Relationship Between Stand Density And Above-Ground Biomass Allocation In Q.Cerris Stands

Erion Istrefi
Ministry of Tourism and Environment
Environmental Services Project
Tirana, Albania
erion.istrefi@yahoo.com

Elvin Toromani
Faculty of Forestry Sciences
Agricultural University of Tirana
Tirana, Albania
elvintoromani@gmail.com

Abstract— **The effects of stem density on tree dimensions, above-ground biomass, and tree components biomass were investigated in six forest stands grouped in low, moderate and high density classes. We hypothesized that stand density may cause substantial differences in tree dimensions, diameter distribution, above-ground biomass and biomass allocation. We assessed the characteristics of Turkey oak (*Q.cerris* L.) sampled trees, across the studied sites to understand the influence of stand density on individual tree dimensions, diameter distribution, tree-level aboveground biomass (AGB), component biomass (stem, branch, foliage), partitioning to components. Sixty seven Turkey oak trees were harvested from 6 sites ranging from 495 to 4175 stems per hectare for development of allometric equations to predict AGB and tree components biomass. Tree-level AGB and component biomass decreased with increasing stand density. Stem partitioning increased with stand density, while foliage and branch partitioning declined. Overall, our results indicate that stand density explains much of the variation in tree characteristics, tree-level AGB and components biomass. Stand density is an important factor which exerts significant influence on the forest stand structure (horizontal and vertical) and biomass stocking of individual trees.**

Keywords— Turkey oak; allometric equation; biomass partitioning; tree number

I. INTRODUCTION

According to Albanian National Forest Inventory (1), the total forest area of Albania is 1,498,957 hectare (ha), of which oak forests occupy 379,873 ha (c.a. 25 % of total forested area). Oak forests managed traditionally as coppice, form pure (260,985 ha) and mixed (118,888 ha) forest stands. Most of the oak forest stands are young (76% of oak forest area) having an age up to 30 years and a standing volume of 9 Million cubic meter (m^3).The total biomass estimated for forests in Albania was 51 Million ton, of which 84% belongs to high forests and 15.8% coppice forests [1]. There are several oak species in Albania, distributed across the country from north to south, and east to west, for instance: Turkey oak (*Quercus cerris* L.), Hungarian oak (*Quercus frainetto* Ten.), Macedonian oak (*Quercus trojana* Webb.), Valonia oak (*Quercus macrolepis* Kotschy.), Pedunculate oak (*Quercus robur* L.), Sessile oak (*Quercus petraea* (Matt) Liebl.), Kermes oak (*Quercus coccifera* L.), Evergreen oak (*Quercus ilex* L.), Downy oak (*Quercus pubescens* Willd.) etc.

Referring the above-mentioned statistics, oak stands play an important role in the carbon balance at country level and the quantification of their biomass and carbon stock as precisely as possible is a challenge for foresters. In Albania, information on forest biomass and carbon stock is scarce compare to other Mediterranean countries. The existing studies are mainly focused on other species growing in natural [2] and artificial forest stands [3]. At present, there is no scientific study or information related to biomass estimation and carbon stock fornatural oak forests in Albania.

Q. cerris is one of the oak species lacking biomass-related information and the structure of these forest stands depends on soil fertility, stand density, competition between trees, management and disturbances [4; 5]. The stem density is an important factor in biomass accumulation of young *Q.cerris* forest stands. Changes in stand density are directly associated with structural changes in diameter distribution, tree height, tree size, photosynthesis and rates of CO_2 exchange [6]. Relatively little is known about the effects of stem density on above-ground biomass (AGB) and on specific tree components biomass. Much of our knowledge on stem density effects is generated from field experiments or artificial stands, which use several indices, like: stand density index (SDI), or leaf area index [7]. Understanding differences in biomass accumulation and its partitioning under different stand density is important, because it helps to explain not only the allocation of biomass among tree components (stem, branch, foliage), but also adaptation of tree characteristics in response to competition. This is important because stand density alters the biomass distribution among tree components as well as influence the composition, structure and function of forests [8]. Accurate estimation of biomass in a given forest, requires the application of appropriate allometric equations [9].

