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DERIVING BIOMASS ESTIMATION EQUATIONS FOR SEVEN PLANTATION HARDWOOD SPECIES

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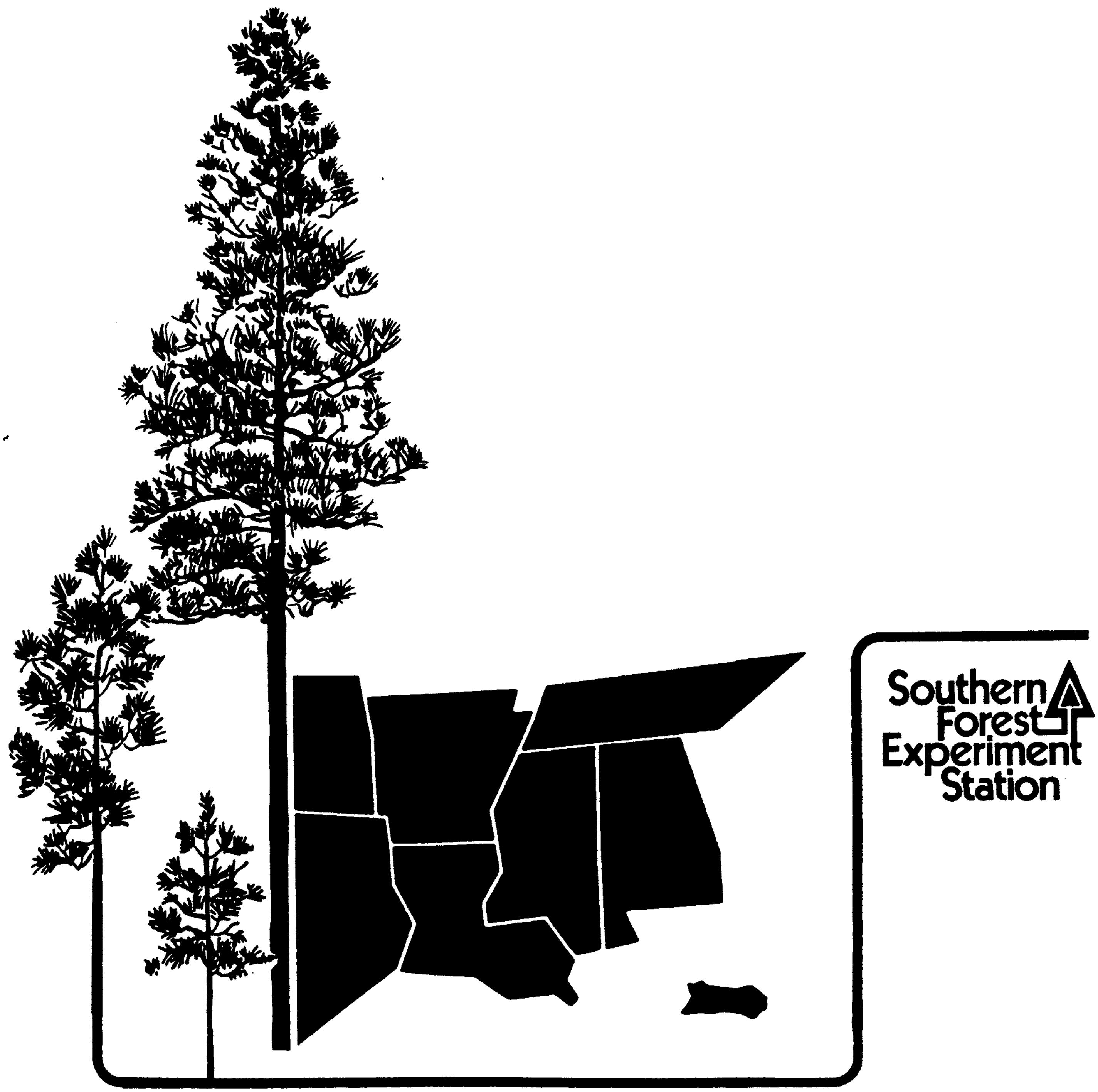

DERIVING BIOMASS ESTIMATION EQUATIONS FOR SEVEN PLANTATION HARDWOOD SPECIES[1/]

Bryce E. Schlaegel and Harvey E. Kennedy, Jr.[2/]

Abstract.--Trees of seven species sampled from a plantation over 7 years were used to derive weight equations to predict primary tree components. The seven species required the use of five different model forms to insure the greatest precision. Regardless of model form, all equations include variables for tree diameter, tree height, age, and number of trees planted. The most precise estimates are found by deriving a separate model and equation for each dependent variable of interest. The modeling effort can be reduced by deriving a single model form for each species, fitting this model to the primary components, and finding component totals by summing predictions. While unbiased estimates are produced, prediction variances are greatly increased.

