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Allometric biomass equations for young trees of four broadleaved species in Albania

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Abstract

Background: Biomass assessment of young forest stands is important because of their role in the carbon cycling. The aim of this study was to develop biomass equations for young broadleaved species growing in natural conditions in Albania.

Methods: Five forest stands were investigated using circular sample plots. Diameter at breast height (DBH) and height (H) from 58 sampled trees ranging in age from 4 to 34 years old of Turkey oak (*Quercus cerris* L.), sweet chestnut (*Castanea sativa* Mill.), European hornbeam (*Carpinus betulus* L.) and manna ash (*Fraxinus ornus* L.) were measured *in situ*. Logarithmic regression equations were used and tested for their performance to estimate aboveground and tree-components biomass for each species using DBH, H and their combination $DBH^2 \times H$ as predictors.

Results: We found that DBH was a reliable predictor for estimation of aboveground and components biomass for young trees but the inclusion of height in biomass allometry did not improve the biomass estimation. We observed differences in scale (β_0) and exponent (β_1) coefficients of biomass models, not only between broadleaved species, but also among tree-components within species. Both coefficients were strongly species-specific and their values reflect differences in biomass stocking rate due to different growth strategies of each species in early development phases.

Conclusions: Allometric equations to estimate aboveground and tree-component biomass appeared to be species-specific, meaning that such models are applicable for species growing at sites with similar ecological conditions. From the tree variables used, DBH was the most reliable predictor of aboveground and individual components biomass, whereas height proved to be a promising predictor for stand biomass. These allometric equations developed for young trees will improve the accuracy of current estimates of forest carbon stock in Albania.

Keywords: biomass model performance, *Carpinus betulus*, *Castanea sativa*, *Fraxinus ornus*, *Quercus cerris*, tree biomass

Introduction

During the last decades, the area of young forests in Albania has been expanding due to intensive management and damage incurred by forest fires. Since young forest stands play a critical role in the forest carbon cycling due to their capacity in dioxide carbon uptake in early growth phases, we urgently need to develop and improve techniques for accurate prediction of their biomass (Lehtonen 2005). One of the most efficient ways to achieve this goal is to use allometric

equations. Such allometric models are commonly used to estimate biomass in mature forests, but these are missing for young forests. They are adequate tools to express biomass in terms of dry mass on the basis of easily measured variables. Most of these equations in the Albanian and international literature use diameter at breast height (DBH at 1.3 m from the ground) and tree height (H) to estimate aboveground biomass (AGB) or tree-components biomass. Other variables such as wood density, crown length, height-to-diameter ratio, or tree

age are also used to improve the accuracy of allometric equations in biomass prediction.

The information on biomass of forest stands is required to assess the amount of carbon stocked in Albanian forests and to estimate changes in carbon stocks to meet reporting requirements of Albania to the United Nations Framework Convention on Climate Change (UNFCCC). For that reason, the development of biomass functions in each country has become an important issue and it is encouraged to be done for most relevant tree species (IPCC 2003). Despite recent developments in remote sensing techniques, biomass allometric models are fundamental to estimating biomass at the tree or stand level.

Few studies on biomass and biomass expansion factors (BEFs) have been reported for forest species in Albania. The first results regarding biomass estimation at country level were provided in the framework of the National Forest Inventory (ANFI 2004). Biomass was calculated using inventory data on stand volume per hectare and biomass expansion factors (BEFs) from other countries with similar site conditions. Omuri (2006) generated allometric equations and determined BEFs for Austrian pine (*Pinus nigra* Arn.), beech (*Fagus sylvatica* L.) and birch (*Betula pendula* L.) ≤ 50 years old in the Shishtavec area, northern-east Albania. Toromani et al. (2011) developed allometric equations for young poplar plantations growing in eastern Albania, in the region of Pogradeci, based on several tree variables. Istrefi et al. (2018) conducted research in several areas in eastern and central Albania to assess aboveground and tree components biomass of Turkey oak (*Quercus cerris* L.) ≤ 0 years by using linear and non-linear allometric models.

Several studies on allometry have been conducted worldwide, where 279 equations have been developed for different tree species and ecological regions (Zianis et al. 2005; Zianis and Mencuccini 2004). These biomass equations were developed for young trees with a threshold of DBH ≥ 10 cm omitting trees with a smaller diameter. Based on our review of the literature, we noted that most biomass equations were developed for mature stands (Wirth et al. 2004; Joosten et al. 2004; Zianis et al. 2005) and only few for young stands (Dutca et al. 2010). Despite the limited number of published equations, for many other forest species growing in Albania the availability of allometric equations is still limited. Therefore, there is still a need for improving existing biomass models and developing new ones for other forest species such as Turkey oak, sweet chestnut (*Castanea sativa* Mill.), European hornbeam (*Carpinus betulus* L.), manna ash (*Fraxinus ornus* L.) and others. From the review in the GlobAllomeTree platform (<http://globallometree.org>, Henry et al. 2013), the only available allometric equations for young trees were for *Cas. sativa*, and *Car. betulus*. Due to the lack of biomass equations for young broadleaved species in Albania, the development of allometric models for biomass estimates remains a challenge for researchers in Albania. The main objective of this study was to develop species-specific allometric equations for predicting aboveground and

tree-components biomass (i.e. stem, branches, and foliage) using several tree variables and to test their accuracy and precision for biomass prediction.

Methods

Study area

Forests in Albania cover an area of 941957 ha (ANFI 2004) distributed over the whole territory. Within project "Assisted Natural Regeneration of Degraded Lands in Albania", the project area was stratified in four ecological zones based on climate, soil, elevation and geology (UNFCCC 2009). The first ecological zone comprises forest areas of Mediterranean shrubs and gariga, while the second ecological zone includes mixed oak forest stands (*Quercus* spp.) with hornbeam (*Carpinus betulus* L.) and other species. The third ecological zone includes European box (*Buxus sempervirens* L.) with common juniper (*Juniperus communis* L.), while the fourth ecological zone comprises alpine vegetation areas with dwarf juniper (*Juniperus nana* Miquel.). Our study was focused on the second ecological zone dominated by pure and mix oak forest stands (Fig. 1). A systematic 1 x 1 km geo-referenced grid using ArcGis program was established, where 19 intersections of this grid were located in the second ecological zone. Eight out of 19 intersections located in young natural forest stands were selected randomly from north-east to central part of Albania. The main species at the research sites were: Turkey oak (*Quercus cerris*), sweet chestnut (*Cas. sativa*), European hornbeam (*Car. betulus*) and manna ash (*Fraxinus ornus*). The study areas have a distinct Mediterranean climate; the mean annual temperatures vary across sites ranging from 8.8°C to 14.4°C (Table 1), with extreme minimum and maximum temperatures of -14°C to 6.2°C and 23.7°C to 30°C, respectively (Harris et al. 2014; www.climexp.knmi.nl). The rainfall time series indicated the presence of spatial and temporal variability in annual and seasonal precipitation sums at all sampling sites. Cinnamon and dark mountain forest soils, the most common in the sampling sites, are deep with moderate fertility as well as high clay content and strong alkalinity (FAO 2015).

