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Diameter measurement in bald cypress

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ABSTRACT

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The usual practice of measuring diameter at 4.5 feet (1.3 m) or D_{bh} is meaningless in wetland tree species such as bald cypress (*Taxodium distichum* (L.) Rich.), due to the presence of fluted basal swells. Since buttress dimensions usually have no consistent relation to volume or form in the tree, the current practice among life-sciences professionals is to measure stem diameter 18 in (50 cm) above 'pronounced' butt swelling. This measure is termed normal diameter (D_n). This paper contrasts the use of six fixed-height diameter-measurement points ranging from 6 ft (1.8 m) to 11 ft (3.4 m) against D_n (a variable-height measurement point) for predicting cubic volume. Results show an increase in precision using the upper five fixed-height measurements over D_n and a considerable increase in precision using diameter measured at 10 ft (3.0 m) and 11 ft (3.4 m). Since results improved only slightly using diameter measured at 11 ft (3.4 m) over 10 ft (3.0 m), diameter at 10 ft (D_{10}) is recommended as a better alternative than D_n for working with cypress.

INTRODUCTION

The cypress resource

Recent forest-survey data (Williston et al., 1980) indicate the volume of commercial cypress growing in the United States to be 5.5 billion[1] ft^3 (155.7 million m^3). Florida and Louisiana contain more than half of this cypress inventory. However, nearly 75% of the stocking in Florida is pond cypress (*Taxodium distichum* var. *nutans* (Ait.) Sweet), a relatively noncommercial species. By contrast, Louisiana's stocking of pond cypress is restricted to five of its 64 parishes, and in none of the five parishes is it a major component of the tree cover (Sternitzke, 1972). Thus, Louisiana's cypress stocking is predominantly bald cypress (*T. distichum* (L.) Rich.), which represents the major bald-cypress resource in the nation.

[1] U.S. billion, 10^9.

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About 32% of the commercial forest land in Louisiana, or approximately 4.4 million acres (1.8 million ha), is classified as oak/gum/cypress type (Rosson et al., 1988). Cypress growing-stock is reported (May and Bertelson, 1986) to be 1463.0 million ft^3 (41.4 million m^3) with the majority (1198.1 million ft^3; 33.9 million m^3), concentrated in the South Delta region (Rosson and Bertelson, 1986). Cypress harvesting has averaged 4.7 million ft^3 (133 100 m^3) annually from 1974 to 1984 (Rosson et al., 1988).

Mensuration problems

The nature of bald-cypress growth has imposed significant problems to mensurationists trying to estimate such characteristics as volume and stem form in the species (Husch et al., 1972). Cypress typically grows in flood-prone areas and permanent swamps. As a response to this environment, bald cypress shows considerable variation in the butt region. Fluted basal swells are typically formed (Fig. 1). These vary in height due to duration and depth of flooding, and the furrows between the 'flutes' or 'flanges' range from very shallow to very deep (Mattoon, 1915; Kurz and Demaree, 1934). Thus, the usual practice of measuring diameter at 4.5 ft (1.3 m), called diameter at breast height (D_{bh}), for volume estimation is meaningless, because buttress dimensions will usually have no consistent relation to the quantity of wood in the tree (Husch et al., 1972).

