PREDICTING SMALL-DIAMETER LOBLOLLY PINE ABOVEGROUND BIOMASS IN NATURALLY REGENERATED STANDS

Kristin M. McElligott, Don C. Bragg, and Jamie L. Schuler[1]

Abstract--There is growing interest in managing southern pine forests for both carbon sequestration and bioenergy. For instance, thinning otherwise unmerchantable trees in naturally regenerated pine-dominated forests should generate biomass without conflicting with more traditional forest products. However, we lack the tools to accurately quantify the biomass in these submerchantable size classes. To help remedy this, we destructively sampled 54 small-diameter loblolly pines (*Pinus taeda* L.) from stands on the Crossett Experimental Forest (CEF) in southeastern Arkansas. After harvesting, each tree was divided into stemwood, foliage and branch, and taproot components, then oven-dried and weighed. We then fit an exponential equation based on the National Biomass Estimator (NBE) to predict aboveground oven-dry biomass as a function of diameter at breast height (d.b.h.). The resulting model fit the sample data well (pseudo-R^2 = 0.996). Comparing the CEF local biomass model with the pine submodel of the NBE suggested that the NBE would consistently underestimate small-diameter loblolly pine biomass on the CEF. While this difference appeared small, its cumulative effect could be appreciable. For example, in a young loblolly pine stand averaging 5 cm d.b.h. and 5,000 stems ha^{-1}, the NBE would predict almost 9 percent less biomass than the new CEF biomass model—a difference of nearly 2 metric tons ha^{-1}. Such locally derived equations offer silviculturists opportunities to better assess the potential of naturally regenerated pine stands to produce fiber and thus may be worth the investment of time and resources to develop.

INTRODUCTION

To better understand the potential influence southern pine forests will have on emerging cellulosic biofuel, bioenergy, and carbon markets, it is imperative that we estimate the quantity of biomass stored in these forests as accurately as possible. Naturally regenerated pine-dominated forests present unique opportunities for these potential markets because they are often overstocked when young, and thinning otherwise unmerchantable material could generate some of the biomass needed to meet biofuel or bioenergy targets without conflicting with more traditional forest products (Koch and McKenzie 1976, Westbrook and others 2007). However, in many regions we lack the tools needed to quantify the biomass in these submerchantable size classes and are therefore unable to accurately estimate the fiber production, total biomass, or carbon in forests (Chaturvedi and Raghubanshi 2013, McGarrigle and others 2011).

Stand-level biomass is typically estimated from an allometric equation that predicts oven-dry biomass for individual stems based on diameter at breast height (d.b.h.) and then summed to yield biomass per unit land surface area (Whittaker and Woodwell 1968). Because of the growing need for landowners to quantify tree biomass, managers often apply equations from other regions, stand conditions, and species than those actually found on the site. Research has repeatedly shown that such application is less than ideal (Bragg 2011, Chave and others 2005, Crow and Schlaegel 1988, Melson and others 2011, Parresol 1999, Payadeh 1981, Ruark and others 1987, Zianis and others 2005) because model choice and implementation can dramatically impact estimates, and errors in biomass estimation can accumulate when used incorrectly [for instance, if applied to dissimilar species or extrapolated beyond the original diameter range for which the model was derived (Chave and others 2005, Fonseca and others 2012, Parresol 1999)].

Small-diameter trees constitute a significant proportion of naturally regenerated forests in southeastern Arkansas. While numerous models capable of predicting aboveground live-tree biomass for southern pines have been developed (Jenkins and others 2003, Newbold and others 2001, Van Lear and others 1986), few of these were actually derived using Arkansas forests and fewer still specifically included small stems. Therefore, to more accurately predict biomass for small-diameter loblolly pines, we developed a site- and species-specific biomass equation for the USDA Forest Service's Crossett Experimental Forest (CEF). To evaluate the predictive ability of this locally fit

[1]Program Technician, Arkansas Forest Resources Center, Monticello, AR 71656; Research Forester, USDA Forest Service, Southern Research Station, Monticello, AR 71656; and Assistant Professor, West Virginia University, Division of Forestry and Natural Resources, Morgantown, WV 26506.

