IMPROVED PREDICTION OF HARDWOOD TREE BIOMASS DERIVED FROM WOOD DENSITY ESTIMATES AND FORM FACTORS FOR WHOLE TREES

David W. MacFarlane and Neil R. Ver Planck[1]

Abstract.—Data from hardwood trees in Michigan were analyzed to investigate how differences in whole-tree form and wood density between trees of different stem diameter relate to residual error in standard-type biomass equations. The results suggested that whole-tree wood density, measured at breast height, explained a significant proportion of residual error in standard-type allometric equations, but whole-tree form factors explained more. However, such form factors are highly variable from tree to tree and may be difficult to predict with any precision from simple tree measurements. Whole-tree form factors were found to be highly correlated with the percentage of total aboveground mass in tree branches, which likely relates to the allometric scaling of the deliquescent hardwood growth form. These results suggest that further studies are needed to understand whole-tree form factors and incorporate them into tree biomass equations.

INTRODUCTION

The basic problem for accurate forest mass inventory is that standing trees cannot be weighed, so biomass estimates must be derived from allometric scaling principles and dimensional measurements of trees, principally tree stem diameter at breast height (d.b.h.). Since trees with the same basic measurements can have very different form and growth rates, allometric-scaling relationships should vary widely over space and time due to differences in tree form and wood density. In principle, if one could measure tree form and wood density on every standing tree, generalized allometric scaling equations could be made very accurate across diverse ecosystems. Wood density can be determined from tree cores (Williamson and Wiemann 2010) or can be derived from published values (Chave et al. 2005). However, wood density estimates are generally taken at breast height and may not represent the whole tree. While methods for estimating the form of the main stem (a.k.a. the bole) of a tree are available (e.g., Flewelling et al. 1998), methods for estimating the form of a whole tree are lacking (but see Cannell 1984).

Here, data from hardwood trees in Michigan were analyzed to investigate how differences in whole-tree form and wood density between trees of different stem diameters relate to residual error in standard-type biomass equations. Methods of predicting whole-tree form from other tree attributes were also examined.

Data

The study location was Fred Russ Experimental Forest, which is owned by Michigan State University (MSU) and is located in Decatur, MI. Following a major storm event, 32 hardwood trees ranging from 15 to 91 cm in size were selected from a larger group of wind-felled trees for whole-tree measurements and destructive sampling. Tree species included American basswood (*Tilia Americana* L.), American beech (*Fagus grandiolia* Ehrh.), black cherry (*Prunus serotina* Ehrh.), slippery elm (*Ulmus rubra* Muhl.),

[1] Associate Professor (DWM) and Graduate Research Assistant (NRV), Michigan State University, Department of Forestry, East Lansing, MI 48824-1222. DWM is corresponding author: to contact, call 517-355-2399 or email at macfar24@msu.edu.

and sugar maple (*Acer saccharum* Marsh.). Beginning at the point where the trunk flares, stem diameter outside bark was measured at 2-meter intervals until the first forking point (defined as the crown base) occurred. From that point, three paths were followed from the first fork to a terminal twig including the dominant path, which was the largest branch leading to an apical control point (i.e., the top of the tree), and two random paths selected using random branch sampling protocols with probability proportional to branch cross-sectional area (Gregoire et al. 1995). In addition to measurements along the path at 2-m intervals, the stem diameter before each forking point and all stem diameters after each forking point were also measured, which allowed for variable probability sampling.

After all measurements were taken, tree discs were removed from all measurement locations starting at d.b.h. The discs were measured and weighed fresh after transport to the laboratory and then dried to a constant mass at 105 °C. Basic wood density was estimated following procedures outlined in Williamson and Wiemann (2010).

Analysis

Whole-tree wood volume (V_W) and mass (M_W) estimates were generated using the sample data and expansion factors derived from random branch sampling (Gregoire et al. 1995), and component volume and mass values were also estimated for branches and the dominant stem. Breast height wood density (ρ) was calculated from the disk removed at breast height, and wood density of the dominant stem, branches, and the whole tree were estimated by dividing the mass by the volume of those components. Diameter of the stem was measured at breast height (D) and stem height (H) was measured. Whole-tree form factor (F) was computed as the ratio of whole-tree volume to a proxy tree volume: $F = V_W / V_P$, where $V_P = ¼\pi D^2 H$.

A standard d.b.h.-based allometric equation was fit to the tree data:

$$M_W = \alpha D^\beta \quad (1)$$

where MW is the dry mass of a whole tree (without leaves), and α and β are the scaling and power coefficients of a power function. The coefficients were estimated with least squares regression. Relative error (RE) in biomass estimation (predicted-observed/observed) from equation 1 was related to ρ and F to determine their contribution to RE.

RESULTS AND DISCUSSION

When the RE of biomass prediction from the equation 1 was regressed against breast-height ρ and whole-tree F, it was found that both explained significant fractions of the relative error in biomass estimation from d.b.h., but F explained a greater proportion of the RE than ρ. While several studies have shown that adding ρ can improve allometric equations (e.g., Chave et al. 2005), there has been little attention to F. However, Canell (1984) showed that the allometric scaling coefficients of aboveground biomass equations derived from stand basal area and average tree height were positively correlated with the percentage of total aboveground biomass comprised of branches, and that the percentage of branches was correlated with average stand F. The results presented here suggest that whole-tree F correlates directly with error in individual tree mass estimation and should be a useful addition to allometric equations, where it can be estimated. However, estimation of F requires that whole-tree volume be estimable on standing trees.

