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Volume Prediction from Stump Diameter and Stump Height of Selected Species in Louisiana[1]

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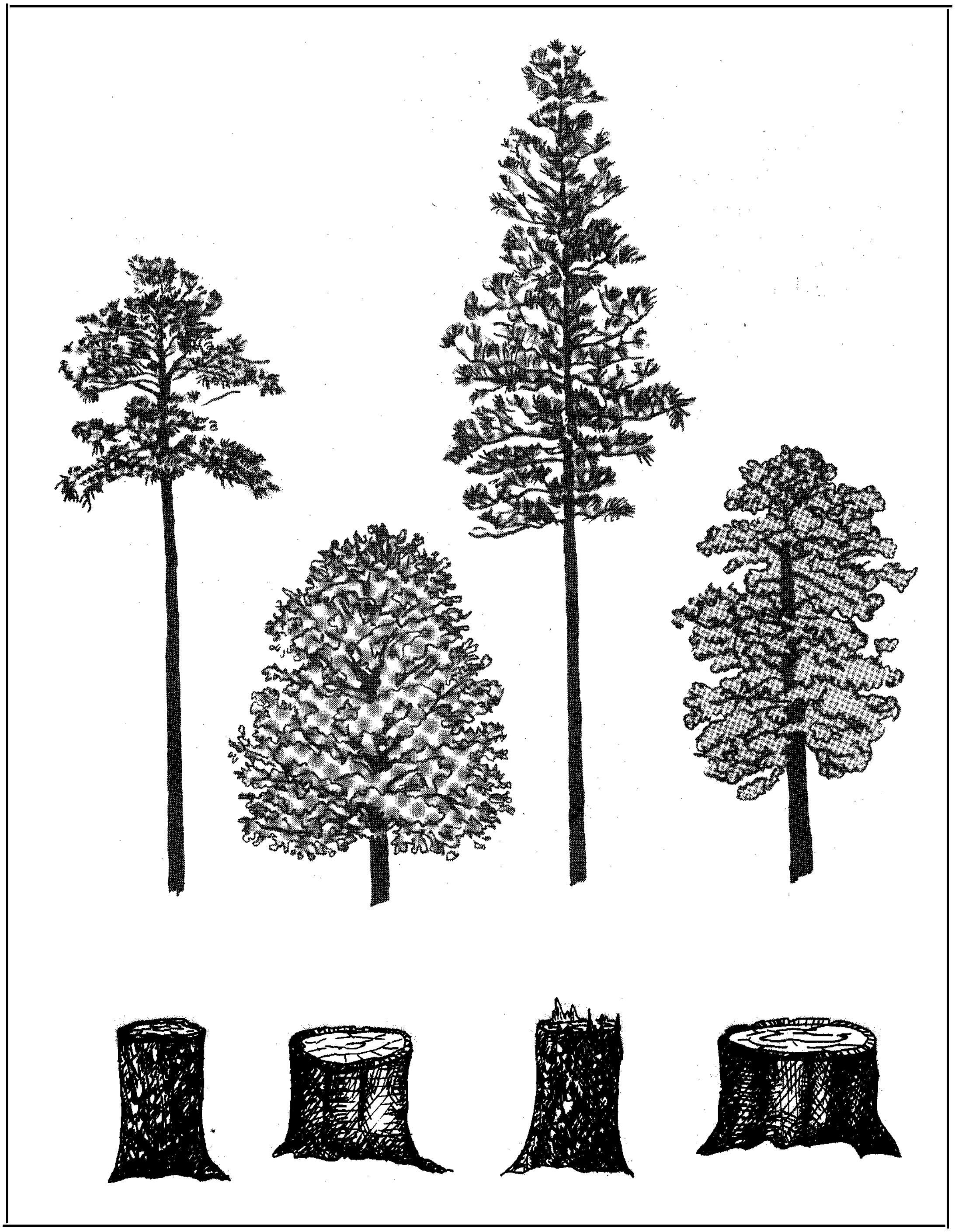

SUMMARY

Equations for predicting cubic foot volumes from stump diameter and stump height are presented for 15 southern species. Of the two separate sets of equations developed, one predicts volumes from stump diameter and the other predicts volume from stump diameter and stump height. In each set, six equations for each species predict total, merchantable, and sawtimber volumes. Two equations for each of the above are presented using stump diameter inside bark and stump diameter outside bark.

Equations were verified on independent test subsets using the F distribution statistic with a significance level of .05. Equations will predict volume within ± 2 standard errors 95 percent of the time.

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INTRODUCTION

Sometimes foresters must estimate the volume of timber harvested from the stumps which remain after logging. This study provides reasonably accurate equations for prediction of the tree volume using stump diameter and stump height as the independent variables.

The Southern Forest Experiment Station's Renewable Resources Evaluation Unit currently remeasures sample plots on a 10 year cycle. Frequently, previously measured trees have been harvested. Volume must be estimated to report removals for the state. Presently, these volumes are calculated from past diameter at breast height, adding the average increment for 5 years and the resultant diameter is used to estimate volume using B&E coefficients[1] and diameter classes. Equations which predict cubic foot merchantable and sawtimber volumes from stumps will also be useful for reporting removals statistics.