INTRODUCTION

The allometric model $Ln(Y) = b_0 + b_1Ln(D^2H)$ is commonly used for predicting volumes and weights of individual trees. It has been used successfully for predicting both aboveground component and total tree biomass of hardwoods and conifers. It is a popular model in that it accurately predicts a number of tree components, has homoscedastic variance, and extrapolates well in both directions, at least for short distances. When predicting tree weights in natural stands, or in plantations of a single age and spacing with only dbh and height data available, it is probably the most reliable model to use.

Estimating volumes and weights of plantation-grown trees where more than one age and spacing are found is more complex. Initial spacing influences crown development, bole form, and growth rate of all tree components. Component growth rate influences fiber content and size, which directly correlate with specific gravity. Specific gravity is inversely related to moisture content, so components with relatively high specific gravity have relatively low moisture content. All these variables are dependent upon the species planted.

To account for these conditions in a tree biomass model, tree characteristics in addition to dbh and height must be measured. Tree diameter and height alone, when used as biomass predictors, were insufficient descriptors of plantation loblolly (Pinus taeda L.) crown biomass (Hepp and Brister 1982), plantation sycamore (Platanus occidentalis L.) (Willson et al. 1982), and natural loblolly bay (Gordonia lasianthus (L.) Ellis) (Gresham 1982).

If a prediction equation for only a single component of the tree is desired, such as bole wood weight or total crown weight, the number of variables to consider is greatly reduced. When evaluating a single component, concentration can be placed on finding the best model to fit this component. Problems with component prediction additivity or a separate model for each component do not arise.

Choosing a model or models for predicting multiple components and component totals involve a number of questions. Do you use the same model form for fitting all tree components? Should a separate equation be fit for each component and component total? Is it best to fit equations to primary components and then add predictions to get totals? Are the equations mathematically additive (Kozak 1970)? Are they additive from a practical viewpoint? Which model or models should one choose? Based on what criteria?

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Schlaegel and Kennedy (1985) fit separate models to individual tree components for plantation sweetgum (Liquidambar styraciflua L.) and water oak (Quercus nigra L.) and found the following: (1) in addition to dbh and total height, tree age and initial planting density are important variables for predicting biomass; (2) the most precise predictions are obtained by fitting a separate model to each prediction variable of interest, requiring a large number of model forms and prediction equations; (3) the number of models and equations can be reduced by fitting separate models to primary components then adding predictions to obtain tree totals, creating unbiased estimates but possibly larger variances; and (4) different tree species require different model forms.

The purpose of this paper is to extend the work of Schlaegel and Kennedy (1985). The goal is to produce individual tree equations in order to estimate biomass on a per acre basis for both primary tree components and for component sums. Primary tree components are bole wood, bole bark, limb wood, limb bark, and leaves. Component sums are total bole, total limbs, total tree wood, total tree bark, total tree (wood and bark) without leaves, and total tree (wood and bark) with leaves. Compromises were necessary to satisfy all desired goals.

THE DATA

The data are from a 7-year-old hardwood plantation growing in a minor stream bottom in southeastern Arkansas, approximately 10 miles south of Monticello. Seven tree species were planted at five spacings in a randomized complete block design of four blocks. Each block contains 35 plots representing the 35 factorial treatment combinations. The species were: sycamore (Platanus occidentalis L.), sweetgum, green ash (Fraxinus pennsylvanica Marsh.), water oak, cherrybark oak (Quercus falcata var. pagodifolia Ell.), Nuttall oak (Q. nuttallii Palmer), and cow (swamp chestnut) oak (Q. michauxii Nutt.)

The five spacings and respective number of trees per acre (in parentheses) were 2 by 8 feet (2723), 3 by 8 feet (1815), 4 by 8 feet (1361), 8 by 8 feet (681), and 12 by 12 feet (303). Spacings were chosen to span from the narrow coppice spacings to the more usual pulpwood and saw log spacings. The 8-foot distance between rows was chosen to allow tending by standard farm equipment.

Each plot consists of 169 trees planted in a rectangular grid of 13 by 13 rows using 1/0 seedlings. The interior 5 rows were designated as permanent remeasurement rows with the outer 4 rows as a buffer.