Measurements to develop allometric equations could be achieved by direct and indirect methods. Direct methods measure the biomass directly by weighing trees in the field, while indirect methods involve the estimate of difficult to measure parameters, like stem volume or tree biomass, from easy to measure tree parameters, like diameter at breast height (DBH) and tree height (H) [10]. Thus, quantifying the relationship of stem density with DBH, tree height (H) and AGB, will assist in understanding how stand density contribute to AGB and tree components.

Our primary aim was to 1) develop allometric models to estimate AGB based on diameter at breast height (DBH) and tree height (H), 2) compare the observed biomass data between forest stands with different density; and 3) examine statistically the effects of stem density on AGB and tree components biomass. Our assumption was that differences in AGB and tree components biomass between investigated forest stands could be attributed to the influence of stand density.

II. MATERIALS AND METHODS

A. *Study area description*

The measurements were carried out in 6 natural stands of Turkey oak located in north-east part of Albania.The distribution of the stands location is shown in Fig.1.

Fig.1: Location of study areas (Sllove (SO); Bushtrice (BU); Melan (ME);Zerqan (ZE);Sopot (SO); Kllopcisht (KL))

The altitude range between 715 and 850 m above sea level (m a.s.l) and the latitude from 41.50 to 41.89 degrees north (Table 1). The *Q.cerris* stands grow under the influence of Hilly Mediterranean climate with an average annual temperature from 9.30 °C to 9.85 °C. The climate is characterized by an uneven rainfall distribution and the mean annual precipitation for the period 1901-2017, ranged from 959 mm to 1010 mm [11].These forest stands grow on moderately deep soils formed during the long-term alteration of the clay bedrocks. The forest stand density varied between 495 and 4170 trees per hectare and the age of trees ranged between 4 and 30 years.

Table 1: Site description including location, latitude (lat), longitude (long), altitude above sea level, mean annual temperature (MAT) and mean annual precipitation (MAP) .

Site	Lat (°N)	Long (°E)	Altitude (m)	MAT (°C)	MAP (mm)
Sllove	41°45'35"	20°24"16"	750	9.56	959
Bushtrice	41°53'34"	20°25'02"	780	9.66	1010
Melan	41°39'17"	20°28'03"	850	9.30	1000
Zerqan	41°30'48"	20°22"04"	715	9.85	1008
Sopot	41°30'8"	20°23'13"	590	10.1	1070
Kllopcisht	41°31'11"	20°31'58"	853	9.52	980

In each forest site five circular sample plots, each 200 m^2 area were established. All trees within these plots having a diameter at breast height over 2 cm (DBH-1.3 m from the ground) were measured by calliper, whereas tree height (H) was measured by ultrasound hypsometer Vertex III (Haglöf Sweden AB, Sweden). Position of each tree in relation to plot centre was recorded by measuring distance from the centre and tree azimuth. Stand density per hectare was estimated based on the tree number found within sample plots divided by sample plots area. After measurements, forest stands were grouped in three density classes classified as: low (495: 450 -540 stems ha^{-1}), moderate (1450: 1400-1500 stems ha^{-1}) and high (4175: 3350 - 5000 stems ha^{-1}) density. Sampling procedure continued with selection of sampled trees in a way they represented the all diameter classes within plots. In total, two to three trees per each diameter class were cut at ground level for biomass estimation. In total 67 trees, dominated by small-size were felled and weight in the field. The small-sized trees (DBH< 20 cm) were felled close to the ground and stratified into trunk, branches and foliage. The fresh mass of the trunk, branches and foliage were weighed using a precision scale with 50 kg capacity and accuracy ± 1%. Three to five subsamples were taken from each of tree organs for determination of dry to fresh mass ratio. They were stored in sealed plastic bags and then sent to the laboratory. The leaf samples were dried at 65°C for 48 hours, while the wood samples were dried at 105°C until a constant weight was attained. The fresh and the dry weight of the samples were measured with an electronic balance. Dry mass of each tree component was determined by the product of fresh mass of the component with fresh to dry mass ratio. Diameter measurements for larger trees (DBH > 20 cm) were carried out at 1.0 m intervals, starting from the base, for branches and trunk, respectively.