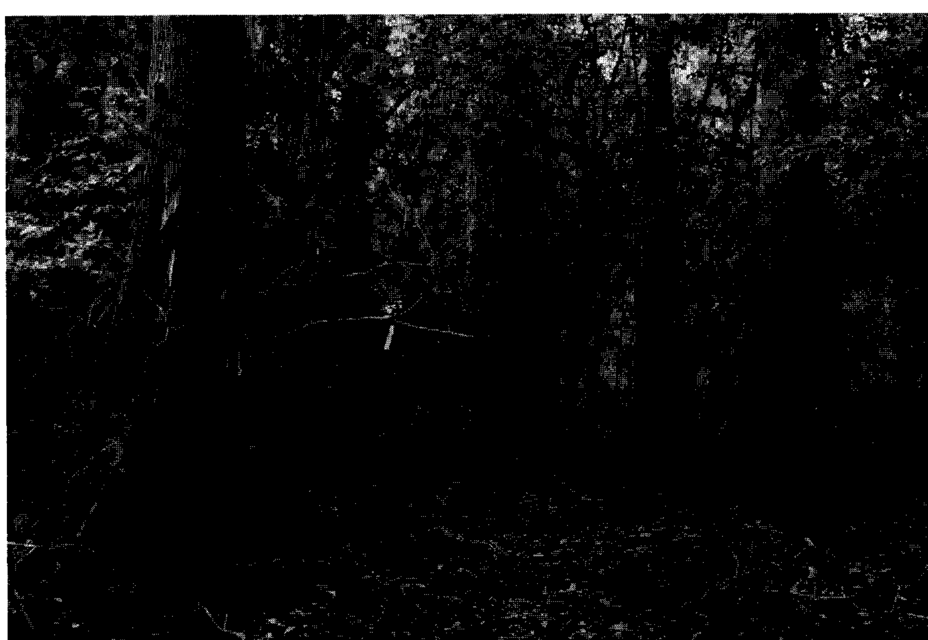

Fig. 1. Examples of fluted basal swells on bald-cypress trees.

Though researchers have successfully used D_{bh} to predict green and dry-weights of bald cypress (Conde et al., 1979; Swindel et al., 1982), these cypress occurred as a minor stand component on a pine flatwood site and were not typical of swamp-grown bald cypress. This paper deals with cypress occurring either in pure stands or as a predominant species in mixed stands.

As a substitute for D_{bh}, measurements of volume on cypress and other swamp species such as tupelo (*Nyssa* sp.) is currently based on diameter measured 18 in (50 cm) above pronounced butt swelling (Forbes, 1955; Avery and Burkhart, 1983). The underlying assumption for this practice is that stem diameter just above the swell is approximately equivalent to what the diameter would be at breast height if the buttress were not present; consequently, this diameter measure is termed 'normal diameter' (D_n).

The use of D_n as a substitute for D_{bh} is questionable; it is not certain that D_n is equivalent to what D_{bh} might be without the buttress. More importantly, individual foresters might disagree on the point where butt swell ceases and, therefore, on the point where diameter should be measured. To determine if a constant, fixed-height diameter can better estimate total stem volume, volumes based on diameters measured at 6 ft (D_6; 1.8 m) to 11 ft (D_{11}; 3.4 m) above the ground were compared to volumes based on D_n. Three foresters were periodically rotated in determining D_n on the sample trees to minimize the effects of one individual's judgement on the point where the measurement should be made.

METHODS

Data collection

Taper data were collected on 157 trees from 26 sites (25 sites with 6 trees and 1 site with 7) located throughout the South Delta region of Louisiana. Tree normal diameters ranged from 6 to 24 in (15–61 cm), and total-tree heights ranged from 46 to 103 ft (14–31 m). The sample trees were felled and total height was measured to the nearest 0.1 ft (0.03 m). Diameter and bark-thickness measurements to the nearest 0.1 in (2.5 mm) were measured at D_n; at 1, 3, 5, 6, 7, 8, 9, 10, 11, 13, 15, and 17 feet (0.3, 0.9, 1.5, 1.8, 2.1, 2.4, 2.7, 3.0, 3.4, 4.0, 4.6, and 5.2 m); and every 4 ft (1.2 m) thereafter throughout the remainder of the stem. The portion of the bole exhibiting flutes was cross-sectioned at the appropriate heights, and solid-wood diameters were measured by inscribing with an expandable hoop the largest possible circle or ellipse (including bark) inside the flutes. Inside-bark and outside-bark volumes (V_{ib}; V_{ob}) for each bolt were calculated using Smalian's formula. Bolt volumes were summed treating the stump as a cylinder and the last section as a cone to obtain total tree volume (V_{ib} and V_{ob}). The sample trees were stratified by 1-in (2.5-cm) D_n classes, and 20% of each class were held out at random (for a total of 37 trees) to create an independent dataset.