Since F was shown to be related to the percentage of whole-tree mass found in the branch component (Cannell 1984), F was plotted as a function of the percentage of mass in branches (Fig. 1a), and they were found to be well correlated (70 percent). MacFarlane (2011) suggested several predictors of

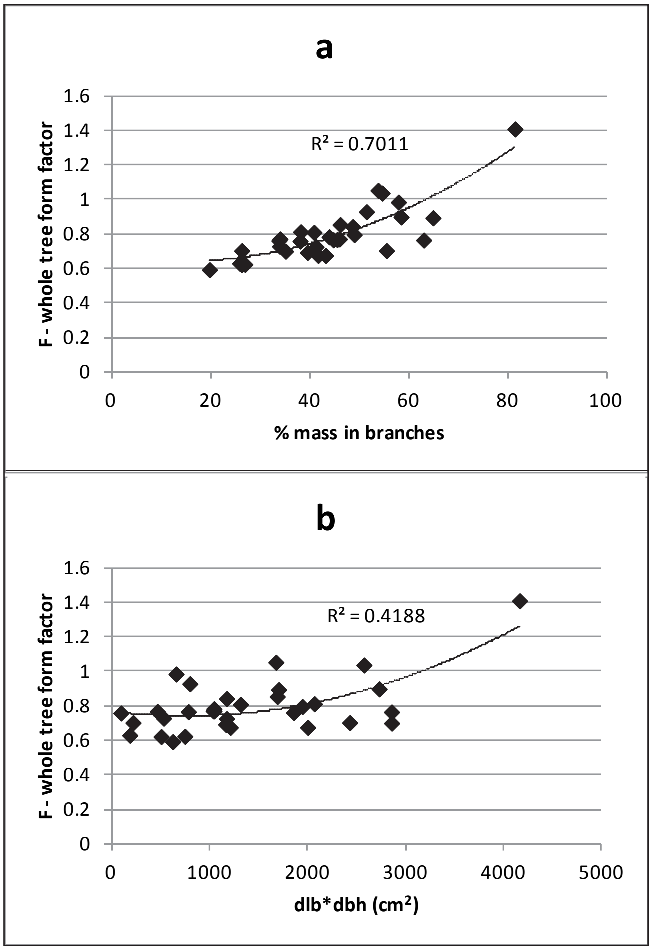

Figure 1.—Whole-tree form factor (F) as a function of: (a) percent mass in branches; and (b) the product of the diameter of the largest branch (d.l.b.) in a tree and the stem diameter at breast height (d.b.h.).

percent branch volume, and these were examined as possible predictors of F. Unfortunately, the best predictor of F, the product of the diameter of the largest branch (d.l.b.) in the tree and d.b.h., explained only about 42 percent of the variation in F (Fig. 1b), which may not be precise enough to improve accuracy of the biomass equation. However, it may be possible to directly estimate whole-tree volume on standing trees (Van Duesen and Roesch 2011) along with standard measurements of d.b.h. and tree height, in which case F could be directly estimated rather than predicted.

ACKNOWLEDGMENTS

This study was funded through a Sustainability Seed Grant from Michigan State University (MSU) and with funds from a joint venture agreement between MSU and the U.S. Forest Service Forest Inventory and Analysis Program, Northern Research Station. Part of D.W. MacFarlane's time was paid for with funds from Michigan AgBioResearch and a Fulbright Scholarship he received. D.W. MacFarlane would also like to thank the Kenya Forest Research Institute who provided logistical support to him while he conducted part of the research while on sabbatical.

LITERATURE CITED

Cannell, M.G.R. 1984. **Woody biomass of forest stands.** Forest Ecology and Management. 8: 299-312.

Chave, J.; Andalo, C.; Brown, S.; Cairns, M.A.; Chambers, J.Q.; Eamus, D.; Fölster, H. [et al.]. 2005. **Tree allometry and improved estimation of carbon stocks and balance in tropical forests.** Oecologia: 145: 87-99.

Flewelling, J.W.; Ernst, R.L.; Raynes, L.M. 2000. **Use of three-point taper systems in timber cruising.** In: Hansen, M.; Burk, T., eds. Integrated tools for natural resources inventories in the 21st century: proceedings of the IUFRO conference. Gen. Tech. Rep. NC-212. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 364-371.

Gregoire, T.G.; Valentine, H.T.; Furnival, G.M. 1995. **Sampling methods to estimate foliage and other characteristics of individual trees.** Ecology. 76(4): 1181-1194.

MacFarlane, D.W. 2011. **Allometric scaling of branch volume in hardwood trees in Michigan, USA: implications for improvements in above-ground forest carbon biomass inventories.** Forest Science. 57(6): 451-459.

Van Deusen, P.; Roesch, F.A. 2011. **Sampling a tree for total volume, biomass, and carbon.** Journal of Forestry. 109(3): 131-135.

Williamson, G.B.; Wiemann, M.C. 2010. **Measuring wood specific gravity…correctly.** American Journal of Botany. 97: 448 -524.