United States
Department of
Agriculture

Forest Service

**Southern Forest
Experiment Station**

New Orleans,
Louisiana

General Technical Report
SO-46
August, 1983

Biomass of Four Hardwoods from Lower Piedmont Pine-Hardwood Stands in Alabama

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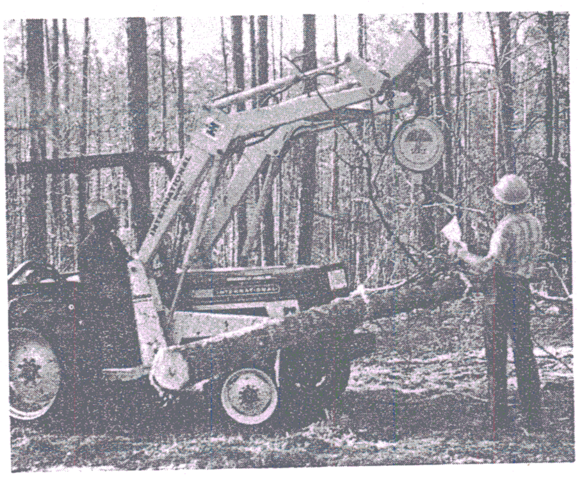

SUMMARY

Biomass data was recorded for 73 trees growing in mixed natural oak-pine stands on Lower Piedmont sites near Auburn, Alabama, during a study of the feasibility of harvesting southern hardwoods by extraction using a Rome TXH Tree Extractor. Harvested trees included sweetgum, hickory (mockernut and pignut), southern red oak, and white oak trees measured from 4 to 11 inches dbh. Collected biomass data included the portion of the below-ground biomass (stump wood — including central root system) that was extracted with the above ground (whole tree) biomass. The extracted below ground biomass averaged 18 percent (green basis) of the complete harvested tree weight. Whole tree above ground biomass, green without foliage, ranged from 78 to 1,135 pounds for sweetgum, 174 to 711 pounds for hickory, 167 to 1,227 pounds for red oak, and 112 to 615 pounds for white oak. Sweetgum had the highest moisture content at 110 percent for total tree wood component and hickory had the lowest at 54 percent. The proportion of stem wood to branch wood ranged from 59 to 89 percent with the larger trees having more stem wood. Specific gravity, density, and moisture content of wood and bark for the four tree species are presented. The proportion of trees in wood and bark and in stem wood and branch wood, both in green and oven-dry conditions, are presented. Regression equations as a function of tree diameter and total height are also presented for complete trees and their components. Tables have been developed for complete tree, whole tree, and main stem biomass.

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INTRODUCTION

There is a growing interest world wide in more complete utilization of forest resources for products and as an energy source (FAO 1976). This interest has created a need for predicting the total biomass of the complete tree according to characteristics that affect its use — what portion is in wood and bark, and what portion is in stem wood and branch wood. This paper presents statistics, prediction equations, and tables for biomass characteristics of four southern United States hardwoods — sweetgum (*Liquidambar styraciflua* L.), hickory (mockernut, *Carya tomentosa* (Poir.) Nutt. and pignut, *C. glabra* (Mill.) Sweet), southern red oak (*Quercus falcata* Michx. var. *falcata*), and white oak (*Q. alba* L.). The tree data was collected in conjunction with a field evaluation of the Rome TXH Tree Extractor (Sirois 1977), and therefore the range of tree sizes, 4 to 11 inches dbh, was limited to the capacity of the machine for harvesting hardwoods. The evaluation of the tree extractor took place near Auburn, Alabama, in natural uneven-aged pine-hardwood stands growing on Lower Piedmont sites.

Definitions of the tree components used in this report are:

Complete Tree — All of the harvested biomass including roots and stump wood extracted from the soil, main stem, and all crown branches without foliage.

Whole Tree — All of the harvested biomass above a 6-inch stump height including main stem and all crown branches without foliage. This portion of the tree may also be called "total tree" in other reports,

Stem — That portion of the tree between a 6-inch high stump and a 3-inch diameter top. This portion of the tree may also be called "bole" in other reports.

Crown — All of the stem above a 3-inch top plus all live branches above and below this point.

PROCEDURES

Field Test

A sample, stratified by dbh for each of the four hardwoods, was selected from two sites. Selected sample trees were dominant or co-dominant in crown form, except that in the small tree size class, 4 to 6 inches dbh, it was necessary to include some intermediate trees. Because the tree extractor was not successful in harvesting all of the selected sample trees, all diameter classes are not fully represented. When additional extraction data was needed and additional trees were available in the area, these trees were harvested and measured. For the purposes of the biomass portions of the study, the dbh classes of the sample trees were:

Class	Range in dbh
4	$3.0 \leq \text{dbh} < 5.0$
6	$5.0 \leq \text{dbh} < 7.0$
8	$7.0 \leq \text{dbh} < 9.0$
10	$9.0 \leq \text{dbh} < 11.0$
12	$11.0 \leq \text{dbh} < 13.0$

The mean and ranges of tree measurements are shown in table I .

