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Predicting Diameters Inside Bark for 10 Important Hardwood Species

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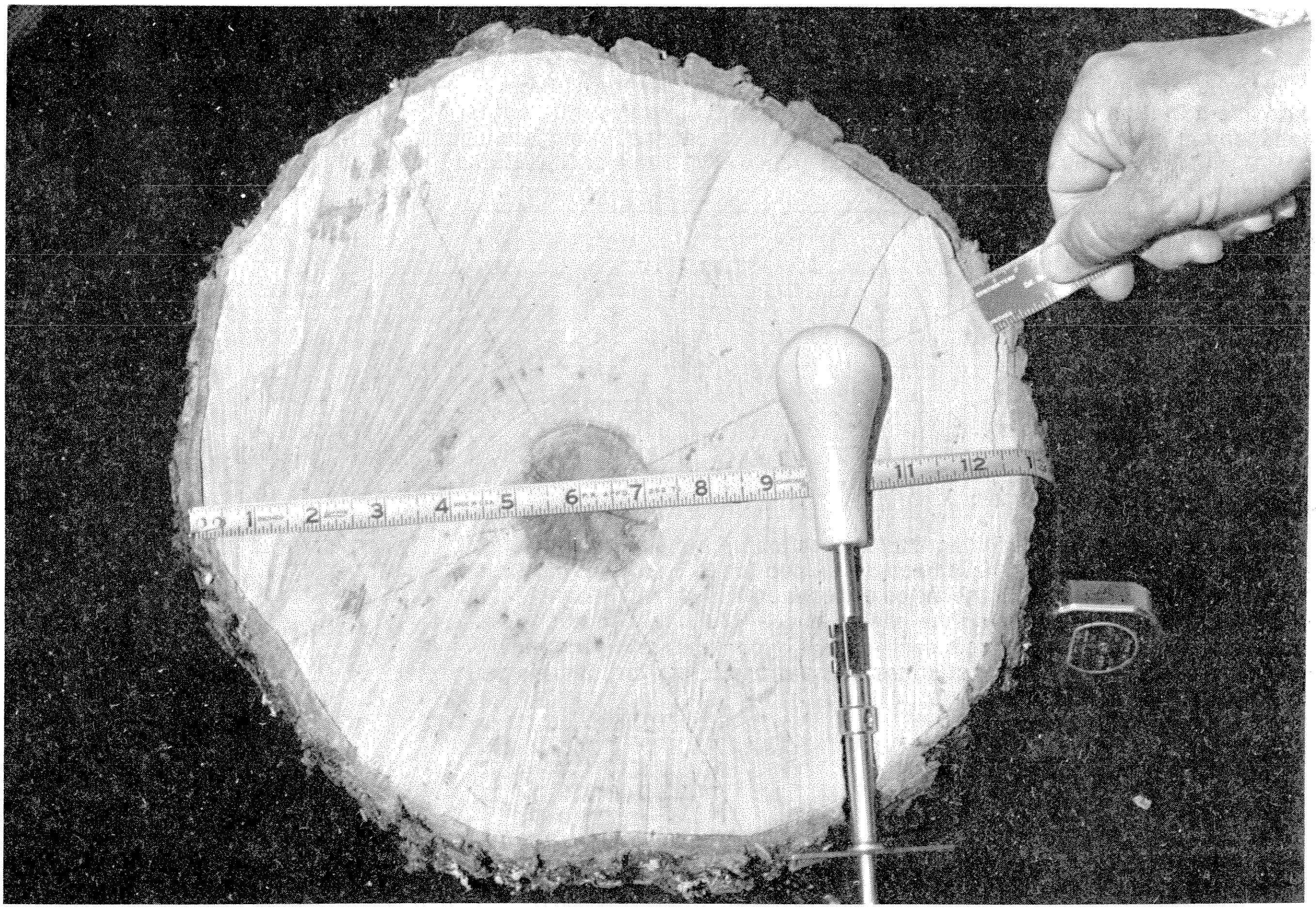

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Abstract

General models for predicting DIB/DOB ratios up the stem, applicable over wide geographic areas, have been developed for 10 important hardwood species. Results indicate that the ratios either decrease or remain constant up the stem. Methods for adjusting the general models to local conditions are presented. The prediction models can be used in conjunction with optical dendrometer measurements or stem taper equations to convert outside bark diameters to inside bark diameters.

