INDIVIDUAL TREE, MERCHANTABLE STEM GREEN WEIGHT AND VOLUME EQUATIONS FOR FOUR BOTTOMLAND HARDWOOD OAK SPECIES IN SOUTHEAST ARKANSAS

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Abstract.—Equations were developed to estimate outside-bark, merchantable stem green weight (lb) and inside-bark merchantable stem volume (ft^3) for sawtimber-sized Nuttall oak (*Quercus texana* Buckley), overcup oak (*Quercus lyrata* Walt.), water oak (*Quercus nigra* L.), and willow oak (*Quercus phellos* L.) found at two bottomland hardwood sites in southeast Arkansas. Sixty-one trees were used in this study. Trees ranged from 43 to 90 years in age (average of 62 years), 12 to 34 inches in diameter at breast height (d.b.h.) (averaging 19.5 inches), 60 to 120 feet in total height (averaging 94 feet), 27 to 77 feet in merchantable height (averaging 53 feet), and 5.4 to 26.0 inches in merchantable top diameter (averaging 11 inches). Equations were developed by species and employ a combined variable, (d.b.h.^{2} * total height), to facilitate ease of use based on commonly measured inventory attributes. The results of this research should assist those inventorying hardwood sawtimber-sized trees by weight or those working with scaling factors (outside-bark weight divided by inside-bark volume) in southern Arkansas.

INTRODUCTION

Recent buying and selling trends for hardwood sawtimber in southern Arkansas have shifted from a volume basis to a weight basis. Many natural resource professionals use board foot volume equations or tables with conversion factors (Daniels 2001) to convert board foot volume to weight. However, during a forest inventory, regression analysis can be used to develop weight equations, eliminating the need to use conversion factors and the potential errors they introduce.

Equations estimating total tree green weight and green weight to a merchantable top have been developed for several hardwood species in the South (Clark et al. 1986, Schlaegel 1981, Schlaegel 1984, Schlaegel and Willson 1983). However, regression equations are typically applicable only to data similar to that used to develop the equations (Myers 1990), and data from southern Arkansas were not included in these endeavors.

Furthermore, bole weight is influenced by wood properties, which can vary between and within species (Koch 1985, Taylor 1977). Wood properties are also inconsistent between geographic regions, which further illustrates the need for hardwood weight equations that are developed for and applied to trees in southeastern Arkansas.

Arkansas contains approximately 18.75 million acres of timberland (U.S. Forest Service 2011). About 69 percent (12.7 million acres) contain hardwoods, with approximately 16 percent (3 million acres) being bottomland hardwoods (Arkansas Forestry Association 2007) that are common to southeastern

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Arkansas. This large amount of bottomland hardwood acreage, in conjunction with the need to inventory hardwood sawtimber by weight, suggests the need for the development of bottomland hardwood sawtimber weight equations in southeastern Arkansas. The objectives of this research were to develop equations to estimate outside-bark, merchantable stem green weight, and inside-bark, merchantable stem volume for sawtimber-sized Nuttall oak (*Quercus texana* Buckley), overcup oak (*Quercus lyrata* Walt.), water oak (*Quercus nigra* L.), and willow oak (*Quercus phellos* L.) found at two bottomland hardwood sites in southeast Arkansas.

METHODS

Study Sites

Two study sites were selected for this project, one on the Felsenthal National Wildlife Refuge (hereafter referred to as Felsenthal) near Crossett, AR, and the other in Hamburg, AR (hereafter referred to as Hamburg). The two sites were selected and utilized because planned harvesting activities as part of ongoing management at each site allowed for access to felled trees, logging equipment, and equipment operators.

The Felsenthal site has an elevation of 65-75 ft above sea level and consists of a Nuttall oak-overcup oak-willow oak-sweetgum (*Liquidambar styraciflua* L.) cover type. This site was subject to frequent flooding. The Hamburg site has an elevation of 135-145 ft above sea level and consists predominately of a cherrybark oak (*Quercus pagoda* Raf.)-water oak (*Quercus nigra* L.)-white oak (*Quercus alba* L.) cover type, but also includes southern red oak (*Quercus falcata* Michx.), shagbark hickory (*Carya ovata* Mill.*)*, and mockernut hickory (*Carya tomentosa* Poir.). This site was not subject to frequent flooding.

Data Collection

Data was collected at each study site, once before tree harvest (inventory data collection stage) and once after tree harvest (harvest data collection stage). The inventory data collection stage at each stand included randomly selecting and measuring subject trees from the trees marked for harvest. D.b.h. (nearest 0.1 inch), diameter (nearest 0.1 inch) at 1 ft above ground, total height (nearest 1 ft), height (nearest 1 ft) to a called 10-inch top, and bark thickness (nearest 0.1 in.) at 4.5 feet above ground were taken on each subject tree using a diameter tape, a vertex hypsometer, and a bark gauge, respectively. Each subject tree was marked with five bands of paint, with a unique ordering of colors per tree, and a number for identification at the logging deck.