The field test took place in April and early May so all trees were harvested and the biomass data was taken before leafing of the trees. Because of the time of the year and the apparent bud swelling it can be safely stated that sap flow had begun and tree moisture contents were more representative of summer conditions than winter dormancy. After extraction of each tree, green weight by components were weighed before the next tree was harvested. Weight data included extracted root and stump weight as harvested without soil, weight of the tree stem from a 6-inch

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Table I.—*Means and ranges of tree measurements for each tree species by dbh class.*

Dbh class	Sample trees	Dbh Average	Dbh Range	Total height Average	Total height Range	Crown ratio Average	Crown ratio Range	Age
inches	*number*	*inches*		*feet*				*years*
Sweetgum								
4	3	4.1	3.8– 4.6	36	34–39	0.44	0.34–0.52	22
6	5	5.6	5.3– 6.0	44	30–56	0.50	0.16–0.67	28
8	6	7.7	7.0– 8.3	57	42–65	0.37	0.37–0.53	32
10	1	10.5	10.5–10.5	72	72–72	0.10	0.10–0.10	42
	15							
Hickory								
4	7	4.5	4.0– 4.9	43	35–51	0.38	0.16–0.53	40
6	5	5.5	5.3– 5.7	48	45–51	0.32	0.22–0.41	39
8	6	7.8	7.1– 8.9	57	45–65	0.37	0.29–0.50	51
	18							
Red Oak								
4	3	4.7	4.5– 4.9	36	34–41	0.50	0.35–0.60	40
6	9	5.7	5.1– 6.9	42	32–55	0.41	0.12–0.68	42
8	5	8.0	7.5– 8.6	49	39–59	0.39	0.21–0.60	50
10	6	9.7	9.0–10.9	54	49–59	0.42	0.36–0.52	45
12	2	11.5	11.1–11.9	51	51–51	0.31	0.28–0.35	52
	25							
White Oak								
4	2	3.9	3.8– 4.0	38	38–39	0.28	0.18–0.38	45
6	4	6.3	6.0– 6.5	43	38–56	0.35	0.16–0.53	34
8	8	7.7	7.0– 8.6	57	43–69	0.38	0.19–0.64	39
	14							

stump height to a 3-inch top without branches, and crown weight including all branch wood. Measured dimensions were length of extracted root to a 6-inch stump height, total height, crown height (butt to first live limb), and height to 3-inch top. Diameters outside bark (dob) were taken at a 6-inch stump, dbh, base of live crown and mid-height (one half of total height). At the time of measurements, sample disks were cut from the tree butt, midpoint, a 3-inch top, and two branch samples (1 to 2 inches dob) for determining moisture, density, and bark content of the trees. The disk samples for subsequent lab tests were sealed in plastic bags to prevent moisture loss.

Laboratory

The laboratory procedures for determining specific gravity and moisture content were similar to those of the Southeastern Forest Experiment Station at Athens, Georgia (Clark and Schroeder 1977). Specific gravity was calculated using green volume and oven-dry weight. For moisture content, samples were dried to a constant weight at an oven temperature of 103°C. Moisture content was calculated on the oven-dry basis. Documentation of additional equations developed for calculation of other parameters and for weighing of moisture, wood, and bark contents of the whole tree for the computer analysis are presented in Appendix III.

Analysis

Weighted least square regression equations were developed for predicting the green and dry weights of wood and bark for complete and whole trees and their components. The independent variables used in the final regressions were dbh and total height. The predictions of tree biomass characteristics are based on the following model.

$$Y = bX$$

where:

Y = predicted tree or component weight
X = D^2Th
D = dbh in inches
Th = total tree height in feet
b = coefficient

By employing a weighing factor of D^2Th to the model to correct for heterogeneous variance about the regression line, it is felt that this simpler model retains the statistical advantages of more common linear models while overcoming their shortcomings (Husch, Miller and Beers 1972 and Cunia 1964).

RESULTS

Biomass

Complete tree data, including harvested roots and stump wood, was collected in addition to the normally reported whole tree, above-ground biomass from a 6-inch stump. The average values for complete trees and the percent of stump biomass have been reported earlier (Sirois 1977). Prediction equations and related tables for complete tree green weight are included in Appendix I. Whole tree biomass, both green and dry weights basis, are shown in table II for the four hardwoods by diameter classes. The average green weight for whole trees ranged from 78 pounds for the smallest (sweetgum in the 4-inch class), to 1,227 pounds for the largest (red oak in the 12-inch class). The proportion of whole tree green weight of wood versus bark averaged 95 percent for sweetgum, 86 percent for hickory, 92 percent for red oak, and 95 percent for white oak (table II). On the green weight basis the proportion of bark decreased with increasing tree size, and the proportion of wood increased. On a dry weight basis the proportions changed only slightly from those of the green weight values.

In addition to reporting the wood and bark composition of the sample whole trees, the proportion of the above ground biomass in stems and branches were also determined. These data are presented in table III on both a green and dry weight basis. On a green weight basis, with data from all diameter classes pooled, the proportion of the whole tree in the stem was 78 percent for sweetgum, 71 percent for hickory, 73 percent for red oak, and 72 percent for white oak. For all of the four species, the stem proportion of the tree increased with dbh. This trend was less definite for red oaks than for the other species. This was due to the greater branching of the crown with a less definite main or central stem.

Table II.—*Average whole tree weights with proportions of wood and bark on both green and dry weight basis*

Dbh class	Total height	Sample trees	Whole tree green weight	Tree component proportions (green)		Whole tree dry weight	Tree component proportions (dry)	
				Wood	Bark		Wood	Bark
inches	*feet*	*number*	*pounds*	*percent*		*pounds*	*percent*	
Sweetgum								
4	36	3	78	92	8	41	93	7
6	44	5	240	93	7	116	93	7
8	57	6	500	95	5	269	95	5
10	72	1	1135	95	5	674	95	5
		15						
Hickory								
4	43	7	174	83	17	111	85	15
6	48	5	254	84	16	161	84	16
8	57	6	711	92	8	458	92	8
		18						
Red Oak								
4	36	3	165	91	9	98	90	10
6	42	9	293	91	9	172	90	10
8	49	5	669	90	10	390	89	11
10	54	6	1118	91	9	664	90	10
12	51	2	1228	95	5	658	94	6
		25						
White Oak								
4	39	2	112	94	6	69	94	6
6	43	4	336	96	4	197	96	4
8	57	8	615	96	4	364	96	4
		14						

Table III.—*Average whole tree weights with proportions of biomass in stems and branches on both a green and oven dry weight basis*