Upper stem diameters measured outside bark (DOB) with an optical dendrometer, or estimated with a stem taper equation, must be converted to diameters inside bark (DIB) to determine the volume of wood alone. Meyer (1946) developed mean DIB/DOB ratios at breast height for several hardwood species in Pennsylvania, but suggested that further experimentation was warranted to determine if the ratios changed up the stem. Koch (1971) investigated the bark volume of five commercial hardwood species in West Virginia and found that the DIB/DOB ratios did in fact change up the stem for trees 4-6 inches dbh. DIB/DOB ratios were essentially constant above a height of 10 feet for larger trees.

Recently, the most common way to convert DOBs to DIBs has been with the three options suggested by Grosenbaugh (1964) for his STX programs. The three options are fitted to sample data via linear or nonlinear least squares procedures, and the option with the best fit is selected as the model to predict DIB from DOB, DBHOB, and DBHIB. The three options are:

Option 1: DIB = DOB * (DBHIB/DBHOB)

Option 2: DIB = DOB * (1 − (1 − DBHIB/DBHOB) * (QUAN/(DENO − DOB/DBHOB)))

Option 3: DIB = DOB * (DBHIB/DBHOB) * (QUAN/(DENO − DOB/DBHOB))

where DBHOB = diameter breast height outside bark, DBHIB = diameter breast height inside bark, and QUAN and DENO are names assigned by Grosenbaugh to model parameters to be estimated in Options 2 and 3. The DIB/DOB ratio is assumed to be constant up the stem in Option 1, increase curvilinearly up the stem in Option 2, and decrease curvilinearly up the stem in Option 3 (Boehmer and Rennie 1976). Grosenbaugh recommended values of 1.0 and 2.0 for QUAN and DENO in Option 2, and 9.0 and 10.0 in Option 3. Local values for QUAN and DENO can be estimated with nonlinear least squares techniques with the constraint that QUAN = (DENO − 1.0) (Brickell 1970).

Mesavage (1969) found that Option 2 proved best for southern pines. Results for hardwoods have indicated that either Option 1 or 3 is appropriate, depending on the species. Wiant and Koch (1974) found that Option 1 performed best for five hardwood species measured in West Virginia. Option 3 was found to be the best overall predictor of DIB for hardwood species in Tennessee when local values of QUAN and DENO were used, but Option 1 performed as well on some species (Boehmer and Rennie 1976). Further investigations by Colaninno et al. (1977) revealed that either Option 1 or 3 was best, depending on the species, for seven hardwood species in northern West Virginia.

General models for predicting DIB/DOB ratios up the stem, applicable over wide geographic areas, are developed in this paper for 10 important hardwood species. Methods for adjusting the models to local conditions are also discussed. While we continue to advocate the use of Grosenbaugh's three options, our data set lacked the necessary bark thickness reading at DBH, so we had to use an entirely new mathematical approach.

Data

The data used in this study were originally collected during the 1960s in conjunction with the development of log and tree grades for hardwoods. A total of 1619 trees were used to develop the DIB/DOB ratios for the 10 hardwood species (Table 1). Scientific names of all species referred to in this study can be found in Little (1978). Most species were sampled in at least two states.

DBHOB was measured to the nearest 0.1 inch on each standing tree. After felling, the trees were bucked into 8- to 16-foot logs, the length of each log being determined by such factors as crook, sweep, and rot. DIB and bark thickness were measured to the nearest 0.1 inch at the small end of each log with a ruler. Two DIB's measured at right angles to each other were averaged to obtain the DIB reading, and four bark thickness readings measured at right angles to each other were averaged to obtain the bark thickness reading. All trees had at least two DIB and bark thickness readings; one tree had seven. Bark thickness was *not* measured at DBH.

Methods

Inspection of the three options listed previously reveals that the DBHIB/DBHOB ratio is needed to determine which option fits the sample data best, and to determine local values for QUAN and DENO. Since the data used in this study lacked the DBHIB/DBHOB ratio, a mathematical model that approximated the three options had to be developed.