Citation for proceedings: Holley, A. Gordon; Connor, Kristina F.; Haywood, James D., eds. 2015. Proceedings of the 17th biennial southern silvicultural research conference. e–Gen. Tech. Rep. SRS–203. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 551 p.

model, we compared our predictions with the commonly used National Biomass Estimator (NBE; Jenkins and others 2003). Additionally, we also contrasted cumulative (per ha) biomass predictions using the local model and the NBE to determine the influence of model choice on stand-level biomass estimates.

MATERIALS AND METHODS

Study Site

This study was conducted on the CEF, which is located 11 km south of the city of Crossett in Ashley County, AR. Established in 1934 by the Forest Service, the CEF covers nearly 680 ha in southeastern Arkansas and is dominated by naturally regenerated forests of loblolly (*Pinus taeda* L.) and shortleaf (*Pinus echinata* Mill.) pine, with a minor hardwood component. The relatively flat, rolling terrain of the CEF varies between 36 and 48 m above sea level, with local differences rarely exceeding 3 m. The soils of the CEF are primarily silt loams with a loblolly pine site index of 25 to 30 m (50 year base age) (Gill and others 1979).

Sample Tree Selection and Measurement

Small-diameter (< 15 cm d.b.h.) loblolly pines were destructively sampled across the naturally regenerated pine-dominated forests of the CEF. Trees of this size were chosen to address logistical issues related to collecting and weighing above- and belowground biomass of large specimens. In addition, the smallest trees from this diameter range (those < 10 cm d.b.h.) are often not sampled when developing biomass equations (Snowdon and others 2000), yet may compose a significant fraction of many forests, including those on the CEF.

Model development entailed destructively sampling these pines. Smaller sample trees were pulled directly from the soil using a small tractor with a hydraulic boom extension lift. Bigger pine trees that could not be lifted from the ground were partially excavated using a backhoe attachment for the tractor, and then pulled. Once out of the ground, pines were separated into aboveground (foliage + branch and stemwood), and belowground (taproot) components. For this study, only the aboveground components were modeled. All components were dried in an air-forced oven at 90^{o} C to a constant weight, and the stem, branch, and foliage components then summed to produce aboveground, oven-dry biomass.

Model Comparison

Aboveground live-tree oven-dry biomass (B_D, in kilograms) values were then fit to the CEF model (based on the NBE) using ordinary least squares regression:

$$B_D = b_0 + e^{b_1 + b_2(ln(d.b.h.))} \qquad (1)$$

where b_i are fitted coefficients. The slightly different NBE also predicts B_D:

$$B_D = e^{-2.5356 + 2.4349(ln(d.b.h.))} \qquad (2)$$

The NBE is a conservative and well-documented national model and is generally considered the standard biomass equation used nationwide by researchers and agencies to estimate tree- and stand-level forest biomass, including the official greenhouse gas inventories for the United States (EPA 2008).

RESULTS

Individual Tree Biomass

We sampled 54 loblolly pines from 0.9- to 15.0-cm d.b.h. (average of 4.6 cm; standard deviation of 3.6 cm). After processing and drying, the measured B_D for these trees ranged from 0.23 to 60.87 kg, averaging 7.19 kg (standard deviation = 12.77 kg).

Local Model Fit

The following CEF biomass model:

$$B_D = 0.174544 + e^{-2.4571 + 2.41911(ln(d.b.h.))} \qquad (3)$$

fit the data well (pseudo-R^2 = 0.996). Not surprisingly, a local equation using a single species did a better job of fitting loblolly pine data from the CEF than the more general NBE (fig. 1). For the size range we considered, the NBE had few prominent departures but consistently underestimated B_D across the sampled d.b.h. range. Because of the scale of figure 1, this propensity was not readily apparent. To better demonstrate the differences between the actual B_D data and both sets of model predictions from the 0- to 15-cm d.b.h. range, we have enlarged that section of sampled data and model predictions for pines up to 5-cm d.b.h. (fig. 2).

