BIOMASS MEASUREMENT AND MODELING CHALLENGES FOR HARDWOOD SPECIES IN THE NORTHERN REGION

James A. Westfall, David W. MacFarlane, and Aaron R. Weiskittel[1]

Abstract.—Biomass models for most commercially important hardwood species in the northern region of the U.S. are often based on data of very limited spatial extent and range of tree characteristics, suggesting uncertain accuracy when applied at regional scales. Also, the current models can have poor predictive ability for the proportions of biomass found in major tree components considered for utilization, namely the merchantable bole, bole tops, tree branches, and foliage. The Forest Inventory and Analysis Program of the U.S. Forest Service is currently undertaking a project to obtain regionally representative data to develop new volume/biomass models. This paper outlines issues related to challenges in data collection and subsequent modeling of biomass components for hardwood species.

INTRODUCTION

A number of tree biomass studies were conducted in the northern region from the late 1970s into the early 1980s (Smith and Brand 1983, Wiant et al. 1977). These studies provided the initial biomass estimation procedures for many hardwood species in the region. However, data collection was often limited to relatively small areas and ranges of tree characteristics. Nonetheless, equations from various sources were adopted by the Forest Inventory and Analysis (FIA) Program (an entity of the U.S. Forest Service) because these equations provided the only opportunity to include biomass estimates in forest resource reports. Due to differences among studies in definitions, data collection protocols, and model forms, predicted values of biomass for trees of a given size could vary considerably. As biomass estimates became increasingly important, FIA implemented a nationally consistent method to estimate individual-tree biomass components (Heath et al. 2009). This change in methodology produced estimates that were sometimes incongruous with those of the earlier models, raising concerns about which method(s) provided the most accurate results (Domke et al. 2012, Westfall 2011). In the absence of data required to make such assessments, FIA has committed to collecting regionally representative biomass data to provide a common basis for biomass estimator development. Although there are several important conifer species in parts of the northern region, the forests are largely dominated by hardwood species. Due to their decurrent form, hardwoods require innovative techniques to appropriately measure and model biomass components.

MEASUREMENT CHALLENGES

Several challenges must be faced when measuring hardwood species for biomass. Foremost, tree form has an unknown effect on allometric scaling relationships and is critical to estimating biomass components. There is an inherent difficulty in recording numerous hierarchical orders of branches and foliage, so a complex measurement and recording system is needed to permit reconstruction of the tree. Measurement protocols should be sufficiently

[1] Research Forester (JAW), U.S. Forest Service, Northern Research Station, 11 Campus Blvd., Suite 200, Newtown Square, PA 19073; Associate Professor (DWM), Michigan State University; Assistant Professor (ARW), University of Maine. JAW is corresponding author: to contact, call 610-557-4043 or email at jameswestfall@fs.fed.us.

prescribed such that no critical information is overlooked or measured incorrectly. Conversely, the detail and cost of measurements should not exceed that needed to meet accuracy objectives in predicting biomass. Also, the protocols must be understandable and intuitive. Theoretically and technically sound protocols are of little use if they cannot be consistently and accurately applied in the field. A related issue is the need to consistently assign tree parts to component categories (e.g., branch vs. top wood), especially as merchantability and utilization standards change over time. Cost (1978) provides examples of field protocols designed for measuring volumes in traditional product categories including sawtimber and pulpwood, but these protocols are not entirely suitable for biomass determination.

To increase efficiency, sampling may be used for branch and foliage components. However, the design of an unbiased, high-precision sampling design is required before widespread implementation. For this study, the first year of data collection will entail a high level of detail for individual-tree measurements, which will allow assessment of various sampling protocols that may be implemented in subsequent years. Obviously, this exercise hinges on successful implementation of the detailed measurement protocols described in the above paragraph. Also, selection of trees that well represent the range of branching and foliage patterns found in the population will be essential.

Unlike many volume attributes, which are based on trees of merchantable size, biomass predictions are needed for smaller trees (e.g., d.b.h. 1.0 inch and greater). Furthermore, current biomass estimates for small trees can be suspect because many existing biomass models are based primarily on trees of merchantable size. Thus, ensuring that sapling-size trees are included in the sample is imperative. However, inclusion of small trees can create measurement challenges because data collection protocols are often specified assuming application to trees of merchantable size (e.g., biomass of the main stem may be defined as that occurring below the 4-inch top diameter). Thus, measurement protocols must be specified such that there is applicability across all tree sizes.

Because prediction models will ultimately be applied to standing trees, a key component in the measurement phase is understanding how measurements of standing trees correlate with more accurate data taken on felled trees. An example would be branch length, which may or may not be needed in addition to branch diameter to accurately predict branch biomass. Perhaps branch allometry suggests that knowledge of branch diameter alone is sufficient to obtain acceptable biomass predictions. Understanding the information needs in this context is important, because branch lengths on standing trees are likely only accurately measured as the linear distance from branch base to tip. However, most branches have some degree of curvature that would not be accounted for in the linear distance measure, and thus recorded branch length would not reflect the actual length. If branch length is vital to branch biomass prediction, differences between linear branch lengths taken on standing trees and the actual length would need to be empirically assessed on trees that are felled. Identifying and accounting for such issues in the data collection process is critical if unbiased estimates of biomass are to be produced based on data elements collected on standing trees (e.g., FIA plots).