DIB/DOB is plotted over DOB/DBHOB for each of the three options in Figure 1 for a tree that has a DBHIB/DBHOB ratio of 0.91. Option 3 is also plotted using DENO = 22.62, a local value for white oak developed by Boehmer and Rennie (1976). Similar shaped lines result for trees with different DBHIB/DBHOB ratios. It is evident from Figure 1 that option 3 can be very closely approximated by the linear relationship between DIB/DOB and DOB/DBHOB. That is,

$$DIB/DOB = \beta_0 + \beta_1 (DOB/DBHOB), \quad \text{(Model 1)}$$

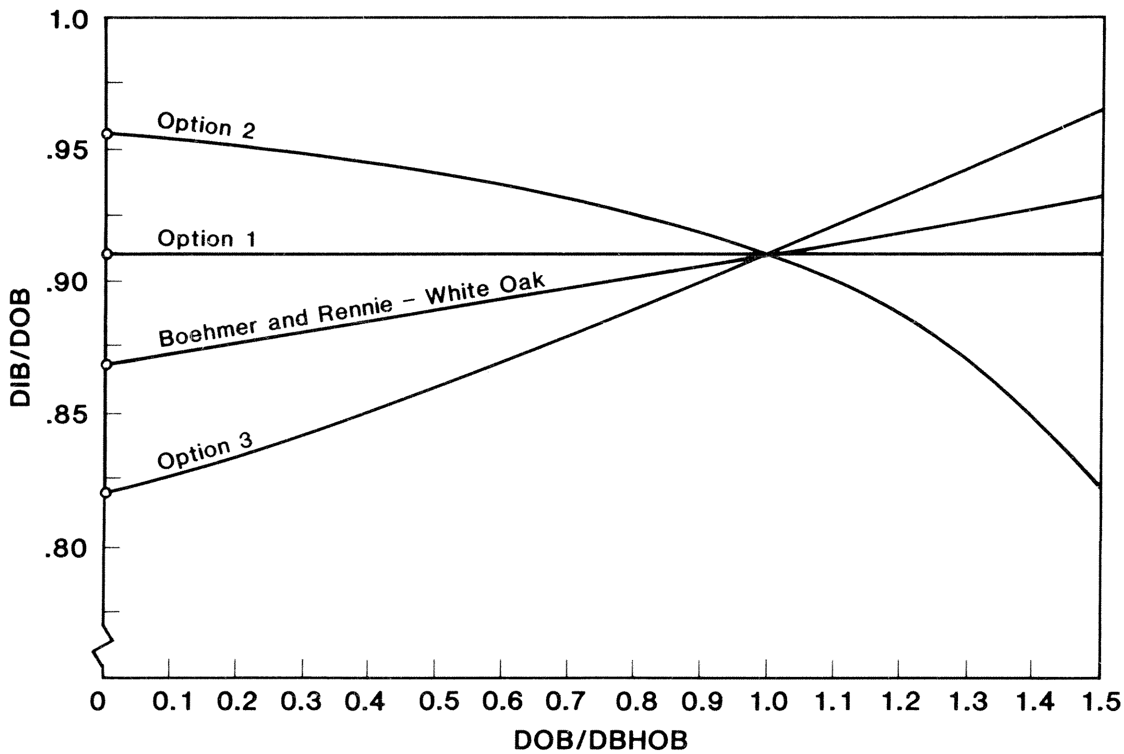
Table 1.—Summary characteristics of data used to develop DIB/DOB ratios.

Species	Location	Number of trees	DBH Minimum-Mean-Maximum		
			Inches		
Chestnut oak	OH, GA, TN, WV, VA	347	11.0	19.8	48.0
Red maple	WV, VT, PA, MI	266	10.5	16.6	33.1
Northern red oak	GA, NC, TN, WV, VA	212	11.7	24.4	38.2
White oak	KY, GA, NC, TN	205	10.3	20.5	35.7
Sugar maple	WV, VT, MI, NH	163	11.3	20.7	29.7
Black oak	GA, NC, TN, VA	159	12.2	21.5	33.8
Yellow-poplar	VA, AL	159	11.4	19.2	32.1
Black cherry	WV, PA	53	11.9	19.3	28.1
Southern red oak	TN	29	13.2	19.1	26.8
American beech	WV	26	12.9	18.4	29.9

for DBHOB and DOB greater than zero. The linear relationship would not as closely approximate Option 2, but Option 2 has not been found to be the best predictor for hardwoods. Model 1 can be fitted to sample tree data to determine the *trend* in the DIB/DOB ratios up the stem even if the DBHIB/DBHOB ratio is not known for each sample tree. If β_1 (estimated from sample data) is not significantly different from zero, then a trend the same as Option 1 would result. If β_1 is positive, trends similar to Option 3 would result, and if β_1 is negative, trends similar to Option 2 would result. The estimated DIB/DOB ratios would still remain constant, increase curvilinearly, or decrease curvilinearly up the stem because the DOB/DBHOB ratio is not a linear function of increasing tree height. The predicted DBHIB/DBHOB ratio from Model 1 would be the DIB/DOB ratio estimated when DOB/DBHOB equals one. That is, the predicted DBHIB/DBHCB ratio equals $\beta_0 + \beta_1$. As discussed later, Model 1 can also be adjusted for application to pass through known DBHIB/DBHOB points.