Dbh class	Total height	Sample trees	Whole tree green weight	Tree component proportions (green)		Whole tree dry weight	Tree component proportions (dry)	
				Stem	Branches		Stem	Branches
inches	*feet*	*number*	*pounds*	*percent*		*pounds*	*percent*	
Sweetgum								
4	36	3	78	57	43	41	59	41
6	44	5	240	82	18	116	75	25
8	57	6	500	84	16	269	84	16
10	72	1	1135	88	12	674	89	11
Hickory								
4	43	7	174	68	32	111	67	33
6	48	5	254	71	29	161	69	31
8	57	6	711	74	26	458	76	24
Red Oak								
4	36	3	165	68	32	98	67	33
6	42	9	293	74	26	172	72	28
8	49	5	669	70	30	390	70	30
10	54	6	1118	72	28	644	69	31
12	51	2	1228	80	20	658	78	22
White Oak								
4	38	2	112	62	38	69	62	38
6	43	4	336	75	25	197	74	26
8	57	8	615	79	21	364	78	22

Wood and Bark Characteristics

The specific gravity, moisture content, and green weight per cubic foot of both wood and bark for the whole trees and their components are reported in table IV. The values for moisture and green weight per pound were very consistent for the two oak species. Both sweetgum and hickory trees had a wide difference in moisture content of the components for wood and bark with associated high variability for measured values. For sweetgum both the stem wood and branch bark had high moisture contents, 162 and 148 percent respectively, while hickory experienced only high moisture content in the branch bark, 148 percent, as compared to 67 percent for the stem bark. Similar differences have been reported for other species of both hardwood and pine (Clark and Schroeder 1977, Taras 1980) and have been related to differences in bark characteristics and sap flow incipient to leafing. Our data was taken at probably the most unstable time of the year for the moisture content measurement, at least for sweetgum and hickory, for our two site and stand conditions. The more consistent results of the two oak species is possibly because they were generally found within a narrower range of site conditions within the two stands and were less advanced in breaking of dormancy. All four species were randomly harvested during the same 2 month period, April and May, and the same laboratory procedures were used in all cases. Overall, the average whole tree values of specific gravity, moisture content, and green weight per cubic foot are in good agreement with other published values for the four hardwood species (McMillin and Manwiller 1980).

PREDICTION EQUATIONS

Regression equations have been developed for predicting the green and dry weights of complete and whole tree biomass and for the components of wood, bark, main stem (tree length to 3-inch top), and crown (including all live branches). These equations are presented by species in tables 1 through 4 in Appendix I.

In comparing values of whole (total tree) weight of southern red oak trees predicted by this equation, developed from trees in south central Alabama, to those predicted for southern red oaks growing on the Highland Rim in Tennessee, using the equation $Y = 0.06632\ (D^2Th)^{1.11245}$ developed by Clark, Phillips, and Hitchcock (1980), we find that it predicts higher weights by 7 to 23 percent depending upon dbh. The percent difference decreases with increasing dbh. This difference is due to difference in tree form rather than differences in form of the equations. The

Table IV.—*Average whole tree and component wood and bark specific gravity, moisture content, and green weight per cubic foot for four hardwoods*

Tree component	Specific gravity	Moisture content	Green wt. per cubic foot
	mean (SD)		
		percent	*pounds*
Sweetgum			
Wood			
Whole tree	0.45 (0.05)	110 (100)	57.6 (22.5)
Stem	0.45 (0.08)	162 (304)	58.7 (21.8)
Branches	0.45 (0.04)	96 (16)	54.5 (5.7)
Bark			
Whole tree	0.42 (0.07)	103 (22)	53.2 (19.9)
Stem	0.40 (0.07)	96 (21)	48.5 (6.6)
Branches	0.46 (0.07)	148 (60)	69.5 (16.5)
Hickory			
Wood			
Whole tree	0.67 (0.03)	54 (3)	65.4 (6.4)
Stem	0.67 (0.03)	66 (3)	65.5 (2.1)
Branches	0.69 (0.07)	51 (3)	65.0 (7.2)
Bark			
Whole tree	0.52 (0.03)	69 (15)	65.7 (59.2)
Stem	0.53 (0.05)	67 (14)	53.0 (2.0)
Braches	0.60 (0.19)	148 (201)	93.3 (74.5)
Red Oak			
Wood			
Whole tree	0.61 (0.04)	74 (8)	65.7 (5.2)
Stem	0.59 (0.03)	79 (8)	65.9 (2.9)
Branches	0.64 (0.05)	64 (9)	65.1 (3.6)
Bark			
Whole tree	0.64 (0.13)	57 (11)	65.6 (57.1)
Stem	0.61 (0.04)	55 (10)	58.9 (4.4)
Branches	0.72 (0.38)	85 (68)	83.6 (53.0)
White Oak			
Wood			
Whole tree	0.64 (0.03)	69 (5)	67.4 (6.8)
Stem	0.64 (0.03)	71 (6)	67.8 (3.0)
Branches	0.64 (0.04)	63 (4)	65.1 (3.2)
Bark			
Whole tree	0.53 (0.05)	73 (22)	58.4 (19.6)
Stem	0.53 (0.05)	71 (26)	56.9 (9.3)
Branches	0.52 (0.14)	111 (123)	62.2 (13.4)

Alabama trees were shorter, with a significantly higher percent of wood in the crown, and had less stem taper for equivalent dbh classes than the Tennessee trees. Also, it should be noted that the Tennessee trees were harvested during the dormant winter months and the Alabama trees during the spring, so the Alabama trees had a higher bark moisture content and therefore higher bark green weight per cubic foot.

The differences in predicted values for whole or total green tree weights indicate the need for using care in applying biomass equations from one region to another, especially if the equations are developed from trees harvested at different times of the year.