The measurements were used to calculate the respective branch and trunk volume. The volume of sections (Vs) of the trunk and big branches was determined by Smalian equation:

$$V_s = \frac{\pi \cdot l}{8} \cdot (D_1^2 + D_2^2) \quad (1)$$

Where: l- is the length of the section; D_1 and D_2 are the diameters of the smaller and larger end of the section, respectively.

The volume of the trunk and big branches was determined by the summation of the sections of the respective organs. The felled trees were stratified into four components or organs namely: (i) trunk; (ii) big branches, with diameter at the base greater than 5 cm, (iii) small branches with basal diameter smaller than 5 cm, and (iv) foliage.

Sample disks were cut from trunk and branches with chainsaw machine. Three disk samples with 5.0 cm thickness were collected from the base, middle and top of the trunk and branches and sent to the laboratory. For accuracy, the wood samples were re-measured with a digital caliper at three points along the length and at two perpendicular directions for the diameter, and then data were used for fresh volume calculation. The wood samples, were oven-dried at 105°C, to attain a constant weight and the dry mass determined with an electronic balance. The foliage samples were oven-dried at 65°C until reached a constant weight and then weighed. The volume and the dry mass measurements were used to calculate wood density. The total AGB of each tree was estimated by the sum of stem-wood over bark, branches and foliage dry weights.

B. *Allometric equation construction*

In order to obtain an allometric equation between biomass data of sampled trees with tree variables (i.e. DBH, H, H/DBH ratio), regression models with best fit with raw data were employed. The allometric equations were developed using SPSS statistical software for Windows [12]. The coefficient of determination (R^2), $R^2_{Adjusted}$ (an indicator of the explanatory power of allometric models), Bias, and Root Mean Square Error (RMSE) were used to evaluate the performance of allometric models or the quality of the fit between the actual data and the predicted data by model for each independent variable [13]. The smaller the values of these statistics, better the prediction of the models. These statistics were calculated as follows:

$$\text{Bias} = \frac{\sum_{i=1}^{n}(y_i - \check{y}_i)}{n} \quad (2)$$

and $$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \check{y}_i)^2}{n}} \quad (3)$$

Where: n is sample number; y_i is observed value of biomass; $\check{y}_i$ is estimated value of biomass.

C. *Statistical analysis*

All statistical analyses were performed in SPSS 24 for Windows, where a 5% significance level was used throughout. We used data from felled trees to analyze differences in tree dimensions, AGB, tree components biomass varying with stand density and to develop models to estimate stem, branches and foliage biomass. The simple linear and non-linear regressions were used to analyze the relationship between stand density and tree - level biomass. The Chi-Square test was performed to evaluate the differences in tree number distribution by diameter classes. One-way Analysis of Variance (ANOVA) and the post hoc Least Significant Difference (LSD) were used to test the effects of tree density on DBH, tree height, diameter distribution, AGB and biomass allocation. In addition, correlation analysis was used to evaluate the relationship between stem, branches and foliage biomass of felled trees with DBH and H for stands having different stem density. Pearson's correlations (r) were considered significant for a p-value lower than 0.05 and for a 95% confidence interval.

III. RESULTS

A. *Stand density effects on individual tree dimensions*

Table 2, depicts some of the tree characteristics at investigated forest stands grouped based on tree density. The tree number per hectare ranges from 495 to 4175, associated with a decrease of available area per each individual tree due to stand density increasing. Stand density has a distinct effect on DBH and height of sampled trees. Means and standard deviations of DBH, height and age were computed to present general characteristics of the felled trees.