The most noticeable difference appeared to be in the smallest of the trees (those < 3 cm d.b.h.), for which the NBE underestimated B_D at a

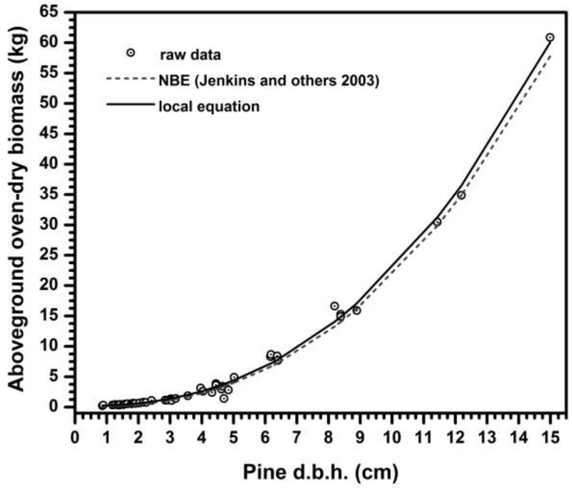

Figure 1--Observed and predicted aboveground live-tree oven-dry biomass as a function of stem diameter for small (up to 15 cm d.b.h.) loblolly pine from the Crossett Experimental Forest.

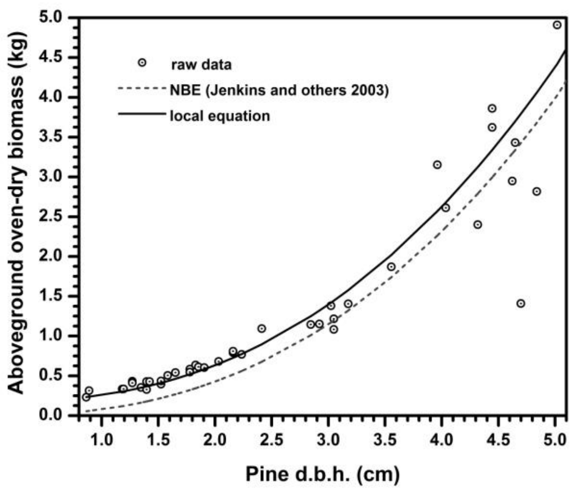

Figure 2--Observed and predicted aboveground live-tree oven-dry biomass as a function of stem diameter for the smallest (0.9- to 5.0-cm d.b.h.) loblolly pines from the Crossett Experimental Forest sampled for this study.

proportionally higher rate with decreasing diameter (table 1). As an example, for a loblolly pine 5 cm in d.b.h., the CEF model forecast an individual stem biomass of 4.4 kg while the NBE predicted 4.0 kg, a relative difference of 9 percent. However, at the smallest size class measured (1.0 cm), the CEF model predicted an individual stem biomass of 0.26 kg and the NBE predicted 0.08 kg, or 70 percent less biomass.

Table 1—Predicted aboveground live oven-dry biomass (B_D) for 1.0-, 2.5-, 5.0-, and 15.0-cm d.b.h. loblolly pines

	----------Modeled B_D----------		
D.b.h.	NBE	Local CEF	Relative difference[a]
--cm--	----------------*kg*--------------		*percent*
1.0	0.08	0.26	70
2.5	0.74	0.96	23
5.0	3.99	4.38	9
10.0	21.56	22.67	5
15.0	57.87	60.15	4

[a]Relative B_D difference = [(NBE B_D – local B_D) / local B_D] × 100.

DISCUSSION

Small-diameter trees can make up a large fraction of biomass in southern pine forests, making the accurate prediction of this component important. A significant initial step in improving the reliability of predictive models is understanding the role of model choice on the quantification of biomass. While this rapidly advancing field has witnessed considerable improvement over the years, many landowners have few other choices than to apply models developed for more general conditions, as is the case with perhaps the most commonly applied design, the NBE. In many instances, the use of generalized forms such as the NBE can be as effective as more site- and species-specific equations applied to individual trees in a stand (Snowdon and others 2000). However, there is also evidence that biomass models developed for other regions or silvicultural origins will yield notably different predictions from those of locally derived equations (Bragg 2011) because of considerable geographic variability in the growth and yield of most tree species (especially loblolly pine) as a function of genetics, site conditions, growth rate, and other factors (Jordan and others 2008, Mitchell and Wheeler 1959, Schultz 1997).