Since the DIB/DOB ratios measured on the same tree are correlated observations, estimates of the coefficients for Model 1, β_0 and β_1, were determined individually for each tree. The sample estimates of the coefficients were then averaged to determine mean values for each species. A multivariate regression analysis was used to determine whether DBHOB had a significant effect on the β's for a given species. The hypothesis $\beta_1 = 0$ was then tested. If β_1 was not significantly different from zero, all DIB/DOB ratios measured for that species were pooled and averaged to obtain a constant DIB/DOB ratio.

Figure 1.—DIB/DOB ratios for Grosenbaugh's three options and Boehmer and Rennie's model for white oak. Based on a tree with DBHIB/DBHOB = 0.91.



Results

Estimates of β_0 and β_1 for the ten species groups are shown in Table 2. DBHOB did not have a significant effect (α = .01) on the β's for any of the species groups. Even though the DBHOB effect was not significant, users should be reminded that mostly larger trees were analyzed in this study. Since β_1 was not significantly different from zero for cherry, southern red oak, or beech, the constant DIB/DOB ratio listed in Table 1 is recommended for these species instead of using the β's.

Results of this study are consistent with other studies for hardwoods in view of the fact that the DIB/DOB ratios were found to either remain constant or decrease up the stem. In particular, the results coincide closely with those found by Boehmer and Rennie (1976). They found that Option 3 was the best for white oak and yellow-poplar if local values of QUAN and DENO were used. Fitting Model 1 to sample data closely parallels fitting local values of QUAN and DENO for Option 3. They also found that Option 1 was as good as Option 3 for southern red oak.

Adjusting Model 1 to Local Conditions

Estimates of β_0 and β_1 listed in Table 2 are applicable over a wide geographic area. However, we highly recommend that the estimates be adjusted to local conditions prior to application.

A sample data set consisting of 92 white oak trees from one location in north-central Kentucky is used to demonstrate adjustments to Model 1. DBHOB ranged from 5.1 inches to 18.2 inches. Two to nine DIB/DOB measurements up the stem, including DBHIB/DBHOB, were recorded for each tree. Test data that included the DBHIB/DBHOB ratio were not available for the other species groups.

The DIB/DOB ratios are plotted over DOB/DBHOB in Figure 2. The decreasing trend of the ratios up the stem is clearly evident. Model 1,

$$DIB/DOB = 0.881 + 0.056\ DOB/DBHOB \quad \text{(Model 1)}$$

is plotted on the graph. While the slope parameter, 0.056, closely approximates that of the sample data, the intercept parameter, 0.881, is clearly too high. Since the DBHIB/DBHOB ratios are known for the sample data, they can be used to adjust Model 1. Adjustments can be made on a stand basis using a sample of the DBHIB/DBHOB ratios, or on an individual tree basis using each DBHIB/DBHOB ratio. In practice, adjustment on a stand basis would probably be more common, but if the DBHIB/DBHOB ratio is known for each tree, as may be the case for studies or sampling schemes utilizing an optical dendrometer, adjustments should be made on a per tree basis. Adjustments are made only on the intercept parameter, β_0. Upper stem DIB/DOB ratios needed to adjust the slope parameter, β_1, are seldom measured in the field. If they are, the best approach then would be to fit completely new parameters to Model 1, or determine which of the options suggested by Grosenbaugh is best.

In order to adjust Model 1 on a stand basis, a random sample of 9 trees (an approximate 10 percent

