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# Stand-Level Green Biomass Equations for Sawtimber-Sized Loblolly Pine Stands

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**Abstract**

Loblolly pine (*Pinus taeda* L.) is commercially the most important timber species in southern Arkansas and the southern United States. Results of stand-level timber inventories have traditionally been reported in terms of volume, yet loblolly pine sawtimber is bought and sold based on biomass. A straightforward stand-level conversion from volume per hectare to biomass per hectare does not exist for Arkansas, thus complicating the valuation of standing loblolly pine sawtimber. Two equations were developed to predict stand-level, outside-bark, green biomass per unit area for loblolly pine stands in southern Arkansas. The merchantable sawlog equation presented herein explained approximately 95% of the variation present and had an average error of 4.2 percent when applied to validation data. The equation for total merchantable biomass explained about 99% of the variation and had an average error of 1.5 percent when applied to validation data. Use of these equations should simplify the valuation of standing timber in loblolly pine sawtimber stands in southern Arkansas.

## Introduction

Loblolly pine (*Pinus taeda* L.) is the predominant timber species in southern Arkansas as well as the southern United States. Of the four southern pine species, loblolly pine is the most hardy and versatile with respect to its ability to reproduce and grow rapidly on diverse sites (Schultz, 1997). There are approximately 13.4 million hectares of loblolly pine forests in the southern United States (Schultz, 1997), collectively containing over 50% of the standing timber volume in the South (Baker and Langdon, 1990). In Arkansas, the area in loblolly pine plantations is forecast to more than double from the nearly 750,000 hectares today to about 1.7 million hectares in 2040 (Wear and Greis, 2002; Prestemon and Abt, 2002). Loblolly pine is thus a very important commercial tree species to the forest landowners and timber industry of Arkansas and the southern United States.

The predominant method of buying and selling timber in Arkansas and the southern United States is by biomass (TimberMart South, 2004). The Arkansas legislature recognized this in the 2003 legislative session by no longer requiring use of the Doyle log rule (a volume-based rule) as the only legal rule for sawlog timber transactions within the state. It is simply more efficient to determine log biomass than log volume. This gain in efficiency does come at a cost – it is now more difficult for a landowner to receive a premium for higher quality large logs (James Guldin, pers. comm.) as a high quality and low quality log of the same dimensions contain the same amount of biomass.

A problem arises, however, in that most forest inventories are conducted in terms of the timber volume and not biomass. The landowner or land manager must then convert from units of volume to units of biomass in order to determine timber value. To aid in this process, individual tree biomass equations have recently been developed for loblolly pine in Arkansas and surrounding regions (Newbold et al., 2000; Posey, 2003). These equations can be applied to individual-tree data collected during forest inventories and used to produce inventory results directly in terms of biomass.

Use of individual-tree biomass equations on inventory data and then summarizing these data are the best techniques to use when estimating stand-level biomass. However, if all that is known for a location are stand summary attributes, such as number of trees per hectare, average height of dominant and codominant trees, basal area per hectare, and/or quadratic mean diameter, the individual-tree biomass equations cannot be used. This situation arises when (a) just the results of a forest inventory are known, (b) a stand-level growth and yield model is being used, or (c) an experienced forester's best estimates are used. Stand-level biomass equations, or those that estimate timber biomass per unit area from stand-level attributes, as opposed to tree-level attributes, are required. Such stand-level equations have not been made publicly available to date for loblolly pine in Arkansas.

While some conversions have been reported (Dicke and McCreight, 1999; Avery and Burkhart, 2002), these factors depend more on the diameters of individual trees composing the stand and not stand-level attributes. One should avoid applying such conversions to the average-sized tree in a stand (an attribute easily obtained from stand-level attributes) due to the nonlinear relationship between tree sizes and conversion factors.

The objectives of this project were to develop outside-bark, green biomass per unit area equations for sawtimber-sized loblolly pine stands that estimate the biomass of (1) the sawlog portion of the trees (2) the tree-length stems to a 10.2 cm top diameter, the minimum diameter for pine pulpwood. Once produced, these equations can be used to predict merchantable sawlog biomass per hectare (objective 1) and total merchantable biomass per hectare (objective 2) for sawtimber-sized loblolly pine stands in southern Arkansas.

## Materials and Methods

Sixteen sawtimber-sized loblolly pine stands, all previously thinned, were visited and inventoried during 2002 (four stands in February, May, August, and November, respectively). The stands were located in Drew, Lincoln, Ashley, and Cleveland counties in southern Arkansas. Five stands were plantations; the remaining 11 stands were of natural origin. Approximately twenty 0.08-hectare plots were located via systematic random sampling within each stand. For each tree found on a plot, the diameter at breast height (DBH, outside-bark diameter measured 1.3 m above ground) and the total height were measured using a diameter tape and a clinometer, respectively, and recorded. The tree attributes were measured in English units in the field and then converted to metric units for the analyses herein. Additionally, the number of 5.2 m logs present was estimated and tallied for each loblolly pine.