BIOMASS TABLES

Biomass tables for green and dry weights of complete tree (including roots and stump), whole tree, and tree length (main stem to 3-inch top) have been produced from the equations of tables 1 through 4 for the four species of hardwoods. The biomass tables 5 through 16 are presented in Appendix II. As indicated in the discussion under *Prediction Equations*, care should be used in applying these table values to other regions that may have trees of different form or green weights per cubic foot of wood and/or bark.

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Appendix I—Prediction tables and related equations

Table 1.—*Sweetgum regression equations for estimating green and oven-dry biomass for trees 3 to 12 inches dbh*

Weight (Y) pounds	Regression equations[1]	Coefficient of determination	Standard error
	Y	R^2	Syx
Complete tree (excluding leaves)			
Green	$Y = .176557\ D^2\ Th$	0.99	0.0035
Dry	$Y = .10139\ D^2\ Th$	0.99	0.0024
Complete tree wood			
Green	$Y = .16823\ D^2\ Th$	0.99	0.0034
Dry	$Y = .09664\ D^2\ Th$	0.99	0.0023
Complete tree bark			
Green	$Y = .00758\ D^2\ Th$	0.96	0.0004
Dry	$Y = .00433\ D^2\ Th$	0.97	0.0002
Whole tree (excluding leaves)			
Green	$Y = .14360\ D^2\ Th$	0.99	0.0032
Dry	$Y = .08262\ D^2\ Th$	0.99	0.0021
Whole tree wood			
Green	$Y = .13602\ D^2\ Th$	0.99	0.0031
Dry	$Y = .07828\ D^2\ Th$	0.99	0.0019
Whole tree bark			
Green	$Y = .00758\ D^2\ Th$	0.96	0.0004
Dry	$Y = .00433\ D^2\ Th$	0.97	0.0002
Stem-stump to 3-inch top no branches			
Green	$Y = .12536\ D^2\ Th$	0.99	0.0028
Dry	$Y = .07281\ D^2\ Th$	0.99	0.0022
Stem wood			
Green	$Y = .11909\ D^2\ Th$	0.99	0.0027
Dry	$Y = .06903\ D^2\ Th$	0.99	0.0021
Stem bark			
Green	$Y = .00627\ D^2\ Th$	0.96	0.0003
Dry	$Y = .00378\ D^2\ Th$	0.96	0.0002
Crown—above 3-inch top plus branches			
Green	$Y = .01824\ D^2\ Th$	0.84	0.0021
Dry	$Y = .00981\ D^2\ Th$	0.88	0.0009
Crown wood			
Green	$Y = .01692\ D^2\ Th$	0.83	0.0020
Dry	$Y = .00926\ D^2\ Th$	0.87	0.0009
Crown bark			
Green	$Y = .00132\ D^2\ Th$	0.93	0.0001
Dry	$Y = .00055\ D^2\ Th$	0.89	0.0000

[1] $Y = bD^2\ Th$, where Y equals weight in pounds, D equals inches dbh, and Th equals feet of total tree height.

Table 2.—*Hickory regression equations for estimating green and oven-dry biomass for trees 3 to 12 inches dbh*

Weight pounds	Regression equations[1]	Coefficient of determination	Standard error
	Y	R^2	*Syx*
Complete tree (excluding leaves)			
Green	Y = .22822 D^2 Th	0.97	0.0101
Dry	Y = .14676 D^2 Th	0.97	0.0064
Complete tree wood			
Green	Y = .20824 D^2 Th	0.97	0.0091
Dry	Y = .13494 D^2 Th	0.97	0.0058
Complete tree bark			
Green	Y = .01611 D^2 Th	0.88	0.0016
Dry	Y = .00937 D^2 Th	0.87	0.0009
Whole tree (excluding leaves)			
Green	Y = 0.18990 D^2 Th	0.97	0.0084
Dry	Y = 0.12241 D^2 Th	0.97	0.0053
Whole tree wood			
Green	Y = 0.17378 D^2 Th	0.97	0.0079
Dry	Y = 0.11304 D^2 Th	0.97	0.0050
Whole tree bark			
Green	Y = 0.01611 D^2 Th	0.88	0.0016
Dry	Y = 0.00937 D^2 Th	0.87	0.0009
Stem-stump to 3-inch top no branches			
Green	Y = 0.14908 D^2 Th	0.99	0.0042
Dry	Y = 0.09407 D^2 Th	0.99	0.0025
Stem wood			
Green	Y = 0.13285 D^2 Th	0.98	0.0043
Dry	Y = 0.08576 D^2 Th	0.98	0.0027
Stem bark			
Green	Y = 0.01417 D^2 Th	0.87	0.0013
Dry	Y = 0.00831 D^2 Th	0.86	0.0008
Crown total—above 3-inch top plus branches			
Green	Y = 0.04705 D^2 Th	0.80	0.0057
Dry	Y = 0.03099 D^2 Th	0.80	0.0040
Crown wood			
Green	Y = 0.04441 D^2 Th	0.80	0.0057
Dry	Y = 0.02960 D^2 Th	0.81	0.0038
Crown bark			
Green	Y = 0.00257 D^2 Th	0.67	0.0005
Dry	Y = 0.00139 D^2 Th	0.66	0.0003

[1]Y = bD^2 Th, where Y equals weight in pounds, D equals inches dbh, and Th equals feet of total tree height.