Table 2: Summary characteristics of the measured forest stands grouped by stem density

Density class	Stem density (tree/ha)	Area per tree (m^2)	Sampled trees	DBH (cm)		Tree height (m)		Age(years)	
				Mean ± SD	Range	Mean±SD	Range	Mean±SD	Range
Low	495	20.2	27	7.59±5.49	2.5-30	5.38 ± 2.14	2.3-9.2	16 ± 8	5 - 29
Moderate	1450	6.9	22	7.14±3.58	2.3-14	5.50 ± 2.67	1.8-10.5	16 ± 3	11 - 20
High	4175	2.4	18	6.83±3.77	2.0-15	6.72 ± 2.15	2.8-10.0	13 ± 7	5 - 21

Regarding DBH, we noticed a decrease in the mean values from low to high density stands, but in contrast values of tree height were increasing. The widest spacing stands (495 trees ha^{-1}), had DBH values 6% and 10 % higher than stands with higher density (1450 trees ha^{-1} and 4175 trees ha^{-1}). This result can be attributed to the fact that in dense forest stands, DBH growth reduced due to horizontal - spacing competition among adjacent trees for securing sunlight and growing space and promoting their height growth. In contrast, trees growing in less dense forest stands have more available growing space and less competition achieving larger dimensions. Contrary to

DBH, tree height was more affected by stand density (Table 2). An increase in tree height by 2% and 20% was found when stand density increased from 495 trees ha^{-1} to 1475 trees ha^{-1} and 4175 trees ha^{-1}, respectively. Although DBH and tree height of sampled trees differ by stand density, One-way Analysis of Variance (ANOVA) applied to test their difference, revealed that difference was not statistically significant (DBH, $p = 0.425$; H, $p = 0.137$). The diagram of tree distribution in diameter classes shows that all studied *Q.cerris* stands are even-aged, characterized by a nearly bell-shaped diameter distribution (Fig. 2). This means that most of the trees are in the average diameter classes. The smallest trees in high density stands are generally spindly, with vigour suppressed by the overstorey. In low density stands we found a wider diameter range than in others, whereas the height range was wider in moderate density stands. In addition we noticed that trees in high density stands were younger than in other stands, but the age range was wider in low density stands.

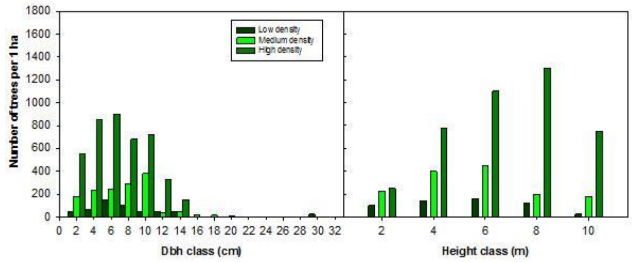

Fig. 2: Tree number distribution by DBH (left) and height (right) plotted in 4 cm diameter classes and 2 m height classes

Chi square test was used to reveal the difference in diameter distribution between low, moderate and high density stands. The estimated Chi-Square value (56.381) was compared to theoretical values for 5% and 1% significance and degree of freedom (DF = 40). In both cases the estimated Chi-Square value was larger than theoretical values (DF = 40; $p < 0.05$ and $p < 0.01$), implying that diameter distribution differs very significantly between forest stands with various density.

B. Biomass as a function of stand density

Table 4, shows mean values of *AGB* and biomass components estimated from sampled trees for low, moderate and high density stands.According to our estimatesmore biomass is stored in dense stands (67.2 t ha^{-1}), where competition process is stronger and trees grow more in height than in diameter. One-way Analysis of Variance (ANOVA) was used to examine whether stand density influence the biomass allocation in the sampled trees. The above-ground biomass and components biomass data of sampled trees grouped in three density classes were used in the ANOVA. An alpha level of 0.05 was used for all analyses. The Fisher test (DF_1=2; DF_2=64) for homogeneity of variance was not significant [$F_{est} < F_{crit}$ (3.14), $p > 0.05$] indicating that assumption for variance homogeneity was met.

