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IS ALLOMETRY FOR ABOVEGROUND ORGAN'S MASS ESTIMATION IN YOUNG NORWAY SPRUCE STANDS AFFECTED BY DIFFERENT TYPE OF THINNING?

Jan Krejza, Radek Pokorný, Irena Marková

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Abstract

KREJZA JAN, POKORNÝ RADEK, MARKOVÁ IRENA: *Is allometry for aboveground organ's mass estimation in young Norway spruce stands affected by different type of thinning?* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 6, pp. 1755–1761

The study focuses on determination of aboveground organ's mass using allometric relationships in Norway spruce stands with different type of thinning management – thinning from below (TfB) and thinning from above (TfA). Allometric functions for predicting of stem, branch, leaf and total aboveground mass were estimated from measurements of basic stem dendrometric parameters. The highest adjusted regression coefficients were found between DBH and biomass of aboveground tree organs (adj. r^2 ranged from 0.91 to 0.98). Multiple linear regressions provide correlation coefficients r^2 from 0.88 to 0.98 for TfB and from 0.90 to 0.98 for TfA. The presented results showed no effect of different type of thinning application on tree allometry.

allometry, mass, Norway spruce, thinning

Pure spruce stands have considerable function in European forest economy. Questions of silviculture practices and carbon sequestration ability of forest stands are discussed very often. After Kyoto protocol (UNFCCC, 1997) it is necessary to obtain a data about increment of forest stands mass in order to specify potential ability of forest stands to sequester atmospheric carbon and contribute to reduction of increasing atmospheric CO_2 concentration. Therefore, forest ecosystems play very important role in the global carbon cycle. During growing season, CO_2 from the atmosphere is consumed by vegetation and stored as a plant mass (Losi *et al.*, 2003; Phat *et al.*, 2004). Accurate knowledge about the spatial distribution of forest mass is important for calculating the sources and sinks of carbon (Houghton, 2005).

However, the carbon stocks in aboveground forest biomass can be derived from continuous forest inventories (Goodale *et al.*, 2002), commonly stem wood volume of merchantable wood only (i.e. over 7 cm at diameter in CR) calculated using growth or yield tables is a basic result. Other parameters such as wood density, biomass expansion factor or specific allometric relationships are necessary for accurate biomass or carbon content evaluation in plants (Huxley and Teissier, 1936). Many studies were conducted to develop simple biomass equation that relates dry biomass of forest tree to its biophysical variables (e.g. DBH, H etc.; Aboal *et al.*, 2005; Brown, 1997; Ketterings *et al.*, 2001; Zianis and Mencuccini, 2004; Pokorný and Tomášková, 2007; Marková and Pokorný, 2010). A considerable amount of literature has sought to find the 'best' biomass regression model for single-species forests (c.f. Wirth *et al.*, 2004). Many from these authors concluded that allometric equations are site specific. Site specificity is given by soil, climate and man-induced management.

Thus, the differences between allometric relationships for aboveground organs mass of Norway spruce estimation in stands with application of the two different types of thinning (i.e. from below and from above), were tested in the presented study.

MATERIALS AND METHODS

This study follows the methodology of Marková and Pokorný (2010) focused on allometric relationships estimation in young Norway spruce (*Picea abies* (L.) Karst.) stand (Tab. II). The measurements were taken in the Rájec-Němčice Long-term Experiment Station, which is situated in a geographical complex of the Drahanská vrchovina upland about 30 km far from Brno to the north direction (Tab. I).

The Norway spruce stand was artificially established by reforesting a clear-cut area. The forest type is characterized as *Abieto-Fagetum* mesotrophicum with *Oxalis acetosella* (Nutrient-medium Fir-Beech, 5S1; Plíva, 1987). The stand was divided into 4 quadrants (A, B, C, D) with an area of 50 x 50 m. Each quadrant was divided into the next four plots with an area of 25 x 25 m (A1–A4, B1–B4, C1–C4, D1–D4) differing in the following management approaches: i) thinning from below (TfB), ii) thinning from above (TfA), iii) sanitary thinning (St) and iv) free of management application (FM). The thinning were applied in 2002, 2005 and 2010. Thinning from above (TfA) removes trees from middle and upper crown classes to open canopy to favor development of most promising trees. Dominant trees are mostly removed some dominant and intermediate trees. In thinning from below (TfB), trees are removed from lower crown classes. This kind of thinnig simulates and accelerates natural processes. Selected dendrometric characteristics of the studied stands are shown in Table II.

