measured data for each tree into formulas, dry branch biomass estimation is obtained for branches with diameters ≥ 5 cm.

$$BB = e^{\ln(b_0) + b_1 \times \ln(DBH)} \times \lambda \quad (1)$$

$$BB = e^{\ln(b_0) + b_1 \times \ln(DBH) + b_2 \times \ln(CR)} \times \lambda \quad (2)$$

$$CR = (H - HLC) / H$$

where BB is branch biomass in kg for branches with diameters ≥ 5 cm, b_0, b_1 and b_2 are the coefficients of function typical for each tree species, DBH in cm, CR is crown ratio, H is tree height in m, HLC is stem height in m, and λ is logarithmic transformation bias because of formula transformation in linear form.

Branch biomass estimation for branches with diameters < 5 cm was obtained by subtraction of branch biomass with diameters ≥ 5 cm and stem and foliage biomass from total aboveground biomass. Total branch biomass is a sum of these two estimations.

TABLE 3

Variables and parameters used for above- and belowground tree biomass calculation.

Tree species	Merchantable wood volume (DBH >5 cm)	Wood density	*Biomass expansion factor (BEF)	*Root to shoot ratio (R/S)
	m^3 ha^{-1}	t m^{-3}	dimensionless	dimensionless
	Research site: Jastrebarski lugovi, f.c. 37			
Pedunculate Oak	86.77	0.62	1.35	0.35
Hornbeam	45.38	0.79	1.4	0.24
Black Alder	32.78	0.51	1.4	0.24
Narrow-leaved Ash	22.01	0.65	1.4	0.24
Other Hardwoods	3.60	0.67	1.4	0.24
	Research site: Delnice, f.c. 60			
Silver Fir	496.97	0.40	1.30	0.32
Common Beech	70.15	0.69	1.39	0.24
Mountain Maple	31.77	0.52	1.40	0.24

* values taken from GPG LULUCF manual (2)

The branch biomass estimation for research site 'Delnice, f.c. 60' was obtained by using Ledermann and Neumann *(22)* formula. Formula (3) was applied in this research to the level of measured variables.

$$DBM \text{ ili } DBNM = e^{(b_0 + b_1 \times \ln(DBH) + b_2 \times (H/DBH) + b_3 \times \ln(CR) + b_4 \times \ln(CWR) + b_5 \times \ln(A) + b_6 \times (DBH/A) + b_7 \times Fork + \ln(\lambda))} \quad (3)$$

where DBM is dry branch biomass in kg, DBNM is dry branch and needle mass in kg (fir), $b_0, \ldots, b_7$ are estimated coefficients of equation typical for tree species, DBH in cm, H is total tree height in m, CR is crown ratio (crown length/tree height), CWR is crown width ratio (crown width/crown length), A is age in years, Fork is a dummy-variable, and λ is logarithmic transformation bias.

Dry branch and needle biomass of silver fir was calculated by using formula (3) with adequate coefficients, and on the empirical basis a branch biomass was estimated as 98.5% of the formula result.

Stem Biomass

For the research site 'Jastrebarski lugovi, f.c. 37', the estimation of stem biomass for each measured tree was obtained based on calculation of stem volume according to Smalian's equation *(23)*. The Smalian's equation is used for volume calculation, taking into account two uttermost SBA values, so that DBH is used for SBA calculation at the beginning of stem, and for the end of stem the diameter was used that was from Šurić's tables of diameter decrement *(24)* combining the measured stem height. For ash (*Fraxinus angustifolia* L.) and elm (*Ulmus sp.*) tables for oak were used, whereas for alder (*Alnus* glutinosa *L.*) we used tables for silver fir/norway spruce. For other hardwoods we used the empiric value according to which the DBH diminishes by 0.5 cm per each meter of stem length. Due to the specific morphology of hornbeam trees (*Carpinus betulus* L.), we used empiric value of diameter decrement of 1.0 cm per meter of stem length for the trees which had DBH greater than 10 cm, and the diameter decrease of 0.4 cm per meter of stem length for thinner trees. Table values were linearly interpolated for each tree according to its dimensions.