Table 4: The values of AGB, tree compartment's biomass and Fisher test by stand density

Density class	**Tree component's biomass (kg/tree)**			**AGB (kg tree^{-1})**		**Above-ground stand biomass (t ha^{-1})**
	Stem	**Branch**	**Foliage**	**Mean + SD**	**Range**	
Low	8.76	2.61	1.13	12.5 ± 11.3	1.80-53.89	6.2
Moderate	7.58	2.06	0.52	10.2 ± 7.6	0.40-23.45	14.8
High	12.6	2.67	0.82	16.1 ± 12.0	1.45-50.30	67.2
F	**1.49**	**2.19**	**1.33**	**1.68**	-	-
p-value	**0.23**	**0.12**	**0.27**	**0.19**	-	-

The *post hoc* Least Significant Difference (LSD) test revealed statistically significant difference by stand density only in branch biomass compartment. The LSD test showed that low density and moderate density stands have lower branch biomass than high density stands and these differences were statistically significant (p = 0.018; p = 0.043). There was no statistically significant difference between the low density stands with moderate (p = 0.183) and high density stands (p = 0.381).

Fig. 3, shows relationship between DBH and biomass components by stand density. We found a positive association between DBH as independent variable and biomass components, because tree component biomass values were increasing due to DBH rising.

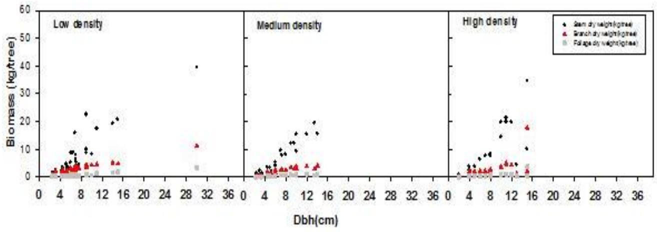

Fig. 3: The component's biomass of sampled trees plotted by DBH classes per low, medium and high density stands

Despite stand density, correlations between AGB and biomass components with DBH were statistically significant ($p < 0.01$), which indicate that breast height diameter is a good predictor of biomass (Table 6). In low and moderate density stands, relationship between DBH with AGB or biomass components was stronger than in high density stands. The correlations between tree height with AGB and tree components biomass were statistically significant in all stands despite their density, but these values were obviously higher in moderate density stands. In low, medium and high density stands, relationship between age as predictor and AGB or tree component's biomass was variable. Thus, in low density stands, statistically significant correlations were found between age versus stem, foliage and AGB biomass. In moderate density stands, significant correlations were found with stem and AGB biomass, whereas in high density stands these correlations were significant with branch and foliage biomass data sets. In low density stands, the H/Dbh ratio was significantly correlated with AGB and tree components biomass, whereas in high density stands was significantly associated with stem and AGB biomass data sets.

Table 6: Pearson's correlation coefficients between tree variables with AGB and tree components biomass. Asterisks indicate 95 %(*) and 99% (**) significance level.

Density class	Tree variables	Pearson's Correlation coefficient			
		Stem Dry weight (kg/tree)	Branch dry weight (kg/tree)	Foliage dry weight (kg/tree)	AGB (kg/tree)
Low	DBH(cm)	0.92**	0.96**	0.97**	0.95**
	H(m)	0.75**	0.69**	0.66**	0.75**
	Age (yr)	0.44*	0.27	0.46*	0.41*
	H/DBH ratio	-0.47*	-0.59**	- 0.62**	- 0.51**
Moderate	DBH(cm)	0.96**	0.92**	0.91**	0.97**
	H(m)	0.96**	0.91**	0.93**	0.97**
	Age(yr)	0.47*	.0.32	0.36	0.45*
	H /DBH ratio	0.32	0.40	0.43	0.35
High	DBH(cm)	0.72**	0.54**	0.56**	0.69**
	H(m)	0.72**	0.52*	0.55**	0.68**
	Age (yr)	0.36	0.42*	0.45*	0.40
	H/ DBH ratio	- 0.50*	-0.35	-0.34	- 0.47*

C. Biomass models

Table 7 and 8, present biomass allometric equations with best performance, developed from data of sampled trees in *Quercus cerris* L. stands with different densities. Such biomass models allow estimating the mass of stem, branches, and leaves, based on DBH and tree height variables.