Computations

Forbes (1955) examined diameter measurement of cypress, and stated it should occur as much as 7–11 ft (2.1–3.4 m) above the ground. Consequently, diameters tested in this study were D_n, D_6, D_7, D_8, D_9, D_{10} and D_{11}. Cubic volumes were estimated using Schumacher and Hall's (1933) logarithmic function:

$$\ln V = \ln b_0 + b_1 \ln D + b_2 \ln H \tag{1}$$

Equation (1) can be rewritten in nonlogarithmic form as:

$$V = b_0 D^{b_1} H^{b_2} \tag{2}$$

Total stem volumes calculated from equation (1) were evaluated over the selected fixed-height diameters and D_n to determine the 'best' diameter-measurement point. The 'fit' statistics used to determine how well volumes from equation (1) fit the sample data were: (1) coefficient of determination (R^2); (2) root mean square error ($S_{y.x}$); and (3) the sum of squared relative residuals (SSRR). The 'validation' statistics used to evaluate estimated volumes against the independent data, which represent the population, were 1) bias ($\bar{D}$), 2) standard deviation of differences (SD), and 3) SSRR. Computational formulas for the above fit and validation statistics are given in Table 1.

Because the absolute variation of volume per tree is expected to increase with tree size, measures of precision such as $S_{y.x}$ and SD are not reliable indicators of variation across size classes. The SSRR statistic is used to relate the size of each residual to its observed value. If variance is stable within each size

TABLE 1

Criteria for evaluating total stem volumes at different diameter-measurement points

Fit statistics — sample data

1) Coefficient of determination:

$$R^2 = 1 - \Sigma \text{Diff}_i^2 / \Sigma (V_i - \bar{V})^2$$

2) Root mean square error:

$$S_{y.x} = \sqrt{\Sigma \text{Diff}_i^2 / (n-p)}$$

3) Sum of squared relative residuals:

$$\text{SSRR} = \Sigma (\text{Diff}_i / V_i)^2$$

Validation statistics — independent data

1) Bias:

$$\bar{D} = \Sigma \text{Diff}_i / n$$

2) Standard deviation of differences:

$$\text{SD} = \sqrt{\Sigma (\text{Diff}_i - \bar{D})^2 / (n-1)}$$

3) Sum of squared relative residuals:

Defined as above

Notation: $\text{Diff}_i = V_i - \hat{V}_i$, observed minus predicted volume on the ith tree; n, = number of observations (trees); p, = number of model parameters.

class, the squared ratios developed for each observation should tend towards uniformity of size within each size class. This will result in lower sums of squared ratios being associated with functions producing more-uniform variances within and across each size class.

RESULTS AND DISCUSSION

Approximately 95% of the sample trees had butt swells ending at 9.5 ft (2.9 m) or less, with the average occurring at 5.7 ft (1.7 m). This is an important consideration in choosing a fixed-height diameter-measurement point for bald cypress, because buttress flutes prevent accurate measure of solid-wood diameter in standing trees. Furthermore, these results should influence the fit and validation statistics associated with the diameter measurement points employed in equation (1).

Values of the fit and validation statistics associated with the diameter measurement points are presented in Table 2. Except for bias ($\bar{D}$), the fit and validation statistics steadily improve as the diameter-measurement point is moved up the tree, and are generally better using D_7 through D_{11} than they are using D_n.

Since approximately 95% of the sample trees had butt swells ending at 9.5 ft (2.9 m) or less, and because the fit and validation statistics generally improved with increasingly higher fixed-height diameters, D_{10} and D_{11} were considered preferable to D_7 through D_9. Individual-tree volume predictions were similar using D_{10} and D_{11}, hence D_{10} might be cc‾sidered as the pre-

TABLE 2

Values of fit and validation statistics associated with different diameter-measurement points

Statistic	Diameter-measurement point						
	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_n
Sample fit data — inside bark							
R^2	0.914	0.943	0.964	0.975	0.981	0.983	0.934
$S_{y.x}$[1]	7.659	6.219	4.916	4.121	3.638	3.443	6.709
	(0.217)	(0.176)	(0.139)	(0.117)	(0.103)	(0.097)	(0.190)
SSRR	2.598	2.326	1.977	1.616	1.438	1.255	3.210
Independent validation data — inside bark							
$\bar{D}$[1]	0.889	1.258	1.410	1.494	0.737	0.279	−0.172
	(0.025)	(0.036)	(0.040)	(0.042)	(0.021)	(0.008)	(−0.005)
SD[1]	6.564	6.203	5.854	5.772	4.371	3.735	5.263
	(0.186)	(0.176)	(0.166)	(0.163)	(0.124)	(0.106)	(0.149)
SSRR	0.727	0.615	0.477	0.472	0.399	0.251	0.874