Since the energy crisis, interest has increased in wood as a source of heat. Some people who invade the National Forests and forest industries' lands in search of firewood cut any tree they desire. In *American Forests,* Rolleston (1980) and Schwarz (1980) investigated the problem of timber rustling in the East and West, respectively.

The value of a stolen tree is determined by many factors. The tree's size-class (sapling, poletimber, or sawtimber) and volume are two major factors. If a forester knows the volume of a tree and its size-class, he could easily calculate the financial value of that tree using the current market price. Predicting volume from stump diameters should be useful to public and private owners of timber.

LITERATURE REVIEW

Available literature on prediction of tree volume from stump diameter is relatively sparse. Most articles predict diameter at breast height (dbh), rather than volume, from stump diameter. Generally, two phases of estimation are suggested. After dbh is predicted from stump diameter, estimated volume is obtained by the use of local volume tables. Study results appear as charts, curves, graphs, tables, regression equations, "rule of thumb" equations, or combinations of the above. The earlier studies use charts whereas the later studies use tables and regression equations.

Studies which utilize graphs, charts, or curves include Hough (1930), Ostrom and Taylor (1938), Rapraeger (1941), and Endicott (1959). Studies which utilize tables or "rule of thumb" for predicting dbh include Cunningham et al. (1947), McCormack (1953), Eie (1959), Almedag and Honer (1973, 1977), and Horn and Keller (1957). Tables for predicting tree volume are presented by Decourt (1973) and Quigley (1954). Studies which utilize regression techniques for predicting dbh include Schaeffer (1953), Bones (1960, 1961), Myers (1963), Lange (1973), McClure (1968), Raile (1977), and others. Regression equations for predicting volume from stump measurements are presented by Nyland (1975).

Review of the literature indicated that prediction of dbh from stump measurement is common, but predictions of volume, also possible, are not. Therefore, a need for methods to predict volume directly from stump measurements exists. Such methods for predicting volume of removed trees are useful both to foresters and owners of private timber lands.

METHODS

Data Collection

In 1973, data used in this study were gathered in Louisiana as part of a wood utilization study. Twenty trees were measured at each of 77 logging sites. Each tree was assigned a site number and a tree number. Measurements were made on the main bole and limbs. The main bole was divided into sections in order to separate stump, sawlog portion, jump butt or cull section, upper stem, pole section, stem section of cull tree, or portions used for a variety of products.

The following items were measured on each tree: stump height, stump diameter, double bark thickness

[1] B&E coefficients give average volume as a second degree function of diameter from volumes in 2 inch diameter classes.

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at stump height, dbh, double bark thickness at dbh, diameters at upper and lower ends of each section, double bark thickness at upper and lower ends of each section, length of each section, and length from the base of the crown to the terminal bud. Each section was assigned a product code. The product codes are stump, sawlog, poletimber, limbs, non-inventory section, or crown left in the woods.

The utilization study used National Forest Survey Handbook standards to assign tree size class. A tree was classified as poletimber if its dbh was between 5.0 inches and 9.0 inches for softwoods and between 5.0 inches and 11.0 inches for hardwoods.[2] A tree was classified as sawtimber if its dbh was greater than 9.0 inches for softwoods or greater than 11.0 inches for hardwoods.[3]

Total cubic foot volume[4] is the volume in the main bole from a one-foot stump to the top of the tree. Merchantable cubic foot volume is the volume in the main bole from a one-foot stump to a height where the diameter outside bark is 4.0 inches or to the place where the length was terminated due to the presence of rot, forks, or other limiting defects. Sawtimber cubic foot volume is the volume from a one-foot stump to the height where the diameter outside bark is 7.0 inches for softwoods and 9.0 inches for hardwoods or to the place were the length was terminated due to the presence of rot, forks, or other limiting defects.[5]

Due to these limiting defects, some trees' merchantable length terminated before reaching the standard 4-inch diameter outside bark for growing stock trees. Similarly, saw log length sometimes terminated before the standard 7-inch diameter outside bark on softwoods or 9-inch diameter outside bark on hardwoods. On these trees, diameter observations were recorded at the place on the main bole where the length was terminated.

Each tree volume (cubic feet) was calculated using a neiloid frustrum and Smalian's formula. The volume between stump height and dbh was calculated using a neiloid frustrum:

$$V = \frac{(4.5 - SHT) \cdot [BASDIB + \{BADBH \cdot (BASDIB)^2\}^{1/3} + \{BASDIB \cdot (BADBH)^2\}^{1/3} + BADBH]}{4}$$

where

V	= Volume (cubic feet)
SHT	= Stump height (feet)
BASDIB	= Basal area of stump diameter inside bark (feet^2)
BADBH	= Basal area of dbh inside bark (feet^2)

The volume above dbh was calculated using Smalian's formula:

$$\sum_{i=1}^{n} \left(\frac{L_i \cdot \pi}{288} \left(\frac{DIB^2_{li} + DIB^2_{ui}}{4} \right) \right)$$

where

DIB_{li}	= Diameter inside bark at the lower or larger end (inches)
DIB_{ui}	= Diameter inside bark at the upper or smaller end (inches)
L_i	= Length of tree section (feet)
π	= 3.14159
n	= number of sections measured
i	= the ith section

Section lengths ranged from less than one foot to a maximum of 17 feet with the majority of the lengths being approximately 8 feet. Stump diameters outside bark ranged from 4.2 to 45.3 inches. For softwoods, stump heights ranged from 0.1 to 1.5 feet with a mean of 0.8 foot. For hardwoods, stump heights ranged from 0.1 to 2.9 feet with a mean of 1.0 foot.