Sampling methodology and procedure

Starting from the main grid (1 x 1 km), biomass sampling plots were established at the intersections of a 200 x 200 m grid. Five sample plots were randomly selected and trees inside circular sample plots (400 m²) were measured. Before conducting the destructive sampling, the diameter at breast height [DBH (cm)] of trees was measured by calliper with ± 1 mm accuracy in two perpendicular directions. Tree heights [H (m)], were measured by ultrasonic hypsometer Vertex III (Haglöf, Sweden). The position of each tree in relation to the plot centre was recorded by measuring the distance from the centre and tree azimuth. In total, three to five trees per sample plot were selected and felled at ground level during the period from June 2016 to October 2017. Fifty-eight sampled trees were partitioned into the three main components (stem, branches and foliage), whereas plant roots were not investigated. The fresh

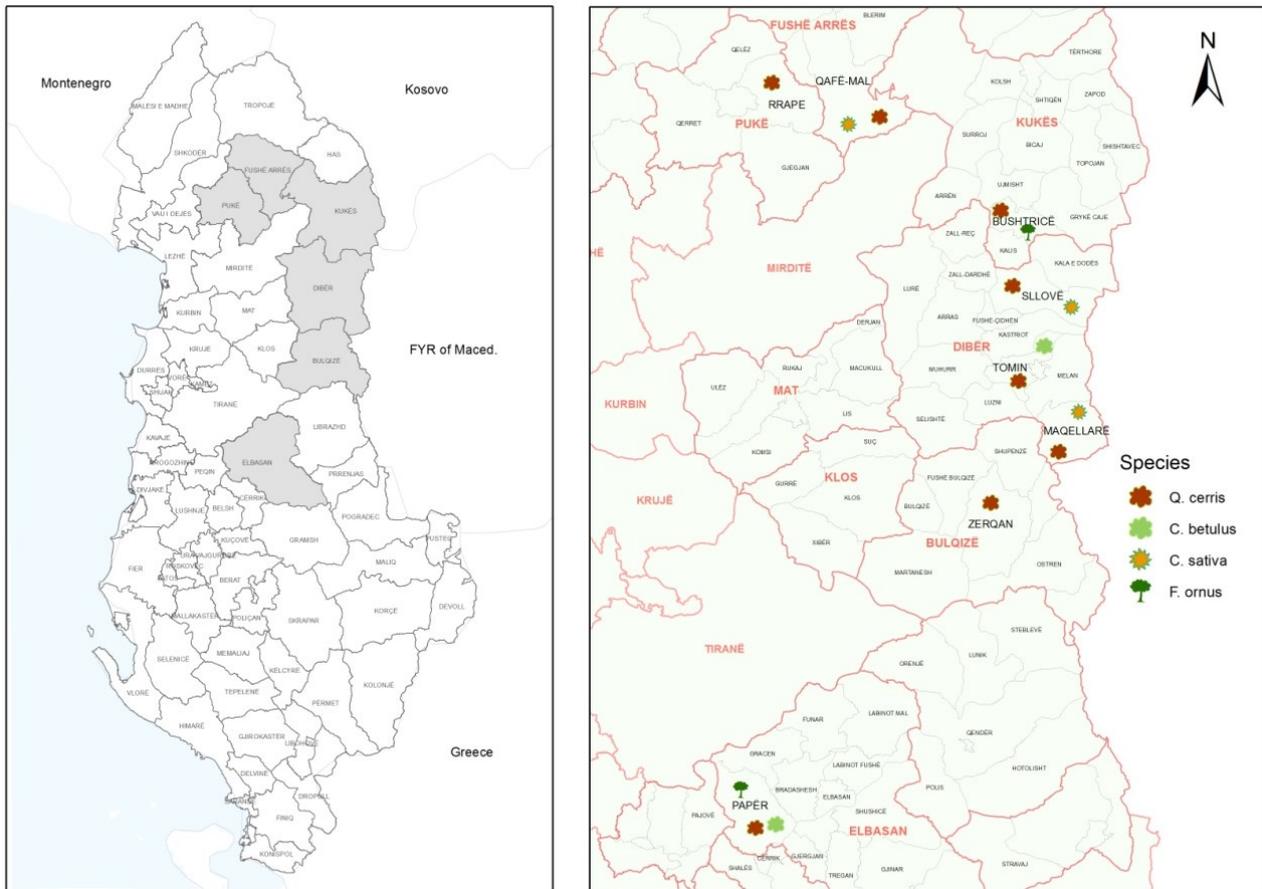


FIGURE 1: Location of the research sites and sampled species

weight of the stem, branches and leaves was weighed in the field using a precision scale with 50 kg capacity and accuracy $\pm 1\%$. The same procedure of destructive analysis was followed at all research sites. Three to five subsamples from each tree-component were stored in sealed plastic bags and then sent to the laboratory of the Faculty of Forestry Sciences in Tirana. Masses of stem discs (2–3 cm thick), branches and foliage samples were weighed. Subsequently, all samples were dried at 70°C temperature, until a constant weight was achieved. Tree-components biomass was assessed on the basis of fresh to oven-dry weight ratio (Eq. 1) of subsamples collected from sampled trees.

$$c = \frac{DW_{\text{subsample}}}{GW_{\text{subsample}}} \quad (1)$$

In those cases where the stem could not be weighed in the field, the diameter over bark was measured at 1-metre intervals from the stem base to the top to determine the log volumes using Newton–Riecke’s equation (Van Laar & Akça 1997). The total AGB of each tree was estimated by the sum of stem-wood, branches and foliage weights.

Development of biomass equations

So far, researchers have used a variety of regression models for estimating tree and tree-components biomass. Biomass data exhibit heteroscedasticity

because the variance differs across observations and for that reason the power function is considered an appropriate model in our study. We transformed the observed data using logarithmic transformation which is commonly used in dimension analysis studies to fit appropriate allometric equations. The following models with this form were fitted to the sampled tree data:

$$\text{Model 1: } \ln DW = \ln \beta_0 + \beta_1 \times \ln DBH \quad (2)$$

$$\text{Model 2: } \ln DW = \ln \beta_0 + \beta_1 \times \ln H \quad (3)$$

$$\text{Model 3: } \ln DW = \ln \beta_0 + \beta_1 \times \ln DBH^2 \times \ln H \quad (4)$$

$$\text{Model 4: } \ln DW = \ln \beta_0 + \beta_1 \ln DBH + \beta_2 \ln H \quad (5)$$

where DW is the aboveground dry biomass, or any of three components (stem, branches, foliage); DBH the diameter at breast height (cm); H the total tree height (m); and β_0 , β_1 and β_2 are the regression coefficients.

