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ALLOMETRIC RELATIONSHIPS FOR THE ESTIMATION OF DRY MASS OF ABOVEGROUND ORGANS IN YOUNG HIGHLAND NORWAY SPRUCE STAND

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Abstract

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This study falls into site-specific studies (here in the Drahanská vrchovina Highland) focusing on the determination of allometric relationships between the stem dendrometric and biomass parameters in young Norway spruce stands. The total aboveground biomass (TB) of a sampled tree with 14.9 m in height and 15.5 cm in stem diameter at 1.3 m (DBH) averaged to 110.3 kg. The stem biomass participated on average by 54%, branch biomass by 24% and needle biomass by 22% on the TB of the sampled spruce tree. TB of the tree and the biomass of individual aboveground tree organs were predicted with the highest accuracy (over 91%) from DBH or a stem diameter at the one tenth of the tree height using allometric-power functions. The stem diameters up to 70% of the relative tree height predicted TB accurately (over 95%) as well. The biomass expansion factors based on the stem volume expansion to TB of the tree, as well as the biomass of each of the aboveground tree organs did not show functional dependency on DBH.

allometry, biomass expansions factors, biomass, *Picea abies*

Forest biomass plays a key role in sustainable management and it has been identified as an important carbon sink (Brown, 2002; Körner, 2005) as the forest biomass contains approximately 80% of all aboveground terrestrial carbon (Goodale *et al.*, 2002). Thus, the knowledge about the development of aboveground biomass over the entire life cycle of a forest is required for an accurate quantification of biomass production and carbon pools. The uncertainty of biomass expansion factors, commonly used for expansion of forest inventory data, is seen as one of the major gaps in carbon accounting on regional and/or national level (Lehtonen *et al.*, 2007).

Allometry describes relations or mutual proportions between different plant organs. As measuring of plant biomass in field conditions is laborious and extremely time consuming, empirical relationships or models are used to estimate the aboveground biomass from in-field easily measurable biometric variables such as stem diameter at a breast-height, i.e. at 1.3 m above the ground surface (DBH), or a tree height (H) (e.g. Zianis and Mencuccini, 2004; Pilli *et al.*, 2006; Pokorný and Tomášková, 2007).

However, allometric equations for biomass estimation have been derived for numerous tree species across geographically and ecologically different regions. These studies have revealed considerable difficulties and uncertainties due to inconsistency in methodology and definitions. Furthermore, site-specific factors, such as varying tree density, soil moisture, nutrients, light, topography, and disturbance, affect forest allometry (e.g. Tatarinov and Cienciala, 2009). For general applicability of the allometric relationship a meta-analysis based on many site specific studies is necessary to be carried out (e.g. Wirth *et al.*, 2004 for *Picea abies*).

Only few studies focus on Norway spruce allometry in the Czech Republic (for juvenile trees – Pokorný and Regner, 1998; Pokorný and Tomášková, 2007; for adult trees – Vinš and Šiška, 1981; Vyskot, 1981; 1990, Černý, 1990; Svoboda *et al.*, 2006a, b). This study partially fills that lack and falls into site-specific studies as it is focusing on the determination of allometric relationships in a chosen young highland Norway spruce stand. Obtained allometric relationships will form the inputs into eco-physiological studies and growth or carbon uptake models. Furthermore, this study helps to cover a lack of information necessary for the calculation of a carbon sink in young ("Kyoto") spruce forests in Central Europe.

MATERIALS AND METHODS

Locality and stand description

The investigated stand is located at the study site of Rájec – Němčice (the Drahanská vrchovina Highland) (Table I).

In spring 1978, the Norway spruce (*Picea abies* [L.] Karst.) stand was artificially established by reforesting a clear-cut area which originated after felling the mature spruce stand. In the next year, interplanting by three-year-old seedlings was done again in a half of the stand area. From the typological point of view, the presented spruce stand is classified as *Abieto-Fagetum mesotrophicum* with *Oxalis acetosella* (5S1) (Plíva, 1987). In studied stand following thinnings were done: about 11–13 % of trees were removed in 2002, about 6 % of stand basal area was removed in 2005 and 2010, resp. Some dendrometric characteristics of the studied spruce stand are shown in Table II and Fig. 1.