Table 1 lists the scientific and common name of each species used. Table 2 lists mean, range, and number of samples for each species or combination of species for which equations were developed. Several trees in the data set had a merchantable top diameter outside bark of less than 4.0 inches. Merchantable top diameter outside bark ranged from 2.0 to 23.5 inches. Sawtimber top diameters outside bark ranged from 7.0 to 26.0 inches. Table 3 presents the name of each species and the number of samples included in the other-hardwoods classification.

Table 1.-*Scientific and common name of species*

Scientific name	Common name
Softwoods	
Pinus elliottii	Slash pine
Pinus echinata	Shortleaf pine
Pinus palustris	Longleaf pine
Pinus taeda	Loblolly pine
Hardwoods	
Quercus alba	White oak
Quercus falcata var *pagodifolia*	Cherrybark oak
Quercus stellata	Post oak
Quercus nigra	Water oak
Quercus falcata	Southern red oak
Carya sps.	Hickory
Liquidambar styraciflua	Sweetgum
Fagus grandifolia	American beech
Nyssa sylvatica	Black tupelo
Liriodendron tuplipifera	Yellow-poplar
Celtis laevigata	Sugarberry

[2]*Forest Survey Handbook, 1967.*

[3]*Ibid.*

[4]This volume is the gross volume. It includes any cull or defect that occurs between the stump and top termination point.

[5]*Forest Survey Handbook.*

Table Z.-*Mean, range', and number of samples for selected parameters in the data sets*

Species	No. samples: Sawtimber	No. samples: Total or merchantable	Dbh: Mean	Dbh: Range	Stump height: Mean	Stump height: Range	Stump diameters: Inside bark range	Stump diameters: Outside bark range	Merchantable top diameters, Inside bark: Mean	Merchantable top diameters, Inside bark: Max.	Merchantable top diameters, Outside bark: Mean	Merchantable top diameters, Outside bark: Max.	Sawtimber top diameters, Inside bark: Mean	Sawtimber top diameters, Inside bark: Max.	Sawtimber top diameters, Outside bark: Mean	Sawtimber top diameters, Outside bark: Max.
Slash Pine	71	137	9.6	3.4-17.2	.7	0.4-1.2	3.6-27.2	4.8-29.1	3.3	5.9	3.7	6.9	6.6	9.9	7.4	11.1
Shortleaf Pine	151	196	12.8	4.5-23.5	.7	0.2-1.2	4.4-24.0	5.3-26.1	4.8	10.9	5.2	12.4	8.3	15.5	9.0	16.2
Longleaf Pine	35	42	13.3	7.5-19.4	.7	0.5-1.3	7.1-20.3	8.5-23.4	4.6	9.0	5.0	9.7	7.8	11.7	8.4	12.3
Loblolly Pine	337	436	13.5	3.0-27.0	.8	0.1-1.5	3.3-28.8	4.2-31.3	4.5	12.0	4.9	12.7	8.5	20.3	9.1	21.8
All Pines	671	914	12.7	3.0-27.0	.8	0.1-1.5	3.3-32.5	4.2-35.4	4.4	12.0	4.8	12.7	8.2	20.3	8.9	21.8
Hickory	30	36	15.0	6.7-24.2	1.1	0.5-1.5	7.9-26.7	9.0-28.2	8.5	17.1	9.3	18.2	12.1	18.6	13.2	19.5
White Oak	57	72	13.9	6.3-23.3	1.1	0.1-2.1	7.4-26.1	7.9-27.5	8.3	22.3	9.0	23.5	11.1	22.1	12.0	23.5
Water Oak	52	62	16.8	6.6-36.9	1.1	0.5-1.8	8.3-41.6	9.0-43.2	8.3	19.6	8.8	20.5	12.7	23.8	13.4	24.8
Post oak	32	68	11.6	4.1-22.6	.9	0.5-1.5	4.9-27.4	6.0-29.0	7.0	19.8	7.8	21.9	10.6	18.1	11.7	20.1
Cherrybark Oak	22	28	15.0	7.3-28.5	1.1	0.5-1.5	8.7-32.1	9.4-34.3	7.1	16.4	7.6	17.2	11.2	16.7	12.0	17.3
S. Red Oak	50	89	11.8	4.4-22.0	1.0	0.4-2.9	4.7-25.9	5.2-27.4	6.4	16.6	7.0	17.4	10.1	16.6	11.1	17.4
Sweetgum	66	119	12.7	4.0-41.4	1.0	0.3-1.5	4.9-27.4	5.3-28.5	6.1	16.9	6.6	17.5	9.9	16.9	10.7	17.5
Black Tupelo	13	23	13.2	6.6-20.2	1.1	0.3-1.5	8.7-26.4	9.6-27.3	6.7	11.3	7.3	12.1	10.4	12.6	11.2	13.3
Yellow-poplar	14	14	17.3	15.3-22.5	1.0	0.5-1.5	16.2-23.4	17.6-25.2	7.6	10.2	8.4	11.0	12.0	15.5	13.0	17.0
Sugarberry	17	21	15.8	8.4-26.2	1.4	1.0-2.5	12.9-32.1	13.7-33.7	8.5	15.3	8.9	16.0	11.8	15.3	12.4	16.0
Beech	13	15	16.4	8.9-21.9	1.2	0.7-1.5	10.5-25.9	10.9-27.0	9.5	16.2	9.7	16.8	14.3	18.0	14.6	18.5
Other Hardwoods	74	113	14.4	4.4-29.8	1.0	0.3-1.5	5.2-34.9	5.8-36.5	7.8	17.7	8.3	18.4	12.4	20.0	13.2	20.9
All Hardwoods	408	619	13.8	4.0-41.4	1.0	0.1-2.9	4.7-43.4	5.2-45.3	7.4	22.3	8.0	23.5	11.2	24.7	12.1	26.0