Within 24 hours of the subject trees being felled during the late summer and early fall of 2005, the harvest data collection stages occurred at the study sites. Several measurements and observations were taken on the merchantable boles after they were brought to the logging deck. Total length (nearest 1 ft), inside-bark diameter (nearest 0.1 inch) at the large and small ends of the merchantable bole, age (yr) at the large end of the merchantable bole, outside-bark diameter (nearest 0.1 inch) and bark thickness (nearest 0.1 inch) at 1 foot intervals for the first 8 feet along the merchantable bole and every 3 feet thereafter, were measured for each tree using a logger's tape, calipers, and a bark gauge. Age was determined by counting the growth rings at the large end of the merchandised bole.

Each merchandised bole was then weighed using a digital load cell (Measurement Systems International Challenger 2, Model 3360, 2 lb. increments, Seattle, WA) suspended from a loader and attached to the merchantable bole with chains and tongs. The load cell capacity was 5 tons, so boles expected to weigh over 4 tons were bucked and weighed in pieces. The merchantable boles from Hamburg were bucked into sawlogs of varying lengths. The oaks were cut into 14.5 ft logs, or multiples thereof. The merchantable boles at Felsenthal were used primarily for pulpwood even though they were of sawtimber size, so no set lengths were cut at that site.

Analysis

Smalian's formula (Avery and Burkhart 2002) was used to calculate inside-bark cubic foot volume for each merchantable bole using the diameter and bark thickness measurements taken along each bole. If needed, the weights of the merchandised boles were summed to obtain outside-bark merchantable stem green weights.

Several independent variables were examined for use in ordinary least squares regressions. The combined variable (d.b.h.^{2} x total height) was selected for use in the final models for two reasons: overall model performance as determined by regression diagnostics, and d.b.h. and total height are attributes commonly measured when collecting forest inventory data. Errors from the regression fits were normally distributed (Shapiro-Wilk tests) and residual plots did not suggest the presence of heteroscedasticity.

RESULTS

Table 1 depicts the sample size, mean, standard deviation, and range of age, d.b.h., total height, merchantable stem length, merchantable stem top diameter, and merchantable stem weight by species for the Felsenthal and Hamburg study sites. The average weight/volume ratio did not differ between study sites (two-sample t test; p-value=0.8573) whereas the d.b.h./total height ratio was larger at the Hamburg site (two-sample t test; p-value<0.0001). Subject trees tended to be slightly older at the Hamburg site which may have led to the difference in the latter ratio.

Merchantable Stem Green Weight Equation

The following equation was chosen as the best model form for estimating merchantable stem length outside-bark green weight:

$$\hat{W}_i = b_0 + b_1 D_i^2 H_i \qquad (1)$$

Where: $\hat{W}_i$ = merchantable stem outside-bark green weight (lb) for tree i,
D_i = d.b.h. (in) for tree i,
H_i = total tree height (ft) for tree i, and
b_0, b_1 = parameters to be estimated.

Estimated parameters and fit statistics for equation 1, by species, appear in Table 2. All slopes were significantly different than 0 at α=0.05.

Table 1.—Mean, standard deviation, and range of subject tree age, d.b.h., total height, merchantable stem length, merchantable stem top diameter, and merchantable stem weight by species (sample size) for the Felsenthal and Hamburg study sites

Species	Mean	Standard Deviation	Minimum	Maximum
		Age (yr)		
Nuttall oak (14)	51.1	10.9	45	75
overcup oak (15)	57.0	12.4	43	78
willow oak (14)	57.4	8.2	44	70
water oak (18)	71.1	15.6	55	90
		D.b.h. (in)		
Nuttall oak	17.9	4.1	12.5	24.3
overcup oak	17.5	4.1	11.8	25.5
willow oak	17.7	4.5	11.7	27.7
water oak	23.4	3.9	18.7	34.0
		Total height (ft)		
Nuttall oak	96.2	10.2	83	106
overcup oak	90.2	9.0	73	105
willow oak	91.9	14.9	60	120
water oak	96.3	12.9	69	113
		Merchantable stem length (ft)		
Nuttall oak	54.4	10.5	36.0	65.0
overcup oak	49.1	10.5	27.0	65.0
willow oak	55.3	14.8	31.0	77.0
water oak	53.1	9.8	31.5	66.0
		Merchantable stem top diameter (in)		
Nuttall oak	10.3	3.8	5.7	21.9
overcup oak	9.4	3.9	5.5	16.7
willow oak	10.6	4.5	5.4	26.0
water oak	13.3	4.1	7.7	21.2
		Merchantable stem outside-bark weight (tons)		
Nuttall oak	1.99	0.78	0.93	3.06
overcup oak	1.79	0.78	0.50	3.33
willow oak	2.13	0.93	0.65	3.58
water oak	3.51	1.23	2.23	7.53
		Merchantable stem inside-bark volume (ft^3)		
Nuttall oak	50.9	26.8	23.1	81.8
overcup oak	45.0	23.3	12.7	84.0
willow oak	54.2	16.5	16.5	97.7
water oak	89.0	37.0	52.7	197.2

