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Estimation of Total Tree Height from Renewable Resources Evaluation Data

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SUMMARY

Many ecological, biological, and genetic studies use the measurement of total tree height. Until recently, the Southern Forest Experiment Station's inventory procedures through Renewable Resources Evaluation (RRE) have not included total height measurements. This note provides equations to estimate total height based on other RRE measurements.

INTRODUCTION

Interest is growing in estimating whole tree volume and biomass relationships for southern tree species (Clark 1978, Taras 1978, Hitchcock 1979). For example, four southern universities¹ are conducting research that uses contemporary procedures for estimating individual tree biomass. These studies are based on felled tree data.

Results of recent studies using these same procedures indicate a strong relation between total tree biomass and diameter-squared-height (d^2h) (Clark 1978). Once these relationships are established, it is possible to estimate individual tree biomass directly from dbh and total height without destructively sampling trees.

The RRE unit at the Southern Forest Experiment Station would like to estimate biomass by using its standard inventory information. Unfortunately, measurements of

individual trees, while including diameter at breast height, have not included total height. The merchantable height and (since 1971) upper stem diameter outside bark at merchantable height have been measured. A need for good estimates of total height exists in RRE research.

A second consideration which requires some attention is that past tree volume equations have generally been restricted to specific top limits. Volume equations for various top limits often crossed illogically (Burkhart, 1980). Future changes in the measurement of tree dimensions should attempt to maintain compatibility with past inventories while offering the flexibility to choose any level of utilization of individual trees by species and/or other criteria. Volume estimation should be more stable when estimated total heights are included in predictive models.

It is possible to estimate total height from past inventory measurements. Diameters and merchantable height permit better height estimates than dbh alone. Thus, a sample of trees from an inventory region can be measured as usual, and include total height. Equations developed to relate total height and standard variables on this sample can then be used to produce reliable estimates of total height for all trees. This estimated total height, along with measured dbh, can improve whole bole volume and biomass estimates considerably.

OBJECTIVE

The objective of this study was to estimate regression coefficients for the computation of total tree height from standard survey measurement variables. Both softwood and hardwood species were included in the study populations.

¹ Auburn University, Louisiana Tech University, Mississippi State University, Stephen F. Austin University in cooperation with the Renewable Resources Evaluation program of Southern Forest Experiment Station.