'Due to the selection of test subsets, ranges for all-pines and all-hard woods data sets may differ from species ranges.

Table J.-*Species and number of trees included in other-hardwoods data set and test subset*

Species	Number of trees
Boxelder	6
Red Maple	4
Water hickory	3
Pecan	12
Persimmon	1
American beech	15
Water locust	3
Honey locust	2
Black walnut	2
Cucumbertree	1
Sweetbay	1
Sassafras	1
Basswood	2
Winged elm	6
American elm	8
Cedar elm	1
Mulberry	1
Black cherry	3
Laurel oak	1
Overcup oak	1
Bur oak	3
Chinkapin oak	2
Swamp chestnut oak	12
Nuttall oak	8
Willow oak	8
Chestnut oak	1
Black oak	11
White ash	7
Green ash	6

Selection of Test Subsets

A species test subset was extracted from every species data set which contained more than 30 sample trees. Each species data set was sorted in ascending order by dbh. The test subset was extracted from the data set by systematic sampling with a random start.

The all-pines test subset consisted of 10 percent of the samples in the all-pines data set. All other test subsets consisted of 20 percent of their respective data set. Black tupelo, yellow-poplar, sugarberry, and beech data sets had less than 30 sample trees; consequently, no test subsets were selected from these species.

The test subset and the remaining data set are mutually exclusive. From here on, reference to the data set excludes all trees in the test subset.

Anomalies in Data Sets

Some anomalies were present within the data sets. The majority of trees were sawtimber size. From table 2, the mean dbh was approximately 14 inches. The distribution of sample trees by dbh class was skewed because the sample came from logging sites. Therefore, prediction equations are most appropriately applied to sawtimber trees.

Some data sets were consistent in having the top diameters larger than the minimum. Hickory merchantable top diameters were generally greater than 4.0 inches. Hickory and post oak sawtimber top diameters were generally greater than 9.0 inches. White oaks greater than 13.0 inches dbh had sawtimber top diameters generally greater than 9.0 inches. The equations developed from these data sets will therefore predict a lower volume than expected for trees which meet the National Forest Survey Handbook standards.[6]

Yellow-poplar dbh's ranged from 15.3 to 22.5 inches. Beech dbh's ranged from 8.9 to 21.9 inches. Volume prediction of poletimber trees for yellow-poplar and beech is not recommended.

Selection of Regression Equation

Trends of linearly increasing absolute residuals with increasing stump diameters indicate that weighted regression techniques may yield better predictive equations. After preliminary analysis using both weighted and unweighted regression techniques, the weighted regression equations were better (Bylin, 1979). The weights used were:

1 / (stump diameter inside bark)

or

1 / (stump diameter outside bark)

The general equation used is:

$$V = b_0 + b_1 \cdot D^2 + b_2 \cdot SHT$$

where

V = Volume in cubic feet (total, merchantable, or sawtimber)

D = Stump diameter in inches (inside or outside bark)

SHT = Stump height in feet

b_i = Coefficients ($i = 0,1,2$)

RESULTS AND DISCUSSION

I tested the hypothesis:

$$H_o : b_2 = 0$$

using unweighted step-wise regression techniques with the partial F-test at .05 level. The hypothesis was not rejected. The results of a previous study (Bylin, 1979) conflict with this finding. Greater variation in stump height in the former study may explain the significance of stump height in that study and the lack of significance in the present one.

[6]Ibid.

Stump height was eliminated from the equations before weighted regression equations were developed. Table 4 presents coefficients of the weighted regression equations, the standard error, the coefficient of determination (R^2), and the number of samples. Mean stump height was 0.8 foot for softwoods and 1.0 foot for hardwoods.

The standard errors ranged from 3.70 cubic feet for post oak to 14.54 cubic feet for beech. The coefficient of determination ranged from .52 for other-hardwoods to .94 for post oak. The majority of R^2's were greater than .78.