Table 2.—Parameter estimates and fit statistics for regressions estimating merchantable stem outside-bark green weight (Equation 1, lb) by species and merchantable stem inside-bark ft^3 volume (Equation 2) by species

Equation/species	Parameter	Estimate	Std. Error	P-value
(1)	b_0	976.705	357.067	0.0181
Nuttall oak	b_1	0.091	0.010	<0.0001
	R^2 = 0.8768 Mean Absolute Residual = 0.22 tons; 11.5 percent			
(1)	b_0	590.363	241.911	0.0297
overcup oak	b_1	0.093	0.007	<0.0001
	R^2 = 0.9388 Mean Absolute Residual = 0.16 tons; 12.0 percent			
(1)	b_0	1,856.557	498.173	0.0025
willow oak	b_1	0.074	0.013	<0.0001
	R^2 = 0.7229 Mean Absolute Residual = 0.40 tons; 23.2 percent			
(1)	b_0	932.704	636.795	0.1624
water oak	b_1	0.111	0.011	<0.0001
	R^2 = 0.8687 Mean Absolute Residual = 0.35 tons; 9.7 percent			
(2)	b_0	9.8351	3.9175	0.0274
Nuttall oak	b_1	0.0012	0.0001	<0.0001
	R^2 = 0.9174 Mean Absolute Residual = 4.55 ft^3; 9.6 percent			
(2)	b_0	6.1863	3.3662	0.0890
overcup oak	b_1	0.0012	0.00009	<0.0001
	R^2 = 0.9308 Mean Absolute Residual = 4.47 ft^3; 14.2 percent			
(2)	b_0	20.0948	6.0789	0.0057
willow oak	b_1	0.0011	0.0002	<0.0001
	R^2 = 0.7784 Mean Absolute Residual = 9.65 ft^3; 22.3 percent			
(2)	b_0	3.5669	8.1739	0.6684
water oak	b_1	0.0016	0.0001	<0.0001
	R^2 = 0.8877 Mean Absolute Residual = 9.05 ft^3; 10.8 percent			

Merchantable Stem Volume Equation

The following equation was chosen as the best model form for estimating merchantable stem length inside-bark ft^3 volume:

$$\hat{V}_i = b_0 + b_1 D_i^2 H_i \qquad (2)$$

Where: $\hat{V}_i$ = merchantable stem inside-bark ft^3 volume for tree i, and all other terms as previously described,

Estimated parameters and fit statistics for equation 2, by species, appear in Table 2. All slopes were significantly different than zero at α=0.05.

DISCUSSION

The work herein provides some simple-to-use equations that can assist those estimating either the outside-bark merchantable green weight or the inside-bark merchantable ft^3 volume for four oak species found in bottomland hardwood stands. The larger-sized trees (Table 1) used in this project are indicative of the trees often found in bottomland hardwood stands and represent size classes for which weight equations may not be readily available.

Validation of the equations is suggested before widespread application since trees from only two stands, though representative of bottomland hardwood stands in southeast Arkansas, were used. The range in subject tree size for willow oak was similar to that of both Nuttall oak and overcup oak, yet the willow oak equations possessed the most error, suggesting more work is needed for this species in particular.

When combined with the scaling factor (outside-bark green weight divided by inside-bark volume), results (see Patterson et al. [2011] and Doruska et al. [2006] for scaling factors for these and other hardwood species in Arkansas) one can easily estimate outside-bark merchantable green weight from inside-bark volume estimates or inside-bark volume from outside-bark merchantable green weights.

Whereas this work focused on the entire merchantable portion of the tree stems, Hurd (2006) developed other weight equations involving slightly more complex functional forms for these and other species that allows one to estimate green weight based on d.b.h. and number of logs or merchantable lengths. As a result, one can estimate the green weights for portions of the merchantable stems using the work by Hurd (2006).

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