The loblolly pine tree closest to the center of each plot was marked (for later identification), felled, merchandized to a tree-length log and transported to a loading deck with a skidder. Once at the loading deck, the biomass of each tree-length log was determined by using chains and tongs to attach the log to a digital load cell (Measurement Systems International, Challenger 2, Model 3360, accurate to 0.91 kg) suspended from a loader. The tree-length logs were bucked into merchantable portions to satisfy Georgia-Pacific Corporation's plywood log specifications (5.2, 7.9, or 10.7 m with a minimum top diameter of 20.3 cm inside bark) and the biomass of each merchandized log was then determined using the load cell.

The biomass of the tree-length logs and merchandized logs were used to develop individual tree biomass equations (Posey, 2003). The following equation, originally presented in English units but converted to metric for presentation herein, estimates the merchantable sawlog, outside-bark, green biomass for individual loblolly pines of sawtimber size:

$$S\hat{W}t_i = 0.4536e^{[1.6543+1.94777\ \ln(DBH_i/2.54)+0.8099\ \ln(Logs_i)]} \qquad (1)$$

where $S\hat{W}t_i$ = predicted merchantable sawlog biomass (kg) for tree $i$,
$DBH_i$ = diameter (cm) at breast height for tree $i$, and
$Logs_i$ = number of 5.2 m sawlogs present in tree $i$.

and equation (2), also converted to metric, estimates the total, merchantable, outside-bark, green biomass for individual sawtimber-sized loblolly pines:

$$T\hat{W}t_i = 0.4536e^{[-0.6769+2.0170\ \ln(DBH_i/2.54)+0.6947\ \ln(TH_i/0.3048)]} \qquad (2)$$

where $T\hat{W}t_i$ = estimated total, merchantable (10.2 cm top) biomass (kg) for tree $i$,
$TH_i$ = total height (m) for tree $i$, and
all other variables as previously defined.

As reported by Posey (2003), the approximate $R^2$ for equation (1) was 96.5%, and the mean absolute residual was 97 kg while the approximate $R^2$ and mean absolute residual for equation (2) were 95.2% and 151 kg, respectively.

Equations (1) and (2) were applied to each inventoried loblolly pine in the study to estimate its respective stem biomass. These biomasses were then summed across each 0.08 ha plot and expanded to biomass per hectare. The resulting biomass per hectare measures were the dependent variables for the two equations developed herein. The following stand-level attributes, sampled at each plot, were available for use as independent variables in the equations developed herein: number of loblolly pine trees per hectare, average height of the dominant and codominant loblolly pine trees, basal area per hectare, and quadratic mean diameter. This plot-based approach to stand-level estimation is a commonly accepted practice when developing stand-level volume or biomass equations (see Matney et al., 1988; Amateis et al., 1995; Lenhart, 1996).

The dataset, consisting of 321 plots, was randomly split into model building (229 plots) and model validation (92 plots) datasets. A variety of linear and nonlinear regression forms were fit to the model building dataset using the SAS® System for Windows (SAS Institute Inc., 1999). For each nonlinear regression fit, the fitted equation was applied to the dataset and the equivalent to sum of squared errors (SSE) and sum of squares total (SST) were manually calculated. An approximate $R^2$ was then found for the nonlinear fits via (SST-SSE)/SST. A host of typical regression diagnostics including the adjusted and/or approximate $R^2$, Shapiro-Wilk test of normality, PRESS statistic, Mallow's $C_p$, DIFFITs, and DFBETAs (Myers, 1990) was used in determining the best fitting regression equations.

The best fitting equations were then applied to the model validation dataset. The equations producing the smallest mean absolute errors and fewest outliers when applied to the validation dataset became the final recommended equations.

## Results and Discussion

A summary of the inventory data collected is provided in Table 1. The wide range of stand conditions and tree sizes encountered in this project suggests that the equations developed herein can be applied to most loblolly pine sawtimber stands found in southern Arkansas.