Experimental design

The 21 trees were chosen in total for the allometric analysis. More precisely, 8 trees were selected from plot TfB and 13 trees from plot TfA. All trees were harvested before the thinning in summer of 2010. Trees from plot TfA were trees from middle and upper crown classe and trees from plot TfB were trees from lower crown classes. This selection is uneven due to the compliance thinning regime in each thinning plots. Under field conditions, the total tree height (H), the living crown length (Hc), stem diameter at the breast height (i.e. 1.3m above the ground surface; DBH) and stem diameters (D) at the each 1m distance along stem vertical profile upward from the stem base were measured. Branch biomass (BB) per each meter strata (including whorl branches and inter-node ones; except the lowest canopy differentiable strata, which include all downward residual branches) was determined after a field cutting of fresh branches in laboratory. From each strata a representative branch of average length was chosen for detail analysis. After drying at 80 °C to the constant weight the representative branch was split into needles and branches. Branch biomass of the representative branch was determined by weighting (KERN 400-47N with accuracy 0.1 g). Weight proportions between fresh and dry biomass of branches were used for the calculation of the whole strata branch biomass. The stem volume (V) was obtained as a sum of individual stem sections volumes, when stems were divided into 1m long sections (strata) and the last section rest at tree top. The total stem volume was estimated from the known length and diameter measured in the middle part of the section, when section is assumed to be of the cylindrical shape. The stem mass (SB) was estimated on the basis of stem volume and stem-wood density. Stem wood density was obtained from stem wood blocks analysis, when they were taken out from middle part of each stem strata.

To evaluate the tree position within the plot, tree competition index (CI) was calculated using the formula presented by Avery and Burkhart (1983). For the evaluation of the tree position 8–10 trees were taken into account.

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

Geographic coordinates	49°29'31" N, 16°43'30" E
Altitude	610–625 m a.s.l.
Bedrock	acid granodiorite[1)]
Soil classification (soil type)	modal oligotrophic Cambisol (KAmd)[2)] Cambisols (CM)[3)] with moder form of surface humus[4)]
Climate characteristics	mean annual air temperature 6.5 °C, mean annual sum of precipitation 717 mm[5)]

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

II: *Dendrometric characteristics (Mean ± Standard deviation) of studied stands before the thinning impact in 2010. TfB- plot with application of thinning from below, TfA- thinning from above.*

	TfB	TfA
Age [year]	31	31
Stand density [tree.ha^{-1}]	2160	1664
average height [m]	15.0 (± 2.2)	13.6 (± 3.3)
DBH [cm]	14.1 (± 3.3)	14.2 (± 4.8)

Statistical processing of data

Statistical processing of data was obtained using SPSS software. Independent Sample Tests were used to test the stem diameter (DBH), height (H) and competition index (CI) like input data for allometry from different stand tending managements. The same tests were used for comparison of dry mass from TfA and TfB. Descriptive statistic, i.e. mean and standard deviation values, were obtained using Excel. In the Excel, different regression functions to the simplest allometric equation were tested. For non-linear regressions 1, 2, 3 were used and for equation 4. was use multiple linear regression. The function with the highest regression coefficient was chosen and presented.

Equation:

$$y = a \times x^{\wedge b} \quad (1)$$

$$y = a \times x^{\wedge 2} - b \times x + c \quad (2)$$

$$y = a \times e^{b \times x} \quad (3)$$

$$y = a + DBH \times b + H \times c + IC \times d \quad (4)$$

RESULTS AND DISCUSSION

Mean values (± standard deviation, SD) of H ,DBH and index of competition in plot with application of thinning from below (TfB) and thinning from above (TfA) are presented in Tab. III.

Total aboveground biomass (TBA) is presented in Tab. IV., and includes the leaves (LB), branches (BB) and stem biomass (SB) per tree and stand.

Stem analysis was performed by form factor. Form factor is defined as the ratio of the volume of a tree to volume of a cylinder having the same length and cross section at a height of 130 cm.

$$F = V/Sh, \quad (5)$$

where, F is the stem form factor, V is the stem volume, S is the basal area, h is the height of the tree. Form factor varies from 0.51 to 0.57 in the plot TfB and from 0.47 to 0.55 in TfA. Mean values are 0.53 for TfB and 0.52 for TfA. Statistical analysis using tests of difference showed no significant difference (α = 0.05) between the plots with different type of thinning application in form factor (P = 0.414).