In the biomass models 2, 3 and 4, β_0 represents the scaling coefficient, while β_1 is the scaling exponent. The natural logarithm transformation linearises the allometric relationships, equalises the variance over the entire range of the dataset and provides comparability with results of previous studies (Zianis et al. 2005; Niklas 2006). However, the transformation introduces a systematic bias into the calculation, therefore to eliminate the bias, the final result is usually multiplied

TABLE 1. Site description including location, longitude (long), latitude (lat), elevation above sea level, mean annual temperature (MAT)* and mean annual precipitation sum (MAPS)*.

Site	Long (°E)	Lat (°N)	Elevation (m)	MAT (°C)	MAPS (mm)
Silove	20°24'16"	41°45'35"	750	9.6	959
Bushtrice	20°25'02"	41°53'34"	780	9.7	1010
Maqellare	20°28'03"	41°39'17"	850	9.3	1000
Zerqan	20°22'04"	41°30'48"	715	9.8	1008
Paper	19°57'42"	41°04'43"	160	14.4	1133
Tomin	20°25'20"	41°41'18"	647	9.8	1030
Rrape	19°57'02"	42°02'45'	805	10.1	1000
Qafe-Mali	20°06'28"	42°08'03'	1160	8.8	1157

*source: www.climexp.knmi.nl

by a correction factor (CF) calculated from the standard error of the estimate (SEE) of the regression (Sprugel 1983):

$$CF = exp \times (SEE^2 / 2) \quad (6)$$

Models were fitted using the regression procedure within the SPSS software (version 24) for Windows (IBM 2006) to relate aboveground tree mass to different measures of felled tree variables including diameter at breast height (DBH), tree height (H), and their combination (DBH² × H).

Biomass model fitting and evaluation

Model fitting was carried out in two phases. First, we eliminated non-significant models ($P > 0.05$) and those with low values of coefficients of determination ($R^2 < 0.5$). Secondly, in order to select the best equations for each species, several goodness-of-fit statistics were examined: the coefficient of determination (R^2), the root mean squared error (RMSE), the root mean squared prediction error (RMSPE) and the mean error (ME).

The coefficient of determination (R^2) indicates the proportion of the total variance explained by the model, whereas the other fitting statistics analyse the accuracy of the biomass estimates. The smaller their values, the better is the biomass model prediction performance (Zeng & Tang 2011). We also applied the reduced major axis (RMA) regression, because the observed data are subject to errors. RMA is more appropriate than standard ordinary least squares (OLS) regression when the independent variable is measured with error (Sokal & Rohlf 2012).

The tree variables (DBH or H) used to predict aboveground biomass are subject to natural variation and measurement errors (especially H) and this fact cannot be neglected (Niklas 2006; Kaitaniemi 2004). The scaling exponent of the RMA regression analysis was estimated using the equation 7:

$$b_{RMA} = \beta_1 / r_{yx} \quad (7)$$

where b_{RMA} is the scaling exponent based on the RMA model, β_1 is the scaling exponent estimated by the least

square model regression (OLS) applied to Eqs. (2–4), and r_{yx} is the correlation coefficient determined from the least square regression (Henry & Aarssen 1999).

Uncertainty of biomass models

Uncertainty is defined as the lack of knowledge of the true value which can be described as a probability density function characterising the range and likelihood of possible values of aboveground or tree-components biomass. It depends on the quality and quantity of applicable data as well as on the predictive ability of allometric equation to estimate biomass. We evaluated the reliability of the biomass models in terms of differences between the estimates obtained from allometric equation and the true value. For that reason, the biomass models developed for each species were used to predict the aboveground and tree-components biomass using sampled tree variables as predictors. Since the biomass equations were directly applied to sampled tree data of the investigated forest species, the components of the errors accounted for are the sampling and biomass model errors (assumed to be small). The key approach is that uncertainty in biomass estimates can be propagated from uncertainties in the biomass data and allometric equation prediction accuracy and its estimation is based on the error propagation equation (Bevington and Robinson 1992). Using this interpretation, a simple equation is used for the uncertainty of the sum, expressed in percentage terms:

$$U = \frac{\sqrt{(U_{st} \cdot DW_{st})^2 + (U_{br} \cdot DW_{br})^2 + (U_f \cdot DW_f)^2}}{(DW_{st} + DW_{br} + DW_f)} \quad (8)$$

where: U is the percentage uncertainty of aboveground biomass in the sum of the quantities (half the 95 percent confidence interval divided by the total (i.e., mean) and expressed as a percentage), DW_{st} , DW_{br} , DW_f are the uncertain quantities of stem, branches and foliage dry weight (kg) predicted by allometric equations, and U_{st} , U_{br} , and U_f are the percentage uncertainties associated with biomass estimates of tree-components (i.e., stem, branches, foliage).

This error propagation equation is applicable for estimation of the overall uncertainty derived by the summed quantities of tree-components biomass estimates by allometric models.

Results

Sampled tree information

The basic characteristics of sampled trees are shown in Table 2. The sampled trees ranged in age from 6 to 34 years, in DBH from 2 to 16 cm and in height from 1.90 to 9.83 m.

A total of 58 sampled trees were analysed in this study. The aboveground and tree-components biomass was computed for the four species (Table 3).

For *Q. cerris* the total tree biomass ranged between 1.07 and 56.34 kg, stem biomass from 0.84 to 34.65 kg, branch biomass from 0.19-17.84 kg, and foliage biomass between 0.04 and 3.84 kg. The relative contribution of

stem biomass to AGB in *Q. cerris* increased from 62% for large diameter classes to 78% for small diameter classes (Fig. 2). The proportion of branch biomass for this species increased from 18% for the small diameter class to 32% for the large diameter class. The ratio of foliage biomass versus AGB increased proportionally with DBH from 4% to 7%, indicating that leaf mass gives a marginal contribution in aboveground biomass. For *Car. betulus*, the AGB ranged from 0.72 to 21.80 kg, stem biomass from 0.40 to 13.12 kg, branch biomass from 0.23 to 6.25 kg, and foliage biomass from 0.09 to 2.43 kg. For this species, the proportion of stem increased from 55% for the small diameter classes to 60% for large diameter classes, while the contribution of branch biomass declined from 32% for the small diameter classes to 29% for large diameter classes. Regardless of the DBH values of *Car. betulus* trees, the relative contribution of foliage biomass was increased from 11.0 to 12.5%.