The equations for predicting sawtimber volumes (C and F) normally had a lower R^2 and a larger standard error. The equations using stump diameter inside bark (A, B, and C) generally had better R^2 and standard errors than the other equations (D, E, and F).

The equations for elm, ash, and beech sawtimber trees were rejected due to low R^2, large standard errors, and small sample size (13-15). Other equations were developed using various combinations of variables. In addition to stump diameter squared, the following were included in a step-wise regression: stump diameter cubed; square root of stump diameter cubed; stump diameter times stump height; stump diameter squared times stump height; stump height; and a third degree polynomial of stump diameter. None of these variables significantly improved the equations.

The inclusion of stump height improved slightly, but not significantly, the equations' volume prediction. Some users of the equations might prefer this slight improvement. Regression equations were developed including stump diameter squared and stump height as independent variables. Table 5 presents the coefficients, standard errors, coefficients of determination (R^2), and number of samples.

Equations in table 5 differ from those in table 4 because stump height is included and unweighted regression was used. The inclusion of stump height in the equations posed a weighting problem since it is often difficult to obtain specific information regarding the nature of the weighting vector (Draper and Smith, 1966). Thus, no weighting was attempted in this case. Equations in table 5 were formulated before those in table 4. Differences in the number of observations between table 4 and 5 result from the identification and rejection of a number of observations due to duplication or coding errors.

Testing the Equations

The equations in table 4 were verified by the comparison of variances or F-test between the equations and the test subsets.

The following hypotheses were tested:

$$H_o: \quad s_t^2 = s_r^2$$

$$H_1: \quad s_t^2 > s_r^2$$

where

s_t^2 = Variance of test subset

s_r^2 = Variance of regression equation (mean square error)

and

s_t^2 = (Σ residuals^2) / (Number of test trees)

F-test $= s_t^2 \,/\, s_r^2$

Those trees in the test subset whose residuals were greater than ± 4 standard errors were reexamined. Examples of the abnormalities of these atypical trees were: the merchantable top diameter was 17.0 inches instead of 4.0 inches; the height of the tree was 20 to 30 feet greater than other trees in the same dbh class; and the difference between stump diameter and dbh was 10.0 inches. Elimination of these trees from the test subset *a posteriori* lead to the adoption of a modified F-test.

Using the F-test or, when required, the modified F-test, all equations failed to be rejected at the .05 significance level.

Results of Test Subsets

Based on the F-tests, all equations presented in table 4 are sufficiently accurate for the prediction of volumes. These equations will predict volume within ± 2 standard errors 95 percent of the time.

Water oak sawtimber equations were the worst predictors of volume. Clues to this poor performance are offered by several unusual characteristics in the data set. Sawtimber top diameter was generally greater than 9.0 inches. This caused the actual volume to be less than the predicted volume. Many trees had large butt swell (large stump diameter) which caused the predicted volume to be larger than the actual volume.

Southern red oak prediction equations slightly overestimate the volume of their test subset. Stump heights, ranging from 0.4 to 2.9 feet (table 2), contributed to the small overestimation. Overestimations were too small to cause rejection of the equations.

In spite of the variety of species within the other-hardwoods data set (table 3), these equations had excellent volume prediction, Both the other-hardwoods

Table 4.—*Equations using stump diameter to predict total, merchantable, and sawtimber volumes.*

