Comparisons of Modeled Height Predictions to Ocular Height Estimates

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ABSTRACT: *Equations used by USDA Forest Service Forest Inventory and Analysis projects to predict individual tree heights on the basis of species and dbh were improved by the addition of mean overstory height. However, ocular estimates of total height by field crews were more accurate than the statistically improved models, especially for hardwood species. Heightpredictionsfrom the improved equations attained the desired measurement quality objective only 57% of the time, while ocular estimates achieved the desiredaccuracy 75% of the time. South. J. Appl. For. 22(4):216–221.*

Measuring tree heights is costly. For extensive surveys such as those conducted by Forest Inventory and Analysis (FIA), it is not usually cost effective to measure the heights of all sampled trees. Tree heights are ultimately used to compute tree volumes, which are then aggregated to population-level estimates of inventory volume. The use of ocular height estimates by FIA has historically produced acceptable sampling errors associated with reported inventory volumes.

FIA plots in the South are measured by experienced, permanent field crews. Crews are trained to visually estimate the heights of trees after calibrating their estimates at each plot by measuring a few trees with clinometers. FIA has also developed regional height equations, based on species and diameter at breast height (dbh), to predict the heights of mortality and cut trees (because most of these are removed from the woods before field crews can measure them). Ocular estimation of tree heights, although cheaper than measured heights, is still time-consuming. It is not known whether the time spent on this endeavor is worthwhile, since the accuracy of ocular height estimates has not been compared to height predictions obtained from equations. If modeled heights compare favorably to ocular estimates, field crews might be relieved of an unnecessary task. Height equations could be programmed into data recorders for visual verification by field crews, who would override the predicted heights only for trees with unusual form or broken tops.

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The objectives of this analysis were threefold:

1. To evaluate the accuracy of regional height models currently in use by FIA in the South.
2. To use additional variables already recorded by field crews in an attempt to make regional height models more site and stand specific.
3. To determine whether height predictions generated by models can replace or augment field-crew ocular estimates of tree height.

METHODS

The Data

Two data sets were used in this analysis-Southern Research Station (SRS) FIA tree-volume data and SRS FIA quality control (QC) data. The FIA volume data set is the result of an ongoing tree-volume study spanning 4 decades across 5 southeastern states (Cost 1978). It contains data for more than 40,000 trees measured in sections from base to tip. These data were used to develop and evaluate the height equations presented in this article.

The QC data were obtained from field checks of FIA crews working in south Georgia. Tree heights estimated by regular field crews were later measured (with poles or clinometers) by QC crews as part of FIA quality-assurance activities (USDA Forest Service 1997). The QC data were used to compare predictions of total tree height from equations with ocular estimates of total tree height by field crews. The portion of the QC data set available for this analysis is relatively small (385 observations) because FIA estimated only *merchantable* height prior to 1995.

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Trees at least 5.0 in. dbh were selected for analysis from species common to both the tree-volume data set and the QC data set. The tree-volume data were divided in half on the basis of plot location number. Trees on even-numbered plots were used to develop height equations, and trees on odd-numbered plots were used to validate the models. Dividing the trees by plot location enabled testing of how well equations based on one set of site and stand conditions predict the heights of trees grown on different sites (as opposed to randomly dividing trees from all sites into two groups). These two subsets of the tree-volume data are referred to as the *estimation* and *validation* data sets, respectively. After selection of the best height models, the QC data were used to compare model predictions with ocular estimates made by field crews.

Height Models

Model (I), the general height equation currently used by SRS FIA, utilizes dbh to predict height:

$$H = b_0 + b_1 * (\log_{10}(D))^{0.5} + b_2 * D^{-2} \qquad (1)$$

where

H = total height (ft),

D = tree diameter (in.) at breast height (dbh), and

b_i = regression parameters estimated from the data.