Starting at age 1, two trees from the second and third buffer rows representative of the remeasurement plot were destructively sampled each fall for a total of seven annual samples.

Field measurements included bole diameter 6 inches above the ground, dbh, total height, height to crown, total bole weight, and total crown weight. Individual bole, limb, and leaf samples were taken and sealed in separate polyethylene bags for laboratory determination of green and dry weights and volumes. One-inch-thick disks were cut from the bole at a 6-inch stump and at intervals of 20, 40, 60, and 80 percent of total tree height. The branch and leaf samples consisted of two representative limbs selected from each quarter of crown length that were consolidated into an eight-branch tree sample; leaves were detached from the branches in the field and bagged separately. Green weights, dry weights, and volumes of bole and branch components were determined in the laboratory by standard laboratory procedures.

Green weights of bole wood and bark for each tree were obtained by multiplying the proportion of each in the bole sample times the total bole green weight measured in the field. Green weights of branch wood, branch bark, and leaves were derived by adding the leaf and branch sample weights, finding the proportion of each component in the sample, and applying the proportions to the total crown weight obtained in the field.

Total dry weight and volume for each component were calculated using the consolidated sample component moisture contents and specific gravities. Moisture content and specific gravity were assumed to be uniform within each component.

All seven species in this study had different growth characteristics. Sycamore and sweetgum were rapid early growers. Sycamore branches typically grow rapidly, spread widely, and prune readily. In contrast, sweetgum branches do not grow as rapidly, crowns close more slowly, and pruning is less rapid. Thus sweetgum tends to have about twice the number of branches as sycamore.

Oaks generally are slower growers than the above species. Of the three red oaks, water oak is the most rapid early grower; it develops wide spreading stout branches which make up about 51% of average tree weight. Cherrybark and Nuttall oak branches are also wide spreading, but less stout; they comprise about 40% of the tree weight.

The seven tree species sampled were different in size, mean component moisture content, specific gravity, dry weight, and component percent of total tree (table 1). Species growth characteristics affect component values. Crown proportions vary from 26% for sycamore to 51% for water oak. Bole wood specific gravity varies from 0.49 for sycamore to 0.70 for cow oak, while bole wood moisture content ranges from 56 to 102% respectively for green ash and sycamore.

Table 1.--Primary component means of trees across all ages and spacings used to construct biomass equations for seven plantation-grown hardwood species

	Sycamore	Sweetgum	Green ash	Water oak	Nuttall oak	Cherrybark oak	Cow oak
Trees in model	229	215	226	190	167	183	143
Number of branches	26	46	21	31	25	25	18
Stump diameter (in)	2.8	2.7	2.6	2.2	2.0	1.9	1.8
Dbh (in)	1.7	1.7	1.5	1.3	1.2	1.1	0.9
Total height (ft)	17.0	15.2	14.4	12.1	10.0	10.6	8.4
Crown height (ft)	5.5	1.3	3.2	0.5	0.6	0.9	0.7
MOISTURE CONTENT							
Bole wood	1.02	0.96	0.56	0.75	0.78	0.66	0.61
Bole bark	1.29	1.86	1.05	1.04	1.21	0.88	1.11
Limb wood	0.99	0.94	0.54	0.63	0.66	0.59	0.62
Limb bark	1.20	1.45	1.01	0.90	0.94	0.85	0.93
Leaves	1.62	1.76	1.33	1.03	1.11	1.01	1.12
SPECIFIC GRAVITY							
Bole wood	0.49	0.51	0.50	0.63	0.61	0.67	0.70
Bole bark	0.41	0.29	0.36	0.50	0.45	0.51	0.40
Limb wood	0.50	0.49	0.51	0.66	0.63	0.69	0.68
Limb bark	0.36	0.28	0.38	0.37	0.39	0.40	0.38
DRY WEIGHT (pounds)							
Bole wood	8.8	7.2	5.7	4.7	3.7	3.6	2.3
Bole bark	1.1	0.9	0.8	1.1	0.6	0.8	0.4
Limb wood	2.8	2.4	2.2	5.0	2.4	2.4	1.0
Limb bark	0.6	0.8	0.5	0.9	0.5	0.5	0.3
Leaves	1.4	1.7	1.4	1.8	1.2	1.4	0.7
PERCENT OF TOTAL DRY TREE W/O LEAVES							
Bole wood	0.66	0.64	0.62	0.40	0.51	0.49	0.58
Bole bark	0.08	0.08	0.09	0.09	0.09	0.11	0.10
Limb wood	0.21	0.21	0.24	0.43	0.33	0.33	0.25
Limb bark	0.05	0.07	0.05	0.08	0.07	0.07	0.07
Leaves	0.11	0.15	0.15	0.15	0.17	0.19	0.17