Equation*	b_0	b_1	SE†	R^2‡	No. samples
Slash Pine					
A	-3.188	.164	5.31	.83	137
B	3.430	.164	5.31	.83	137
C	-6.073	.171	8.04	.59	71
D	-3.981	.123	5.68	.81	137
E	-4.225	.123	5.67	.81	137
F	-7.493	.130	8.57	.55	71
Shortleaf Pine					
A	-2.522	.186	6.26	.92	196
B	2.566	.182	6.39	.91	196
C	-3.526	.174	7.66	.81	151
D	-3.453	.152	6.93	.90	196
E	-3.466	.149	7.06	.89	196
F	-4.710	.144	8.38	.77	151
Longleaf Pine					
A	.603	.137	4.33	.87	42
B	.508	.134	4.63	.85	42
C	-1.514	.133	4.45	.83	35
D	-.043	.107	4.48	.87	42
E	-.134	.105	4.76	.85	42
F	-2.156	.104	4.50	.82	35
Loblolly Pine					
A	-5.256	.189	9.71	.89	436
B	-5.452	.186	9.66	.89	436
C	-9.012	.183	11.21	.79	337
D	-7.198	.158	10.32	.87	436
E	-7.376	.156	10.26	.87	436
F	-11.627	.155	11.74	.77	337
All Pines					
A	-4.319	.184	8.05	.89	914
B	-4.458	.181	8.01	.89	914
C	-6.659	.176	9.61	.79	671
D	-6.073	.153	8.80	.88	914
E	-6.192	.150	8.74	.87	914
F	-9.073	.148	10.32	.76	671
Hickory					
A	-3.681	.144	7.60	.88	36
B	-1.708	.118	7.43	.84	36
C	-.929	.093	6.96	.74	30
D	-6.099	.126	7.37	.89	36
E	3.613	.103	7.35	.85	36
F	3.366	.083	6.55	.77	30
Sweetgum					
A	-2.575	.132	7.01	.86	119
B	-1.996	.120	6.54	.85	119
C	-6.901	.120	8.97	.63	66
D	-3.360	.121	7.06	.85	119
E	-2.706	.110	6.56	.85	119
F	-8.916	.113	9.02	.62	66
Beech					
A	-2.388	.142	14.46	.67	15
B	-3.713	.126	11.51	.71	15
D	1.725	.131	14.54	.66	15
E	3.354	.117	11.44	.72	15
White Oak					
A	-4.004	.128	7.91	.80	72
B	-1.111	.100	6.16	.80	72
C	1.793	.087	6.17	.69	57
D	-4.979	.113	8.20	.79	72
E	1.943	.088	6.28	.80	72
F	-2.827	.078	6.41	.67	57
Cherrybark Oak					
A	-1.833	.126	9.66	.89	28
B	-1.113	.113	9.93	.86	28
C	5.736	.108	9.68	.81	22
D	-2.236	.112	9.77	.89	28
E	-1.504	.100	9.95	.86	28
F	-6.233	.096	9.74	.81	22
Post Oak					
A	-2.054	.106	3.70	.94	68
B	-1.037	.085	3.75	.90	68
C	1.800	.064	5.36	.57	32
D	2.962	.090	3.93	.93	68
E	-1.738	.071	3.91	.90	68
F	1.125	.054	5.41	.57	32
Water Oak					
A	1.208	.112	11.06	.90	62
B	.222	.103	11.07	.89	62
C	2.654	.078	11.21	.75	52
D	.380	.103	11.00	.91	62
E	-.592	.095	10.93	.89	62
F	1.901	.072	11.19	.76	52
Southern Red Oak					
A	-1.552	.112	4.63	.89	89
B	.042	.090	3.82	.88	89
C	-2.429	.087	4.84	.73	50
D	-2.176	.095	4.92	.87	89
E	-.410	.076	4.08	.87	89
F	-2.827	.073	5.18	.70	50
Sugarberry					
A	2.290	.073	6.79	.83	21
B	3.707	.059	7.06	.75	21
C	-1.267	.056	6.34	.72	17
D	1.843	.068	6.93	.83	21
E	3.248	.055	7.09	.75	21
F	-2.084	.052	6.24	.74	17
Black Tupelo					
A	.523	.101	9.16	.75	23
B	.653	.092	8.88	.73	23
C	6.715	.059	7.47	.54	13
D	-.649	.092	8.90	.77	23
E	.549	.084	8.52	.75	23
F	5.727	.054	7.60	.53	13
Yellow-poplar					
A	-5.930	.198	13.00	.66	14
B	-8.151	.193	13.66	.63	14
C	-15.190	.183	12.70	.63	14
D	-2.401	.165	13.65	.63	14
E	-5.086	.162	14.13	.60	14
F	-12.518	.154	13.15	.60	14

Table 4.-*Equations using stump diameter to predict total, merchantable, and sawtimber volumes.--Continued*

Equation*	b_0	b_1	SE†	R^2‡	No. samples	Equation*	b_0	b_1	SE†	R^2‡	No. samples
Other Hardwoods						All Hardwoods					
A	1.249	.108	11.34	.78	113	A	-.924	.117	9.33	.83	619
B	.643	.097	10.29	.77	113	B	-.841	.103	8.96	.80	619
C	5.708	.068	9.88	.52	74	C	.290	.084	9.46	.62	408
D	.556	.097	11.33	.78	113	D	-2.108	.105	9.51	.82	619
E	-.047	.087	10.18	.78	113	E	-1.863	.093	9.16	.80	619
F	4.498	.063	9.66	.54	74	F	-1.000	.077	9.64	.61	408

*A. $TV = b_0 + b_1 \cdot SDIB^2$
B. $MV = b_0 + b_1 \cdot SDIB^2$
C. $SV = b_0 + b_1 \cdot SDIB^2$
D. $TV = b_0 + b_1 \cdot SDOB^2$
E. $MV = b_0 + b_1 \cdot SDOB^2$
F. $SV = b_0 + b_1 \cdot SDOB^2$
†SE = Standard error (cubic feet).
‡R^2 = Coefficient of determination.

TV = Total volume (cubic feet)
MV = Merchantable volume (cubic feet)
SV = Sawtimber volume (cubic feet)
SDIB = Stump diameter inside bark (inches)
SDOB = Stump diameter outside bark (inches)
b'_i = Coefficients

Table B.-*Equations using stump diameter and stump height to predict total, merchantable, and sawtimber volumes.*