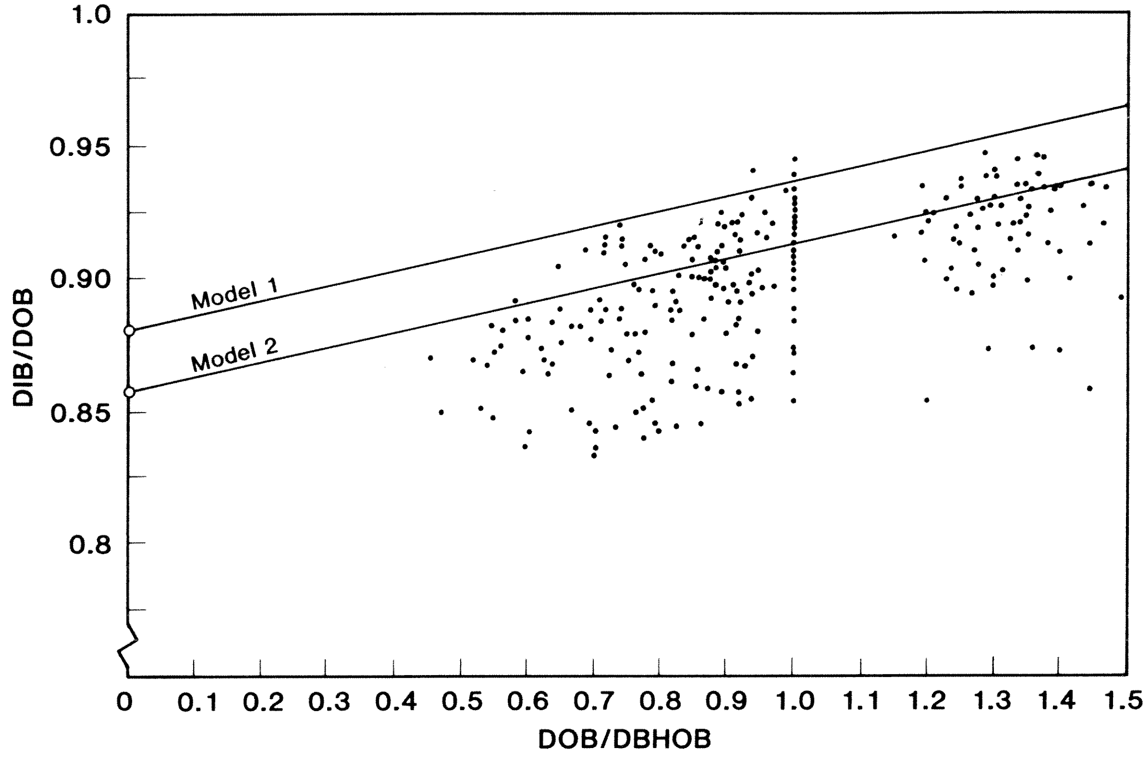
Table 2.—Estimated values of β_0 and β_1 for ten hardwood species groups.

Species	β_0	Standard error, β_0	β_1	Standard error, β_1	H_0:[a] $\beta_1 = 0$	Mean[b] DIB/DOB
Chestnut oak	0.774	0.008	0.149	0.011	**	—
Red maple	.919	.005	.045	.006	**	—
Northern red oak	.864	.007	.084	.010	**	—
White oak	.881	.009	.056	.011	**	—
Sugar maple	.873	.013	.060	.017	**	—
Black oak	.832	.011	.103	.015	**	—
Yellow-poplar	.840	.008	.087	.011	**	—
Black cherry	.934	.009	.017	.012	N.S.	0.947
Southern red oak	.888	.024	.040	.033	N.S.	.916
American beech	.931	.022	.035	.025	N.S.	.961

[a]N.S. = not significant, ** = significant at α = .01 level.

[b]Calculated for use only if β_1 not significantly different from zero.

Figure 2.—DIB/DOB ratios for 92 white oak sample trees.



sample) was drawn from the 92 trees. The mean DBHIB/DBHOB ratio for the nine randomly-selected trees was 0.913. Since the predicted DBHIB/DBHOB using Model 1 was ($\beta_0 + \beta_1$) = 0.937, the regression line must be "shifted" down to pass through the point (1, 0.913). The adjusted model becomes

$$DIB/DOB = \beta_0^* + 0.056\ DOB/DBHOB, \quad \text{(Model 2)}$$

where

$$\beta_0^* = (\text{Mean DBHIB/DBHOB ratio}) - (\beta_0 + \beta_1) + \beta_0$$
$$= (\text{Mean DBHIB/DBHOB ratio}) - \beta_1,$$
$$= 0.913 - 0.056 = 0.857.$$

Model 2 is also plotted in Figure 2. The adjusted model passes through the mean DBHIB/DBHOB ratio of the sample trees, 0.913, when DOB = DBHOB, and also provides a better fit to all data points.

When DBHIB/DBHOB ratio is known for each tree, Model 1 can be adjusted to pass through the point (1, DBHIB/DBHOB) for each tree. The adjusted model for each tree then becomes

$$DIB/DOB = \beta_0^{**} + \beta_1\ DOB/DBHOB, \quad \text{(Model 3)}$$

where

$$\beta_1^{**} = (DBHIB/DBHOB)_i - \beta_1,$$

and $(DBHIB/DBHOB)_i$ is the ratio for the ith tree.