Mean sample tree provides large difference between plot TfA and TfB. Difference is uneven due to the selection and compliance thinning regime in each thinning plot. Stand biomass was obtained from inventory of all trees in the plots TfA and TfB, and then new allometric function for different type of thinning was applied on this data.

Differences in stand biomass level were on average about: 10% in TBA, 16% in SB, 3% in BB and 1% in LB advancing in contrary thinning from below (TfB).

Statistical analysis using tests of difference showed no significant difference (α = 0.05) between the plots with different type of thinning application in stem diameter (P = 0.535), tree height (P = 0.677) and tree competition index (CI; P = 0.205).

The allometric relationships were constructed to derive leaf, branch, stem and total aboveground biomass (Fig. 1). All allometric relationships demonstrated high values of regression coefficient r^2. There, the maximum correlation values were achieved for DBH (adjusted correlation coefficient r^2ranging varied from 0.91 to 0.98 for TfB plot and from 0.95 to 0.98 for TfA plot). Allometric relationships with tree height (H) showed correlation coefficients r^2 ranging from 0.71 to 0.91 for TfB and from 0.66 to 0.87 for TfA. Correlation coefficient for competition index varied from 0.74 to 0.87 for TfB and from 0.62 to 0.88 for TfA.

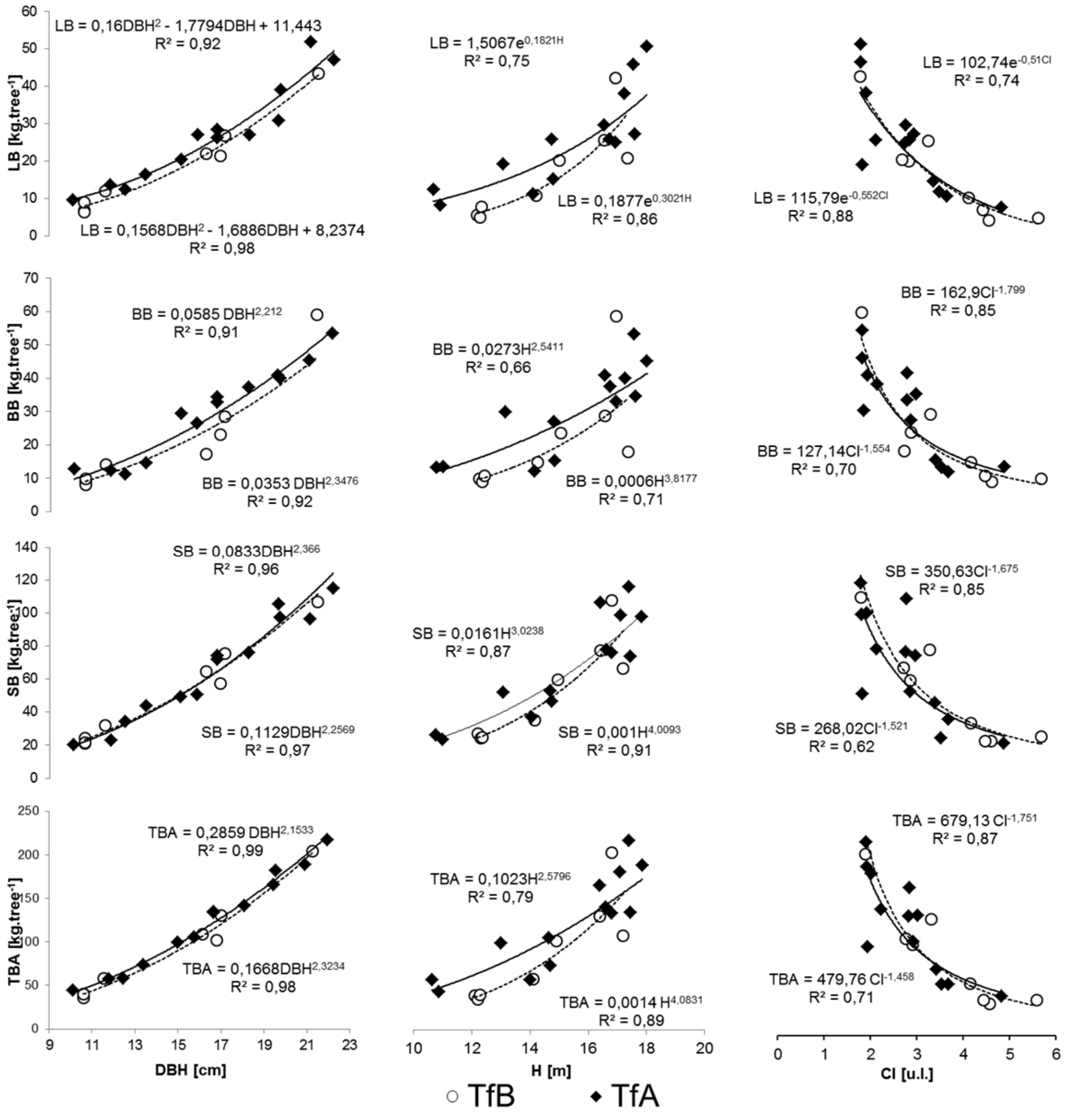
Multiple linear regressions provided correlation coefficients r^2 from 0.88 to 0.98 for TfB and from 0.90 to 0.98 for TfA. Only three cases of multiple linear regression were reported more accurate model than