Equation*	b_0	b_1	b_2	SE†	R^2‡	No. Samples	Equation*	b_0	b_1	b_2	SE†	R^2‡	No. Samples
Slash Pine							White Oak						
A	-9.361	.153	10.093	6.33	.82	137	A	-12.130	.124	8.654	8.75	.81	73
B	-9.593	.153	10.051	6.34	.82	137	B	6.392	.092	6.814	6.31	.82	73
C	-15.064	.156	13.876	8.52	.61	71	C	-15.498	.083	12.868	6.27	.78	58
D	-10.385	.115	10.375	6.65	.80	137	D	-13.545	.110	8.833	9.00	.80	73
E	-10.616	.115	10.332	6.65	.80	137	E	7.510	.082	6.850	6.36	.82	73
F	-16.790	.120	14.056	8.95	.57	71	F	-17.416	.075	13.534	6.44	.77	58
Shortleaf Pine							Cherrybark Oak						
A	-4.602	.180	4.426	7.38	.90	196	A	-3.346	.125	1.763	12.29	.88	28
B	-4.732	.176	4.559	7.53	.89	196	B	-4.857	.110	4.299	12.41	.85	28
C	-5.475	.166	5.170	8.75	.80	151	C	-5.716	.109	-.408	13.61	.82	22
D	-6.289	.147	5.478	8.07	.88	196	D	-2.377	.111	.429	12.43	.88	28
E	-6.381	.144	5.623	8.22	.87	196	E	-4.020	.098	3.108	12.46	.85	28
F	-7.018	.135	6.237	9.50	.77	151	F	-4.991	.097	-1.524	13.76	.82	22
Longleaf Pine							Post Oak						
A	3.749	.140	-4.964	4.92	.86	43	A	-5.903	.103	4.747	4.26	.94	68
-B	3.699	.137	-4.892	5.29	.84	43	B	-5.438	.077	6.477	4.31	.90	68
C	1.486	.134	-3.932	5.33	.81	36	C	-1.101	.056	4.794	5.63	.59	32
D	3.898	.111	-6.248	5.21	.85	43	D	-6.785	.088	4.464	4.59	.93	68
E	3.845	.108	-6.145	5.55	.82	43	E	-6.095	.066	6.285	4.51	.89	68
F	1.537	.105	-4.758	5.57	.79	36	F	-3.275	.050	5.497	5.54	.60	32
Loblolly Pine							Water Oak						
A	-13.587	.185	11.177	11.88	.87	436	A	-3.441	.112	4.619	12.58	.92	62
B	-13.843	.183	11.255	11.82	.87	436	B	-2.925	.104	2.970	12.85	.90	62
C	-23.889	.174	20.326	13.29	.79	337	C	2.540	.075	1.338	13.86	.80	52
D	-15.558	.155	10.904	12.36	.86	436	D	-4.173	.103	4.377	12.49	.92	62
E	-15.787	.153	10.971	12.28	.86	436	E	3.685	.096	2.766	12.63	.90	62
F	-26.456	.148	20.121	13.65	.78	337	F	1.865	.070	1.241	13.83	.80	52
All Pines							Southern Red Oak						
A	10.776	.181	9.029	9.95	.88	914	A	-1.644	.115	-.486	5.48	.88	89
B	-10.956	.178	9.079	9.90	.88	914	B	-.136	.087	.752	4.41	.87	89
C	-16.384	.169	13.888	11.54	.80	671	C	1.476	.084	-.183	5.38	.78	50
D	-12.963	.151	9.223	10.60	.86	914	D	-2.133	.098	-.887	5.78	.86	89
E	-13.109	.149	9.259	10.52	.86	914	E	-.480	.074	.489	4.71	.85	89
F	-19.244	.143	14.143	12.07	.78	671	F	1.518	.072	-.708	5.72	.76	50

Table 5.—*Equations using stump diameter and stump height to predict total, merchantable, and sawtimber volumes.*—Continued

Equation*	b_0	b_1	b_2	SE†	R^2‡	No. Samples
Hickory						
A	-7.247	.135	5.392	8.58	.88	36
B	-5.236	.108	5.835	8.34	.83	36
C	-5.156	.089	4.406	8.64	.73	30
D	-10.750	.121	5.793	8.04	.89	36
E	-8.017	.096	6.176	8.02	.84	36
F	10.536	.082	6.241	7.87	.77	30
Sweetgum						
A	-4.396	.129	2.750	8.50	.82	119
B	2.592	.116	1.609	7.80	.82	119
C	-13.361	.122	5.388	9.68	.65	66
D	-5.073	.119	2.363	8.49	.82	119
E	3.208	.107	1.215	7.75	.82	119
F	-15.405	.114	5.610	9.67	.65	66
Beech						
A	-33.518	.075	46.426	12.90	.95	15
B'	-27.434	.066	38.208	11.02	.95	15
D	-32.765	.062	48.550	13.16	.94	15
E	-26.762	.054	40.055	11.27	.95	15
Yellow-poplar						
A	-40.982	.240	16.916	13.45	.69	14
B	-44.836	.238	19.644	14.18	.66	14
C	-46.355	.220	16.694	14.06	.63	14
D	-36.493	.201	16.656	14.21	.65	14
E	-41.361	.200	19.717	14.74	.63	14
F	-42.710	.185	16.617	14.61	.61	14