In cases of thinner trees which have dimensions lesser than table values, the diameter decrement was empirically estimated to 0.5 cm per meter of length up to the stem height. To trees with the dimensions greater than in Šurić's tables, the diameter at the stem end was estimated by subtracting 1 cm for each additional meter of stem from the diameter calculated according to the last table percentage, at the same time using interpolation.

The stem biomass estimation for site 'Delnice, f.c. 60' is conducted as shown further. As data on stem height for most trees were lacking the overall volume of trees was calculated by using the Schumacher-Hall equation *(23)* and domestic parameters for certain species. Parameters for beech were used according to Špiranec *(25),* for silver fir according to Špiranec *(26),* and for maple the parameters for narrow-leaved ash – dry type *(27)*. For the estimation of aboveground tree biomass in t/ha, the calculated volume was enlarged by 2% and multiplied with the basic wood density. Afterwards stem biomass was evaluated for each tree by subtraction of estimated branch biomass from the aboveground biomass. For silver fir, due to the morphology of species where the stem stretches up to the very peak of tree crown and where branches are distributed sideward in branch-collars and are relatively thin, the overall tree biomass represents stem biomass.

Foliage/needle biomass

Taking into account that there are no published equations, i.e. models, for the foliage biomass estimation in domestic scientific literature in this research we used the appropriate estimation models from foreign literature. Thereby for the foliage biomass estimation of oak, ash, hornbeam, beech, maple and other hardwoods except alder, the model was chosen for beech according to Bartelink *(28)*. The analytical form of the model is:

$$FL = 0.0167 \times (DBH)^{2,951} \times (H)^{-1,101} \quad (4),$$

where the FL stands for foliage biomass in kg, DBH is in cm, and H stands for the height of tree in m.

For alder, the model was used according to Johannson (*29*) and is shown in equation (5).

$$FL = 0.00239 \times (DBH)^{1,32535} \quad (5)$$

As previously described, for silver fir the estimation of dry needle biomass is gained by the formula *(3)* so that 1.5% of calculated value according to the equation is the needle biomass estimation.

RESULTS AND DISCUSSION

Results of laboratory analyses

According to conducted analyses of plant material samples collected at the site 'Jastrebarski lugovi, f.c. 37', the contents of carbon in dry matter of stem and branches of oak were within the limits of 47.81–49.96% with the average value of 49.11%, while the average portion of carbon in foliage dry matter was 48.75%. By analyzing the samples of other tree species the following portions of carbon were identified; for hornbeam in stem and branches 48.52–49.81%, average 49.21%, and in foliage the average of 50.37%; for ash in stem and branches the range between 48.74 and 50.01%, average 49.19%, while in the foliage it was on average 49.31%. In stem and branches of alder, the proportion of carbon was within the range of 48.85 to 50.74 %, average 49.68%, while in the foliage it was 55.04%.

By analyzing samples of plant material collected at the site 'Delnice, f.c. 60' the following contents of carbon in dry matter of biomass were identified. The proportion of carbon in dry biomass of silver fir stem was within the limits of 48.22 to 49.54%, with the average value of 48.74 %, while the average value in needle dry matter was 51.17%. By analyzing the samples of stem and branches of beech the proportion of carbon identified was within the range of 47.30–48.03%, average 47.56%, whereas in stem and branches of mountain maple it was within the range of 47.84 to 48.66%, with the average proportion of 48.24% in dry matter.

The overall result of the abovementioned analysis is that the content of carbon in any component of forest woody biomass is on average around 50% of dry matter quantity, which justifies further application of that value taken over from the IPCC methodology *(2)* in calculations of carbon content.

The results of carbon proportion according to the relative position of samples in the tree were not stated, neither were any conclusions drawn in that sense predominantly due to a relatively small number of sampled trees.