Table 1. Range of stand-level inventory data used to develop the stand-level biomass equations.

| Attribute | Mean | Standard Deviation | Minimum | Maxim |
|---|---|---|---|---|
| Average height of dominant pines (m) | 23.7 | 2.9 | 16.3 | 36.6 |
| Pine Site index (m, base age 25) | 18.9 | 2.6 | 11.6 | 29.8 |
| Pine trees per ha | 124.4 | 53.8 | 12.4 | 321.2 |
| Pine basal area ($m^2$) per ha | 15.4 | 5.3 | 3.9 | 31.1 |
| Pine quadratic mean diameter (cm) | 41.0 | 6.4 | 29.4 | 82.0 |
| Pine merch. sawlog biomass (kg per ha) | 121,466 | 47,152 | 21,814 | 254,926 |
| Pine total merch. biomass (kg per ha) | 188,673 | 68,843 | 46,645 | 392,457 |

The following functional form was determined to be most effective in estimating both merchantable sawlog and total, merchantable, outside bark, green biomass per hectare for sawtimber-sized loblolly pine stands:

$$\hat{WT}_i = a \times QMD_i^b \times HD_i^c \times TPH_i^d \quad (3)$$

where $\hat{WT}_i$ = estimated pine kilograms (merchantable sawlog or total merchantable) per hectare for stand *i*,
$QMD_i$ = pine quadratic mean diameter (cm) for stand *i*,
$HD_i$ = average height (m) of dominant and codominant pine trees for stand *i*,
$TPH_i$ = pine trees per hectare for stand *i*, and
*a, b, c,* and *d* are parameters that were estimated.

Parameter estimates for the respective equations appear in Table 2. All parameters were significant at ?=0.05, as the approximate 95% confidence intervals for each respective parameter estimate excluded 0.0. Fit statistics for the two regressions appear in Table 3.

The fit for the total merchantable biomass equation explained more of the variation (99.8%) in the dependent variable than the comparable merchantable sawlog biomass equation (94.7%). This was an expected result even though the total merchantable biomass per hectare is larger than the merchantable sawlog biomass per hectare (Table 1). The number of sawlogs in a given tree is determined by merchantability limits and specifications whereas the length (or height) to a 10.2 cm top is not. Therefore, the height to a 10.2 cm top (or the length of a tree-length log) is more consistent from tree to tree than the number of sawlogs present from tree to tree.

The mean absolute residual (average of the absolute values of each observation's predicted value minus its actual value) is relatively small for each fitted equation (Table 3). Note that the magnitude of the mean absolute residual did not change much when the fitted regression equations were

Table 2. Parameter estimates for equation (3) when fit to the merchantable sawlog and total merchantable biomass data, respectively.

| Dependent Variable (kg per ha) | Parameter | Estimate | Approximate Standard Error | Approximate 95% Confidence Interval |
|---|---|---|---|---|
| Merch. sawlog biomass | a | 0.0250 | 0.0074 | (0.0105 , 0.0396) |
| | b | 2.0314 | 0.0727 | (1.8882 , 2.1746) |
| | c | 0.9567 | 0.0636 | (0.8315 , 1.0820) |
| | d | 1.0132 | 0.0201 | (0.9735 , 1.0529) |
| Total merch. biomass | a | 0.0896 | 0.0043 | (0.0811 , 0.0982) |
| | b | 1.9832 | 0.0119 | (1.9596 , 2.0067) |
| | c | 0.7717 | 0.0104 | (0.7511 , 0.7923) |
| | d | 0.9992 | 0.0033 | (9.9927 , 1.0057) |

Table 3. Fit statistics for equation (3) when fit to the merchantable sawlog and total merchantable biomass data, respectively.

| Dependent Variable | Approximate $R^2$ | Standard Error of the Estimate (kg per ha) | Mean Absolute Residual [Standard Deviation] (kg per ha) |
|---|---|---|---|
| Merch. sawlog biomass | 94.7% | 11,183 | 8,294 [7,374] |
| Total merch. biomass | 99.8% | 2,838 | 1,902 [2,077] |

applied to the validation dataset (Table 4). When the absolute residuals are standardized by dividing them by the respective biomass per hectare estimated from each plot in the validation dataset, the average error is 1.5% for total merchantable biomass and 4.2% for merchantable sawlog biomass.

The practical application of the subject matter discussed in this paper truly rests in the use of English units rather than metric units that compose the standard of scientific presentation. Table 5 contains the conversion factors that should be used when converting from the metric units used in this paper to the corresponding English units to be used when applying these results.

## Conclusions

In the southern U.S., most timber is bought and sold by biomass, yet most forest inventories report only stand-level volume. Converting from volume to biomass requires individual-tree data that are not always available. This paper presents regression equations that predict merchantable sawlog and total, merchantable, outside-bark green biomass per unit area for most loblolly pine sawtimber stands of southern Arkansas.