Equation*	b_0	b_1	b_2	SE†	R^2‡	No. Samples
Sugarberry						
A	7.898	.069	2.638	6.88	.86	21
B	8.377	.055	-2.107	7.28	.77	21
C	1.349	.056	-1.829	6.17	.83	17
D	7.382	.063	-2.393	7.18	.84	21
E	7.854	.050	-1.884	7.41	.76	21
F	.678	.051	1.522	6.24	.82	17
Black Tupelo						
A	-7.758	.080	13.810	10.23	.73	23
B	-4.191	.076	9.092	10.28	.68	23
C	13.135	.034	24.299	6.22	.71	13
D	-9.585	.075	14.012	9.65	.76	23
E	-5.925	.071	9.161	9.68	.72	23
F	14.189	.033	24.360	6.21	.71	13
Other Hardwoods						
A	-12.412	.103	15.340	11.43	.83	85
B	8.891	.093	10.774	10.91	.81	85
C	6.345	.059	1.951	10.66	.57	56
D	-13.697	.093	16.108	11.49	.83	85
E	-10.283	.085	11.403	10.82	.81	85
F	4.117	.055	3.162	10.62	.58	56
All Hardwoods						
A	-4.239	.110	5.222	11.34	.81	620
B	-2.599	.099	2.973	10.99	.79	620
C	2.936	.076	.267	11.44	.65	409
D	5.584	.100	5.029	11.39	.81	620
E	-3.792	.090	2.824	11.08	.79	620
F	.925	.070	.665	11.45	.65	409

*A. $TV = b_0 + b_1 \cdot SDIB^2 + b_2 \cdot SHT$
B. $MV = b_0 + b_1 \cdot SDIB^2 + b_2 \cdot SHT$
C. $SV = b_0 + b_1 \cdot SDIB^2 + b_2 \cdot SHT$
D. $TV = b_0 + b_1 \cdot SDOB^2 + b_2 \cdot SHT$
E. $MV = b_0 + b_1 \cdot SDOB^2 + b_2 \cdot SHT$
F. $SV = b_0 + b_1 \cdot SDOB^2 + b_2 \cdot SHT$

TV = Total volume (cubic feet)
MV = Merchantable volume (cubic feet)
SV = Sawtimber volume (cubic feet)
SDIB = Stump diameter inside bark (inches)
SDOB = Stump diameter outside bark (inches)
SHT = Stump height (feet)
b'_i = Coefficients

†SE = Standard error (cubic feet).
‡R^2 = Coefficient of determination.

and the all-hardwoods equations generally overestimated volume of small trees (≤ 10 inches dbh). The other-hardwoods and all-hardwoods equations were tested on yellow-poplar, sugarberry, beech, and black tupelo. These equations overestimated the volume for sugarberry and underestimated the volume for yellow-poplar and beech. The all-hardwoods equations predicted black tupelo volume very well, and can be used to predict volumes of beech and black tupelo. Volume for yellow-poplar and sugarberry, however, should not be predicted using the all-hardwoods or other-hardwoods equations.

Since the beech sawtimber equations were rejected, all-hardwoods sawtimber equations on the beech data set were tested. Using the F-test, the equations failed to be rejected. For beech sawtimber volume prediction, the all-hardwoods sawtimber equations can be used.

Longleaf pine equations in table 5 were verified using the F-test. The F-test failed to reject any of the equations. Without further testing of the other species equations, all equations presented in table 5 were judged accurate enough to predict volume. These equations have the same confidence level for prediction of volumes as those in table 4.

Using the Equations

The equations presented in table 4 and table 5 are most applicable in Louisiana. Prediction of tree volume for other species, other locations, or outside the range of stump diameters should be verified with an independent sample data set. The equations should not be used to predict volume of trees with stump diameters less than 5.0 inches. For example, hickory equations are valid only for trees with stump diameters between 9.0 and 28.2 inches. Ranges of stump diameters are presented in table 2. In using equations from table 4, the stump height should be close to the mean of 1.0 foot for hardwoods and 0.8 foot for softwoods.

The all-pines equations can be used on loblolly, slash, longleaf, and shortleaf pine, although they would be less accurate than each individual species equations. The other-hardwoods and all-hardwoods equations can be used to predict volume of most hardwoods species. As illustrated with yellow-poplar and sugarberry, these equations may overestimate or underestimate the volume of particular species.

These equations are invalid when applied to irregular stumps, i.e. those with rot, large cracks, etc.

CONCLUSION

Predicting volume directly from stump dimensions is useful in many situations. The Renewable Resources Evaluation Unit can now use these equations to calculate directly volume of cut trees which were not in the previous survey. These equations can be used to obtain the volume of stolen trees. Researchers who have lost permanent trees in their experiment can obtain estimates of volume from these equations.

These equations predict gross volumes. Estimation of gross volume ignore any cull or defect that might have been present in the tree.

Similar studies are planned for Alabama and other southern states. These studies will include measurement of diameter at one-half foot intervals from ground level to dbh to improve volume calculations. To insure accurate results, the maximum length of any section shall be 8 feet.

Using these equations, total, merchantable, and sawtimber volumes are predicted accurately. Equations presented in tables 4 and 5 will predict the volume within $\pm$ 2 standard errors 95 percent of the time.

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Equations for predicting cubic foot volumes from stump diameter and stump height.

Additional keywords: Volume, sawtimber volume, total volume, merchantable volume, stump diameter, stump height.