In addition to dbh, other modelers (Matney and Sullivan 1982, Baldwin and Feduccia 1987, Zarnoch et al. 1991) have found some or all of the following independent variables to be significant predictors of tree height: stand age, site index, height of dominants and codominants, and stand density. These or related variables recorded by FIA crews were added to Model (1) in an attempt to make it more site specific. This was accomplished with stepwise regression, where various combinations and transformations of dbh and the following variables were entered into the model:

Mean overstory height (*MOH*).—For the estimation data set, mean overstory height was computed by averaging the heights of all dominant and codominant trees at each plot location. In the validation and QC data sets, MOH was computed from the heights of the first three overstory trees encountered at each location, which is similar to the ocular calibration procedure used by field crews at each site.

Stand age (A).-The relationship between tree age and tree height is commonly expressed in terms of site index. However, the concept of site index has limited utility for the uneven-aged stands of mixed species to which FIA models must apply (Husch et al. 1972). Site index was rejected as a potential independent variable for this reason, but it seemed promising to utilize the relationship between mean overstory height and mean stand age as a potential surrogate for classic site index. Thus, stand age and combinations of stand age and mean overstory height were considered as candidates for inclusion in the model.

Crown ratio (CR).-Crown ratio is the ratio of live crown length to total tree length, expressed in increments of 10% (coded as: 1 = 0–9%, 2 = 10–19%, . . . , 10 = 90–100%). Crown ratio was considered because it provides an indication of competition experienced by individual trees. For many species, open-grown trees tend to have higher crown ratios and are generally shorter than trees of equivalent dbh grown under competition for light. Other measures of competition, such as stand basal area, were not utilized because average stand conditions do not necessarily apply to individual trees; and because such measures would not be available to the field crew until plots are completely surveyed, making the use of height equations on field data recorders logistically difficult.

Crown class (CC).-Mean overstory height roughly fixes the upper height limit at a given plot location. Crown class was added to approximate the position of individual trees in the canopy. Crown class was specified as a dummy variable with four discrete classes: 1 = dominant; 2 = codominant; 3 = intermediate; 4 = overtopped.

Evaluation Statistics

Statistics used to evaluate model predictions and crew estimates are defined as follows:

Bias.-Bias, the difference between the mean predicted or estimated value and the mean measured (true) value (Cochran 1977), is defined as:

$$\Sigma(\hat{Y}_i - Y_i) / N$$

where

$\hat{Y}_i$ = the modeled height prediction or ocular estimate for the ith value of the validation or QC data set,

Y_i = the measured height for the ith value of the validation or QC data set, and

N = the number of observations in the validation or QC data set.

Root mean squared error (*RMSE*).—Mean squared error (MSE) is a relative measure of overall accuracy. The closer it is to 0, the greater the accuracy of the estimates. MSE has two components-variance and squared bias (Cochran 1977). Differences among MSEs are therefore the result of differences in the variance and/or bias of model predictions. Our analysis utilizes the square root of MSE as an evaluation statistic:

$$RMSE = (\Sigma(\hat{Y}_i - Y_i)^2 / N)^{0.5}$$

Variance is easily obtained by subtracting bias squared from MSE.

Percent absolute deviation *(PAD).-PAD* is the mean absolute difference between predicted (or estimated) values and measured values, expressed as a percentage of the measured value (Dougherty et al. 1995). It is the average percentage that estimates deviate from measured values (disregarding sign), and is computed as:

$$PAD = (\Sigma(|\hat{Y}_i - Y_i| Y_i) / N) * 100$$

Within measurement quality objective (*WMQO*).— The southern FIA measurement quality objective for tree height is ±10%. **WMQO** is the percentage of height predictions or estimates within 10% of the measured height:

$$WMQO = (\Sigma W_i / N) * 100$$

where

$$W_i = 1 \text{ if } (|\hat{Y}_i - Y_i| / Y_i) * 100 = 10$$

or

$$W_i = 0 \text{ if } (|\hat{Y}_i - Y_i| / Y_i) * 100 = 10$$

Results and Discussion

Model Solutions

Fits of Model (1) to the estimation data set indicate that Model (1) is probably mis-specified (Table 1). Model intercepts and coefficients fluctuate widely from one species to the next, and parameter estimates for D^{-2} *are* statistically nonsignificant in almost every case. Also, the signs on some of the coefficients are illogical. Height and the reciprocal of dbh should be negatively correlated, yet some of the coefficients for the D^{-2} term are positive. In general, Model (1) R^2's by species are fairly low, ranging from 0.28 to 0.63. Despite these problems, examination of model residuals plotted over the independent variables showed no apparent trends.