DERIVING AND EVALUATING THE EQUATIONS

The basic independent variables used to develop the biomass models are bole diameter at an approximate 6-inch stump (D6), total height (H), age (A), and number of trees planted per acre (N). Although additional measurements were obtained for the felled sample trees, only these four were available for all trees on the study remeasurement plots. For the first year or two, many trees were less than 4.5 feet in height, thus dbh measurements were not available. The primary purpose for developing the prediction equations is to estimate annual plot biomass starting at year one. Transformation and combination of the 4 basic independent variables produced 12 independent variables that could be used to develop the equations (table 2). These 12 were chosen after screening up to 25 variables for each species (Schlaegel and Kennedy 1985).

To develop the models and equations, some decisions and compromises were made. Predictions for 11 dry weight variables for each species were needed, but the number of separate models needed to be kept to a minimum. Schlaegel and Kennedy (1985) indicate that the most precise estimates for each desired component could be found by deriving a separate model and equation for each component. However, unbiased estimates could be found by finding a single suitable model and fitting this model to all primary components and then adding these predictions to obtain component totals. This technique increases the variance for some of the predictions, thus increasing the error for individual tree estimates.

For this paper, it was decided to accept the increased variance for some component predictions and keep the number of equations to a minimum. For each species, a single model was

Table 2.--The 12 independent variables available for use in developing the biomass equation

Variable	Variable definition
D6	Bole diameter at a 6-inch stump.
H	Total height.
N	Number of trees planted per acre.
A	Tree age in years.
Ln(D6)	Ln is the natural logarithm.
Ln(N)	
$1/A^2$	
$D6^2H$	
$Ln(D6^2H)$	
$[Ln(D6^2H)]^2$	
[Ln(N)]/A	
N/A	

found and fitted to the five primary component dry-weight variables.

The stepwise procedure of Minitab[3] was used to fit equations to predict the five dry-weight variables. Dry weight was chosen since it was believed to be more important to estimate dry weight than either green weight or volume. The stepwise procedure employs the technique of forward selection/backward elimination, which both adds variables to and eliminates variables from the equation, with each variable's contribution to the reduction sum of squares being tested at $\alpha = 0.05$.

The five models found for each species by this technique were then evaluated and a single model selected for each species. Five different model forms were found for the seven species (table 3). These 5 models utilized 7 of the 12 available variables from table 2.

All component prediction models for the seven species produced unbiased equations (table 4), evaluated by comparing statistics produced by converting predicted values back to original units (Schlaegel 1982). The most precise and least variable equations for all species are the bole wood equations followed by bole bark. Coefficients of variation for bole wood range from 16% to 25% and for bole bark from 23% to 40%.

Limb and leaf equations produce less precise estimates. Coefficients of variation range from 37% for cow oak limb wood to 72% for green ash limb wood. These relatively poorer equations reflect the difficulty in predicting crown components when no measures of crown size are incorporated into the equation. It is likely that crown predictions could be significantly improved had measures such as crown length and bole diameter at the crown base been included. These crown variables were not included since they were not measured on the permanent sample plots.

It must be pointed out that all these equations will produce unbiased per acre estimates. But the relatively large coefficients of variation indicate that predictions for specific, individual trees will vary widely, and relatively low confidence can be placed on these individual estimates.

The regression coefficients for predicting primary component dry weights for the seven species are given in table 5 along with predictor variable significance. When a single model form is used to predict all primary components, predictor variables that are not significant are sometimes included. Inclusion of a nonsignificant variable contributes little to the reduction sum of squares, increases the number of parameters, increases equation variance, and therefore reduces the reliability of estimating a particular component for a specific tree. But using the same model form and retaining nonsignificant variables helps assure additivity of components to total values (Kozak 1970).

It is interesting to note in table 5 the pattern of the significant variables for each species. The $D6^2H$ term is always significant when predicting both bole wood and bole bark for all species; this variable is the volume (weight) index variable of a conic section. Measures of both age and initial planting density are significant predictors of bole components except for sweetgum, indicating the effect of both age and spacing on bole form. When crown closure takes place and limb mortality becomes significant, the $D6^2H$ index variable becomes less important and the planting density and stem diameter measures increase in relative importance in predicting crown components.