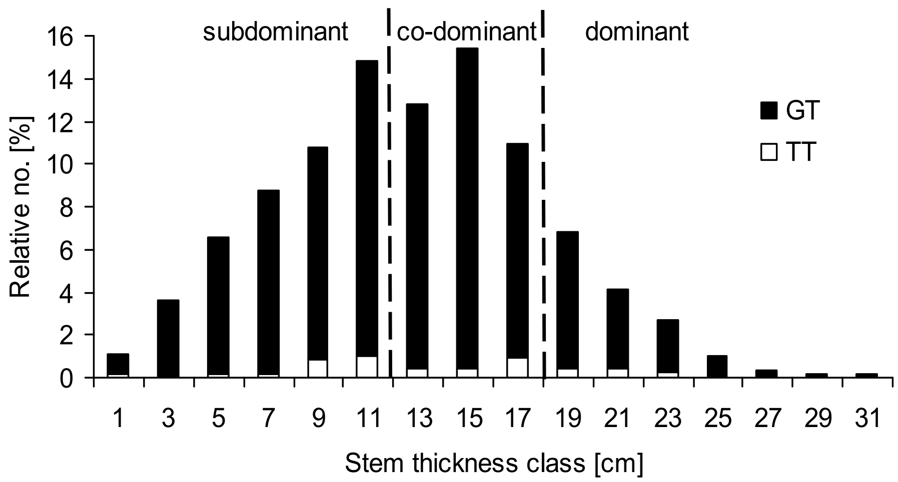
I: *Description of the study site of Rájec – Němčice*

Geographic coordinates	**49°29´ N, 16°43´ E**
Altitude	610–625 m a. s. l.
Geological subsoil	acid granodiorite
Soil classification (soil type)	modal oligotrophic Cambisol (KAmd')[1)] Cambisols (CM)[2)] with moder form of surface humus[3)]
Climate characteristics	mean annual air temperature 6.5 °C, mean annual sum of precipitation 717 mm[4)]

[1)] Němeček *et al.*, 2001, [2)] WRB, 2006, [3)] Menšík *et al.*, 2009, [4)] Hadaš, 2002

II: *Brief characteristics of the studied spruce stand in the end of the growing season 2008*

Stand density [tree.ha^{-1}]		**2 700**
Tree origin on the studied plot [%]	planting	56
	natural regeneration	44
Tree height [m]	mean value	13.6
Stem diameter at breast height [cm]	mean value	12.7



1: *Tree representation per stem thickness classes in the studied plot. GT denotes growing trees and TT denotes trees marked for thinning (5 % of GT in summer 2010). Dashed lines separate three groups of trees with different canopy strata occupation.*

Experimental design

For the allometric analysis, 7 randomly chosen representative trees from each of the tree-groups (Fig. 1), it means 21 trees in total, were harvested before the thinning in summer of 2010. Under field conditions, the total tree height (H), the living crown length (Hc), the stem diameter at the breast height (i.e. 1.3 m above the ground surface; DBH) and stem diameters (D) at the each 1 m distance along stem upward from the stem base were measured. Stem diameters at relative tree heights (i.e. in step of 1/10 of H) were derived as distance weighted mean values from the nearest up- and down-measured D values. In laboratory, dry needle (LB) and branch (BB) biomass per each 1m strata (include whorl branches and upward inter-node ones; except the lowest canopy differentiable strata, which include all downward residual branches) was determined after a field cutting of fresh branches. After a fresh weighting of the strata's branches, one representative whorl branch was chosen and weighted separately. After its drying at 80 °C to the constant weight (half-daily repeated) and splitting into needles and branches, dry needle and branch biomass of the representative branch was determined (KERN 400-47N with accuracy 0.1g). Weight proportions between fresh and dry biomass of branch and needle biomass were used for the calculation of the whole strata dry branch and needle biomass, respectively. The stem volume (V) was obtained as a sum of individual stem segments volumes, when each of the stems was divided into 1 m long segments. Thus, the total stem volume was estimated as a sum of all the stem segments volume values. A cylindrical shape of each stem segment was assumed. Stem dry biomass (SB) was estimated as a sum of dry weights of two stem segments, when their fresh weight was reduced by fresh (Wf) to dry (Wd) weight ratio of small trunk blocks cut out from the middle part of each of the 2m-long segments. Therefore, the relative stem water content (Wc) (Fig. 2) could be estimated along the stem vertical profile as:

$$Wc = 100 - (Wd/Wf) \times 100. \qquad \text{(Eq. 1)}$$

Stand-level biomass expansion factors (BEFs) that convert stem volume directly into the individual aboveground tree organ dry biomass were calculated as a simple ratio:

$$BEFi = Bi/V. \qquad \text{(Eq. 2)}$$

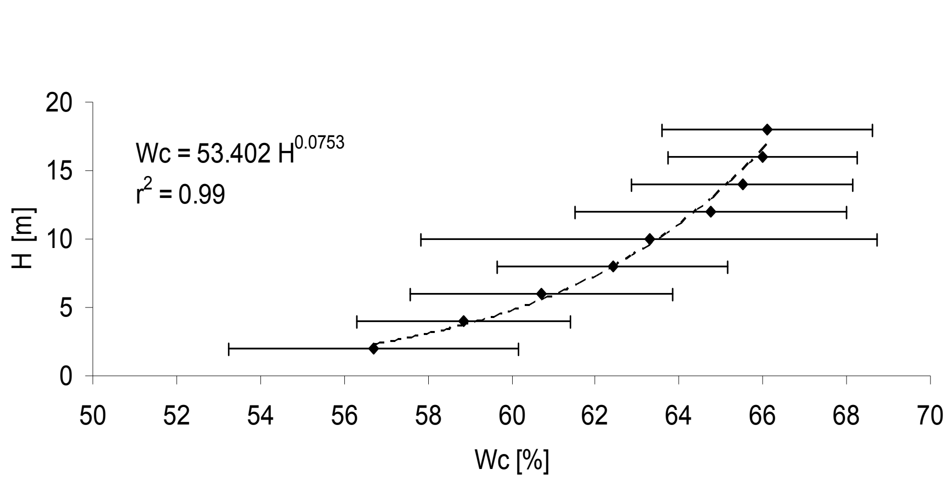
Bi is dry biomass of i- tree component and V is stem volume.

Statistical processing of data

Normal-like distribution of data was presumed due to a low number of sampled trees and their uniform selection across the stem diameter classes. Therefore, mean and standard deviation values were calculated using Excel. In the Excel, different regression functions to seek the simplest allometric equation were tested. The function with the highest regression coefficient was chosen and presented in this publication.

RESULTS AND DISCUSSION

The average sampled tree (± SD) with the 14.9 m (± 2.3) in H and 15.5cm (± 3.5) in DBH had the total aboveground biomass of 110.3 kg (± 56.2) that comprised of 60 kg (± 29.4) of stem biomass, 26.6 kg (± 15.0) of branch biomass and 23.7 kg (± 12.9) of leaf biomass. Therefore, stem biomass participated on average (± SD) by 54 % (± 4 %), branch biomass by 24 % (± 3 %) and needle biomass by 22 % (± 2 %) on the total aboveground dry biomass of the sampled spruce tree. These proportions are comparable with the results from an age-related young mountain forest stand in the Beskydy Mts. (Pokorný and Tomášková, 2007) or even from Norway spruce grown on abandoned farmland in Sweden (Johansson, 1999). The tree organ-biomass