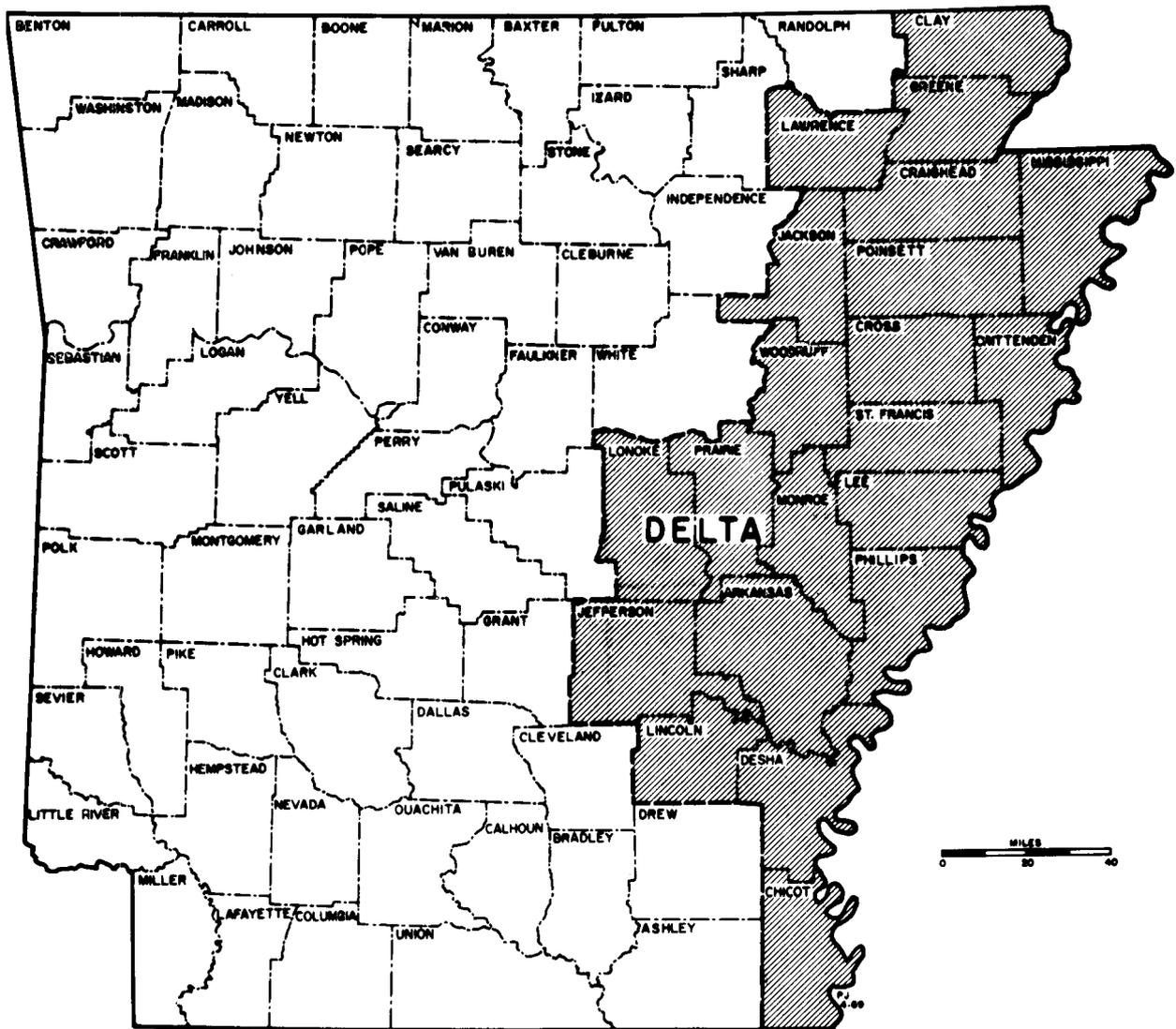


Figure 1.— *The Delta forest survey region of Arkansas.*

METHODS

A pilot study for the estimation of total height using standard survey data was run in Units I and II of Arkansas (fig. 1). These two units were located in the Mississippi Delta region of the state and were considered to have species composition and population characteristics that would represent some of the estimation problems in the Southern Forest Experiment Station area. Existing survey sample locations were revisited and total height was measured on each tree. In addition, some temporary plots were established by using standard procedures in order to increase the size of the sample. On these sup-

plementary plots, all pertinent plot and individual tree measurements—including total height—were made.

A list of variables considered relevant to the current problem is included (table 1). Several additional variables such as site index and damage class were examined, but later excluded as poor predictors. The sample was subdivided into species and species groups based on numbers of observations, analysis of simple statistics on the samples, and standard RRE species groups.

Analysis was performed on individual species or species groups to determine the height prediction equation. "Best" equations were chosen to maintain both F statistic significance and R^2 values as high as possible (table 5).

Not all individual species or groups of interest (e.g. swamp chestnut oak, and select white oak) were represented in sufficient numbers to allow estimation of total height on the species by itself. Dummy variate methods were used to "separate" individual species in some groups.

Analysis of species groups 3 and 6 indicated a significant increase in the R^2 value when dummy variates representing individual species within the group were introduced into models. For example, regression model 6 showed an increase in the R^2 value with the addition of a dummy variable for swamp chestnut oak. To apply the equation coefficients, data is entered for each variable as usual. A 1 is entered in the equation with the coefficient - 9.70 if the species is swamp chestnut oak. If not, a 0 is entered. Species and species groups are listed in table 2. Basic sample statistics are presented in table 3.

RESULTS

Regression equations were run for each species or species group. Merchantable bole length is the single most important independent variable in all species and diameter at the top of the bole is usually next in importance. Diameter at breast height (dbh) and the square of pole top diameter contributed significantly to many of the regressions. Coefficients are presented in table 4.

Use of these equations results in a marked improvement in prediction of height over the use of dbh alone. A typical R^2 for dbh is 0.5 while regressions for selected variable rapidly approached 0.9 in many of the regressions. Standard errors of the estimates (root mean squared error) also improved notably. In table 5, R^2 values for simple linear regression equations based on dbh alone are included to indicate the improvement obtained by using multiple regressions.

CONCLUSIONS

The estimating equations should be of value in the estimation of total height from past inventories. Based on the height, estimates of above-ground bole volume and biomass may be obtained using existing biomass equation (Clark 1978, et al.). Total height of trees can be estimated using dbh, improved estimates can be obtained using merchantable height and diameter outside bark. Height regressions incorporating standard RRE variables provide a marked increase in the R^2 over the use of dbh alone.

The use of these equations is limited to Units I and II in Eastern Arkansas at present. Continuing research will expand the species list and the geographical applicability. The survey is currently measuring total heights on trees in Tennessee.