TESTING EQUATION ADDITIVITY

The relative precision of adding predictions from component equations to estimate tree totals was tested for all seven species (table 6). For each species the predictions from the primary component equations were added to produce tree totals and these totals compared to the species model fitted to these tree totals. For instance, predictions for bole wood and bole bark were added to estimate total bole weight; this total was then compared to the species model fitted to total bole weight. No species showed any decrease in relative precision as indicated by bias nor any increase in prediction variability, indicated by standard error and coefficient of variation. So, for a species, a single model can be found to estimate separate components and the estimates summed to predict component totals. This allows the number of equations per species to be kept to a minimum.

[3] Available from Minitab Inc., 215 Pond Laboratory. Pennsylvania State University, University Park, PA 16802.

Table 3.--The independent variables used to develop biomass estimation equations for seven plantation hardwoods[1/]

Species	Independent variables[2/]						
	$Ln(D6^2H)$	$Ln(N)$	$[Ln(N)]/A$	$Ln(D6)$	N/A	$1/A^2$	D6
Sweetgum	X	X		X	X		X
Sycamore	X	X		X		X	
Green ash	X		X				
Water oak	X		X	X			
Nuttall oak	X		X				
Cherrybark oak	X		X	X			
Cow oak	X		X				X

1/ The basic model form for all species is $Ln(Y) = b_0 + \sum_{i=1}^{p} b_i X_i$.

2/ D6 = bole diameter at a 6-inch stump, H = total height, N = number planted per acre, A = tree age in years, Ln = natural logarithm.

SUMMARY

Deriving a single model form for a species and fitting this model to the primary tree biomass components of bole wood, bole bark, limb wood, limb bark, and leaves simplifies the modeling effort when predicting a large number of variables. Estimates are unbiased, but prediction variance is greater than if separate models are fitted to each major component and component total.

The most precise estimates are obtained by fitting a separate model form to each green-weight, dry-weight, and volume variable for which predictions are needed. If this had been done in this study, a total of 217 separate models and equations would have to be derived and fitted, 31 models for each of seven species. The penalty for choosing a single model for each species is decreased precision caused by increased equation variation.

A further simplification would be to fit a single model to all species. Again, estimates would be unbiased, but prediction variance would be further increased. Tree species vary sufficiently in early biomass accumulation and response to competition to eliminate the use of this simplification. Tree and stand measures included in the model should reflect the characteristics of the species, but the user must be able to obtain these measures. Including tree age and number of trees planted in the equations does not require additional field measurements since this information is already known.

Table 4.--Hardwood plantation tree dry-weight equation statistics after transforming back to original units