2: *Changes of mean stem wood relative water content (Wc) with tree height (H). Whiskers denote standard deviation (n = 21).*

proportions relate to tree genetic predispositions (Kilpeläinen *et al.*, 2010), stand development phase (i.e. age), competition, health status and growing conditions (e.g. Johansson, 1999; Kantola and Mäkelä, 2006; Svoboda *et al.*, 2006a, b). Specifically, during the first ten-twenty years of growth, these proportions change extremely; stem and branch biomass increase, whereas root and needle biomass decrease (e.g. Somogyi *et al.*, 2007, Pajtík *et al.*, 2008). In comparison to middle-aged and mature stands, stem biomass increases continuously, whereas branch and leaf mass do not vary so much (Kantola and Mäkelä, 2006).

DBH as one of many dendrometric parameters, falls into easily measurable ones, which are widely used in a forest inventory. Mutual correlations among stem and crown dendrometric parameters can be found due to mechanical and physiological interconnections (e.g. Kantola and Mäkelä, 2006). These correlations are species and site specific as they are affected by many variables, from which the age (Pilli *et al.*, 2006) and the tree competition play one of crucial roles (Pokorný and Tomášková, 2007; Teobaldelli *et al.*, 2009). In presented data, the logarithmical function described stem diameter at the breast height (DBH) to tree height (H) relationship the most precisely ($r^2 = 0.79$, n = 21):

$$H = 8.1161 \ln(DBH) - 7.0949. \quad \text{(Eq. 3)}$$

Allometric relationships between easily measurable dendrometric parameters, such as DBH, H, HC or V as derived parameter and total tree biomass or biomass of tree components, take the form of different functions, i.e. from linear throughout logarithmically transformed to exponential or power functions with one or many covariates (e.g. Wirth *et al.*, 2004; Muukkonen, 2007).

The highest regression coefficients (Table III) between the stem diameter at the breast height (Fig. 3A) or the tree height (Fig. 3B) and biomass of aboveground tree components were found for power and/or exponential functions. Presented regression coefficients showed that DBH is a better predictor of all aboveground tree components biomass comparing to H. Additionally, HC compared to H correlated with DBH and biomass tree components less.

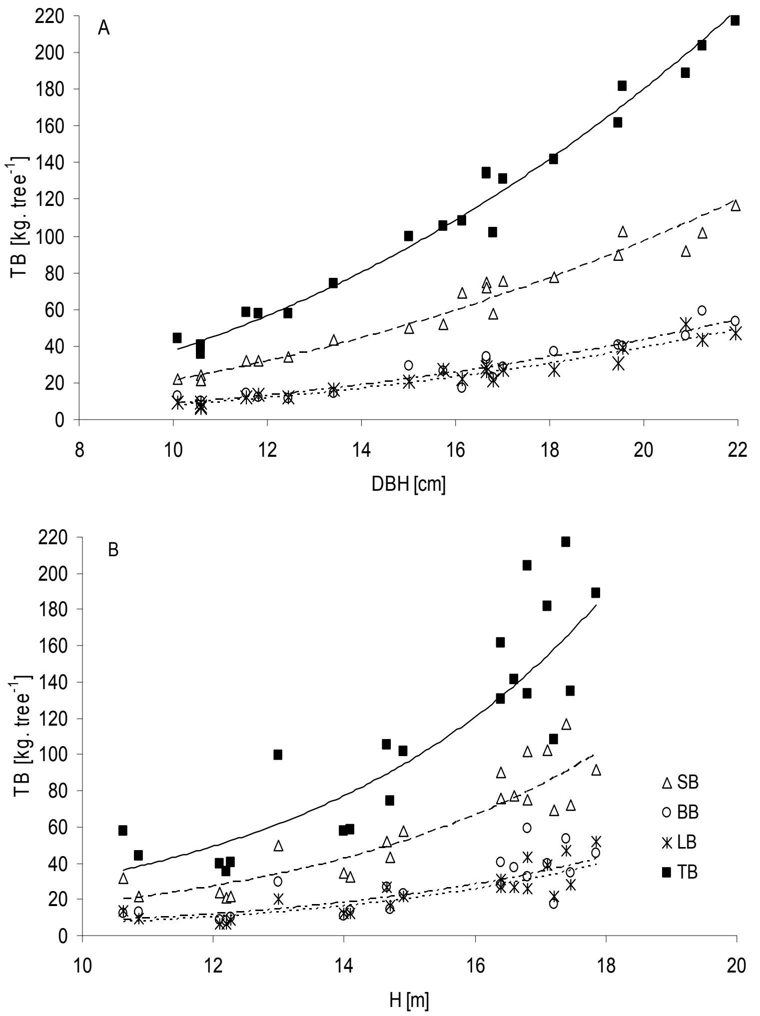
If we took the stem diameters (D) into the relation with TB at the different relative tree height positions (Fig. 4), then the total aboveground biomass could be predicted with more than 95% accuracy up to 7/10 of H, afterwards the regression coefficients rapidly decreased with the tree height (0.85 for D in 8/10 of H, 0.68 for D in 9/10 of H). However, the recalculated or directly measured stem diameter at a relative tree height confirms general application in allometry better than DBH measured at a fixed tree height (Fehrmann and Kleinn, 2006), in our fitted dataset DBH and D at 1/10 of H predicted total aboveground as well as biomass of individual aboveground tree organs with almost the same accuracy (98 % of TB, 97 % of SB, 91 % of BB and 94 % of LB). As 1/10 of mean sample tree height was on average at 1.49 m and measuring height for DBH at 1.3 m (i.e. 11.5 % of H) above the ground, DBH and D1/10 nearly corresponded. For that reason, also the stem form factor describing a stem shape did not differ when based on DBH or D at 1/10 of H, and it averaged to 0.49 ± 0.02 (± SD, n = 21). Vallet *et al.* (2006) presented that the form factor highly varied in stems with low circumference (ca up to 120 cm) and after that, it continuously decreases with the stem diameter (or circumference) increase.