Attempts to improve the FIA height model by adding variables to make it more site specific were moderately successful. Of the variables and associated transformations included in the stepwise regression, $(\log_{10}(D))^{0.5}$ and *MOH* were by far the most important. The partial sums of squares of these two variables accounted for nearly all of the explained variation in almost every case. In addition to these, crown ratio and crown class improved some of the models slightly. However, the marginal contributions of the two crown variables ultimately convinced us to drop them in favor of a simpler model. Stand age was significant only in the height model for planted loblolly. The general nonsignificance of age is probably a consequence of multicollinearity between mean overstory height and stand age, and the imprecision of age estimates in natural stands. Based on these results, Model (2), specified as follows, is proposed as an alternative to Model (1):

$$H = b_0 + b_1 * (\log_{10}(D))^{0.5} + b_2 * MOH \qquad (2)$$

In contrast to Model (1), fits of Model (2) to the estimation data indicate that Model (2) is stable (Table 1).

Table 1. Model statistics and parameter estimates for fits of two height estimation models to the estimation data set.

	Model (1)[a]						Model (2)[b]					
	Model statistics			Parameter estimates			Model statistics			Parameter estimates		
Species	R^2	$RMSE^c$	CV^d	b_0	b_1	b_2	R^2	$RMSE^c$	CV^d	b_0	b_1	b_2
Natural slash	0.59	8.6	15.9	-76.047	138.183	-104.154	0.84	5.3	9.9	–63.918	83.321	0.711
$Pr > \|t\|$				0.001	0.001	0.368				0.001	0.001	0.001
Planted slash	0.51	7.3	14.4	-92.355	153.715	71.239	0.91	3.2	6.2	-38.932	51.425	0.827
$Pr > \|t\|$				0.056	0.001	0.794				0.001	0.001	0.001
Longleaf	0.28	9.4	15.5	41.464	25.821	-577.557	0.76	5.5	9.0	43.853	58.883	0.768
$Pr > \|t\|$				0.099	0.260	0.003				0.001	0.001	0.001
Natural loblolly	0.49	10.3	19.5	-73.067	128.472	-21.661	0.83	5.9	11.2	–62.917	73.717	0.826
$Pr > \|t\|$				0.001	0.001	0.863				0.001	0.001	0.001
Planted loblolly	0.59	6.7	13.9	–117.469	174.186	109.633	0.83	4.3	8.9	–64.001	84.942	0.642
$Pr > \|t\|$				0.291	0.102	0.864				0.001	0.001	0.001
Pondcypress	0.36	9.1	16.7	39.957	23.874	-596.794	0.55	7.6	14.0	–66.126	80.719	0.749
$Pr > \|t\|$				0.318	0.512	0.053				0.001	0.001	0.001
Red maple	0.56	8.3	14.9	-59.232	115.219	67.380	0.62	7.7	13.9	-58.130	92.900	0.362
$Pr > \|t\|$				0.037	0.001	0.758				0.001	0.001	0.001
Sweetgum	0.63	8.6	14.5	–115.190	173.198	300.069	0.71	7.5	12.7	-83.898	118.258	0.455
$Pr > \|t\|$				0.001	0.001	0.098				0.001	0.001	0.001
Blackgum	0.56	9.5	18.4	–111.800	163.114	224.615	0.72	7.6	14.7	-94.688	114.527	0.577
$Pr > \|t\|$				0.001	0.001	0.308				0.001	0.001	0.001
Laurel oak	0.54	8.3	15.2	-73.312	123.708	314.204	0.63	7.5	13.6	-50.185	77.885	0.458
$Pr > \|t\|$				0.002	0.001	0.090				0.001	0.001	0.001
Water oak	0.54	8.4	14.6	-78.339	132.360	273.113	0.69	6.9	12.0	-58.626	86.590	0.491
$Pr > \|t\|$				0.002	0.001	0.191				0.001	0.001	0.001