III: *Mean values of height, DBH and competition index of tree applied to the allometric analysis (± standard deviation, SD)*

	TfB	TfA
Sampled trees	8	13
Height [m]	14.5 (± 2.2)	15.2 (±2.5)
DBH [cm]	14.3 (± 4.0)	16.3 (± 3.7)
Competition index	3.7 (± 1.2)	2.9 (± 0.9)

IV: *Leaf (LB), branch (BB), stem (SB) and total aboveground biomass (TBA) of mean sample tree from plot with application of thinning from below (TfB; n = 8) and from above (TfA; n = 13) SD- standard deviation*

	TfB		TfA	
	Mean [kg.tree^{-1}]	**Stand [t.ha^{-1}]**	**Mean [kg.tree^{-1}]**	**Stand [t.ha^{-1}]**
LB	18.4 (± 12.7)	40,178	26.9 (± 13.0)	39,615
BB	21.1 (± 16.9)	44,286	30.0 (± 13.8)	42,878
SB	50.5 (± 31.1)	110,204	66.0 (± 31.6)	94,873
TBA	89.9 (± 58.7)	195,701	123.2 (± 55.6)	177,229



1: *Allometric relationships between stem diameter at the breast height (DBH), tree height (H) and index of competition (CI), leaf biomass (LB), branch biomass (BB), stem biomass (SB) and total aboveground biomass (TBA). Empty circles and dashed line represent the trees from plot with application of thinning from below (TfB) and full diamonds and solid line represent the trees from plot with application of thinning from above (TfA).*

V: *The final parameter values of multiple linear regression model (eq. 4) for different type of thinning (TfA, TfB), and the mean corrected r^2 of the regression estimated for the total aboveground biomass and individual components*

Biomass component	Type of thinning	Parameter values				
		a	b	c	d	r^2
Total aboveground biomass	TfB	–166,908	15,815	0,455	6,398	0,964
	TfA	–157,125	17,159	–1,243	6,908	0,983
Leaves biomass	TfB	–23,866	3,254	–0,322	0,102	0,958
	TfA	–31,241	3,897	–0,540	1,002	0,903
Branch biomass	TfB	–9,962	5,755	–3,709	0,645	0,882
	TfA	–28,709	4,222	–0,753	0,492	**0,951**
Stem biomass	TfB	–123,392	7,989	2,603	5,862	**0,980**
	TfA	–127,450	9,908	0,490	8,626	**0,973**

simple regression. All parameters of multiple linear regressions are presented in Tab. V.

The results showed no effect of different type of thinning on tree allometry, particularly no statistically significant differences were found in relationships for leaf (P = 0.945), branch (P = 0.906), stem (P = 0.859) and total aboveground biomass (P = 0.993) estimation. Slight difference is apparent in the suppressed trees, specifically for estimation of leaf and branch biomass. Suppressed and a weaker trees in plots with application of thinning from above (TfA) produced more biomass, then the same or even slightly thicker and higher trees from plot with application of thinning from below (TfB).