For *F. ornus*, the AGB per tree ranged from 1.83 to 12.09 kg, stem biomass from 0.96 to 7.20 kg, branch biomass

TABLE 2. Summary of information of sampled trees used to develop the biomass functions

Tree species	Number of trees	Age (years)	DBH (cm)	H (m)
<i>Quercus cerris</i>	18	8–27	2.00–15.00	2.75–9.83
<i>Carpinus betulus</i>	17	6–34	2.00–16.00	2.30–9.10
<i>Fraxinus ornus</i>	16	6–26	2.20–7.50	1.90–8.00
<i>Castanea sativa</i>	7	7–15	3.20–12.00	2.75–9.60

TABLE 3. Summary statistics of aboveground and tree-components biomass of felled trees (DBH, diameter at breast height (cm), H, total tree height (m), DW_{st} , stem dry weight (kg), DW_{br} , branch dry weight (kg), DW_f , foliage dry weight (kg), AGB, aboveground tree biomass (kg))

Species	Number of trees	Values	Tree variable					AGB
			DBH	H	DW_{st}	DW_{br}	DW_f	
<i>Q. cerris</i>	18	Min	2.00	2.75	0.84	0.19	0.04	1.07
		Max	15.00	9.83	34.65	17.84	3.84	56.34
		Mean	6.51	4.43	7.97	3.46	0.74	12.16
		SD	3.40	1.77	9.24	4.25	0.92	14.23
<i>Car. betulus</i>	17	Min	2.00	2.30	0.40	0.23	0.09	0.72
		Max	16.00	9.10	13.12	6.25	2.43	21.80
		Mean	6.94	5.28	3.85	3.31	1.23	8.40
		SD	4.67	2.25	2.82	2.90	1.08	6.71
<i>F. ornus</i>	16	Min	2.20	1.90	0.96	0.65	0.12	1.83
		Max	7.50	8.00	7.20	4.23	1.94	12.09
		Mean	4.48	4.55	3.24	2.23	0.61	6.07
		SD	1.85	1.69	1.86	1.09	0.53	3.38
<i>Cas. sativa</i>	7	Min	3.20	2.74	1.10	0.46	0.30	1.85
		Max	12.00	9.60	16.72	9.22	5.15	31.09
		Mean	7.74	6.20	9.65	5.68	2.82	18.15
		SD	2.76	2.07	4.90	2.89	1.59	9.30

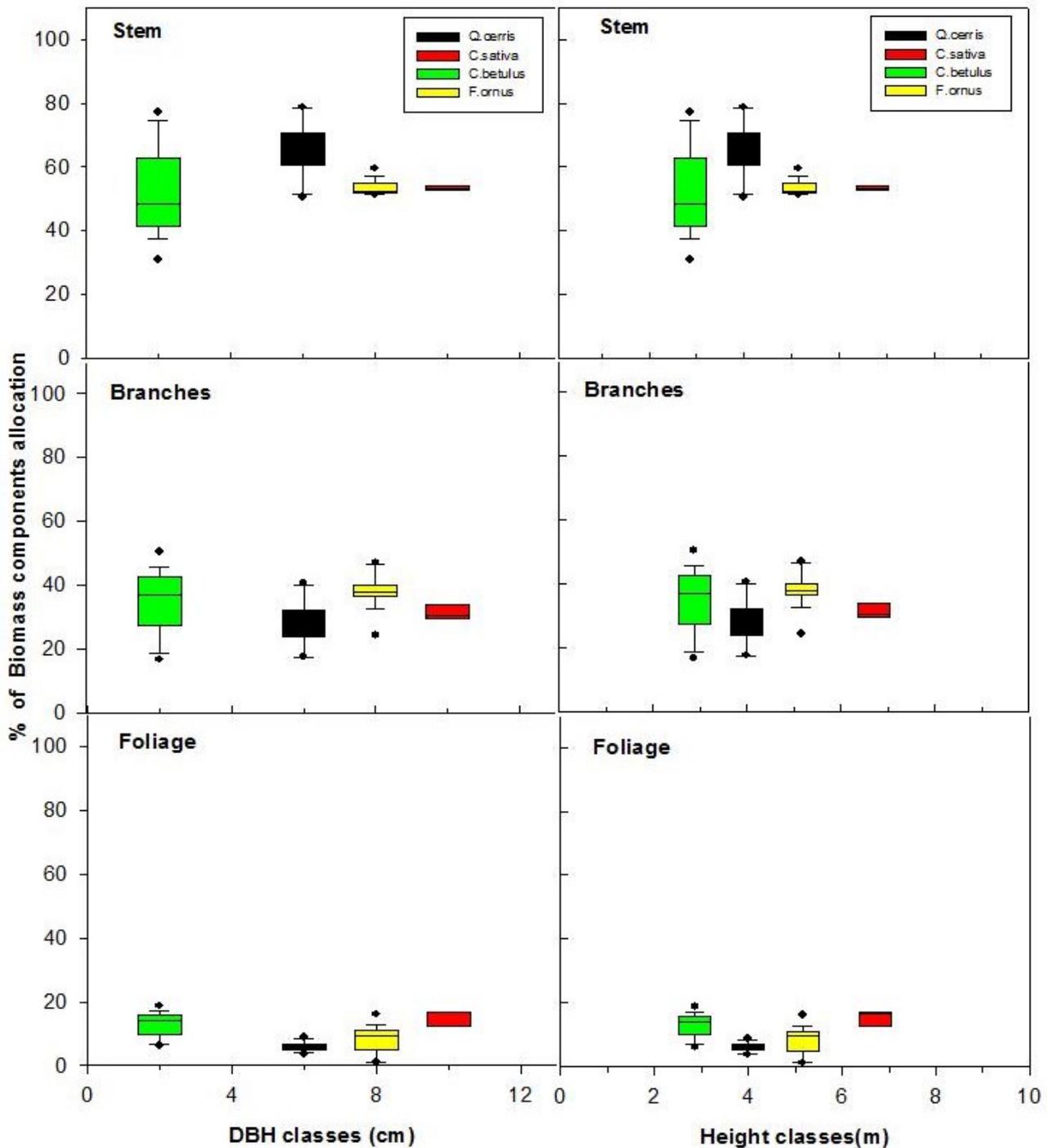


FIGURE 2: Box plots of biomass components (in percentages) by forest species estimated by field destructive sampling by DBH (1.3 m from the ground) and tree height (H) classes.

from 0.65 to 4.23 kg, and foliage biomass from 0.12 to 1.94 kg. For *F. ornus*, the proportion of stem biomass increased proportionally with DBH from 53% to 60%, while the branch and foliage biomass proportions were inversely related to sampled tree DBH. The proportion of branch and foliage biomass in small diameter classes were 41.3 % and 7.4%, whereas in large diameter classes they were 33.2 % and 16.1 % respectively.

For *Cas. sativa*, the aboveground biomass per tree

ranged from 1.85 to 31.09 kg, stem biomass from 1.10 to 16.72 kg, branch biomass from 0.46 to 9.22 kg and foliage biomass from 0.30 to 5.15 kg. For *Cas. sativa*, the proportion of stem biomass was 54 % and 59 % for small and large diameter classes, respectively. The relative proportion of branch biomass increased proportionally with DBH from 25% to 30%, but the proportion of foliage biomass was equal (16% of the AGB) for small and large diameter classes.