[a] $H = b_0 + b_1 \bullet (\log_{10}(D))^{0.5} + b_2 \bullet D^{-2}$; where H = tree height (ft), and D = diameter at 4.5 ft (in.).
[b] $H = b_0 + b_1 \bullet (\log_{10}(D))^{0.5} + b_2 \bullet MOH$; where H = tree height (ft), D = diameter at 4.5 ft (in.) and MOH = mean overstory height.
[c] $RMSE$ = root mean squared error from the regression solution.
[d] CV = coefficient of variation from the regression solution: $(RMSE / \bar{Y})\,100$.

Table 2. Means and ranges of variables used for fitting tree height estimation models to the estimation data set.

		Total tree ht (H)			Dbh (D)			Mean overstory ht (MOH)		
Species	N	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
		(ft)			(in.)			(ft)		
Natural slash	967	53.9	20.0	90.0	8.6	5.0	20.9	53.9	22.0	76.1
Planted slash	212	51.0	29.0	80.0	7.3	5.0	14.0	51.4	31.0	73.5
Longleaf	491	60.5	25.0	89.0	10.5	5.0	26.4	59.3	27.3	81.7
Natural loblolly	874	52.9	17.0	93.0	10.0	5.0	23.0	52.5	27.3	78.5
Planted loblolly	49	47.8	27.0	67.0	7.8	5.2	11.9	50.2	27.5	62.5
Pondcypress	143	54.7	20.0	86.0	9.7	5.1	22.3	55.8	40.0	68.4
Red maple	115	55.6	29.0	95.0	10.5	5.0	41.8	60.5	43.6	84.0
Sweetgum	257	59.2	26.0	113.0	10.0	5.0	31.7	59.3	31.5	87.6
Blackgum	195	51.9	25.0	93.0	10.1	5.0	32.7	58.8	33.8	78.5
Laurel oak	153	54.7	30.0	95.0	11.4	5.0	29.6	59.0	34.8	75.8
Water oak	165	57.3	30.0	91.0	10.9	5.0	30.1	60.2	28.5	87.6

All parameter estimates are significant, they do not fluctuate much among species, and all coefficients behave logically. As expected, tree height is positively correlated with dbh and mean overstory height. Model (2) R^2's, root mean squared errors, and coefficients of variation are better than corresponding values from Model (1) in every case. As with Model (1), no trends were apparent in the residuals from Model (2).

Distributions of the variables used in Models (1) and (2) are provided in Table 2.

Model Validation

Comparisons of the two models using the validation subset of the tree-volume data provide further evidence that Model **(2)** is superior (Table 3). The following results are significant:

1. For all species combined, the *RMSE* for Model (2) is 2.2 ft less than the *RMSE* for Model (1), indicating an improvement in statistical accuracy. This improvement can be attributed to reduction in variance, because the bias associated with both models is about the same (0.7 ft).
2. Model (2) height predictions deviate from measured heights by an average of 9.7%, while the corresponding *PAD* for Model (1) is 14.2%. Model (2) yields better height predictions for all species evaluated, with the largest improvement noted for softwoods.
3. Nearly two-thirds (63.6%) of Model (2) height predictions were within 10% of measured height, while less than half (47.0%) of Model (1) predictions were comparably accurate.

Table 3. Comparisons of predictions from two height estimation models using the validation data set.