Component	Mean: Sample (lbs)	Mean: Predicted (lbs)	Fit index	Bias (lbs)	t for bias	(df)	Std. error (lbs)	Coef. var. (%)
Sycamore - $Ln(Y) = b_0 + b_1 Ln(D6*D6*H) + b_2(1/A^2) + b_3 Ln(N) + b_4 Ln(D6)$								
Bole wood	8.830	8.596	0.964	0.234	0.11	224	2.094	23.7
Bole bark	1.063	1.028	0.950	0.035	0.12	224	0.278	26.1
Limb wood	2.823	2.992	0.839	-0.169	-0.10	224	1.682	59.6
Limb bark	0.595	0.624	0.874	-0.029	-0.11	224	0.279	47.0
Leaves	1.437	1.459	0.761	-0.022	-0.03	224	0.760	52.9
Sweetgum - $Ln(Y) = b_0 + b_1 Ln(D6*D6*H) + b_2 Ln(D6) + b_3 Ln(N) + b_4(N/A) + b_5(D6)$								
Bole wood	7.235	7.358	0.982	-0.123	-0.11	209	1.170	16.2
Bole bark	0.918	0.935	0.930	-0.017	-0.07	209	0.269	29.3
Limb wood	2.414	2.402	0.887	0.012	0.01	209	1.013	42.0
Limb bark	0.768	0.770	0.868	-0.002	-0.01	209	0.342	44.6
Leaves	1.696	1.703	0.836	-0.007	-0.01	209	0.776	45.7
Green ash - $Ln(Y) = b_0 + b_1 Ln(D6*D6*H) + b_2 Ln(N)/A$								
Bole wood	5.712	5.723	0.973	-0.011	-0.01	223	0.996	17.4
Bole bark	0.801	0.779	0.858	0.022	0.07	223	0.317	39.6
Limb wood	2.240	2.203	0.753	0.037	0.02	223	1.621	72.4
Limb bark	0.508	0.497	0.721	0.011	0.03	223	0.362	71.3
Leaves	1.364	1.328	0.602	0.036	0.04	223	0.971	71.2
Water oak - $Ln(Y) = b_0 + b_1 Ln(D6*D6*H) + b_2 Ln(D6) + b_3 Ln(N)/A$								
Bole wood	4.698	4.670	0.957	0.029	0.02	186	1.172	24.9
Bole bark	1.077	1.100	0.907	-0.023	-0.06	186	0.381	35.4
Limb wood	4.977	4.923	0.915	0.054	0.02	186	2.194	44.1
Limb bark	0.901	0.893	0.892	0.008	0.02	186	0.401	44.5
Leaves	1.767	1.759	0.854	0.008	0.01	186	0.723	40.9
Nuttall oak - $Ln(Y) = b_0 + b_1 Ln(D6*D6*H) + b_2 Ln(N)/A$								
Bole wood	3.698	3.777	0.966	-0.079	-0.09	164	0.884	23.9
Bole bark	0.636	0.630	0.940	0.006	0.03	164	0.206	32.4
Limb wood	2.423	2.461	0.893	-0.038	-0.03	164	1.256	51.8
Limb bark	0.538	0.542	0.914	-0.004	-0.02	164	0.222	41.2
Leaves	1.249	1.238	0.830	0.011	0.02	164	0.609	48.8
Cherrybark oak - $Ln(Y) = b_0 + b_1 Ln(D6*D6*H) + b_2 Ln(D6) + b_3 Ln(N)/A$								
Bole wood	3.583	3.615	0.955	-0.032	-0.04	179	0.858	23.9
Bole bark	0.816	0.821	0.928	-0.005	-0.02	179	0.246	30.2
Limb wood	2.394	2.535	0.877	-0.141	-0.14	179	1.030	43.0
Limb bark	0.499	0.518	0.825	-0.019	-0.08	179	0.236	47.2
Leaves	1.413	1.431	0.816	-0.018	-0.03	179	0.528	37.4
Cow oak - $Ln(Y) = b_0 + b_1 Ln(D6*D6*H) + b_2(D6) + b_3 Ln(N)/A$								