Table 7: Allometric models using breast height diameter (cm) as predictor of biomass and respective statistics (coefficient of determination (R^2); adjusted root mean square error ($R^2_{Adjusted}$), bias and root mean square error (RMSE) for low, moderate and high density stands

Density class	Components	Equations	*p-value*	R^2	R^2_{Adj}	Bias (kg)	RMSE (kg)
Low	Stem	$\ln DW = 0.322 + 1.551 \cdot \ln DBH$	< 0.05	0.85	0.84	1.34	1.40
	Branch	$DW = 0.254 + 0.363 \cdot DBH$	< 0.05	0.93	0.91	0.00	0.31
	Foliage	$DW = 0.117 \cdot DBH - 0.139$	< 0.05	0.95	0.94	0.00	0.02
	AGB	$\ln AGB = 0.694 + 1.381 \cdot \ln DBH$	< 0.05	0.88	0.87	0.36	1.20
Moderate	Stem	$DW = 1.623 \cdot DBH - 3.841$	< 0.05	0.92	0.91	0.02	1.72
	Branch	$\ln DW = 2.245 \cdot \ln DBH - 2.015$	< 0.05	0.90	0.89	1.70	1.78
	Foliage	$\ln DW = 0.546 \cdot \ln DBH - 0.504$	< 0.05	0.86	0.85	1.53	1.71
	AGB	$AGB = 2.05 \cdot DBH - 4.255$	< 0.05	0.94	0.93	0.01	1.69
High	Stem	$\ln DW = 0.372 \cdot \ln DBH^{1.512}$	< 0.05	0.75	0.73	1.40	1.57
	Branch	$\ln DW = 0.384 \cdot \ln DBH^{0.955}$	< 0.05	0.49	0.45	0.26	0.75
	Foliage	$\ln DW = 0.08 \cdot \ln DBH^{0.998}$	< 0.05	0.53	0.50	0.62	1.02
	AGB	$\ln AGB = 0.754 \cdot \ln DBH^{1.343}$	< 0.05	0.70	0.68	0.46	0.66

According to R^2, Bias and RMSE values, the biomass models that performed better were not the same across independent variables and forest stands with variousdensity. The linear and logarithmic models using DBH as predictor, performed better in low and moderate density stands,whereas logarithmic biomass models were used in biomass estimation of dense Turkey oak stands. The R^2 values of developed models are high. However, in the trees which grow in sparse stands (0.85 ; 0.93 ; 0.95 ; 0.88) and moderate density (0.92 ; 0.90 ; 0.86 ; 0.94), the R^2 values of the allometric models are higher than the R^2 values of the sampled trees growing in dense stands (0.75 ; 0.49 ; 0.53 ; 0.70). Bias and the RMSE of the biomass equations were different; the largest values of bias and RMSE were found to high and moderate density *Q.cerris* stands.

Table 8: Allometric models using tree height (H) as predictor of biomass and respective statistics (coefficient of determination (R^2; Adjusted root mean square error ($R^2_{Adjusted}$), Bias and root mean square error (RMSE) for low, moderate and high density stands