Frequency distribution of sampled tree variables

All species exhibited different frequency distributions of diameter at breast height, where the biggest tree number occurred in the 2, 4 and 6 cm diameter classes (Fig. 3). The sampled *Car. betulus* trees had DBH values across the full range of diameter classes, whereas the frequency distribution of other species was noticeably concentrated in the smallest DBH classes which ranged from 2 to 10 cm. Fifty-three trees comprising 94% of the total number of sampled trees in all species had a DBH \leq 6 cm. Regarding tree height, similar patterns in frequency distribution were observed for all species. A greater proportion of trees occurred in the mid-height range and a regular frequency decline of trees and a flattening of the curves towards the largest height classes was observed. We found a strong relationship between DBH and tree height (H) for all species (Table 4). The R^2 values of the applied linear models were always significant

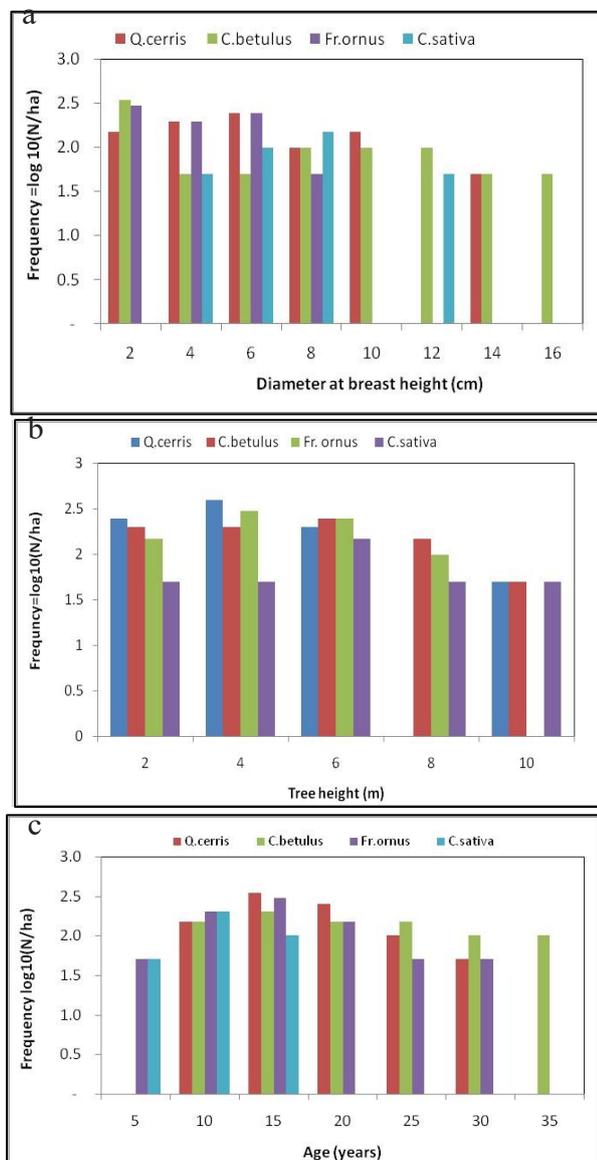


FIGURE 3: Log-transformed frequency distribution (number per ha) of diameter at breast height (a), height (b) and age (c) of all sampled trees. The x-axis values are the central values of each class.

($P < 0.05$), with a lower value in *F. ornus*, probably due to the characteristics of this species in young development phases.

For all studied species, age distributions were produced using 10-year age classes (Fig. 3c). In *Q. cerris*, *Car. betulus* and *F. ornus* we noticed a unimodal pattern in age distributions, typical for even-aged forest stands with few trees in young and old age classes. By contrast, in *Cas. sativa*, was observed the lack of a typical age distribution as well as the absence of mature trees in the forest stand.

Relationship between AGB and tree variables

Visual examination of the biomass data (Fig. 4) revealed the existence of a strong relationship between DBH (and/or $DBH^2 \times H$) and AGB on the logarithmic scale. The values of the correlation coefficient (r) between AGB and DBH varied between 0.92 ($P < 0.05$) for *F. ornus* and 0.96 ($P < 0.05$) for the other species. In addition, correlation between AGB and $DBH^2 \times H$ ranged from $r = 0.89$ ($P < 0.05$) for *F. ornus* to $r = 0.97$ ($P < 0.05$) for *Car. betulus* and remained in the same level for the two other species. The relationship between AGB and tree height was clearly weaker for all species, where the values of the correlation coefficient varied from 0.78 ($P < 0.05$) for *F. ornus* to 0.92 ($P < 0.05$) for *Cas. sativa*. There was also evidence of changing variance in AGB values among species associated with an increasing value from *Cas. sativa* to *F. ornus*.

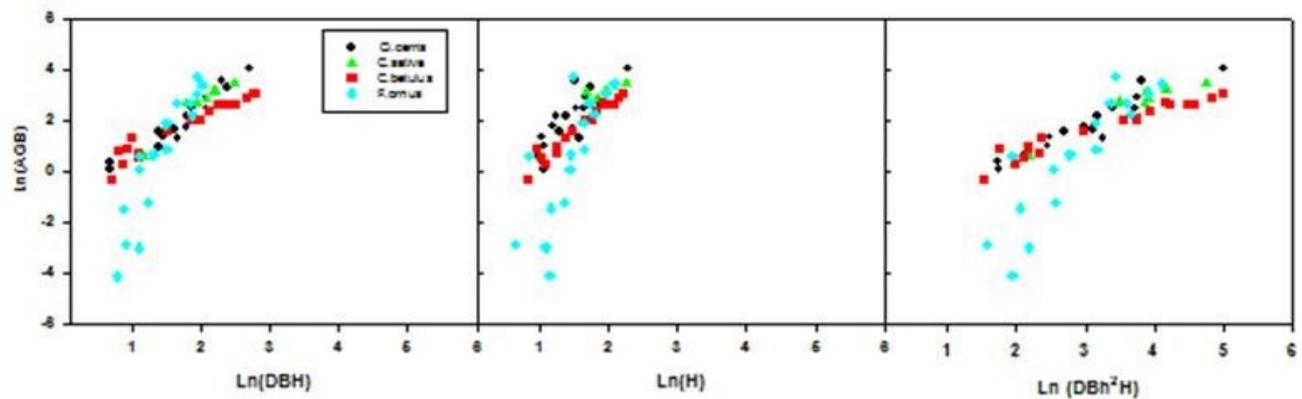
Biomass model evaluation

The coefficient estimates and goodness-of-fit statistics (i.e. R^2 , RMSE, RMSPE, ME) of all biomass models for the four species (after applying the logarithmic transformation) are shown in Table 5. These statistics were significant at $P < 0.05$ level, indicating that the fitted biomass equations performed well. The most reliable model fitting was obtained for aboveground and stem biomass, while the model fitting for foliage and branch biomass was less reliable with relatively lower R^2 , RMSE and high ME. In Model 1, which uses DBH as predictor, the values of the coefficient of determination (R^2) indicated that the fitted model explained between 75% and 97% of the observed biomass variance. We noted that R^2 values were different between biomass models, tree-components and across species. The lowest values of the coefficient of determination (R^2) were observed in Model 3, which uses the product of squared DBH with tree height as predictors, whereas the highest values occurred in Model 1 and Model 4. The R^2 values indicated that fitted models explained between 62% and 95% of the biomass variance per tree-component for all studied species with mean values of 75%, 79% and 82% of variance in foliage, branch and stem biomass, respectively, whereas the AGB equation explained on average 84% of the total observed variance. The inclusion of tree height (H) as independent variable in the Model 2, did not improve the goodness-of-fit statistics for biomass prediction of tree-components in *Q. cerris*, *F. ornus* and *Cas. sativa*.