It is therefore quite possible that the use of a general national-scale allometric equation may underestimate the biomass of some species and overestimate the biomass of others, resulting in errors in calculating the biomass of the forest as

Table 2—Per ha differences in stand-level predicted pine-only aboveground biomass (B_D) and potential carbon dioxide equivalent (CO_2e) revenue, assuming the given stocking at the specified average tree d.b.h.

			-----Modeled B_D-----		---Modeled CO_2e---		-------Potential CO_2e revenues------		
D.b.h.	Stocking	Basal area	NBE	Local CEF	NBE	Local CEF	NBE	Local CEF	Difference
--cm--		*--m^2--*	*metric tons*				*dollars*		
1.0	5,000	0.4	0.4	1.3	0.7	2.4	9.90	32.52	22.62
2.5	5,000	2.5	3.7	4.8	6.8	8.8	92.16	120.06	27.91
5.0	5,000	9.8	19.9	21.9	36.6	40.2	498.32	547.30	48.98
10.0	3,000	23.6	64.7	68.0	118.7	124.8	1,616.73	1,699.40	82.68
15.0	2,500	44.2	144.7	150.4	265.5	275.9	3,615.94	3,758.41	142.48

[a] $CO_2e = B_D \times 0.5 \times 3.67$
[b] Potential revenues assumes \$13.62 per ton of CO_2e, as experienced in February 2013 California Air Resources Board allowance auction (California ARB 2013).

a whole (Zhou and Hemstrom 2009). The underestimates of loblolly pine from the CEF predicted by the NBE almost certainly arose from how the pine submodel of the NBE was derived. The NBE pine equation is not specific to loblolly pine; rather, it was generated from "pseudodata" produced by 43 different equations using 14 different species of *Pinus* ranging from eastern white pine (*Pinus strobus* L., specific gravity = 0.34) to longleaf pine (*Pinus palustris* Mill., specific gravity = 0.54) (Jenkins and others 2003, 2004). Because of this generality, and the fact that southern pine species such as loblolly and shortleaf (specific gravities = 0.47) often have significantly denser wood than most other pines (Miles and Smith 2009), it is not surprising the NBE under-predict loblolly pine sampled on the CEF. These results demonstrate the importance of locally derived models, especially when biomass predictions are extrapolated to stands.

Even though the absolute differences between the CEF local biomass model (equation 3) and the NBE (equation 2) are not dramatic for individual loblolly pines in this sample range (table 1), subtle and consistent biases for individual trees can have a major cumulative impact when scaled up to stand- or regional-scale estimates. For example, in a very young loblolly pine forest averaging 5,000 stems ha^{-1} and 1.0 cm in d.b.h., the CEF biomass model predicted biomass of over three times the amount forecast by the NBE (1.3 versus 0.4 tons ha^{-1}). In a thinned pine stand with 2,500 stems ha^{-1} averaging 15.0 cm in d.b.h., the NBE predicted B_D of 144.7 tons ha^{-1} of biomass, while the CEF model yielded 150.4 tons, a difference of 5.7 tons (table 2).

Such a disparity may not be noticed if the biomass products are weight-scaled at a mill, but those purchased in terms of standing stocks may be affected greatly. Sequestered carbon, for instance, can be traded (sold) in the form of carbon dioxide equivalents (CO_2e) stored in trees based on modeled values. Converting the biomass predictions of both the NBE and local CEF models to CO_2e, and then assuming the February 2013 price (\$13.62 per ton of CO_2e) of carbon allowances on the California Air Resources Board market (California ARB 2013) makes this point clearly. For the 15-cm d.b.h. scenario, this difference amounts to \$142.48 ha^{-1} difference between the model outcomes (table 2). A consistent disparity simply from using a different model, with no change to tree size or stocking, has considerable economic and silvicultural implications. Whether in terms of more traditional forest products (chips, pulpwood, or even hog fuel) or the new currency of sequestered carbon, failure to capture the actual value of the biomass on a given parcel is detrimental to the landowner and may also misrepresent the carbon stored by a particular treatment, especially when a large number of small-diameter stems are involved.