Table 3.—*Red Oak—regression equations for estimating green and oven-dry biomass for trees 3 to 12 inches dbh*

Weight pounds	Regression equations[1]	Coefficient of determination	Standard error
	Y	R^2	*Syx*
Complete tree (excluding leaves)			
Green	Y = 0.23398 D^2 Th	0.99	.0056
Dry	Y = 0.13033 D^2 Th	0.98	.0041
Complete tree wood			
Green	Y = 0.21583 D^2 Th	0.99	.0046
Dry	Y = 0.11901 D^2 Th	0.98	.0034
Complete tree bark			
Green	Y = 0.01547 D^2 Th	0.83	.0014
Dry	Y = 0.00987 D^2 Th	0.81	.0010
Whole tree (excluding leaves)			
Green	Y = 0.20134 D^2 Th	0.99	.0047
Dry	Y = 0.11308 D^2 Th	0.98	.0036
Whole tree wood			
Green	Y = 0.18587 D^2 Th	0.99	.0039
Dry	Y = 0.10321 D^2 Th	0.98	.0029
Whole tree bark			
Green	Y = 0.01547 D^2 Th	0.83	.0014
Dry	Y = 0.00987 D^2 Th	0.81	.0010
Stem-stump to 3-inch top no branches			
Green	Y = 0.14857 D^2 Th	0.99	.0015
Dry	Y = 0.08112 D^2 Th	0.99	.0011
Stem wood			
Green	Y = 0.13534 D^2 Th	0.99	.0017
Dry	Y = 0.07258 D^2 Th	0.99	.0007
Stem bark			
Green	Y = 0.01323 D^2 Th	0.84	.0012
Dry	Y = 0.00854 D^2 Th	0.82	.0008
Total crown—above 3-inch top plus branches			
Green	Y = 0.05177 D^2 Th	0.84	.0046
Dry	Y = 0.03197 D^2 Th	0.83	.0031
Crown wood			
Green	Y = 0.05025 D^2 Th	0.84	.0046
Dry	Y = 0.03060 D^2 Th	0.83	.0029
Crown bark			
Green	Y = 0.00232 D^2 Th	0.77	.0003
Dry	Y = 0.00137 D^2 Th	0.72	.0002

[1]Y = bD^2 Th, where Y equals weight in pounds, D equals inches dbh, and Th equals feet of total tree height.

Table 4.—*White Oak—regression equations for estimating green and oven-dry biomass for trees 3 to 12 inches dbh*

Weight pounds	Regression equations[1]	Coefficient of determination	Standard error
	Y	R^2	*Syx*
Complete tree (excluding leaves)			
Green	$Y = 0.22314\ D^2\ Th$	0.99	.0048
Dry	$Y = 0.13150\ D^2\ Th$	1.00	.0024
Complete tree wood			
Green	$Y = 0.21466\ D^2\ Th$	0.99	.0046
Dry	$Y = 0.12645\ D^2\ Th$	0.99	.0023
Complete tree bark			
Green	$Y = 0.00693\ D^2\ Th$	0.97	.0003
Dry	$Y = 0.00415\ D^2\ Th$	0.95	.0003
Whole tree (excluding leaves)			
Green	$Y = 0.17998\ D^2\ Th$	0.99	.0036
Dry	$Y = 0.10633\ D^2\ Th$	0.99	.0019
Whole tree wood			
Green	$Y = 0.17305\ D^2\ Th$	0.99	.0034
Dry	$Y = 0.10218\ D^2\ Th$	0.99	.0018
Whole tree bark			
Green	$Y = 0.00693\ D^2\ Th$	0.97	.0003
Dry	$Y = 0.00415\ D^2\ Th$	0.95	.0003
Stem-stump to 3-inch top no branches			
Green	$Y = 0.14856\ D^2\ Th$	0.99	.0015
Dry	$Y = 0.08112\ D^2\ Th$	0.99	.0011
Stem wood			
Green	$Y = 0.14208\ D^2\ Th$	0.99	.0023
Dry	$Y = 0.08315\ D^2\ Th$	0.99	.0012
Stem bark			
Green	$Y = 0.00579\ D^2\ Th$	0.98	.0002
Dry	$Y = 0.00351\ D^2\ Th$	0.95	.0002
Crown total—above 3-inch top plus branches			
Green	$Y = 0.03211\ D^2\ Th$	0.80	.0044
Dry	$Y = 0.01966\ D^2\ Th$	0.81	.0027
Crown wood			
Green	$Y = 0.03097\ D^2\ Th$	0.80	.0043
Dry	$Y = 0.01902\ D^2\ Th$	0.81	.0026
Crown bark			
Green	$Y = 0.00114\ D^2\ Th$	0.78	.0002
Dry	$Y = 0.00064\ D^2\ Th$	0.75	.0001

[1] $Y = bD^2\ Th$, where Y equals weight in pounds, D equals inches dbh, and Th equals feet of total tree height.

Appendix II—Biomass tables

Table 5
SPECIES: SWEETGUM
COMPONENT : COMPLETE TREE(STEM+BRANCHES+STUMP)

DBH INCHES	20	30	40	50	60	70	80	90
	COMPLETE TREE GREEN WEIGHT (LBS.)							
3	31.78	47.67	63.56	79.45	95.34			
4	56.50	84.75	113.00	141.25	169.49			
5	88.28	132.42	176.56	220.70	264.84	308.97		
6	127.12	190.68	254.24	317.80	381.36	444.92		
7		259.54	346.05	432.56	519.08	605.59	692.10	
8		338.99	451.99	564.98	677.98	790.98	903.97	
9		429.03	572.04	715.06	858.07	1001.08	1144.09	1287.10
10		529.67	706.23	882.78	1059.34	1235.90	1412.46	1589.01
11			854.54	1068.17	1281.80	1495.44	1709.07	1922.71
12			1016.97	1271.21	1525.45	1779.69	2033.94	2288.18

REGRESSION EQ.: Y = 0.17655694*(DBH * DBH * TOTAL HEIGHT)

Table 6
SPECIES: HICKORY
COMPONENT : COMPLETE TREE(STEM+BRANCHES+STUMP)