MODELING CHALLENGES

Several challenges are also faced when considering biomass model development for hardwood species. First, one must consider the sample size needed to establish statistically significant relationships between predictor variables and biomass values. Due to the wide variation in tree characteristics, more samples are likely needed for hardwoods than for softwoods. Unfortunately, the number of sample trees is often limited due to financial constraints. In these situations, it is advisable to estimate the minimum sample size deemed necessary and ensure resources exist to attain that base level of sampling. Given that an appropriate number of sample trees have been determined, additional work is needed to specify tree selection processes. For example, it may be desirable to specify numbers of trees to be sampled by size class, form or crown architectural characteristics, and/or spatial distribution. These specifications should be thoroughly evaluated, because substantial effort may be incurred to find and measure certain relatively rare occurrences, e.g., very large d.b.h. trees. On the other hand, one must also consider that sampling trees based on frequency alone would be sub-optimal in that most sample trees would be near the middle of the distribution(s) of selection criteria and relatively little information would be obtained at the lower and upper ranges. Such an approach could lead to poor predictions for trees that do not exhibit characteristics represented in the modeling data. The goal is for the sample to cover the widest range of variation in tree size and form attributes across the geographic range of occurrence; however, this must be balanced within practical cost and time constraints.

Another major issue is that the spatial variation in species-specific allometric scaling coefficients of hardwoods is largely unknown. Due to the high cost of felled-tree data, characterizing changes in biomass parameters across various gradients (e.g., latitude, longitude, and elevation) will require ancillary standing-tree information. The types and amounts of ancillary data needed to capture these shifts in hardwood tree allometry must be determined. Due to the limitations of measuring standing trees from ground-position, the ability to obtain accurate measurements of specified data elements also must be assessed, which includes both unobstructed lines-of-sight and types of equipment required. Finally, a statistically defensible method to incorporate these data into the analysis must be developed.

Potential grouping of species having similar characteristics should also be evaluated. For hardwood species, this may be particularly difficult due to the excessive geographic and phenotypic variation. Typically, such groupings have been accomplished using genera or categorical classification, such as oak/hickory, although different growth habits among species within such groups may make them unsuitable for aggregation when modeling biomass. The best-case scenario is to have pre-determined groupings such that the sampling effort can be lessened by having group-level (vs. species-level) sample size requirements. However, one then assumes the risk of having species within groups that actually are not as similar as expected. In the absence of reliable information on aggregation criteria, caution should be exercised in grouping species before data collection.

A final consideration is the duration of the data collection effort. One option is to set the sample size requirements for model development and cease fieldwork once those requirements are met. An alternative scenario would be to not only develop biomass models from the initial effort, but also to continue to collect data as well. One potential option would be to incorporate needed biomass measurements into existing Timber Products Output (TPO) studies conducted by FIA (Wharton and Birch 1999). This would provide a continual stream of additional information that could be used to periodically update existing models. While the latter approach seems more desirable from a scientific viewpoint, there are programmatic issues for FIA because biomass predictions for trees on inventory plots change over time, which can be problematic for some clients, e.g., reprocessing of older data with newer biomass values will produce different analytical results. Implementation of a continual data collection paradigm would need to be carefully considered before implementation to provide balance between the best scientific practices and program credibility.

CONCLUSION

Measuring and modeling biomass for hardwood species is not a trivial exercise. Due to the decurrent form, substantial effort may be needed to collect multi-level branch and foliage data. The data also need to be collected consistently across various species, tree sizes/forms, and field personnel. Thus, field protocols must be explicitly defined and consistently interpreted. Obtaining reliable data for hardwoods also requires an understandable and intuitive protocol for recording the extensive measurements, such that the tree can later be accurately reconstructed or re-analyzed as utilization standards change.

A primary difficulty faced in modeling biomass of hardwood species is establishing relationships between biomass and usual mensurational variables such as d.b.h and total height. The wide range of tree forms assumed by hardwood species creates substantial variability, which may require large sample sizes to develop models having acceptable degrees of predictive accuracy. Particularly, it is necessary to empirically describe how relationships between biomass components change in relation to various factors (e.g., tree size and form). Practical constraints on felled-tree data collection suggest that ancillary information from standing trees will be necessary to further refine model predictions for local accuracy and that grouping of species may be helpful in attaining sufficient sample sizes. However, the techniques by which these issues are best addressed must still be developed and evaluated.

LITERATURE CITED

Cost, N.D. 1978. **Multiresource inventories—a technique for measuring volumes in standing trees.** Res. Pap. SE-196. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 18 p.

Domke, G.M.; Woodall, C.W.; Smith, J.E.; Westfall, J.A.; McRoberts, R.E. 2012. **Consequences of alternative tree-level biomass estimation procedures on U.S. forest carbon stock estimates.** Forest Ecology and Management. 270: 108-116.

Heath, L.S.; Hansen, M.H.; Smith, J.E.; Miles, P.D.; Smith, B.W. 2009. **Investigation into calculating tree biomass and carbon in the FIADB using a biomass expansion factor approach.** In: McWilliams, W.; Moisen, G.; Czaplewski, R., comps. Forest Inventory and Analysis (FIA) Symposium 2008. Proc. RMRS-P-56CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 26 p.

Smith, W.B.; Brand, G.J. 1983. **Allometric biomass equations for 98 species of herbs, shrubs, and small trees.** Res. Note NC-299. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.

Westfall, J.A. 2011. **A comparison of above-ground dry-biomass estimators for trees in the northeastern United States.** Northern Journal of Applied Forestry. 29: 26-34.

Wharton, E.H.; Birch, T.W. 1999. **Trends in timber use and product recovery in New York.** Res. Note NE-367. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 7 p.

Wiant, H.V., Jr.; Sheetz, G.E.; Golaninno, A.; DeMoss, J.C.; Castaneda, F. 1977. **Tables and procedures for estimating weights of some Appalachian hardwoods.** West Virginia University Agricultural and Forestry Experiment Station Bull. 659T. 36 p.