CONCLUSIONS

Expanding markets for biomass in energy production improves the silvicultural opportunities for balancing sawtimber and woody biomass by providing much-needed small-diameter and low-grade markets (Koning and Skog 1987). Southern forests provide an abundance of underutilized wood, such as logging residues and small-diameter timber. Using this material for bioenergy markets could alleviate the competition with traditional timber commodities while providing multiple forest management options for increased growth, improved forest health, and supplemental income (Munsell and Germain 2007). However, accurate biomass estimations from stem to stand scale and across a range of size classes are needed to better realize these opportunities in emerging woody bioenergy markets and carbon accounting procedures being implemented by various commercial enterprises and regulatory agencies (for example, California ARB 2009). The determination of biomass quantities in the face of carbon-driven forest management may also impact forest policy (Galik and others 2013).

While general models like the NBE make the simulation process easier and yield reasonable biomass estimates for many species with little to no existing biomass information, it can obscure significant differences resulting in potentially major consequences for forest managers and landowners. The availability of locally derived equations, such as our model for small-diameter loblolly pine on the CEF, offers silviculturists a means to better assess the potential of naturally regenerated pine stands to produce fiber, and thus may be worth the investment of time and resources to develop.

ACKNOWLEDGEMENTS

We would like to thank Rick Stagg and Kirby Sneed for their contributions to this project. This research was supported by Agriculture and Food Research Initiative Competitive Grant number 2009-35103-05356 from the USDA National Institute of Food and Agriculture, the Arkansas Forest Resources Center, and the Southern Research Station of the USDA Forest Service.

LITERATURE CITED

Bragg, D.C. 2011. Modeling loblolly pine above-ground live biomass in a mature pine-hardwood stand: a cautionary tale. Journal of the Arkansas Academy of Science. 65: 31-38.

California ARB [Air Resources Board]. 2009. California's 1990-2004 greenhouse gas emissions inventory and 1990 emissions level. California Environmental Protection Agency, Air Resources Board technical support document. http://www.arb.ca.gov/cc/inventory/doc/methods_v1/ghg_inventory_technical_support_document.pdf. [Date accessed: May 8, 2013].

California ARB [Air Resources Board]. 2013. Quarterly auction 2. http://www.arb.ca.gov/cc/capandtrade/auction/february_2013/auction2_feb2013_summary_results_report.pdf. [Date accessed: May 7, 2013].

Chaturvedi, R.K.; Raghubanshi, A.S. 2013. Aboveground biomass estimation of small diameter woody species of tropical dry forest. New Forests. 44(4): 509-519.

Chave, J.; Andalo, C.; Brown, S. [and others]. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia. 145: 87-99.

Crow, T.R; Schlaegel, B.E. 1988. A guide to using regression equations for estimating tree biomass. Northern Journal of Applied Forestry. 5: 15-22.

EPA [U.S. Environmental Protection Agency]. 2008. Inventory of U.S. greenhouse gas emissions and sinks: 1990–2006. EPA 430-R-08-005. Washington, DC: U.S. Environmental Protection Agency Office of Atmospheric Programs. [Not paged].

Fonseca, W.; Alice, F.E.; Rey-Benayas, J.M. 2012. Carbon accumulation in aboveground and belowground biomass and soil of different age native forest plantations in the humid tropical lowlands of Costa Rica. New Forests. 43: 197-211

Galik, C.S.; Murray, B.C.; Mercer, D.E. 2013. Where is the carbon? Carbon sequestration potential from private forestland in the southern United States. Journal of Forestry. 111: 17-25.

Gill, H.V.; Avery, D.C.; Larance, F.C.; Fultz, C.L. 1979. Soil survey of Ashley County, Arkansas. Washington, DC: U.S. Department of Agriculture Soil Conservation Service. 92 p. In cooperation with: the U.S. Department of Agriculture Forest Service and the Arkansas Agricultural Experiment Station.