DBH INCHES	20	30	40	50	60	70	80	90
	COMPLETE TREE GREEN WEIGHT (LBS.)							
3	41.08	61.62	82.16	102.70	123.24			
4	73.03	109.54	146.06	182.57	219.09			
5	114.11	171.16	228.22	285.27	342.32	399.38		
6	164.32	246.47	328.63	410.79	492.95	575.10		
7		335.48	447.30	559.13	670.96	782.78	894.61	
8		438.17	584.23	730.29	876.35	1022.41	1168.47	
9		554.56	739.42	924.28	1109.13	1293.99	1478.84	1663.70
10		684.65	912.86	1141.08	1369.30	1597.51	1825.73	2053.94
11			1104.57	1380.71	1656.85	1932.99	2209.13	2485.27
12			1314.52	1643.16	1971.79	2300.42	2629.05	2957.68

REGRESSION EQ.: Y = 0.22821611*(DBH * DBH * TOTAL HEIGHT)

Table 7
SPECIES: RED OAK
COMPONENT : COMPLETE TREE(STEM+BRANCHES+STUMP)

DBH INCHES	TOTAL HEIGHT IN FEET 20	30	40	50	60	70	80	90
	COMPLETE TREE GREEN WEIGHT (LBS.)							
3	42.12	63.17	84.23	105.29	126.35			
4	74.87	112.31	149.75	187.18	224.62			
5	116.99	175.48	233.98	292.47	350.97	409.46		
6	168.47	252.70	336.93	421.16	505.40	589.63		
7		343.95	458.60	573.25	687.90	802.55	917.20	
8		449.24	598.99	748.73	898.48	1048.23	1197.97	
9		568.57	758.09	947.62	1137.14	1326.66	1516.19	1705.71
10		701.94	935.92	1169.90	1403.88	1637.85	1871.83	2105.81
11			1132.46	1415.57	1698.69	1981.80	2264.92	2548.03
12			1347.72	1684.65	2021.58	2358.51	2695.44	3032.37

REGRESSION EQ.: Y = 0.23397923*(DBH * DBH * TOTAL HEIGHT)

Table 8
SPECIES: WHITE OAK
COMPONENT : COMPLETE TREE(STEM+BRANCHES+STUMP)

DBH INCHES	TOTAL HEIGHT IN FEET 20	30	40	50	60	70	80	90
	COMPLETE TREE GREEN WEIGHT (LBS.)							
3	40.16	60.25	80.33	100.41	120.49			
4	71.40	107.10	142.81	178.51	214.21			
5	111.57	167.35	223.14	278.92	334.70	390.49		
6	160.66	240.99	321.31	401.64	481.97	562.30		
7		328.01	437.34	546.68	656.02	765.35	874.69	
8		428.42	571.23	714.03	856.84	999.65	1142.45	
9		542.22	722.96	903.70	1084.44	1265.18	1445.92	1626.66
10		669.41	892.54	1115.68	1338.81	1561.95	1785.08	2008.22
11			1079.97	1349.97	1619.96	1889.95	2159.95	2429.94
12			1285.26	1606.57	1927.89	2249.20	2570.52	2891.83

REGRESSION EQ.: Y = 0.22313517*(DBH * DBH * TOTAL HEIGHT)

Table 9
SPECIES: SWEETGUM
COMPONENT : WHOLE TREE(STEM+BRANCHES)

DBH INCHES	TOTAL HEIGHT IN FEET 20	30	40	50	60	70	80	90
	WHOLE TREE DRY WEIGHT (LBS.)							
3	25.85	38.77	51.70	64.62	77.54			
4	45.95	68.93	91.90	114.88	137.86			
5	71.80	107.70	143.60	179.50	215.40	251.30		
6	103.39	155.09	206.78	258.48	310.18	361.87		
7		211.09	281.46	351.82	422.18	492.55	562.91	
8		275.71	367.62	459.52	551.43	643.33	735.23	
9		348.95	465.26	581.58	697.90	814.21	930.53	1046.85
10		430.80	574.40	718.00	861.60	1005.20	1148.80	1292.40
11			695.03	868.78	1042.54	1216.29	1390.05	1563.81
12			827.14	1033.92	1240.71	1447.49	1654.28	1861.06

REGRESSION EQ.: Y = 0.14360029*(DBH * DBH * TOTAL HEIGHT)

Table 10
SPECIES: HICKORY
COMPONENT : WHOLE TREE(STEM+BRANCHES)

DBH INCHES	TOTAL HEIGHT IN FEET 20	30	40	50	60	70	80	90
	WHOLE TREE DRY WEIGHT (LBS.)							
3	34.18	51.27	68.36	85.45	102.54			
4	60.77	91.15	121.53	151.92	182.30			
5	94.95	142.42	189.90	237.37	284.84	332.32		
6	136.73	205.09	273.45	341.81	410.18	478.54		
7		279.15	372.20	465.25	558.29	651.34	744.39	
8		364.60	486.13	607.67	729.20	850.73	972.27	
9		461.45	615.26	769.08	922.89	1076.71	1230.53	1384.34
10		569.69	759.58	949.48	1139.38	1329.27	1519.17	1709.06
11			919.10	1148.87	1378.65	1608.42	1838.19	2067.97
12			1093.80	1367.25	1640.70	1914.15	2187.60	2461.05

REGRESSION EQ.: Y = 0.18989605*(DBH * DBH * TOTAL HEIGHT)

Table 11
SPECIES: RED OAK
COMPONENT : WHOLE TREE(STEM+BRANCHES)