The merchantable sawlog equation explained about 95% of the variation present and had an average error of 7,951 kg per ha (or 4.2%), while the total merchantable equation explained over 99% of the variation present and had an average error of 2,763 kg per hectare (or 1.5%). Additionally, the wide range of stand conditions visited during the course of this project allow the developed equations to be applied generally to sawtimber-sized loblolly pine stands in southern Arkansas. Given the current and projected future importance of loblolly pine to the timber industry in Arkansas, the equations developed herein should aid current and future timberland owners and managers in valuing their stands.

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Table 4. Summary attributes from applying the fitted regression equations to independent validation data.

| Dependent Variable | Mean Absolute Residual (kg per ha) | Standard Deviation (kg per ha) |
|---|---|---|
| Merch. sawlog biomass | 7,951 | 6,537 |
| Total merch. biomass | 2,763 | 3,262 |

Table 5. Conversions factors to use when changing from metric to English units and vice versa[1].

| Metric Unit | Divide By | To Obtain English Units |
|---|---|---|
| Centimeters (cm) | 2.54 | Inches |
| Meters (m) | 0.3048 | Feet |
| Hectares (ha) | 0.4047 | Acres |
| Sq. meters per hectare (m2/ha) | 0.2296 | Sq. feet per acre |
| Kilograms (kg) | 0.4536 | Pounds |
| Kilograms (kg) | 907.18 | Tons |
| Kilograms per hectare (kg/ha) | 2242 | Tons per acre |
| Trees per hectare | 2.471 | Trees per acre |

[1] To convert from English to metric units, multiply the English units in the third column by the conversion factors provided in the second column to obtain the metric units in the first column.

## Literature Cited

**Amateis, R. L., P. J. Radtke, and H. E. Burkhart.** 1995. TAUYIELD: a stand-level growth and yield model for thinned and unthinned loblolly pine plantations. Virginia Tech Loblolly Pine Growth and Yield Research Cooperative Report No. 82, Blacksburg, VA. 38 pp.

**Avery, T. E., and H. E. Burkhart.** 2002. Forest Measurements. 4th ed. McGraw-Hill Inc. New York. 456 pp.

**Baker, J. B., and G. O. Langdon.** 1990. Loblolly pine (Pinus taeda L.). In: Burns R. M. and B.H. Honkala, coordinators. Silvics of North America. Volume 1, Conifers. USDA Forest Service. Agricultural Handbook 654. p. 497-512.

**Dicke, S., and J. McCreight.** 1999. Pine volume to weight conversions. Mississippi State University Extension Service Publication 2244. 4 pp. Available via the INTERNET:http://www.msucares.com/pub/pub2244.pdf. Accessed 11 June 2002.

**Lenhart, J. D.** 1996. Total and partial stand-level yield prediction for loblolly and slash pine plantations in east Texas. South. J. Appl. Forestry 20:36-41.

**Matney, T. G., A. D. Sullivan, J. R. Ledbetter, and R. M. Farrar.** 1988. Stand-level cubic-foot volume ratio equations for planted loblolly pine on site-prepared land on the mid-south Gulf Coastal Plain. South. J. Appl. Forestry 12:7-11.

**Myers R. H.** 1990. Classical and modern regression with applications. 2nd ed. PWS-Kent Publishing Co. Boston, MA. 488 pp.

**Newbold, R. A., V. C. Baldwin Jr., G. Hill, and M. A. Dunn.** 2000. Loblolly plantation weight equations for north Louisiana. Louisiana State University Agricultural Center Pub. 2801. Baton Rouge, LA. 4 pp.

**Posey, T. E.** 2003. Individual-tree green weight equations and tables for loblolly pine (*Pinus taeda* L.) sawtimber in the coastal plain of Arkansas. University of Arkansas. M.S. Thesis, Monticello. Monticello, AR. 89 pp.

**Prestemon, J. P., and R. C. Abt.** 2002. Chapter 13: Timber products supply and demand. In: D.N. Wear and J. G. Greis, editors. Southern Forest Resource Assessment. Gen. Tech. Rep. SRS-53. U.S. Department of Agriculture, Forest Service, Southern Research Station, Ashville, NC. pp. 299-325.

**SAS Institute, Inc.** 1999. SAS® System for Windows Release 8.01. Cary, NC.

**Schultz, R. P.** 1997. Loblolly Pine: the ecology and culture of loblolly pine. USDA Forest Service, Southern Forest Experiment Station. Agricultural Handbook No. 713. 493 pp.

**TimberMart South.** 2004. TimberMart South Market Newsletter 4th Quarter 2003. University of Georgia, Athens9, GA. 15 pp.

**Wear, D. N., and J. G. Greis.** 2002. Southern Forest Resource Assessment. U.S. Department of Agriculture, Forest Service Southern Research Station. Asheville, NC. 635 pp.