Table 1.—List of variables*

Variables in the regression model	
$Y = b_0 + b_1 \times (x_1) + \dots + b_{11} \times (x_{11}) + e$ are:	
X(1)	= double bark thickness (at breast height) (inches)
X(2)	= Diameter breast height (inches)
X(3)	= bole length to merchantable top (4.0 inches dob or merchantable limits) (feet)
X(4)	= saw log top diameter outside bark (dob inches)
X(5)	= saw log mid dob (diameter at 1/2 sawlog height) (inches)
X(6)	= pole top dob (inches)
X(7)	= pole mid dob† (inches)
X(8)	= crown ratio (crown length as a decimal proportion of total height)
X(9)	= stump dob (inches)
X(10)	= transformation (1)
X(11)	= transformation (2)
Y	= total height (feet)
transformation (1) = $X(3) - 4.5/X(2) + X(6)/(1 - X(6))/X(2)$	
transformation (2) = $X(6) ** 2$, pole top dob squared.	
All variables are as measured in RRE surveys and reference to exact measurement technique can be found in the Survey Field Manual for Arkansas.	

*Variables included in one or more regression equation. Variables were each tested for significant contribution to the regression.

†Dob at h = $X(3)/2$ for pole timber; at h = $(X(3) + \text{saw log length})/2$ for saw timber trees.

Table 2.—Species and species groups

Survey I.D.		
1. 110	Shortleaf pine	<i>Pinus echinata</i>
2. 400,401	Hickories	<i>Carya spp.</i>
3. 531,541,544	Beech and Ash	<i>Fagus sp., Fraxinus spp.</i>
4. 611	Sweet gum	<i>Liquidambar styraciflua</i>
5. 691,693	Tupelos	<i>Nyssa spp.</i>
6. 802,825	Select White Oaks	<i>Quercus alba, Q. prinus</i>
7. 813,833,834	Select Red Oaks	<i>Quercus rubra, Q. falcata</i> <i>Q. shumardii</i>
8. 835	Post Oak	<i>Quercus stellata</i>
9. 812,822,831,837	Other Oaks	<i>Quercus spp.</i>
10. 971,972	Elms	<i>Ulmus spp.</i>

Table 3.—Basic statistics for species

Species or species group ¹	Number of observations	Dbh		Height	
		Mean	Standard deviation	Mean	Standard deviation
1	22	11.2	3.6	54.5	11.5
2	58	12.1	5.5	64.5	17.5
3	50	13.9	6.8	70.0	18.0
4	64	11.8	4.8	66.0	18.5
5	31	13.9	6.1	60.0	16.0
6	86	12.6	5.7	62.0	16.5
7	50	18.4	7.6	78.0	17.0
8	59	12.1	5.9	53.0	12.0
9	132	12.4	5.8	63.5	15.0
10	38	10.4	5.4	54.5	16.6

¹Species or species group as designated in table 2.

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Table 4.—Regression coefficients

Species ¹	b ₀	b ₁	b ₂	b ₃	b ₄	b ₅	b ₆	b ₇	b ₈	b ₉	b ₁₀	b ₁₁	b _(d)
Softwood													
1	11.1	.....	.....	0.810	.....	.....	5.94	-1.763	.....	.....	.....	.....	.....
Hardwood													
2	16.7	.....	.....	1.049	.....	.....	7.09	-1.927	.....	.....	.....	-0.173	.....
3	51.6	-21.2	1.612	0.508	-0.185	.....	.....	.....	.....	.....	.....	0.027	-15.8(a)
4	22.0	.....	1.007	0.558	.....	.....	1.96	.....	.....	.....	.....	.....	.....
5	17.1	.....	-1.022	0.906	.....	.....	.....	.....	5.22	.....	.....	.....	.....
6	25.0	.....	.....	-0.634	.....	.....	2.60	.....	.....	.....	0.657	0.429	9.70(b)
7	10.2	.....	.....	0.932	.....	.....	3.86	.....	.....	.....	.....	-0.050	.....
8	20.3	.....	-0.301	0.755	0.237	.....	1.91	.....	.....	.....	.....	.....	.....
9	23.9	-10.2	-0.123	0.986	0.088	.....	5.04	.....	.....	4.16	.....	-0.038	.....
10	29.9	.....	-0.414	0.869	.....	0.892	2.26	.....	-3.34	.....	.....	.....	.....

(a) beech

(b) swamp chestnut oak

¹Species or species groups as designated in table 2.

Table 5.—Regression statistics

Species	R ^{2*} Equation	F [†] Regression	SEE [‡]	R ² Dbh alone	
1	0.91	59.6	18,3	3.82	0.68
2	0.87	74.4	52,5	6.36	0.65
3	0.85	47.3	44,5	7.59	0.55
4	0.67	39.5	60,3	11.15	0.60
5	0.75	19.7	26,4	8.48	0.44
6	0.84	93.2	69,5	7.62	0.61
7	0.81	63.7	46,3	7.63	0.32
8	0.86	80.1	54,4	4.81	0.54
9	0.74	60.7	125,6	8.35	0.23
10	0.85	37.2	34,5	7.33	0.74

*Coefficient of multiple determination.

†F value and degrees of freedom for regression, P = 0.05.

‡Standard error of the estimate.