Jenkins, J.C.; Chojnacky, D.C.; Heath, L.S.; Birdsey, R.A. 2003. National-scale biomass estimators for United States tree species. Forest Science. 49: 12-35.

Jenkins, J.C.; Chojnacky, D.C.; Heath, L.S.; Birdsey, R.A. 2004. Comprehensive database of diameter-based biomass regressions for North American tree species. Gen. Tech. Rep. NE-319. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Research Station. 45 p.

Jordan, L.; Clark, A.; Schimleck, L.R. [and others]. 2008. Regional variation in wood specific gravity of planted loblolly pine in the United States. Canadian Journal of Forest Research. 38: 698- 710.

Koch, P.; McKenzie, D.W. 1976. Machine to harvest slash, brush, and thinnings for fuel and fiber - a concept. Journal of Forestry. 74: 809-812.

Koning, J.W.; Skog, K.E. 1987. Use of wood energy in the United States - an opportunity. Biomass. 12: 27–36.

McGarrigle, E.; Kershaw, J.A.; Lavigne, M.B. [and others]. 2011. Predicting the number of trees in small diameter classes using predictions from a two-parameter Weibull distribution. Forestry. 84: 431-439.

Melson, S.L.; Harmon, M.E.; Fried, J.S.; Domingo, J.B. 2011. Estimates of live-tree carbon stores in the Pacific Northwest are sensitive to model selection. Carbon Balance and Management. 6:2. 16 p.

Miles, P.D.; Smith, W.B. 2009. Specific gravity and other properties of wood and bark for 156 tree species found in North America. Res. Note NRS-38. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station. 35 p.

Mitchell, H.L.; Wheeler, P.R. 1959. Highlights of Mississippi survey: the search for wood quality. Forest Farmer. 18: 4-6.

Munsell, J.F.; Germain, R.H. 2007. Woody biomass energy: an opportunity for silviculture on nonindustrial private forestlands in New York. Journal of Forestry. 105: 398-402.

Newbold, R.A.; Baldwin, V.C., Jr.; Hill, G. 2001. Weight and volume determination for planted loblolly pine in north Louisiana. Res. Pap. SRS-26. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 19 p.

Parresol, B. 1999. Assessing tree and stand biomass: a review with examples and critical comparisons. Forest Science. 45: 573-593.

Payadeh, B. 1981. Choosing regression models for biomass prediction equations. Forestry Chronicle. 57: 229-232.

Ruark, G.A.; Martin, G.L.; Bockheim, J.G. 1987. Comparison of constant and variable allometric ratios for estimating *Populus tremuloides* biomass. Forest Science. 33: 294-300.

Schultz, R.P. 1997. Loblolly pine: the ecology and culture of loblolly pine (*Pinus taeda* L.). Agric. Handb. 713. Washington, DC: U.S. Department of Agriculture. 493 p.

Snowdon, P.; Eamus, D.; Gibbons, P. [and others]. 2000. Synthesis of allometrics, review of root biomass and design of future woody biomass sampling strategies. National carbon accounting system Tech. Rep. 17. Canberra, Australia: Australian Greenhouse Office. 113 p.

Van Lear, D.H.; Taras, M.A.; Waide, J.B.; Augspurger, M.K. 1986. Comparison of biomass equations for planted vs. natural loblolly pine stands of sawtimber size. Forest Ecology and Management. 14: 205-210.

Westbrook, M.D.; Greene, W.D.; Izlar, R.L. 2007. Utilizing forest biomass by adding a small chipper to a tree-length southern pine harvesting operation. Southern Journal of Applied Forestry. 31: 165-169.

Whittaker, R.H.; Woodwell, G.M. 1968. Dimension and production relations of trees and shrubs in the Brookhaven Forest, New York. Journal of Ecology. 56: 1-25.

Zhou, X.; Hemstrom, M.A. 2009. Estimating aboveground tree biomass on forest land in the Pacific Northwest: a comparison of approaches. Res. Pap. PNW-RP-584. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 18 p.

Zianis, D.; Muukkonen, P.; Mäkipää, R.; Mencuccini, M. 2005. Biomass and stem volume equations for tree species in Europe. Silva Fennica Monographs. 4. 63 p.