Biomass results and carbon content according to main components of living trees

The results of biomass estimation and the sequestered carbon according to components of living trees (Table 4) are in accordance with the fact that the largest portion of the aboveground part of tree volume represents the stem. At the site 'Jastrebarski lugovi, f.c. 37' 147.38 t ha^{-1} of stem biomass (63.07 t ha^{-1} for oak) was estimated and at the site 'Delnice, f.c. 60' 229.03 t ha^{-1} of stem biomass (from that 179.70 t ha^{-1} of silver fir). The roots represent a significantly smaller fraction of tree biomass and, depending on the tree species according to *(2),* it amounts to around ¼ of the total aboveground tree biomass. For the site 'Jastrebarski lugovi, f.c. 37' 48.48 t ha^{-1} of root biomass was estimated and for the 'Delnice, f.c. 60' site 104.40 t ha^{-1}. Branch biomass is the value which, in addition to ecological factors, significantly depends on the morphology of a particular species. Therefore the branch biomass of silver fir was distinctively small (29.0 t ha^{-1}) in relation to the stem biomass (179.7 t ha^{-1}), which is the consequence of species morphology. For the site 'Jastrebarski lugovi, f.c. 37', 17.91 t ha^{-1} of branch biomass was estimated, and for 'Delnice, f.c. 60' site 45.44 t ha^{-1} of branch biomass.

The minor component of a tree, when taking into account the biomass quantity, are leaves, i.e. needles (fir). Estimation of foliar biomass for site 'Jastrebarski lugovi, f.c. 37' was 3.39 t ha^{-1}, and for the site 'Delnice, f.c. 60' the estimation of foliar biomass was 1.80 t ha^{-1}, whereas the needle biomass was almost negligible (0.44 t ha^{-1}). The carbon stored in foliar biomass relatively rapidly becomes the source of CO_2 emissions due to the fall of leaves of continental broadleaves at the end of vegetation period and start to decay.

This study was, in methodological sense, pioneer- and pilot-research in Croatian forestry; the methodology involved a great number of research operations and methods whose choice depended on the type of the data collected and estimated. Therefore, in order to insure the key dendrometric data that are crucial for the biomass estimation, custom field survey was chosen. On the other hand, in case of future similar research to be performed for the purpose of estimation of woody biomass and carbon quantity according to tree components on the scale larger than the stand, it is possible to use the »Hrvatske šume ltd.« enterprise database, and consider all state forests. Other data used in this research were either directly taken or they were adjusted from different literature sources, and then compared with the results of custom laboratory analyses of the collected samples. Such analytic approach only confirmed the results based on similar studies of the carbon content in biomass of living tree, i.e. in its particular components.

Research goal was accomplished and supported with forest woody biomass and sequestered carbon results, providing methodology to be considered for for opera-

TABLE 4

Results of biomass and sequestered carbon estimation according to the components of living trees for the research sites.

Tree species	Stem		Branches		Roots		Foliage	
	t ha^{-1}	tC ha^{-1}	t ha^{-1}	tC ha^{-1}	t ha^{-1}	tC ha^{-1}	t ha^{-1}	tC ha^{-1}
Research site: Jastrebarski lugovi, f.c. 37								
Pedunculate Oak	63.07	31.54	7.92	3.96	25.42	12.71	1.63	0.82
Hornbeam	42.96	21.48	6.47	3.24	12.05	6.03	0.76	0.38
Black Alder	22.21	11.11	0.77	0.38	5.62	2.81	0.43	0.22
Narrow-leaved Ash	17.05	8.53	2.52	1.26	4.81	2.41	0.46	0.23
Other Hardwoods	2.09	1.04	0.23	0.11	0.58	0.29	0.11	0.06
Total	147.38	73.70	17.91	8.95	48.48	24.25	3.39	1.71
Research site: Delnice, f.c. 60								
Silver Fir	179.7	89.85	29.00	14.50	82.70	41.35	0.44	0.22
Common Beech	38.31	19.16	10.83	5.42	16.15	8.08	1.22	0.61
Mountain Maple	11.02	5.51	5.61	2.81	5.55	2.78	0.58	0.29
Total	229.03	114.52	45.44	22.73	104.40	52.21	2.24	1.12

Biomass values are expressed in t ha^{-1}; Carbon values are in tonnes of carbon (tC ha^{-1})

tional usage in Croatian forestry sector and for possible further optimization. By applying optimized methodology to forestry by integrating it, for example, in the process of making forest management plans or in the process of revenue planning, it would be possible obtain an information about woody biomass and carbon stored in it for any forest stand or stand components (tree species, volume increment, wood assortments). Presumptions for this are the existence of unified database about Croatian forests, locally developed BEF's and initiative from appropriate authority (Ministry). Final result of such implementation would be qualitative and certified data on forest carbon pool size in Croatia, which is important for future Croatian reporting necessary according to climate related international treaties.

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