Density class	Components	Equations	*p-value*	R^2	R^2_{Adj}	Bias (kg)	RMSE (kg)
Low	Stem	$\ln DW = 0.287 + 1.878 \cdot \ln H$	< 0.05	0.77	0.76	1.54	1.56
	Branch	$\ln DW = 0.418 + 1.117 \cdot \ln H$	< 0.05	0.59	0.57	1.29	1.83
	Foliage	$\ln DW = 0.058 + 1.415 \cdot \ln H$	< 0.05	0.63	0.62	1.57	2.76
	AGB	$\ln AGB = 0.662 + 1.637 \cdot \ln H$	< 0.05	0.76	0.75	1.07	1.31
Moderate	Stem	$DW = 2.183 \cdot H - 4.415$	< 0.05	0.92	0.91	0.00	1.65
	Branch	$\ln DW = 2.303 \cdot \ln H - 1.575$	< 0.05	0.86	0.85	1.71	1.78
	Foliage	$\ln DW = 0.597 \cdot \ln H - 0.42$	< 0.05	0.88	0.87	1.53	1.71
	AGB	$AGB = 2.754 \cdot H - 4.957$	< 0.05	0.94	0.94	0.02	1.81
High	Stem	$\ln DW = 0.156 \cdot \ln H^{2.165}$	< 0.05	0.70	0.68	1.53	1.70
	Branch	$\ln DW = 0.236 \cdot \ln H^{1.334}$	< 0.05	0.43	0.40	0.48	0.79
	Foliage	$\ln DW = 0.045 \cdot \ln H^{1.428}$	< 0.05	0.50	0.47	0.57	0.89
	AGB	$\ln AGB = 0.354 \cdot \ln H^{1.912}$	< 0.05	0.65	0.63	1.32	1.44

Note: H- total height (m); DW- dry weight (kg/tree)

In allometric models using tree height as predictor, logarithmic models were mostly used to estimate tree biomass. Based on goodness fit statistics, the performance of biomass equations was different across tree components and stand densities. The highest values of R^2 were reached in moderate and low density *Q.cerris* stands and the lowest values in high density stands. In low density stands the lowest bias and RMSE values were found in AGB, while the highest values in foliage estimation. Stem biomass was the most accurate dependent variable estimated by the allometric models for moderate density stands, while the branch biomass was less accurately estimated. In high density stands, the biomass equations provided accurate estimation for stem component, but did not perform well in branch mass estimation.

D. Stand density effects on above-ground biomass allocation

The partitioning of tree biomass into basic fractions as stem, branches and foliage is shown in Fig. 3. The relative percentage of biomass varied among tree - components and between stands having different density. The stem was the biggest fraction ranging from 70% in low dense stands to 75 % in high density stands.

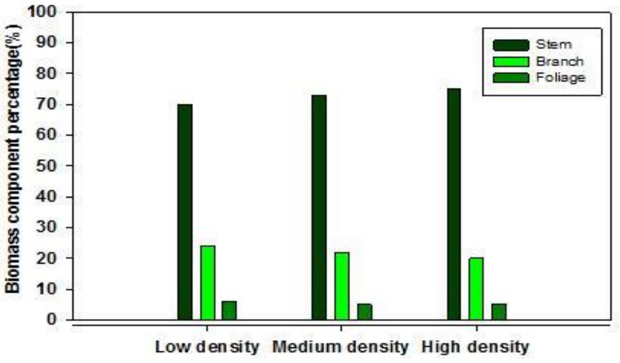

Fig. 3: The share of above-ground biomass components by stand density

In contrast, mass of branches and foliage was decreasing from less to denser forest stands. Thus, in low dense stands, sampled trees had the largest fraction of branches (24%) and foliage (6%), whereas trees from high density stands had the lowest values of crown mass (branches 20%; foliage 5%). We noted a negative relationship between stand density and foliage percentage. The branches accounted 79.4 to 81.4 % of the total crown biomass, whereas the foliage mass contribution at crown biomass is increasing with stem density rising. The share of crown biomass versus above-ground biomass is decreased from sparse stands (36%) to high density stands (28%).

IV. Discussion

In this study, we reported important results about the impacts of stand density on individual tree dimensions, above-ground biomass and tree components biomass. In natural forest stands, the stem density is an important factor to be considered not only during scientific research, but also in the management decision because it affects standing volume, forest stand biomass, wood log size, considered important to meet the production objectives.