		Measured ht			Model (1)[a] ht predictions				Model (2)[b] ht predictions			
Species	N	Mean	Min	Max	*RMSE*[c]	Bias	*PAD*[d]	*WMQO*[e]	*RMSE*[c]	Bias	*PAD*[d]	*WMQO*[e]
		(ft)					(%)		(ft)		(%)	
Natural slash	982	51.9	21.0	95.0	8.2	0.9	14.0	48.0	5.8	0.2	8.8	66.0
Planted slash	198	48.8	27.0	72.0	6.6	1.6	11.6	57.1	3.9	1.0	6.6	83.8
Longleaf	542	56.3	28.0	87.0	9.4	3.5	15.0	47.8	6.3	2.1	9.0	67.2
Natural loblolly	806	54.6	19.0	98.0	9.1	-1.2	14.4	42.9	7.0	0.7	10.1	62.5
Planted loblolly	19	53.4	25.0	78.0	7.2	-0.4	12.5	42.1	3.5	-0.8	6.0	89.5
Pondcypress	119	52.5	22.0	93.0	13.0	2.6	23.6	31.9	7.3	1.5	12.1	56.3
Red maple	90	51.2	31.0	87.0	7.8	1.5	12.8	48.9	6.9	0.8	11.0	56.7
Sweetgum	228	57.8	27.0	105.0	8.4	-1.5	11.8	48.2	7.3	-0.8	10.8	55.3
Blackgum	155	54.1	22.0	88.0	8.4	-0.2	13.4	49.0	8.0	0.5	13.0	51.0
Laurel oak	133	55.6	22.0	91.0	9.5	0.1	15.0	44.4	8.1	0.3	12.5	55.6
Water oak	103	52.8	27.0	80.0	8.1	2.1	13.1	60.2	8.0	0.5	12.8	50.5
All softwoods	2,666	53.4	19.0	98.0	8.9	0.9	14.6	46.3	6.2	0.8	9.2	66.2
All hardwoods	709	55.0	22.0	105.0	8.5	0.0	13.0	49.5	7.7	0.1	11.9	53.9
All species	3,375	53.7	19.0	105.0	8.8	0.7	14.2	47.0	6.6	0.7	9.7	63.6

[a] $H = b_0 + b_1 \bullet (\log_{10}(D))^{0.5} + b_2 * D^{-2}$; where H = tree height (ft), and D = diameter at 4.5 ft (in.).
[b] $H = b_0 + b_1 \bullet (\log_{10}(D))^{0.5} + b_2 \bullet MOH$; where H = tree height (ft), D = diameter at 4.5 ft (in.) and MOH = mean overstory height.
[c] *RMSE* = root mean squared error.
[d] *PAD* = percent absolute deviation.
[e] *WMQO* = percentage of predictions within 10% measurement quality objective.

Table 4. Comparisons of Model (2)[a] height predictions and ocular height estimates using the quality control data set.

Species	N	Measured ht Mean	Min	Max	Model (2) ht predictions *RMSE*[b]	Bias	*PAD*[c]	*WMQO*[d]	Ocular ht estimates *RMSE*[b]	Bias	*PAD*[c]	*WMQO*[d]
		(ft)			(ft)		(%)		(ft)		(%)	
Natural slash	172	57.5	24.0	86.0	6.6	-1.5	8.3	69.8	6.0	0.3	7.7	76.2
Planted slash	11	25.9	21.0	30.0	3.6	-2.0	11.5	45.5	2.2	-0.2	7.1	72.7
Longleaf	8	53.3	38.0	71.0	8.3	4.7	14.9	37.5	4.2	-3.0	7.2	62.5
Natural loblolly	63	35.0	25.0	86.0	4.0	-2.8	9.3	57.1	2.9	-2.2	7.4	71.4
Planted loblolly	11	38.5	32.0	43.0	4.7	-3.5	10.2	54.5	1.9	-0.5	4.5	100.0
Pondcypress	13	48.0	35.0	65.0	5.3	-0.8	8.3	61.5	3.5	-0.2	6.0	84.6
Red maple	24	53.8	30.0	78.0	12.5	-1.7	19.3	33.3	5.4	-2.0	8.3	70.8
Sweetgum	12	56.6	43.0	84.0	10.6	5.0	18.4	25.0	6.2	-1.4	9.7	50.0
Blackgum	26	47.4	26.0	78.0	8.2	-0.5	14.9	46.2	5.4	-2.3	6.4	80.8
Laurel oak	12	52.8	36.0	78.0	9.5	-0.9	16.0	25.0	8.4	0.3	10.8	58.3
Water oak	33	53.1	32.0	80.0	8.6	-2.6	12.3	48.5	4.7	0.5	6.9	75.8
All softwoods	278	49.9	21.0	86.0	5.9	-1.7	8.9	64.0	5.1	-0.4	7.4	75.9
All hardwoods	107	52.2	26.0	84.0	9.8	-0.8	15.6	39.3	5.7	-1.0	7.8	71.0
All species	385	50.5	21.0	86.0	7.2	-1.4	10.8	57.1	5.3	-0.6	7.5	74.5