Behind allometric relationships, the stand-level biomass expansions factors (BEFs) could predict directly throughout a conversion of the stem volume the individual aboveground tree organ dry biomass (Fig. 5). BEFs for the leaf and branch biomass estimation stayed nearly constant within the interval of harvested trees DBHs. BEFs for the stem and total aboveground biomass slightly decreased with increasing DBH. These results related to the stand age and the sampled trees DBH interval (Lehtonen *et al.*, 2007; Teobaldelli *et al.*, 2009) and agreed with these presented by Lehtonen *et al.* (2004), when foliage and branch BEFs show similar trends with increasing stand age. However, the trends of BEFs with increasing DBH were showed, these were found under statistical significance (Fig. 5). A thinning can disrupt continuity in a functional relationship between BEFs or the biomass production and the stand age (Johansson, 1999; Teobaldelli *et al.*, 2009).

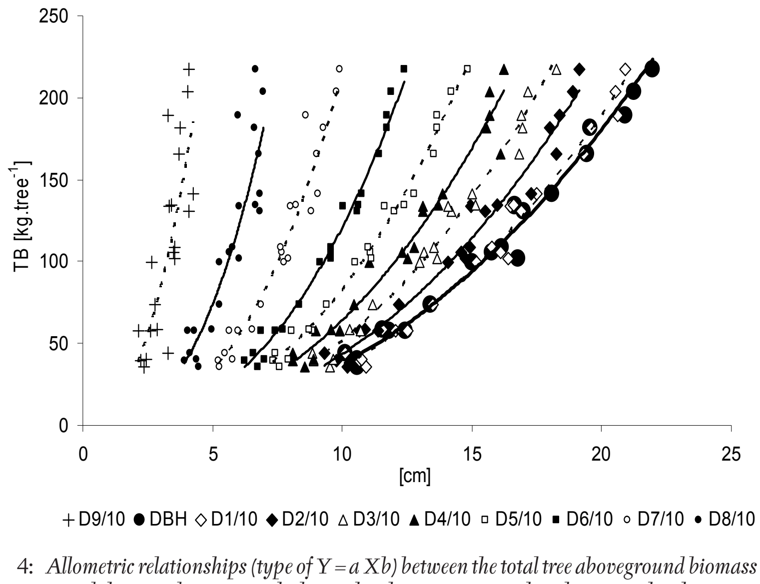
Average BEFs (± SD) for the stem volume conversion into aboveground tree organs biomass were as following: 0.75 (± 0.11) for TB, 0.41 (± 0.05) for SB, 0.18 (± 0.04) for BB and 0.16 (± 0.03) for LB.