The density effects on stem volume in forests have been widely studied, but relatively little attention has been given to the influence of density effects on above-ground biomass and on specific tree components biomass. As expected, there was an evident effect of stem density on individual stem DBH, tree height, above-ground biomass and it's partitioning in stem, branch and foliage components. We found evidences about the important effect of stem density on mean values of DBH and tree height (H). Thus, mean DBH decreased, while mean height increased from low to high density stands.In agreement with previous studies [14; 15], we found that trees growing in closed stands show higher investment in height growth relative to circumference growth than in open stands. This may be interpreted as ‘a race for sunlight’, where individual trees in dense stands maximize their height growth to meet their demands for light. Stand density was clearly an important factor affecting tree distribution among diameter classes at stand -level as verified by the Chi-Square test.

Across studied stands, the lowest values of AGB were observed in forest stands having a low density, whereas the highest values were observed in dense forest stands. Quantification of diameter distributions allows the forest managers to relate the parameters of the distribution to stand density [16]. According to our estimates more biomass is stored in dense stands, because competition process is stronger and trees grow more in height than in diameter. Weaker competition stimulates stem diameter growth more than tree height growth and causes smaller form coefficient of stems but the share of branches increases [17]. It is well known from allometry theory that larger trees in low density stands require more space compared to small trees for sustaining their growth [18; 19].

Stand density effect on tree components biomass (stem, branches, and foliage) was more evident in branch biomass between moderate and high density stands. It indicates that if stand density is increasing, the branch biomass is decreasing due to competition of standing trees for sunlight and growing space.

In the present study, the allometric models developed for all measured trees had a relatively higher value of R^2 (Table 7 and 8) in low and moderate density stands. Referring Bias and RMSE, biomass equations had the largest values in high and moderate density stands. As a result, it is recommended that allometric equations developed in this study, might be use for simplicity as well as for accuracy reasons. The use of such allometric models may led to systematic errors if they are applied in stands of different structure (stand density, competition) compared to the model data.

As expected, diameter at breast height showed a better predictive capacity than tree height, but the use of tree height as a second independent variable improved the accuracy only in biomass models developed for forest stands having a moderate density. It is recognized that diameter at breast height is more frequently used as predictor variable of biomass, because it is less difficult to measure, compared to tree height [20]. In contrast, other authors found a significant improvement of biomass models accuracy when tree height was used as biomass predictor [21]. These models are convenient to use in practice, since DBH and H are easy to measure standard variables in forest inventories. Other authors have reported that allometric models change with species, stand density and they are useful for understanding the structure and dynamics of forests and the competitive interactions among trees [22]. The relationship between DBH versus AGB, stem, branch and foliage biomass was significant in all studied stands despite their density, but the strongest linkage was found in low and moderate density stands. In addition, tree height resulted to be significantly correlated with AGB and tree components biomass, but this association was obviously weaker than relationship with DBH. The differences across forest stands with various densities were also affected by the sampled tree age. We found significant relationship between age versus stem, foliage and AGB biomass in sparse stands. In moderate density stands, significant correlation was found only with stem biomass, whereas in high density stands these correlations were significant with branch and foliage biomass data set. In low density stands, the height to stem DBH ratio was significantly correlated with AGB and tree components biomass, but in high density stands this association was stronger with stem and AGB biomass. This study shows that stand density has important effects on above-ground biomass and its partitioning along tree components. As expected the stem was the biggest fraction ranging from 70% in low density to 75 % in high density stands. In contrast the relative contribution of branches and foliage to AGB is lower in high density stands. This fact can be attributed to competition for light among trees in very dense forests and is consistent with findings reported earlier [23]. We found in this study a negative relationship between the share of tree crown mass in the total above-ground biomass with stand density. The share of tree crown mass in the total above-ground biomass is also an indicator of competition. Open grown trees have wider crowns than closed canopy trees [24] as a result of smaller competition. Such a biomass allocation strategy allows trees to rapidly occupy available canopy space, thereby optimizing sunlight utilizing capacity due to stand density.

V. CONCLUSION

The results of this study show that tree diameter is a better predictor for the estimation of single tree biomass and also the biomass allocation pattern. The relationship between height and biomass was significantly affected by stem density. Increasing stem density stimulate trees to allocate more to height growth therefore making them thinner. Therefore, this variation of growth pace between stem density and biomass affects tree allometry and biomass allocation.

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