The values of root mean square error (RMSE) varied among species and ranged between 0.18 and 4.46. All

TABLE 4. Relationship between DBH and H, R^2 and values of parameters $\ln\beta_0$ and β_1

Species	Dependent variable	Independent variable	R^2	Regression coefficients	
				$\ln\beta_0$	β_1
<i>Q. cerris</i>	DBH	H	0.802	0.326	0.467
<i>Car. betulus</i>	DBH	H	0.970	0.689	0.474
<i>F. ornus</i>	DBH	H	0.752	0.018	0.788
<i>Cas. sativa</i>	DBH	H	0.823	-0.091	0.683

FIGURE 4: Relationship between aboveground biomass (AGB) and diameter at breast height (DBH), tree height (H) and $DBH^2 \times H$ on a logarithmic scale for all studied species.

biomass models used in this study produced the most reliable estimates for AGB and stem wood biomass, whereas the least accurate estimates were derived for branch and leaves biomass. Most of the mean error (ME) values obtained from all biomass models were close to zero, indicating that all allometric equations except Model 2 provided accurate prediction of biomass. The values of this statistic obtained from biomass model 2 were far from zero, implying that allometric equations using tree height as a predictor performed the poorest. The dominance of positive values of ME indicated that the biomass models provided an underestimate of the aboveground or tree-component biomass, whereas in those cases when this statistic was negative, the biomass was overestimated. In this study we found differences between species in b_{RMA} values for relationships between AGB versus DBH, H and their combination ($DBH^2 \times H$) (Table 6). In the case of DBH, two out of four values for *Q. cerris* and *Cas. sativa* were significantly different from the others. In the allometric models using tree height (H) as biomass predictor, the b_{RMA} values decreased from *Q. cerris* to *F. ornus*. The lowest values of the scaling exponent of RMA regression were found in Model 3, which uses the predictor variable ($DBH^2 \times H$) for biomass estimate, whereas the highest values were obtained by Model 2, where total height was the only biomass predictor.

In contrast to the b_{RMA} values, correction factor scores (CF) showed less variability across tree-components and species. The largest differences in CF values were found between foliage biomass and DBH in Model 1 (Table 6). When tree height was the predictor, we observed less variation in CF values compared to DBH

and a wider range of CF values in stem (1.010–1.070) and AGB (1.010–1.060). The largest values of CF were obtained when DBH^2 and H were used as predictors in the allometric Model 3, whereas the largest values at species level were found in *F. ornus* and *Cas. sativa*.

Uncertainty of biomass models

In order to assess the bias of allometric equations in biomass prediction, the quantitative estimates of uncertainty were applied. The uncertainty estimates of the biomass models developed in this study ranged from 1 to 24.6%, depending on the species and tree-components (Table 7). The highest bias was found for biomass Model 4, while the best model based on uncertainty values was the allometric Model 3, where $DBH^2 \times H$ was the predictor variable. When considering the bias values of biomass models by forest species, the highest values were found in *Cas. sativa*, and the lowest values in *Q. cerris*. The uncertainty of biomass models increased from foliage to stem biomass indicating that stem biomass was estimated more accurately.

Discussion

Allometric equations

Four regression models developed to predict aboveground and tree-components biomass were evaluated for their performance and accuracy of the estimates. The multiple regression models which used DBH and total tree height (H) were the most accurate. The logarithmically transformed model using DBH alone as an independent variable performed better meeting the criteria of accuracy and biomass prediction

TABLE 5. The coefficients estimate and goodness-of-fit-statistics of log-transformed biomass equations (R^2 , coefficient of determination, RMSE, root mean squared error, RMSPE, root mean squared prediction error, ME, mean error) for Models 1–4.

Biomass		Species													
Com- ponent		<i>Q. cerris</i>							<i>Car. betulus</i>						
		Model coefficients			Goodness-of-fit statistics				Model coefficients			Goodness-of-fit statistics			
		$\ln \beta_0$	β_1	β_2	R^2	RMSE	RMSPE	ME	$\ln \beta_0$	β_1	β_2	R^2	RMSE	RMSPE	ME
1	Stem	-0.303	1.901	-	0.85	1.26	1.22	1.22	-0.474	1.371	-	0.96	0.94	0.88	1.67
	Branch	-0.599	1.918	-	0.82	1.69	1.65	1.26	-0.060	1.158	-	0.93	1.45	1.39	0.81
	Foliage	-0.959	1.895	-	0.75	2.74	2.72	0.77	-0.773	1.636	-	0.93	2.05	2.00	0.54
	AGB	-1.420	1.886	-	0.93	1.09	1.05	1.06	-1.148	1.633	-	0.97	0.33	0.26	0.34
2	Stem	-0.587	2.628	-	0.68	1.56	2.28	1.45	-0.617	2.263	-	0.95	1.33	1.31	1.31
	Branch	-0.819	2.650	-	0.72	2.02	1.93	1.93	-0.696	1.927	-	0.92	1.80	0.57	3.71
	Foliage	-1.113	2.615	-	0.71	3.13	3.07	1.12	-1.288	1.527	-	0.92	3.09	3.08	1.60
	AGB	-1.525	2.618	-	0.72	1.34	1.23	1.21	-1.527	2.688	-	0.96	1.25	1.23	1.20
3	Stem	0.610	0.027	-	0.65	1.33	1.06	0.76	0.217	0.017	-	0.74	1.59	0.95	1.03
	Branch	-0.204	0.026	-	0.61	1.34	1.13	0.77	-0.499	0.024	-	0.71	1.15	1.36	0.75
	Foliage	-1.751	0.026	-	0.62	1.34	1.12	0.77	-1.487	0.024	-	0.71	1.32	1.94	0.87
	AGB	1.056	0.026	-	0.65	1.32	1.08	0.76	0.767	0.020	-	0.75	2.29	1.11	-1.94
4	Stem	-1.933	1.798	0.224	0.93	0.72	0.64	0.64	-2.190	-0.084	2.162	0.90	0.26	0.18	-0.43
	Branch	-2.715	1.781	0.213	0.88	0.38	0.36	0.00	-3.471	0.195	2.386	0.92	0.36	0.29	0.01
	Foliage	-4.270	1.743	0.267	0.88	0.38	0.35	0.00	-4.433	0.216	2.346	0.91	0.36	0.29	0.00
	AGB	-1.467	1.760	0.227	0.93	0.28	0.24	0.04	-1.787	0.084	2.130	0.95	0.22	0.18	0.00