[a] $H = b_0 + b_1 * (\log_{10}(D))^{0.5} + b_2 \cdot MOH$: where H = tree height (ft), D = diameter at 4.5 ft (in.) and MOH = mean overstory height
[b] *RMSE* = root mean squared error.
[c] *PAD* = percent absolute deviation.
[d] *WMQO* = percentage of predictions within 10% measurement quality objective.

Table 5. Comparisons of volume predictions based on Model (2)[a] heights with volume predictions based on ocular heights, using the quality-control data set.

Species	N	Vol by measured ht Mean	Min	Max	Vol by Model (2) ht *RMSE*[b]	Bias	*PAD*[c]	*WMQO*[d]	Vol by ocular ht *RMSE*[b]	Bias	*PAD*[c]	*WMQO*[d]
			(ft)				(%)		(ft)		(%)	
Natural slash	172	8.6	0.5	44.7	1.6	-0.4	9.9	66.3	1.5	0.0	9.2	69.2
Planted slash	11	0.8	0.4	1.2	0.2	-0.1	24.2	9.1	0.1	0.0	15.7	36.4
Longleaf	8	10.3	1.9	20.3	1.2	0.5	19.2	37.5	0.9	-0.5	9.2	62.5
Natural loblolly	63	3.7	0.6	72.0	0.7	-0.3	14.6	28.6	0.5	-0.1	11.8	42.9
Planted loblolly	11	2.5	1.2	5.1	0.4	-0.3	14.7	36.4	0.2	0.0	6.4	90.9
Pondcypress	13	5.6	1.8	15.6	0.9	-0.2	8.7	61.5	0.6	-0.1	6.2	92.3
Red maple	24	9.3	1.5	43.1	2.5	0.0	20.3	33.3	1.1	-0.3	8.7	70.8
Sweetgum	12	9.5	1.3	28.8	2.1	0.6	24.0	16.7	1.1	-0.4	12.6	41.7
Blackgum	26	10.7	1.4	85.2	2.0	0.3	17.5	46.2	1.9	-0.8	6.9	69.2
Laurel oak	12	17.5	2.9	88.1	4.0	0.2	16.5	33.3	4.0	1.6	11.4	50.0
Water oak	33	13.6	1.6	114.3	2.0	-0.5	12.5	45.5	0.8	0.1	7.1	75.8
All softwoods	278	6.8	0.4	72.0	1.4	-0.3	11.9	53.2	1.2	0.0	9.8	63.7
All hardwoods	107	11.9	1.3	114.3	2.4	0.0	17.2	38.3	1.8	-0.1	8.5	66.4
All species	385	8.3	0.4	114.3	1.7	-0.2	13.4	49.1	1.4	-0.1	9.4	64.4

[a] $H = b_0 + b_1 \cdot (\log_{10}(D))^{0.5} + b_2 \cdot MOH$; where H = tree height (ft), D = diameter at 4.5 ft (in.) and MOH = mean overstory height.
[b] *RMSE* = root mean squared error.
[c] *PAD* = percent absolute deviation.
[d] *WMQO* = percentage of predictions within 10% measurement quality objective.