Different silvicultural practices in the past have undoubtedly influenced tree structure at the stand level. Liu and Westman (2009) tested a function of Marklund´s (1988) allometric functions for estimation of spruce biomass. They tested these functions in forest stands where no cuttings have been performed during 40-year period and where Marklund´s functions were based on random sampling in managed populations of Swedish Forest Service forests. Liu´s and Westman´s (2009) study showed that the Marklund´s allometric functions consistently overestimated crown compartment biomass on the plots without forest management. Allometric relationships in our study showed similar differences. The plots with thinning from above (TfA) showed higher biomass production for suppressed or subdominant trees, comparing to them from plot with thinning from below (TfB). Data variability of the crown compartments was much higher than stem data. Statistical analysis showed that this difference is not statistically significant; however we can expect bigger difference for plots with totally different management system (e. g. thinning from above / no thinned plots).

Reduction in forest stand density leads to rapid enlargement and occupation of open canopy space by the crowns of remaining trees in stand (Nord-Larsen 2002, Shibuya *et al*., 2005). In consequence, trees respond to thinning by development of sun adapted foliage with a high production activity (Misson *et. al*., 2003; Mäkinen and Isomäki, 2005; Eriksson, 2006) and by enhancing stem diameter increment. Similarly, Table IV. shows differences in stand level data between the leaf, branch, stem and total aboveground biomass of TfA and TfB plot, respectively. Difference in aboveground tree organs biomass allocation is obvious for stem and total aboveground biomass. The difference between plots in the stem biomass is appreciable, but according to stand density higher stem biomass for individual tree in TfA comparing to TfB was assumed. The effect of thinning application on aboveground biomass increment of forest stand is commonly evident during next several years (Eriksson, 2006).

Suppressed tree in an old stand can show the similar size as a dominant tree in a young stand, however they exhibit significantly different biomass allocation patterns (Mäkelä, 1997). In this situation, stem biomass is noticeably higher in plot with thinning from above (TfA) than thinning from below (TfB). In plot (TfA), stem biomass is located in fewer trees and therefore plots with application of thinning from above can provide thicker and better quality stems in a short time (Tab. IV).

The growing stock of leaf and branch biomass is at the same level with a slight predominance of TfB. The improved light conditions produced by a thinning from above (TfA) leads to new production of needles after the thinning, and trees in a TfA stand have obtained good growth potential for the coming years (Kilpeläinen *et al*., 2010).

Our experimental plots with different type of thinning applications differing in stand density (i.e. 2160 tree.ha^{-1} in TfB and 1664 tree.ha^{-1} in TfA) show similar competition Index values (due to high variability; i.e. 3.71 ± 1.19 in TfB and 2.85 ± 0.87 in TfA). Therefore, high amount of small trees around a target tree resulted in the same competition as for target tree surrounding by small amount of large trees. Several authors reviewed competition indices with respect to their usefulness in predicting of tree growth (Biging and Dobbertin, 1995; Danielse *et al*., 1986; Tome and Burkhart, 1989). According to these authors, competition indices by themselves explain a disappointingly small proportion of variation in tree growth. Therefore, similar competition index in presented TfB and TfA plots showed no difference in allometric relationships.

CONCLUSIONS

The set of allometric equations to predict aboveground plant organ biomass in young Norway spruce plots (with DBH ranging from ca 10 to 22 cm) with different type of thinning application was presented for two dendrometric parameters – DBH and H, and CI easily derived from distance measurements and DBH of inner trees. Results showed DBH as the best and easily measureable dendrometric parameter for the evaluation of leaf (LB), branch (BB), stem (SB) and total aboveground biomass (TBA) comparing to H and CI.

DBH and CI correlated well with all aboveground plant organ mass; lower correlations were detected for H, however the correlation were still significant.

No effect of different type of thinning on tree allometry was detected; however allometric equations for biomass estimation from tree height as an input parameter differ especially for suppressed trees. These trees exhibited higher proportion of dry biomass, particularly for leaves and branches in plot with application of thinning from above (TfA).

Higher production of biomass on stand level was found in stand with application of thinning from below TfB (total aboveground biomass 196 t.ha^{-1}) comparing to stand with thinning from above TfA (total aboveground biomass 177 t.ha^{-1}).

SUMMARY

The set of allometric equations to predict above ground plant organ biomass of young Norway spruce trees under different type of thinning application (i.e. from above TfA and from below TfB) was presented. However, plots differ in stand density (2160 tree.ha^{-1} in TfB and 1664 tree.ha^{-1} in TfA), competition Index showed insignificantly different values (i.e. 3.71 ± 1.19 in TfB and 2.85 ± 0.87 in TfA). The highest adjusted regression coefficients were found between DBH and biomass of aboveground tree organs (adj. r^2 ranged from 0.91 to 0.98). Multiple linear regressions provide correlation coefficients r^2 from 0.88 to 0.98 for TfB and from 0.90 to 0.98 for TfA. The presented results showed no effect of different type of thinning application on tree allometry. Contrariwise, production on stand level was higher in stand with application of thinning form below (total aboveground biomass 196 t.ha^{-1}) comparing to stand with application of thinning form above (total aboveground biomass 177 t.ha^{-1}).

