Individual-tree Green Weight Equations for Loblolly Pine (*Pinus taeda* L.) Sawtimber in the Coastal Plain of Arkansas

Travis E. Posey, Paul F. Doruska, and David W. Patterson[1]

Abstract.— Loblolly pine (*Pinus taeda* L.) weight equations were developed to predict outside-bark, green bole weight to a 4-inch diameter-inside-bark (dib) top and an 8-inch dib top in southeast Arkansas. Trees were sampled from 8 different tracts over the first half of 2002: 4 tracts during winter and spring, respectively. The sampled trees ranged from 10 to 30 inches diameter at breast height (d.b.h.) and from 45 to 100 feet in total height. Parameter estimates did not differ significantly by season. The developed equations were compared with others published in the Southeast. Not surprisingly, the equations developed here outperformed the others examined for these data.

Weight scaling has become popular in the southern United States for buying and selling loblolly pine (*Pinus taeda* L.) saw logs. At most sawmills, saw logs are bought and sold exclusively by weight (primarily by the U.S. ton – 2000 pounds) to save time and money. However, sawtimber inventory volumes in south Arkansas are usually calculated in terms of Doyle board feet. It is difficult to compare the value of a stand based on a timber volume inventory ($/MBF) to the prices offered at the mill ($/U.S. ton) because of the different units involved. Volume tables developed in south Arkansas are readily available for conducting stand inventories in both cubic feet and board feet. However, there are few publicly available equations or tables that accurately report saw log weight for this region. The need exists for calculating inventory results by weight rather than volume for this region. We undertook a project to:

1. Develop loblolly pine sawtimber-sized tree weight equations using trees sampled in southeast Arkansas;
2. Determine the differences, if any, in bole weight equation parameters between winter and spring; and
3. Compare the equations developed with published equations from the Southeastern United States.

Methods

Procedure

All study sites were located in southeast Arkansas on land owned by Plum Creek Timber Company. Some 155 saw log-sized loblolly pine trees were sampled in eight stands. Eighty-one trees were weighed during February 2002, and 74 were weighed in May 2002. This allowed seasonal differences in weight equations to be examined. Table 1 summarizes the information for stands sampled during winter and spring.

Each stand was visited twice, once before and once after harvest. The first visit consisted of locating and measuring the trees that would later be weighed. In each stand, 20 loblolly pine trees (≥ 10” d.b.h. class) were selected by systematic random sampling. Several measurements including d.b.h. (inches), number of 17-foot logs, total height (feet), and bark thickness

Table 1.—*Mean and standard deviation (in parentheses) of inventory data by season*

Attribute	Winter 2002	Spring 2002
Basal area (sq. ft/acre)	76.0 (8.1)	69.5 (14.5)
Pine trees/acre	58.8 (6.2)	67.9 (18.9)
Site index (ft. base age 25)	65.6 (6.1)	60.3 (5.3)
D.b.h. (in.)	15.1 (0.7)	13.2 (0.4)
Total height (ft.)	80.5 (5.0)	64.4 (3.7)
Age (yrs.)	37.0 (2.4)	34.3 (3.5)
Weight (lbs.)	2,903.2 (518.0)	2,759.5 (429.8)

[1] Graduate Student, Assistant Professor, and Research Professor, respectively, Arkansas Forest Resources Center, University of Arkansas School of Forest Resources, Monticello, AR 71656. Phone: 870–460–1993; fax: 870–460–1092; e-mail: doruska@uamont.edu.

Table 2.—*Distribution of sample trees by d.b.h. and total height class*

D.b.h. class	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**Total**
						Total height by 5-ft class							
10	1	1	1		1	1	2						7
12	1		3	3	2	5	5	6	1				26
14				5	5	5	17	10	7	2	2		53
16				1	2	4	9	4	4	3	2	2	31
18						1	6	5	4	3	2	2	23
20							2		3	2	2		9
22							1					1	2
24													0
26									1			1	2
28										1			1
30								1					1
Total	2	1	4	9	10	16	43	26	20	10	10	4	155

(inches) at breast height were taken on each of the study trees using a diameter tape, clinometer, and a bark gauge. Table 2 shows the distribution of all study trees based on d.b.h. and total height. After all measurements were taken, each tree was numbered and marked with paint for identification on the log deck.