Biomass		Species													
Com- ponent		<i>F. ornus</i>							<i>Cas. sativa</i>						
		Model coefficients			Goodness-of-fit statistics				Model coefficients			Goodness-of-fit statistics			
		$\ln \beta_0$	β_1	β_2	R^2	RMSE	RMSPE	ME	$\ln \beta_0$	β_1	β_2	R^2	RMSE	RMSPE	ME
1	Stem	0.983	1.418	-	0.88	1.02	0.99	1.00	-1.600	2.153	-	0.96	1.37	1.36	1.43
	Branch	0.013	1.405	-	0.83	1.02	1.00	1.00	-0.693	2.066	-	0.94	2.03	2.00	1.82
	Foliage	-0.073	1.231	-	0.79	3.47	3.39	2.39	-1.131	2.328	-	0.87	0.81	2.21	2.18
	AGB	-1.610	2.748	-	0.92	3.06	2.42	1.36	-1.253	2.143	-	0.97	0.23	0.18	0.00
2	Stem	1.523	1.281	-	0.62	0.65	0.59	0.50	-0.262	2.253	-	0.81	1.24	1.20	1.54
	Branch	-0.248	1.234	-	0.48	4.46	4.43	2.40	-0.588	2.164	-	0.72	1.83	1.78	1.80
	Foliage	1.539	2.459	-	0.43	3.27	3.12	3.10	-1.030	2.423	-	0.79	2.10	2.07	2.10
	AGB	-1.540	2.459	-	0.66	3.46	2.84	1.34	-1.163	2.271	-	0.80	1.11	1.06	1.12
3	Stem	0.285	0.031	-	0.70	0.78	0.72	0.58	0.920	0.021	-	0.60	1.31	1.29	0.97
	Branch	0.004	0.029	-	0.75	0.86	0.68	0.63	0.255	0.023	-	0.54	1.37	1.44	0.99
	Foliage	-2.511	0.061	-	0.53	0.87	1.65	0.65	-0.412	0.023	-	0.61	1.29	1.35	0.94
	AGB	0.899	0.032	-	0.73	1.80	0.74	1.23	1.502	0.022	-	0.62	1.24	1.34	0.91
4	Stem	-0.948	1.503	-0.123	0.91	0.18	0.16	0.00	-3.516	1.517	0.732	0.94	0.19	0.16	0.01
	Branch	-1.156	1.027	0.256	0.89	1.16	1.15	-1.15	-3.176	1.939	0.456	0.91	0.74	0.73	0.64
	Foliage	-4.976	2.809	-0.078	0.67	0.76	0.63	0.00	-2.089	1.629	0.512	0.91	0.24	0.22	0.58
	AGB	-0.376	1.413	0.006	0.91	0.18	0.15	0.00	-1.643	1.709	0.519	0.93	0.21	0.17	-0.04

TABLE 6. Values of the scaling exponent (b_{RMA}) of reduced major axis regression and the biomass correction factor (CF) by species and allometric models used in the study

Model	Biomass component	<i>Q. cerris</i>		<i>Car. betulus</i>		<i>F. ornus</i>		<i>Cas. sativa</i>	
		b_{RMA}	CF	b_{RMA}	CF	b_{RMA}	CF	b_{RMA}	CF
1	Stem		1.280		1.020		1.170		1.056
	Branch	1.971	1.270	1.392	1.040	1.478	1.240	2.197	1.071
	Foliage		1.432		1.040		1.140		1.060
	AGB		1.030		1.030		1.210		1.060
Stem	1.070		1.020		1.010		1.051		
2	Branch	3.097	1.060	2.310	1.040	1.577	1.030	2.535	1.065
	Foliage		1.060		1.040		1.050		1.057
	AGB		1.060		1.040		1.010		1.056
	Stem		1.255		1.295		1.063		1.215
3	Branch	1.194	1.298	0.860	1.286	0.733	1.041	1.140	1.337
	Foliage		1.285		1.284		1.636		1.233
	AGB		1.243		1.159		1.060		1.247
	Stem		1.052		1.058		1.020		1.038
4	Branch		1.093		1.081		1.020		1.070
	Foliage		1.089		1.082		1.424		1.060
	AGB		1.050		1.029		1.021		1.046

TABLE 7. Uncertainty estimates of biomass models by forest species and tree-components

Model	Biomass component	Uncertainty (%) of biomass models by species and tree components			
		<i>Q. cerris</i>	<i>Car. betulus</i>	<i>F. ornus</i>	<i>Cas. sativa</i>
1	Stem	3.70	2.70	2.40	5.00
	Branch	4.00	3.00	3.40	6.00
	Foliage	4.50	3.50	3.50	6.60
	AGB	2.33	1.75	1.73	3.51
2	Stem	2.95	3.95	2.80	5.25
	Branch	3.24	4.25	3.40	5.70
	Foliage	4.15	4.70	3.70	6.80
	AGB	1.95	2.75	3.14	3.74
3	Stem	1.00	1.40	2.30	1.50
	Branch	1.30	2.80	3.40	2.70
	Foliage	1.70	3.20	3.50	5.40
	AGB	1.26	1.24	3.03	3.41
4	Stem	4.30	9.00	6.10	6.50
	Branch	6.10	17.00	7.80	10.30
	Foliage	9.00	17.36	22.80	24.60
	AGB	3.44	11.85	6.54	12.72

quality. As suggested by other studies, DBH is more accurately measured and therefore, is relatively more reliable when is used as single independent variable to develop biomass equation (Chave et al. 2005; Pastor et al. 1984; Mosseler et al. 2014) than other tree variables

such as tree height (Hosoda & Lehara 2010; Hunter et al. 2013). We observed that inclusion of tree height as single predictor variable did not improve the biomass model accuracy and this finding is consistent with that reported by Johansson (1999). In contrast, other

authors have found a significant improvement in model accuracy statistics when tree height was used as biomass predictor (Reed & Tome 1998), but this variable might be more useful for stand biomass estimates than for individual tree (Wang et al. 2013). In general, allometric models were more robust for stem and aboveground biomass than for branch and foliage biomass. Stem and aboveground biomass showed less variation than other tree components, and this may be related to the variation of local conditions, tree position in the canopy and sunlight availability.

The coefficients of log-transformed allometric biomass equations differed between species. We found that the scaling exponent (b_{RMA}) in regression equation varied among species and tree variables used as predictors, indicating that such models are species-specific and that the use of a common scaling coefficient for different species would lead to bias in biomass prediction. Our values of b_{RMA} (2.05 for DBH and 2.38 for tree height) differed from that used by West et al. (1999). These authors suggested that AGB should be scaled with DBH according to a universal value of scaling exponent ($b_{\text{RMA}} = 8/3$, i.e. 2.67), which depends on the tree architecture. West et al. (1999) assumed that using a universal value of b is not acceptable, especially when trees are growing under different environmental conditions. Although our sampled trees were growing under similar site conditions, the b_{RMA} value in allometric models developed in this study were different from those reported earlier by Zianis and Mencuccini (2004). Therefore, we conclude that the scaling exponent value is probably mainly affected by species traits and their growth during the juvenile period (Poorter et al. 2015). Pilli et al. (2006) reported three different scaling exponent values for juvenile ($b = 2.08$), adult ($b = 2.66$) and mature ($b = 2.51$) trees, whereas Niklas (2004) reported scaling exponents close to 1.0 in the case of young plants, while for large plants the exponents declined to below 0.75. In contrast, we found that tree age is associated with a decrease of b from 2.2 (age class 1–10 years) to 2.0 (age class 11–20 years). Moreover, we observed that the variability of the scaling exponent was lower for stem biomass than for branch and foliage biomass. The scaling exponent values varied across species and were different from those reported in a previous study. Thus, Blujdea et al. (2012) reported for the same allometric model a higher value for *F. excelsior* ($b = 3.04$) and a lower value for *Quercus* species ($b = 1.22$). The most reliable fitted model for estimation of aboveground biomass was the multiple regression function (Model 4). Based on the goodness-of-fit-statistics (R^2 ; RMSE; RMSPE), all our biomass models produced the most reliable estimates for AGB and stem biomass and the least accurate estimates for branch and foliage biomass. Most of the mean error (ME) values obtained from the biomass models were close to zero, indicating that all allometric equations except Model 2 could provide accurate estimates.