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REFERENCES

ABOAL, J. R., AREVALO, J. R. and FERNANDEZ, A., 2005: Allometric relationships of different tree species and stand above ground biomass in the Gomera laurel forest (Canary Islands). *Flora – Morphology, Distribution, Functional Ecology of Plants,* 200, 3: 264–274. ISSN 0367-2530.

BIGING, G. S. and DOBBERTIN, M., 1995: Evaluation of competition indices in individual tree growth models. *Forest Sci.,* 41, 2: 360–377. ISSN 0015-749X.

BROWN, S., 1997: Estimating Biomass and Biomass Change of Tropical Forests: a Primer (*FAO Forestry Paper*-134), FAO, United Nations, Rome. Available online: http://www.fao.org/docrep/w4095e/w4095e00.htm.

DANIELS, R. F., BURKHART, H. E. and CLASON T. R., 1986: A comparison of competition measures for predicting growth of loblolly pine trees. *Can. J. For. Res*., 16, 6: 1230–1237. ISSN 1208-6037.

ERIKSSON, E., 2006: Thinning operations and their impact on biomass production in stands of Norway spruce and Scots pine. *Biomass and Bioenergy*, 30, 10: 848–853. ISSN 0961-9534.

GOODALE, C. L., APPS, M. J., BIRDSEY, R. A., 2002: Forest carbon sinks in the northern hemisphere. *Ecological Applications*, 12, 3: 891–899. ISSN 1051-0761.

HADAŠ, P., 2002: Temperature and precipitation conditions in the high elevation spruce stands of the Drahanská vrchovina upland. *Ekologia-Bratislava*, 21, 1: 69–87. ISSN 1377-947X.

HOUGHTON, R. A., 2005: Aboveground forest biomass and the global carbon balance. *Global Change Biology*, 11, 6: 945–958. ISSN 1365-2486.

HUXLEY, J., S., TEISSIER, G., 1936: Terminology of relative growth. *Nature,* 137, 3471: 780–781.

KETTERINGS, Q. M., COE, R., VAN NOORDWIJK, M., AMBAGAU, Y., PALM, C. A., 2001: Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. *Forest Ecology and Management*, 146, 1–3: 199–209. ISSN 0378-1127.

LIU, C., WESTMAN, C., J., 2009: Biomass in a Norway spruce—Scot pine forest: a comparison of estimation methods. *Boreal Env. Res*., 14, 5: 875–888. ISSN 1797-2469.

LOSI, C. J., SICCAMA, T. G., CONDIT, R. and MORALES, J. E., 2003: Analysis of alternative methods for estimating carbon stock in young tropical plantations. *Forest Ecology and Management,* 184, 1–3: 355–368. ISSN 0378-1127.

MÄKELÄ, A., 1997: A carbon balance model of growth and self-pruning in trees based on structural relationships. *For. Sci.,* 43, 1: 7–24. ISSN 0015-749X.

MÄKINEN, H., ISOMÄKI, A., 2005: Thinning intensity and long-term ganges in increment and stem form of Norway spruce trees. *For. Ecol. Manag*., 201, 2–3: 295–309. ISSN 0378-1127.

MARKLUND, L. G., 1988: Biomass functions for pine, spruce and birch in Sweden. *Dep. of Forest Surveying, Swedish Univ. of Agric. Sciences*, Umeå, Report 45, 73 pp. Available online http://www.metla.eu/julkaisut/workingpapers/2007/mwp053.pdf.

MARKOVÁ, I., POKORNÝ, R., 2011: Allometric relationships for dry mass of aboveground organs estimation in young highland Norway spruce stand. *Acta univ. agric. et silvic. Mendel. Brunen.,* 59, 6: 217–224. ISSN 1211-8516.

MENŠÍK, L., FABIÁNEK, T., TESAŘ, V. and KULHAVÝ, J., 2009: Humus conditions and stand characteristics of artificially established young stands in the process of the transformation of spruce monocultures. *Journal of Forest Science*, 55, 5: 215–223. ISSN 1212-4834.