III: *Parameters (a, b) of the best data fitted power and exponential functions (Eq. type) describing relationship between the stem diameter at the breast height (A part of Table) and tree height (B part of Table) and the total aboveground biomass (TB) or its components (SB – stem biomass, BB – branch biomass, LB – leaf biomass). r^2 – regression coefficient, n = 21.*

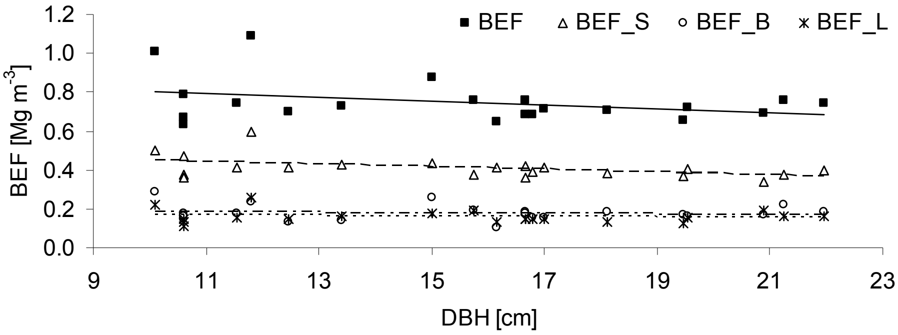
Eq. type	**A: $Y = a X^b$**			**B: $Y = a^{bX}$**		
Coef.	a	b	r^2	a	b	r^2
TB	0.2002	2.2718	0.98	3.3678	0.2238	0.79
SB	0.1325	2.2035	0.97	1.8519	0.2238	0.83
BB	0.0326	2.3454	0.91	0.8553	0.2186	0.66
LB	0.0326	2.3665	0.94	0.6549	0.2292	0.74



3: *Total tree aboveground biomass (TB) compartments according to the stem diameter at the breast height (DBH, panel A) and tree height (H, panel B). Fitting curve equations and coefficients of determination are described in Table III.*



4: *Allometric relationships (type of Y = a Xb) between the total tree aboveground biomass (TB) and the stem diameter at the breast height (DBH) or at the relative tree height (D per each 1/10 of tree height), n = 21*



5: *Biomass expansion factors for an estimation of the total aboveground biomass (BEF), stem (BEF_S), branch (BEF_B) and leaf (BEF_L) biomasses and their dependence on the stem diameter at the breast height (DBH). The linear fittings are not statistically significant.*

SUMMARY

Only few studies focus on Norway spruce allometry in the Czech Republic. This study partially fills that lack and falls into site-specific studies as it is focusing on the determination of allometric relationships from a chosen young highland Norway spruce stand in the Drahanská vrchovina Highland. The total aboveground biomass (TB) of a sampled tree with 14.9 m in height and 15.5 cm in stem diameter at 1.3 m (DBH) amounted to 110.3 kg. The stem biomass participated on average by 54%, branch biomass by 24% and needle biomass by 22% on the TB of the sampled spruce tree. TB of the tree and the biomass of individual aboveground tree organs were predicted with the highest accuracy (over 91%) from DBH or the stem diameter at the one tenth of the tree height. The stem diameters up to 7/10 of the relative tree height predicted TB of tree accurately (over 95%) as well. The biomass expansion factors based on the stem volume expansion to tree TB, as well as the biomass of each of the aboveground tree organs did not show a statistically significant relationship between DBH.

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