Bole wood	2.315	2.323	0.966	-0.008	-0.02	139	0.405	17.5
Bole bark	0.408	0.412	0.933	-0.004	-0.03	139	0.094	23.0
Limb wood	1.028	1.071	0.898	-0.043	-0.11	139	0.385	37.5
Limb bark	0.269	0.277	0.858	-0.008	-0.07	139	0.113	42.1
Leaves	0.699	0.706	0.744	-0.007	-0.02	139	0.364	52.0

Table 5.--Regression coefficients for predicting tree component dry weight in pounds for seven plantation-grown hardwood species

b_i	Variable	Bole wood	Bole bark	Limb wood	Limb bark	Leaves
		Component				
		Sycamore				
b_0		-2.10436	-4.09308	0.78273	-0.57789	-0.30283
b_1	Ln(D6*D6*H)	1.33284*	1.26052*	-0.36171	-0.34113	0.21624
b_2	1/A	-1.12969*	-0.97473*	-0.088921	-0.13560	1.24302*
b_3	Ln(N)	-0.13154*	-0.10050*	-0.26767*	-0.23383*	-0.29276*
b_4	Ln(D6)	-1.54981*	-1.49418*	3.37434*	2.99319*	1.20284
		Sweetgum				
b_0		-3.38351	-5.32810	0.096097	-1.08010	2.16531
b_1	Ln(D6*D6*H)	1.49310*	1.42119*	0.26128	0.11456	-0.17235
b_2	Ln(D6)	-1.40658*	-1.54674*	2.37321*	1.95062*	2.34384*
b_3	Ln(N)	-0.081033*	-0.050261	-0.35283*	-0.25856*	-0.49199*
b_4	N/A	0.000072042	0.00010883	0.00037494*	0.00017967	0.00055153*
b_5	D6	-0.069874	-0.0028038	-0.28159*	-0.069110	-0.048175
		Green ash				
b_0		-2.09149	-3.40103	-4.51899	-5.23275	-4.30690
b_1	Ln(D6*D6*H)	0.83351*	0.70486*	1.03455*	0.89508*	0.83482*
b_2	Ln(N)/A	-0.16860*	-0.15970*	0.084758*	0.073367*	0.28024*
		Water oak				
b_0		-2.81133	-4.93776	-1.84446	-3.63301	-1.96590
b_1	Ln(D6*D6*H)	1.12749*	1.41682*	0.38177*	0.50590*	0.17480
b_2	Ln(D6)	-0.68999*	-1.38680*	1.69820*	1.17682*	1.65964*
b_3	Ln(N)/A	-0.070464*	-0.064806*	0.018063	0.064855*	0.15496*
		Nuttall oak				
b_0		-1.65323	-3.25885	-3.30526	-4.66307	-3.12966
b_1	Ln(D6*D6*H)	0.81376*	0.78939*	0.97743*	0.93023*	0.77146*
b_2	Ln(N)/A	-0.29881*	-0.35473*	0.053885	0.11499	0.14695*
		Cherrybark oak				
b_0		-2.60800	-4.56676	-1.05491	-2.89633	-1.50438
b_1	Ln(D6*D6*H)	1.19224*	1.38894*	0.034858	0.22455	0.11061
b_2	Ln(D6)	-1.00733*	-1.46433*	2.39587*	1.70510*	1.65199*
b_3	Ln(N)/A	-0.10479*	-0.092130*	-0.049771	-0.0027919	0.12258*
		Cow oak				
b_0		-2.16114	-3.69396	-3.23207	-4.28720	-2.95046
b_1	Ln(D6*D6*H)	0.96531*	0.92414*	0.72405*	0.67825*	0.49936*
b_2	D6	-0.18710*	-0.19344*	0.28610*	0.23169	0.32807*
b_3	Ln(N)/A	-0.070087*	-0.081374*	-0.013833	0.011919	0.071525