Freese's (1960) chi-square test for accuracy was employed to determine how well these models predicted the 712 DIB/DOB ratios for the 92 white oak trees. The error limits, expressed as a percentage of the average DIB/DOB ratio, that can be expected to include 95 percent of the deviations between actual and predicted DIB/DOB ratios (5% probability level) are shown in Table 3. The error limits for DIB would be the same as those for the DIB/DOB ratios. As anticipated, the error limits were substantially smaller for Models 2 and 3 than for Model 1, with Model 3 being the smallest.

The mean square errors (MSE) of the differences between actual and predicted DIB/DOB ratios were also calculated for the three models (Table 3). Approximate F-tests for significance were calculated by dividing the larger MSE by the smaller MSE. The MSE for Model 2 was significantly smaller than the MSE for Model 1, and the MSE for Model 3 was significantly smaller than the MSE for Model 2.

Discussion

Trends in the DIB/DOB ratios up the stem for 10 important hardwood species were developed in this study. The coefficients in Table 2 can be used with Model 1 to predict DIBs from DOBs. However, we strongly recommend that a sample of the DBHIB/DBHOB ratios from the stand of interest be used to adjust Model 1 to produce Model 2. If the DBHIB/DBHOB ratio is known for every tree, Model 3 is recommended.

The prediction equations developed in this study should be usable in studies that employ optical dendrometers to measure DOB's up the stem. The equations can also be used in conjunction with taper-based volume equations such as those developed by Martin (1981) for Appalachian hardwoods or those by Hilt (1980) for upland oaks. The taper-based systems integrate over predicted DOB's to predict outside-bark volumes. The equations in this study would be used to convert the predicted DOB's to predicted DIB's. A numerical integration routine would then be used to calculate inside-bark volumes.

Table 3.—Error limits from chi-square tests of accuracy, mean square errors, and F-tests for the three prediction models.

Model	Error[a] limits	MSE	F-test[b]
1	7.9	0.954	
			3.482**
2	4.3	0.274	
			1.299**
3	3.7	0.211	

[a]Expressed as a percent of the mean DIB/DOB ratio, 5% probability level.

[b]F = (Larger MSE/smaller MSE), (712,712) degrees of freedom, ** = significant at the α = .01 probability level.

Literature Cited

Boehmer, W. D.; Rennie, J. C. **Predicting diameter inside bark for some hardwoods in west Tennessee.** Wood Sci. 8:209-212; 1976.

Brickell, James E. **Test of an equation for predicting bark thickness of western Montana species.** Res. Note INT-107. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1970. 7 p.

Colaninno, A.; Sheetz, C. E.; DeMoss, J. C.; Wiant, Jr., H. V. **Which STX bark option is best for certain Appalachian hardwoods?** South. J. Appl. For. 1:25; 1977.

Freese, Frank. **Testing accuracy.** For. Sci. 6:139-145, 1960.

Grosenbaugh, L. R. **STX-FORTRAN-4 program for estimates of tree populations from 3P sample-tree measurements.** Res. Pap. PSW-13. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1964; 76 p.

Hilt, Donald E. **Taper-based system for estimating stem volumes of upland oaks.** Res. Pap. NE-458. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1980. 12 p.

Koch, C. B. **Bark volume of yellow-poplar, red, black, and scarlet oak and red maple in West Virginia.** Bull. 602T. Morgantown, WV: West Virginia University Agricultural Experiment Station; 1971. 20 p.

Little, Elbert L. **Important forest trees of the United States.** Agric Handb. 519. Washington, DC: U.S. Department of Agriculture; 1978. 70 p.

Martin, Jeff. **Taper and volume equations for selected Appalachian hardwood species.** Res. Pap. NE-490. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1981. 22 p.

Mesavage, C. **Converting dendrometer estimates of outside-bark stem dimensions to wood dimensions on major southern pines.** Res. Note SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1969. 4 p.

Meyer, H. Arthur. **Bark volume determination in trees.** J. For. 44: 1067-1070; 1946.

Wiant, Harry V.; Koch, C. B. **Predicting diameters inside bark from outside bark measurements on some Appalachian hardwoods.** J. For. 72:775; 1974.

Hilt, Donald E.; Rast, E. D.; Bailey, H. Predicting diameters inside bark for 10 important hardwood species. Res. Pap. NE-531. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1983. 7 p.

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