DBH INCHES	20	30	40	50	60	70	80	90
			TOTAL HEIGHT IN FEET					
			WHOLE TREE DRY WEIGHT (LBS.)					
3	36.24	54.36	72.48	90.60	108.72			
4	64.43	96.64	128.86	161.07	193.29			
5	100.67	151.00	201.34	251.67	302.01	352.34		
6	144.96	217.45	289.93	362.41	434.89	507.38		
7		295.97	394.63	493.28	591.94	690.60	789.25	
8		386.57	515.43	644.29	773.14	902.00	1030.86	
9		489.26	652.34	815.43	978.51	1141.60	1304.68	1467.77
10		604.02	805.36	1006.70	1208.04	1409.38	1610.72	1812.06
11			974.48	1218.11	1461.73	1705.35	1948.97	2192.59
12			1159.72	1449.65	1739.58	2029.50	2319.43	2609.36

REGRESSION EQ.: Y = 0.20133972*(DBH * DBH * TOTAL HEIGHT)

Table 12
SPECIES: WHITE OAK
COMPONENT : WHOLE TREE(STEM+BRANCHES)

DBH INCHES	20	30	40	50	60	70	80	90
			TOTAL HEIGHT IN FEET					
			WHOLE TREE DRY WEIGHT (LBS.)					
3	32.40	48.60	64.79	80.99	97.19			
4	57.59	86.39	115.19	143.99	172.78			
5	89.99	134.99	179.98	224.98	269.97	314.97		
6	129.59	194.38	259.17	323.97	388.76	453.55		
7		264.57	352.76	440.95	529.15	617.34	705.53	
8		345.56	460.75	575.94	691.13	806.32	921.51	
9		437.35	583.14	728.93	874.71	1020.50	1166.28	1312.07
10		539.94	719.93	899.91	1079.89	1259.87	1439.85	1619.83
11			871.11	1088.89	1306.67	1524.44	1742.22	1960.00
12			1036.69	1295.87	1555.04	1814.21	2073.39	2332.56

REGRESSION EQ.: Y = 0.17998153*(DBH * DBH * TOTAL HEIGHT)

Table 13
SPECIES: SWEETGUM
COMPONENT : MAIN STEM TO 3IN DIB

DBH INCHES	TOTAL HEIGHT IN FEET 20	30	40	50	60	70	80	90
	STEM GREEN WEIGHT (LBS)							
3	22.57	33.85	45.13	56.41	67.70			
4	40.12	60.17	80.23	100.29	120.35			
5	62.68	94.02	125.36	156.70	188.04	219.38		
6	90.26	135.39	180.52	225.65	270.78	315.91		
7		184.28	245.71	307.13	368.56	429.99	491.42	
8		240.69	320.92	401.16	481.39	561.62	641.85	
9		304.63	406.17	507.71	609.26	710.80	812.34	913.88
10		376.08	501.44	626.81	752.17	877.53	1002.89	1128.25
11			606.75	758.44	910.12	1061.81	1213.50	1365.18
12			722.08	902.60	1083.12	1263.64	1444.16	1624.68

REGRESSION EQ.: Y = 0.12536120*(DBH * DBH * TOTAL HEIGHT)

Table 14
SPECIES: HICKORY
COMPONENT : MAIN STEM TO 3IN DIB

DBH INCHES	TOTAL HEIGHT IN FEET 20	30	40	50	60	70	80	90
	STEM GREEN WEIGHT (LBS)							
3	26.83	40.25	53.67	67.09	80.50			
4	47.71	71.56	95.41	119.26	143.12			
5	74.54	111.81	149.08	186.35	223.62	260.89		
6	107.34	161.01	214.68	268.34	322.01	375.68		
7		219.15	292.20	365.25	438.30	511.34	584.39	
8		286.23	381.65	477.06	572.47	667.88	763.29	
9		362.26	483.02	603.77	724.53	845.28	966.04	1086.79
10		447.24	596.32	745.40	894.48	1043.56	1192.64	1341.72
11			721.55	901.93	1082.32	1262.71	1443.10	1623.48
12			858.70	1073.38	1288.05	1502.73	1717.40	1932.08

REGRESSION EQ.: Y = 0.14908016*(DBH * DBH * TOTAL HEIGHT)

Table 15
SPECIES: RED OAK
COMPONENT : MAIN STEM TO 3IN DIB

DBH INCHES	TOTAL HEIGHT IN FEET 20	30	40	50	60	70	80	90
	STEM GREEN WEIGHT (LBS)							
3	26.74	40.11	53.48	66.86	80.23			
4	47.54	71.31	95.08	118.85	142.63			
5	74.28	111.43	148.57	185.71	222.85	259.99		
6	106.97	160.45	213.94	267.42	320.91	374.39		
7		218.39	291.19	363.99	436.79	509.59	582.39	
8		285.25	380.33	475.42	570.50	665.58	760.67	
9		361.02	481.36	601.70	722.04	842.38	962.72	1083.06
10		445.70	594.27	742.84	891.41	1039.98	1188.54	1337.11
11			719.07	898.84	1078.60	1258.37	1438.14	1617.90
12			855.75	1069.69	1283.63	1497.56	1711.50	1925.44

REGRESSION EQ.: Y = 0.14856791*(DBH * DBH * TOTAL HEIGHT)

Table 16
SPECIES: WHITE OAK
COMPONENT : MAIN STEM TO 3IN DIB

DBH INCHES	TOTAL HEIGHT IN FEET 20	30	40	50	60	70	80	90
	STEM GREEN WEIGHT (LBS)							
3	26.62	39.93	53.23	66.54	79.85			
4	47.32	70.98	94.64	118.30	141.96			
5	73.94	110.91	147.87	184.84	221.81	258.78		
6	106.47	159.70	212.94	266.17	319.41	372.64		
7		217.37	289.83	362.29	434.75	507.21	579.66	
8		283.92	378.56	473.20	567.83	662.47	757.11	
9		359.33	479.11	598.89	718.67	838.44	958.22	1078.00
10		443.62	591.49	739.37	887.24	1035.12	1182.99	1330.86
11			715.71	894.64	1073.56	1252.49	1431.42	1610.34
12			851.75	1064.69	1277.63	1490.57	1703.50	1916.44