Soon after the first visit to each stand, logging contractors from Georgia Pacific Corp. harvested the trees. Each study tree was felled and brought to a designated log deck where it was delimbed and topped at approximately 4 inches dib. Within 2 days of felling, the felled trees were measured and weighed. Measurements taken on each of the felled study trees include length (feet) to a 4-inch dib top, dib at both ends, age, and heartwood diameter at both ends. Each study tree was then weighed using a digital scale, loader, chains, and tongs. Then the trees were bucked into merchantable lengths to satisfy Georgia Pacific's saw log specifications (17, 26, or 35 feet with a minimum top diameter of 8-inches inside bark). The same measurements that were taken on the felled study trees, including weight, were then taken on each of the merchantable saw logs. Each measurement taken (before and after harvest) was used later as a potential independent variable in creating regression equations.

Analysis

Data from 40 trees were set aside as a validation data set and data from the remaining 115 trees were used in building the regression models. Typical regression diagnostics were used in comparing and selecting the best equation forms. Indicator variables were used to determine if equation parameters varied significantly between winter and spring. The validation data set served as an additional diagnostic for comparing equations. The equations that best predicted weight to a 4-inch dib top and weight to an 8-inch dib top were chosen based on the diagnostics and indicator variable significance.

Model Comparisons

The final weight equations were compared with three published equations developed in the Southeast:

1. Newbold *et al.* (2001),
2. Clark and Saucier (1990), and
3. Baldwin (1987).

Each of these models was applied to the validation data set and the residuals were used to compare models. The models developed, which were created using only the regression data set, were also applied to the validation data.

Results and Discussion

Predicting Weight to a 4-inch DIB Top

Natural log transformations were needed to assure normality of errors. The best independent variables for predicting outside-bark green bole weight to a 4-inch dib top were d.b.h. and total tree height. The final 4-inch dib weight equation developed from the regression data set was:

$$\ln(\hat{W}t_i) = -0.1341 + 2.0178 \ln(D_i) + 0.5726 \ln(H_i) \qquad (1)$$

Where: $\hat{W}t_i$ = Predicted green weight (lbs.) outside bark to a 4-inch dib top for tree i,

D_i= d.b.h. (in.) for tree i, and

H_i= Total tree height (ft) for tree i.

All parameters were significant at the 0.05 α-level. The R^2 for equation (1) was 0.95 and the mean absolute residual was 236.34 pounds. The indicator variables were not significant for the intercept (p-value = 0.2969), $\ln(D_i)$ partial slope (p-value = 0.3467), or $\ln(H_i)$ partial slope (p-value = 0.2925), indicating that there was not enough evidence to conclude a significant difference in 4-inch dib weight equation parameters between winter and spring.

Table 3 compares the residuals obtained by applying each equation to the validation data set. It appears that all the equations overpredicted weight to a 4-inch dib top on average. According to the standard deviation and the mean absolute residual, which indicate on average how far off the regression line the actual values are, equation (1) appears to be best at predicting tree weight in south Arkansas. It was expected that our equation would be better at predicting weight of trees in validation data acquired in this study. However, this was the most objective means of comparison available.

Figure 1 depicts the results when the four equations were applied to the validation data set. There is little difference in predicted weights between any of the equations. The variation in predicted weights between models supports the idea that specific gravity varies somewhat by geographic location. As figure 1 shows, the equation developed by Clark and Saucier (1990) consistently estimates the lowest weight relative to the other equations. This is followed (in order from lightest to heaviest) by equation (1), Newbold *et al.* (2001) and Baldwin (1987). This corresponds to the variation in loblolly pine specific gravity by location found by the USDA (1965). Loblolly pine specific gravity in the Southeastern United States tends to increase from east to west and from north to south. This illustrates the impacts of using weight equations in this region that were developed in other geographic locations.

Figure 1.—*Comparison of 4-inch dib top equations using the validation data set.*

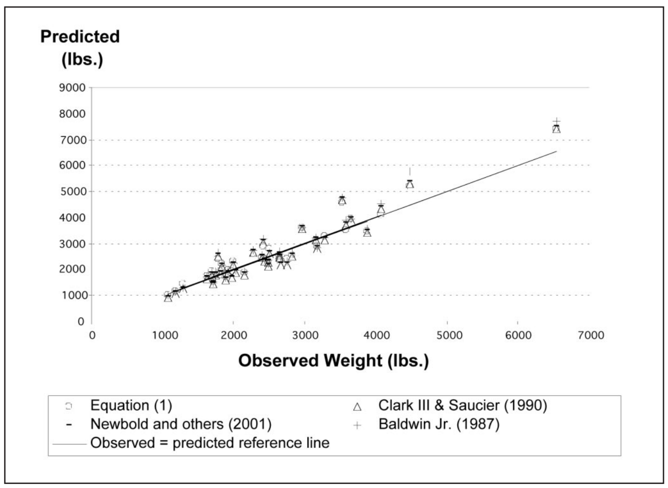


Table 3.—*Comparison of 4-inch dib top weight equations*

Attribute (lbs.)	Equation (1)	Clark and Saucier (1990)	Newbold *et al.* (2001)	Baldwin (1987)
Mean residual	-87	-25	-118	-146
Standard deviation	345	401	404	429
Mean abs. residual	253	300	299	309
Max. residual	430	583	492	454
Min. residual	-1,066	-1,139	-1,240	-1,275