[1]Values in ft^3 (m^3).

ferred constant, fixed-height diameter-measurement point, since it provides similar results as D_{11} and should be somewhat easier to measure in practice.

Finally, equation (1) was evaluated using diameters measured at D_{10} and D_n. Relative to D_n, use of D_{10} resulted in substantial improvements in most of the statistical values. A review of Table 2 shows R^2 increasing from 0.93 to 0.98, $S_{y.x}$ dropping from 6.7 ft^3 (0.19 m^3) to 3.6 ft^3 (0.10 m^3), and SD dropping from 5.3 ft^3 (0.15 m^3) to 4.4 ft^3 (0.12 m^3). Similar improvements occurred for the outside-bark data. These analyses indicate that use of D_{10} for total stem volume estimation provides volume estimates superior to those from D_n. Consequently, D_{10} is recommended as a better diameter-measurement point for bald cypress. For trees with swell heights over 9.5 feet (2.9 m), D_n should still be used.

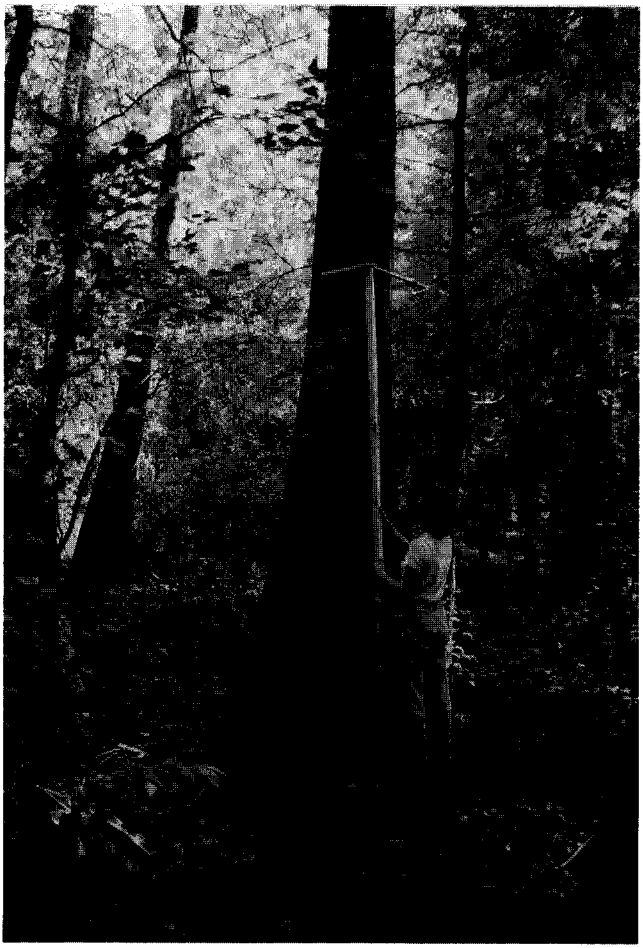

Fig. 2. Forester measuring diameter at 10 ft (3.0 m) on a bald-cypress tree using a pole caliper.

SUMMARY AND CONCLUSIONS

This study considered the effects of buttresses on volume estimation for bald cypress. Solid wood diameters in a buttress were determined by cross sectioning and inscribing a circle or elipse inside the flutes. Diameter measured at 10 ft (3.0 m) above the ground, termed D_{10}, proved to be a better diameter-measurement point than the currently used normal diameter (D_n), measured 18 in (50 cm) above butt swell. A pole caliper as described by Ferree (1946) can be used to measure D_{10} (Fig. 2). The methodology on comparing fixed-height diameters against D_n should be applicable to any buttressed species.

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