In Albania, as in other European countries, biomass estimates based on allometric equations and BEFs have been applied without any quantitative estimates of uncertainty. Therefore, information on the overall error

occurring with the use of biomass models is missing. The uncertainty estimates of the biomass ranged from 1.0 to 24.6%, depending on the species, tree components and biomass model applied. The uncertainty in the biomass estimates of *Cas. sativa* was high because the number of sampled trees used to generate allometric equations was low. By contrast, the lowest values of error were found in *Q. cerris* where the number of trees used to develop the biomass models was the highest. The uncertainty results indicate that the applicability of biomass models needs to be carefully evaluated, especially for the presence of bias, before using these in other geographic areas or in other countries.

Contribution of tree-components to total AGB

For all species studied, stem wood was the main contributor to the total AGB, followed by branches and foliage. The fact that the highest proportion of the AGB is allocated in the stem has been documented in previous studies, with proportions ranging from 50% to 92% for different species (Fonseca et al. 2011). Our results are within the same range varying from 52% (*Car. betulus*) to 65% (*Q. cerris*). The proportions of biomass of each tree component relative to AGB are consistent with those reported by Blujdea et al. (2012) for several broadleaved species growing in Romania. As expected, the proportion of biomass allocated to stems increased with tree size. As trees grow, age and size-related changes in tree shape and form alter the contribution of stem to whole-tree biomass increment (Bartelink 1998). In contrast, the relative contribution of branches and foliage to AGB decreased. We found that the biomass allocation to each tree-component differed among species, suggesting that their proportion relative to AGB depends on tree species in a mixed stand and stem density.

Allometric equation comparison with previous models

The literature and GlobAllomeTree repository (<http://globallometree.org>, Henry et al. 2013) contain numerous allometric equations for different trees species from the Mediterranean basin and other regions. Such allometric equations to estimate tree biomass have been developed for various species growing under different site conditions. We noticed that information about biomass equations for *Q. cerris* and *F. ornus* is missing in the GlobAllomeTree web platform (Table 8), and the equations developed in this study can enrich the database.

The allometric equations we developed used variables from 58 sampled trees growing in specific sites representing a small region. Some authors suggest that biomass regression equations developed for a site or region can be used to predict tree biomass in other places (Wirth et al. 2004). To verify that, we compared the results provided by Model 3 developed in our study with allometric models found in the GlobAllomeTree platform for *Car. betulus* and *Cas. sativa*. We could not do the same comparison for other species because our models differed from those found in this platform. The average values of AGB estimates from each allometric equation were compared using one-way ANOVAs. Means

TABLE 8. Allometric equations found in the GlobAllomeTree platform for species included in this study

Nr	Allometric equation	Number of trees	R ²	Location	Source
Quercus spp.					
1	Log Biomass = - 0.883 + 2.14·Log (DBH)	33	n.a.	Austria	Hochbichler, (2002).
2	Log AGB = - 3.1009 + 2.6996 Log(DBH)	18	1.0	England	Bunce (1968).
Car. betulus					
3	AGB = (0.0485×(DBH) ² × (H)) + 5.4	78	0.94	France	Hoellinger (1987)
4	AGB = (0.0325×(DBH) ² × (H)) + 6.7	78	0.94	France	Hoellinger (1987)
Cas. sativa					
5	AGB = (0.045×(DBH) ² × (H)) - 2.6	142	0.96	France	Hoellinger (1987)
6	AGB= (0.038×(DBH) ² × (H)) - 1.9	142	0.96	France	Hoellinger (1987)

were separated using Tukey HSD post-hoc test. In the case of *Car. betulus* we found that the mean values of biomass estimated from each model were significantly different ($F=7.162$; $P=0.002$), whereas in the case of *Cas. sativa* this difference was not significant ($F=1.739$; $P=0.204$). The results of the *post-hoc* test revealed significant differences in the mean AGB values estimated by our model for *Car. betulus* and those of Hoellinger (1987) (i.e. model 3 ($P=0.002$) and model 4 ($P=0.022$) in Table 8). In contrast, the results of the *post-hoc* test for *Cas. sativa* indicated no significant difference between the AGB estimated by our model and those of Hoellinger (1987) (i.e. models 5 ($P=0.212$) and 6 ($P=0.352$) in Table 8). This suggests that the use of allometric equations needs to consider factors such as species characteristics, age, soil fertility and climate (Madgwick & Satoo 1975). Another limitation in the use of biomass equations is the range of values of independent variables. Extrapolation below or above these ranges could lead to substantial differences between the true and predicted values (Zianis & Mencuccini 2003). Since allometric relationships between biomass and tree variables vary across species, tree size and age, the use of such models in other geographic areas is not suggested because this may lead to incorrect estimations (Harding & Grigal 1986; Wang et al. 2002; Zianis & Mencuccini 2003; Zabek & Prescott 2006). Finally, the biomass equations were developed on a relatively narrow DBH and H range and their application to large trees outside these ranges may be associated with larger errors in biomass prediction.

Conclusions

The dataset from 58 young trees representing four broadleaved species were used to develop allometric equations to estimate aboveground and tree-components biomass. The intention is to use these equations in biomass estimation for respective species in the framework of the National Forest Inventory. Stem and AGB biomass by DBH were the most accurately predicted, whereas the use of tree height as biomass predictor was associated with a decrease in prediction accuracy. The possibility of estimating young tree biomass by forest yield tables or forest inventory data

is limited due to the lack of biomass expansion factors. Since few biomass equations exist and there is a need for their development, further investigations in other ecological zones and other species should be conducted in Albania.

List of abbreviations

AGB, aboveground biomass; BEFs, biomass expansion factors; CF, correction factor; DBH, diameter at breast height; H, tree height; IPCC, Intergovernmental Panel on Climate Change; ME, mean error; RMSE, root mean squared error; RMSPE, root mean squared prediction error; UNFCCC, United Nations Framework Convention on Climate Change.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

NÇ and BTH undertook the fieldwork and data collection, ET did the data processing, statistical analysis, and EI wrote the manuscript. All authors read and approved the manuscript.

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