REGRESSION EQ.: Y = 0.14787370*(DBH * DBH * TOTAL HEIGHT)

Appendix III—Documentation

DOCUMENTATION FOR HARDWOOD BIOMASS PROGRAM

1. The percent of wood (green) and bark (green) are calculated for each section of the stem (butt, mid, 3-in top) and for each branch, using the weights obtained from lab samples.

$$\%\ \text{wood} = \frac{\text{total wood weight}}{\text{total disk weight (wood + bark)}} \times 100$$

$$\%\ \text{bark} = \frac{\text{total bark weight}}{\text{total disk weight (wood + bark)}} \times 100$$

2. The proportional weighting factor (FW), for section of the stem, was calculated using the equation:

$$FW_{section} = \frac{DIB^2_{section}}{DIB^2_{butt} + DIB^2_{mid} + DIB^2_{top}}$$

The numerator is the square of the DIB at the section for which the weighing factor is to be calculated.

3. The weighted percents wood (green) and bark (green) for the stem are determined by applying the weighting factor of the section to the percent of wood and bark for the section, as determined in #1. The weighted percents for each section are summed to get the weighted percent for each stem. The weighted percent of wood and bark for the branches are averaged, because only two branches were sampled and no branch diameters were recorded.

Weighted % wood =
$$\Sigma^{top}_{butt} FW_{section} \times \%\ \text{wood}_{section}\ (\#1)$$

Weighted % bark =
$$\Sigma^{top}_{butt} FW_{section} \times \%\ \text{bark}_{section}\ (\#1)$$

Weighted % wood (Branches) =

$$\frac{\%\ \text{wood (Branch 1)} + \%\ \text{wood (Branch 2)}}{2}$$

Weighted % bark (Branches) =

$$\frac{\%\ \text{bark (Branch 1)} + \%\ \text{bark (Branch 2)}}{2}$$

4. The total green weight of wood and bark for each tree is determined by using the equation:

Total weight of wood =

$$\frac{\text{stem weight (lbs)} \times \%\ \text{wood}}{100} + \frac{\text{branch weight} \times \%\ \text{wood}}{100}$$

Total weight of bark =

$$\frac{\text{stem weight} \times \%\ \text{bark}}{100} + \frac{\text{branch weight} \times \%\ \text{bark}}{100}$$

5. The percent moisture (dry wt. basis) in the wood, for each section of the stem and each branch are calculated:

% moisture in wood =

$$\frac{\text{green wt. of sample} - \text{dry wt. of sample}}{\text{dry wt. of sample}} \times 100$$

and can be greater than 100%.

6. The dry weight of wood in the stem is calculated by:

$$W_{wdl} = \frac{W_{sg} \times W_{ds}}{1 + \frac{\%\ M}{100}}$$

Where;
W_{wdl} = calculated dry wt. of wood in stem
W_{sg} = green wt. of stem
W_{ds} = weighted % wood for the stem ÷ 100
% M = weighted % moisture for the stem

7. The dry weight of the wood in the branches is calculated by:

$$\text{dry wt. of wood} = \text{green top wt.} \times \left(\frac{\text{weighted \% wood}}{100}\right) \div \left(1 + \frac{\text{weighted \% moisture}}{100}\right)$$

8. The percent moisture (dry wt. basis) for the bark, at each section of the stem and for each branch are calculated by:

% moisture in bark =

$$\frac{\text{green wt. of sample} - \text{dry wt. of sample}}{\text{dry wt. of sample}} \times 100$$

9. The weighted percent moisture (M) for the bark on the stem and branches are calculated by:

weighted % M {in bark} =

$$[\% M_{butt} \times DIB^2_{butt} + \% M_{mid} \times DIB^2_{mid} + \% M_{top} \times DIB^2_{top}] \div [DIB^2_{butt} + DIB^2_{mid} + DIB^2_{top}]$$

weighted % M in {bark on branches} =

$$\frac{\% M \text{ (Branch 1)} + \% M \text{ (Branch 2)}}{2}$$

10. The dry weight of bark (W_{db}) on the stem is calculated by:

$$W_{db} = \frac{W_{sg} \times W_{bs}}{1 + \frac{\% M}{100}}$$

W_{db} = Calculated dry wt. of bark on the stem
W_{sg} = green wt. of stem
W_{bs} = weighted % bark for the stem ÷ 100
% M = weighted % moisture in bark on stem.

11. The dry weight of bark in the branches is calculated by:

$$\text{dry wt. of bark} = \text{green top wt.} \times \left(\frac{\text{weighted \% wood}}{100}\right) \div \left(\frac{1 + \text{weighted \% moisture}}{100}\right)$$

12. Total dry weight of each tree is the sum of the components:
Total dry wt. of tree = dry wt. wood (stem) + dry wt. bark (stem) + dry wt. wood (branches) + dry wt. bark (branches)

Sirois, Donald L. Biomass of four hardwoods from Lower Piedmont pine-hardwood stands. Gen. Tech. Rep. SO-46. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1983. 18 p.

Biomass equations for complete tree, whole tree, and stem wood, with and without bark, both green and dry, are presented for four southern hardwoods — sweetgum (*Liquidambar styraciflua* L.); hickory, both mockernut and pignut (*Carya tomentosa* (Poir.) Nutt. and *C. glabra* (Mill.) Sweet); red oak (*Quercus falcata* Michx. var. *falcata*); and white oak (*Q. alba* L.). Weight tables are also provided for the whole tree and stem wood of the four hardwoods.

Keywords: Whole tree, complete tree, prediction equations, biomass.

☆U.S. GOVERNMENT PRINTING OFFICE: 1983- 675-876/104