MISSON, L., VINCKE, C., DEVILLEZ, F., 2003: Frequency response sof radial growth series after different thinning intensities in Norway spruce (*Picea abies* (L.) Karst.) stands. *For. Ecol. Manag.,* 177, 1–3: 51–63. ISSN 0378-1127.

NĚMEČEK, J., MACKŮ, J., VOKOUN, J., VAVŘÍČEK, D. and NOVÁK, P., 2001: *Taxonomic classification system of soils of the Czech Republic (in Czech)*. Praha: ČZÚ, Praha, 79. ISBN 80-238-8061-6.

NORD-LARSEN, T., 2002: Stand and site productivity response following whole-tree harvesting in early thinning of Norway spruce (*Picea abies* (L.) Karst.). *Biomass and Bioenergy*, 23, 1: 1–12. ISSN 0961-9534.

PHAT, N. K., KNORR, W. and KIM, S., 2004: Appropriate measures for conservation of terrestrial carbon stocks--Analysis of trends of forest management in Southeast Asia. *Forest Ecology and Management*, 191, 1–3: 283–299. ISSN 0378-1127.

PLÍVA, K., 1987: *Typological Classification System "ÚHUL"*. Brandýs nad Labem, ÚHUL, 52 p. (in Czech). Available online ftp://ftp.uhul.cz/public/typologie/Typologicky_klasifikacni_system_UHUL_Pliva_1987.pdf.

POKORNÝ, R., TOMÁŠKOVÁ, I., 2007: Allometric relationships for surface area and dry mas sof young Norway spruce aboveground organs. *Journal of Forest Science*, 53, 12: 548–554. ISSN 1212-4835.

KILPELÄINEN, A., ROUTA, J., PELTOLA, H., ZUBIZARRETA-GERENDIAN, A., PULKKINEN, P. and KELOMÄKKI, P., 2010: Effects of genetic entry and competition on above ground biomass production of Norway spruce grown in southern Finland. *Forest Ecol. Manag.*, 259: 2327–2332. ISSN 0378-1127.

SHIBUYA, M., HASABA,, M., YAJIMA, T., TAKAHASHI, K., 2005: Effect of thinning on allometry and needle-age distribution of trees in Abies stands of norther *Japan. J. Forest Res.*, 10, 1: 15–20. ISSN 1610-7403.

TOME, M. and BURKHART, H. E., 1989: Distance-dependent competition measures for predicting growth of individual trees. *Forest Sci.*, 35, 3: 816–831. ISSN 0015-749X.

UNFCCC (United Nations Framework Convention on Climate Change), 1997: Kyoto Protocol. Available online http://unfccc.int/kyoto_protocol/items/2830.php.

WIRTH, C., SCHUMACHER, J. and SCHULZE, E.-D., 2004: Generic biomass functions for Norway spruce in Central Europe - a meta analysis approach toward prediction and uncertainty estimation. Tree Physiol., 24: 121–139. ISSN 1758-4469.

WRB, IUSS Working Group WRB, 2006: *World reference base for soil resources 2006*. 2nd edition. World Soil Resources Reports No. 103. Rome: FAO, 128 p. ISBN 92-5-105511-4.

ZIANIS, D. and MENCUCCINI, M., 2004: On simplifying allometric analyses of forest biomass. *For. Ecol. Manag.*, 187, 2: 311–332. ISSN 0378-1127.

Address

Ing. Jan Krejza, Department of Silviculture, Faculty of Forestry and Wood Technology, Mendel University in Brno, 613 00 Brno, Czech Republic, Global Change Research Centre, 603 00 Brno, Czech Republic, doc. Ing. Radek Pokorný, Ph.D. Department of Silviculture, Faculty of Forestry and Wood Technology, Mendel University in Brno, 613 00 Brno, Czech Republic, Laboratory of Plant Ecological Physiology, Institute of Systems Biology and Ecology Academy of Sciences, CzechGlobe- Centre for Global Climate Change Impact Studies, 603 00 Brno, Czech Republic, doc. RNDr. Irena Marková, CSc., Department of Forest Ecology, Faculty of Forestry and Wood Technology, Mendel University in Brno, 613 00 Brno, Czech Republic, e-mail: xkrejza@node.mendelu.cz, honza.krej@seznam.cz, radek.pokorny@mendelu.cz, pokorny.r@czechglobe.cz, markova@mendelu.cz