Predicting Weight to an 8-inch DIB Top

As with the 4-inch dib top equation, the natural log transformation was needed to assure normality of errors. The best independent variables for predicting outside bark green merchantable saw log weight to an 8-inch top were d.b.h. and the number of 17-foot logs in the tree. The final 8-inch dib top equation built from the regression data set was:

$$\ln(\hat{W}t_i) = 1.5810 + 1.9772\ln(D_i) + 0.8174\ln(Logs_i) \quad (2)$$

Where: $\hat{W}t_i$= Predicted green weight (lbs.) outside bark to an 8-inch dib top for tree i,

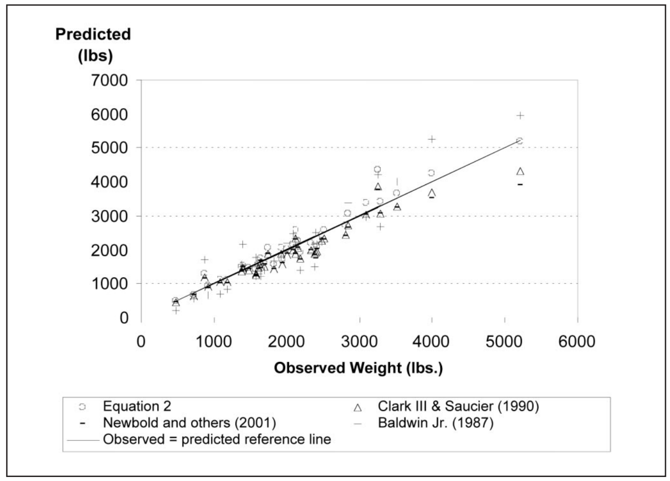
D_i= d.b.h. (in) of tree i, and

$Logs_i$= Number of 17-foot logs in tree i.

All parameters were significant at the 0.05 α-level. The R^2 for equation (2) was 0.97 and the mean absolute residual was 139.79 pounds. The indicator variables were not significant for the intercept (p-value = 0.2851), $\ln(D_i)$ partial slope (p-value = 0.2428), or $\ln(Logs_i)$ partial slope (p-value = 0.2965), indicating that there was not enough evidence to conclude a significant difference in 8-inch dib top weight equation parameters between seasons.

The residual summary in table 4 shows that on average, equation (2) slightly overpredicts weight to an 8-inch dib top, whereas the others underpredict the weight. The residuals show that there are more differences between 8-inch dib top equations than between 4-inch dib top equations. The differences between predicted and actual weight for each observation in the validation data set can be seen in figure 2. The variation in the weights predicted by the equations clearly increases as actual tree weight increases. According to table 4, equation (2) seems to be most similar to the equation developed by Clark and Saucier (1990).

Figure 2.—*Comparison of 8-inch dib top equations using the validation data set.*



Discussion and Conclusion

The best independent variables for predicting green bole weight to a 4-inch dib top were d.b.h. and total tree height. D.b.h. and the number of logs explained the most variation in green bole weight to an 8-inch dib top. There were no significant differences in 4-inch or 8-inch dib top equation parameters between winter and spring. It is important to note that the eight stands used in this study were extremely variable in site characteristics (moisture, soil type, etc.); therefore, confounding effects obviously exist. The site variability probably causes as much variation within seasons as between seasons. A more appropriate way to test seasonality would be to visit the same stands during different seasons. However, this was not possible for this study. Therefore, the only sound conclusion to be drawn here regarding seasonality is that there were no differences in weight equation parameters between winter and spring when averaging across all types of sites used in this study. Our equations were

Table 4.—*Comparison of 8-inch dib top weight equations*

Attribute (lbs.)	Equation (1)	Clark and Saucier (1990)	Newbold *et al.* (2001)	Baldwin (1987)
Mean residual	-41	163	188	18
Standard deviation	254	248	289	478
Mean abs. residual	171	229	249	380
Max. residual	316	880	1,294	903
Min. residual	-1,119	-595	-501	-1,276

most similar to the equations created by Clark and Saucier (1990), which were developed in Georgia and the surrounding States. The 4-inch and 8-inch dib top equations presented in this study should be sufficient for estimating outside-bark green bole weight of loblolly pine sawtimber in south Arkansas.

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