Modeled Heights vs. Crew Ocular Estimates

Although Model (2) is an improvement over Model (l), ocular height estimates from field-crews are superior to Model (2), as evidenced by the following comparisons from the QC data set (Table 4):

1. Across all species, the *RMSE* associated with the ocular estimates is 1.9 ft less than the corresponding value for Model (2).
2. Field crews out-performed the model for all species evaluated, but the difference is more pronounced for the hardwoods. For all softwoods combined, the *PAD* from measured height was 8.9% for Model (2) predictions and 7.4% for the **ocular** estimates. Viewing all hardwoods combined, the PAD for Model (2) predictions was twice the PAD of the crew estimates (15.6% vs. 7.8%).
3. Model (2) height predictions met the target measurement quality objectives only 57.1% of the time while field crews achieved the desired measurement quality objective 74.5% of the time.

Based on these results, the use of height equations on data recorders is not recommended. The availability of inferior height predictions from models would adversely influence field crew's ocular estimates.

Effect of Modeled and Ocular Heights on Volume Predictions

Ultimately, FIA height estimates are used in the computation of volume. FIA calculates gross cubic-foot volume (V) with the equation:

$$V = b_0 + b_1 * D^2 * H$$

Measured, predicted, and crew-estimated heights from the QC data set were processed through this equation to determine if better height estimates from field crews translate into improved tree-volume predictions. Only one value for D was assigned to each tree (the D measured by the QC crew), so differences in volume predictions shown in Table 5 are solely the result of differences among height estimates.

Results of the volume comparisons reinforce the conclusions drawn from the height comparisons. Tree-volume predictions based on ocular height estimates are more accurate than those based on modeled heights, especially for hardwoods.

Conclusions

Regional total-height models based on species and dbh are substantially improved by adding mean overstory height as an independent variable. Even so, the enhanced equations are inferior to ocular height estimates from field crews, particularly for hardwood species. Height predictions from the improved equations attained the desired measurement quality objective 57% of the time, while ocular estimates achieved the desired accuracy 75% of the time. Unless an 18% marginal reduction in measurement quality is tolerable (32% for hardwoods), height equations should not replace independent ocular estimates by well-trained, experienced field crews.

Literature Cited

BALDWIN V.C., JR., AND D.P. FEDUCCIA. 1987. Loblolly growth and yield prediction for managed West Gulf plantations. USDA For. Serv. Res. Pap. SO-236. 27 p.

COCHRAN, W.G. 1977. Sampling techniques. Ed. 3. Wiley, New York. 428 p.

COST, N.D. 1978. Multiresource inventories-a technique for measuring volumes in standing trees. USDA For. Serv. Res. Pap. SE-196. 18 p.

DOUGHERTY, P.M., ET AL. 1995. Effects of stand development and weather on monthly leaf biomass dynamics of a loblolly pine (*Pinus taeda*) stand. For. Ecol. Manage. 72:213–227.

HUSCH, B., C.I. MILLER, AND T.W. BEERS. 1972. Forest mensuration. Ed. 2.. The Ronald Press Company, New York. 410 p.

MATNEY, T.G., AND A.D. SULLIVAN. 1982. Compatible stand and stock tables for thinned and unthinned loblolly pine stands. For. Sci. 28 (1):161–171.

USDA FOREST SERVICE. 1997. Southern annual forest inventory system (SAFIS) quality assurance plan. Internal document available from the Southern Res. Sta., Asheville, NC. 31 p.

ZARNOCH, S.J., D.P. FEDUCCIA, V.C. BALDWIN, JR., AND T.R. DELL. 1991. Growth and yield model predictions for thinned and unthinned slash pine plantations on cutover sites in the West Gulf region. USDA For. Serv. Res. Pap. SO-264.32 p.