* This variable associated with this coefficient is significant at $\alpha = 0.05$.

Table 6.—Comparing fitted equations to summed predictions from component equations for seven plantation-grown hardwood species

Component	Mean predicted (lbs)	Fit index	Bias (lbs)	t for bias	(df)	Std. error (lbs)	Coef. var. (%)	Mean predicted (lbs)	Fit index	Bias (lbs)	t for bias	(df)	Std. error (lbs)	Coef. var. (%)
	Fitted equations							Summed predictions from component equations						
Sycamore														
Total bole	9.613	0.965	0.279	0.12	(224)	2.295	23.2	9.624	0.965	0.268	1.81	(219)	2.303	23.3
Total limbs	3.603	0.855	-0.185	-0.10	(224)	1.887	55.2	3.616	0.853	-0.198	-1.60	(219)	1.923	56.3
Tree wood	11.632	0.959	0.020	0.01	(224)	2.979	25.6	11.588	0.959	0.065	0.33	(219)	3.018	25.9
Tree bark	1.653	0.948	0.004	0.01	(224)	0.446	26.9	1.652	0.946	0.005	0.17	(219)	0.456	27.5
Tree w/o leaves	13.269	0.961	0.041	0.01	(224)	3.308	24.9	13.240	0.960	0.070	0.32	(209)	3.435	25.8
Tree w/leaves	14.655	0.958	0.092	0.02	(224)	3.706	25.1	14.698	0.958	0.048	0.20	(204)	3.894	26.4
Sweetgum														
Total bole	8.288	0.980	-0.135	-0.10	(209)	1.370	16.8	8.293	0.980	-0.141	-1.53	(203)	1.386	17.0
Total limbs	3.166	0.889	0.016	0.01	(209)	1.307	41.1	3.172	0.890	0.009	0.11	(203)	1.324	41.6
Tree wood	9.720	0.980	-0.071	-0.04	(209)	1.612	16.7	9.761	0.978	-0.112	-0.98	(203)	1.714	17.8
Tree bark	1.693	0.946	-0.008	-0.02	(209)	0.438	26.0	1.705	0.942	-0.020	-0.64	(203)	0.460	27.3
Tree w/o leaves	11.402	0.979	-0.067	-0.04	(209)	1.922	17.0	11.465	0.977	-0.131	-0.96	(191)	2.125	18.7
Tree w/leaves	13.103	0.977	-0.073	-0.03	(209)	2.291	17.6	13.169	0.975	-0.138	-0.87	(185)	2.498	19.2
Green ash														
Total bole	6.493	0.971	0.019	0.02	(223)	1.167	17.9	6.502	0.971	0.011	0.14	(220)	1.172	18.0
Total limbs	2.694	0.754	0.053	0.03	(223)	1.944	70.8	2.700	0.757	0.048	0.37	(220)	1.948	70.9
Tree wood	7.881	0.944	0.071	0.03	(223)	2.146	27.0	7.925	0.944	0.026	0.18	(220)	2.159	27.2
Tree bark	1.268	0.876	0.040	0.08	(223)	0.507	38.8	1.276	0.878	0.032	0.97	(220)	0.506	38.7
Tree w/o leaves	9.131	0.939	0.129	0.05	(223)	2.592	28.0	9.201	0.940	0.058	0.34	(214)	2.616	28.2
Tree w/leaves	10.360	0.918	0.263	0.08	(223)	3.382	31.8	10.529	0.925	0.094	0.44	(211)	3.323	31.3
Water oak														
Total bole	5.767	0.965	0.008	0.01	(186)	1.291	22.4	5.770	0.966	0.006	0.06	(182)	1.303	22.6
Total limbs	5.802	0.913	0.077	0.03	(186)	2.562	43.6	5.816	0.915	0.063	0.34	(182)	2.571	43.7
Tree wood	9.557	0.943	0.119	0.04	(186)	3.097	32.0	9.593	0.944	0.083	0.37	(182)	3.097	32.0
Tree bark	1.979	0.943	0.000	0.00	(186)	0.576	29.1	1.993	0.942	-0.014	-0.34	(182)	0.585	29.6
Tree w/o leaves	11.537	0.950	0.117	0.03	(186)	3.447	29.6	11.586	0.951	0.068	0.28	(174)	3.523	30.2
Tree w/leaves	13.185	0.947	0.237	0.06	(186)	3.922	29.2	13.345	0.954	0.076	0.29	(170)	3.847	28.7
Nuttall oak														
Total bole	4.406	0.968	-0.072	-0.07	(164)	1.005	23.2	4.406	0.968	-0.072	-0.93	(161)	1.014	23.4
Total limbs	2.994	0.899	-0.033	-0.02	(164)	1.461	49.3	3.004	0.899	-0.042	-0.38	(161)	1.472	49.7
Tree wood	6.212	0.959	-0.091	-0.05	(164)	1.717	28.1	6.238	0.959	-0.117	-0.88	(161)	1.737	28.4
Tree bark	1.169	0.952	0.005	0.02	(164)	0.345	29.3	1.172	0.953	0.002	0.08	(161)	0.346	29.5
Tree w/o leaves	7.375	0.961	-0.079	-0.04	(164)	1.986	27.2	7.410	0.961	-0.114	-0.75	(155)	2.046	28.0
Tree w/leaves	8.520	0.953	0.025	0.01	(164)	2.481	29.0	8.649	0.954	-0.104	-0.55	(152)	2.538	29.7
Cherrybark oak														
Total bole	4.435	0.957	-0.036	-0.04	(179)	1.028	23.4	4.437	0.957	-0.038	-0.51	(175)	1.040	23.6
Total limbs	3.045	0.875	-0.151	-0.12	(179)	1.233	42.6	3.053	0.875	-0.160	-1.78	(175)	1.251	43.2
Tree wood	6.058	0.939	-0.081	-0.05	(179)	1.710	28.6	6.151	0.938	-0.173	-1.38	(175)	1.743	29.2
Tree bark	1.324	0.911	-0.009	-0.02	(179)	0.434	33.0	1.340	0.910	-0.025	-0.77	(175)	0.442	33.6
Tree w/o leaves	7.380	0.938	-0.087	-0.04	(179)	2.068	28.3	7.490	0.937	-0.196	-1.30	(167)	2.161	29.6
Tree w/leaves	8.708	0.932	-0.003	-0.00	(179)	2.478	28.5	8.921	0.933	-0.216	-1.20	(163)	2.579	29.6
Cow oak														
Total bole	2.733	0.969	-0.009	-0.02	(139)	0.449	16.5	2.734	0.969	-0.011	-0.29	(135)	0.456	16.7
Total limbs	1.345	0.901	-0.048	-0.10	(139)	0.473	36.5	1.348	0.900	-0.051	-1.31	(135)	0.482	37.2
Tree wood	3.364	0.959	-0.020	-0.03	(139)	0.683	20.4	3.394	0.958	-0.051	-0.90	(135)	0.697	20.3
Tree bark	0.685	0.926	-0.008	-0.05	(139)	0.176	26.0	0.688	0.926	-0.011	-0.75	(135)	0.178	26.3
Tree w/o leaves	4.047	0.960	-0.026	-0.03	(139)	0.801	19.9	4.082	0.959	-0.062	-0.93	(127)	0.843	21.0
Tree w/leaves	4.748	0.949	-0.028	-0.03	(139)	1.048	22.2	4.789	0.949	-0.069	-0.79	(123)	1.121	23.3

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