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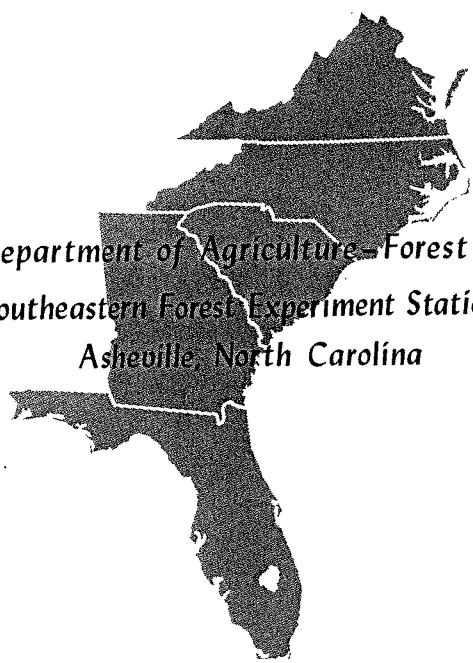

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INTRODUCTION

Increment cores have been used to evaluate such tree characteristics as age, rate of growth, percentage of various types of tissue, chemical composition, and density. Of the wood characteristics listed, density has come to be of considerable interest to numerous researchers, since it is highly correlated with the strength properties, workability, and weight of wood. Pulp companies are using wood density to help them predict pulp yield. Geneticists and forest managers are using density as a criterion for selecting superior trees for seed orchards and tree breeding studies. Although increment cores have been used to good advantage in evaluating some properties, their value in estimating tree density or the density of large pieces of wood is still open to question. For instance, some studies show that increment cores tend to give higher density values than *normal*, whereas others show that increment cores give low specific gravity values. Some show significant differences between cores and larger pieces, whereas others do not. The relative amount of variation which can be accounted for by increment cores in statistical analyses is high in some studies and low in others. Researchers still don't know how many cores to use or whether to use only part of each core.

The purpose of the cooperative study reported here between the Southeastern Forest Experiment Station and the Forest Products Laboratory was to develop information on tree-increment core specific gravity relationships. The study was designed to show the relationships between tree specific gravity and (1) the specific gravity of only a part of a single increment core, (2) the specific gravity of one whole increment core, (3) the specific gravity of the average of several increment cores, and (4) other tree characteristics such as age, diameter, tree volume, and height.

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PAST WORK

Markwardt and Paul (1946) evaluated increment core specific gravity determinations with those obtained from standard 2 x 2 x 6-inch specific gravity blocks. The average specific gravity of 50 increment cores of true mahogany (Swietenia sp.) was 0.548, compared to 0.560 for the blocks. For African mahogany (Khaya sp.) the averages were 0.486 and 0.491, respectively. Although the core values were lower in both cases, they were not statistically significant, Spurr and Hsuing (1954) checked the specific gravity of increment cores with wood blocks taken at 3 different heights from 14 jack pine trees. The average specific gravity of the cores (0.370) was slightly lower than the average specific gravity of wood blocks. Although the difference was slight, it was significant. The standard error of the difference, however, was only 0.003, and the investigators concluded that the two samples were comparable. Larson (1957) compared specific gravity results obtained from two different size increment cores (0.157-inch diameter and ½-inch diameter) and found that the smaller cores gave consistently higher specific gravities than the larger increment cores. He suggested that this difference resulted from a reduction in the volume of the larger specimens --a reduction caused by compression forces during extraction.

Zobel and Rhodes (1955) made an analysis on 50 trees to determine the within-tree variability at breast height in an effort to establish the number of sample cores that should be taken from each tree. Three cores were removed from each of 50 trees at 120-degree intervals. The standard deviation for these data was 0.02. They reasoned that one core would give them the precision they desired, and used one core as an indicator of tree gravity.

Wahlgren and Fassnacht (1959) reported significant relationships between increment cores taken at breast height position and the total tree specific gravity as estimated from a series of disks taken at 4-foot intervals up the tree to a 4-inch top. Data were collected on four species of southern yellow pine, namely, shortleaf, loblolly, slash, and longleaf pine. The statistical regressions developed from these data explained at best only 53 percent of the variation in only one of the species--loblolly pine.

Gilmore et al. (1961) also explored the possibility of using increment cores to estimate tree specific gravity of shortleaf pine and loblolly pine in southern Illinois. Forty-seven shortleaf pine and 39 loblolly pine were used in this study. It was conducted in a similar fashion to the study made by Wahlgren and Fassnacht except for the fact that the material was from plantation stock and two cores were removed from each tree, one at breast height and one at stump height. Their shortleaf pine data show a considerably higher reduction in unexplained variation than the Mississippi data of Wahlgren and Fassnacht, as well as a smaller standard error about the regression line' (table 1). In the case of shortleaf pine in Mississippi, only 46 percent of the variation is explained by the reciprocal of core gravity, which, according to Wahlgren and Fassnacht, explained more of the variability than specific gravity of the core alone. Their standard error for shortleaf is also rather high, 0.023. Gilmore's data show 64percent of the variability explained by a single increment core and a somewhat smaller standard error, 0.017. In loblolly pine the difference between the two studies was not so great, but Gilmore's data had a lower standard error. For loblolly pine from Mississippi, 53 percent of the variability was explained by the reciprocal of core gravity and the standard error about the regression line was 0.021. Gilmore's data for a core taken at breast height showed 50 percent of the variation explained and had a standard error of 0.017. Further statistical manipulation of the data by Gilmore et al. showed that the regression of tree specific gravity on the product of specific gravities for cores taken at l-foot and 4.5-foot locations gave the best fit of the data. Correlation coefficients for this relationship were 0.851 and 0.764 for shortleaf pine and loblolly pine, respectively (table 1). Standard error about regression for both species was 0.015.

Table I. --Correlation coefficients and standard error of estimates for tree to core specific gravity relationships in Illinois and Mississippi studies

	Correlation coefficient		Standard error of estimate	
	Illinois 1/	Mississippi 2/	Illinois 1/	Mississippi 2/
SHORTLEAF PINE				
Tree specific gravity on core specific gravity at 4.5 feet	0.801	0.682	0.017	0.023
Tree specific gravity on product of **cores' specific gravity at 1 and 4.5 feet**	0.851	--	0.015	--
LOBLOLLY PINE				
Tree specific gravity on core specific gravity at 4.5 feet	0.707	0.729	0.017	0.021
Tree specific gravity on product of **cores' specific gravity at 1 and 4.5 feet**	0.764	--	0.015	--

1/ Data from Gilmore et al. (1961).
2/ Data from Wablgren and Fassnacht (1959).

FIELD PROCEDURE

One hundred and seventy-nine slash pine and longleaf pine trees were sampled for this study from two counties in southern Georgia. Data on tree size and areas cut are in table 7 of the Appendix.

Before the trees were felled, four increment cores were removed with a calibrated borer from each tree at breast height. The first core was taken at random and the remaining three cores at 90-degree intervals in a clockwise direction from the random core. The green length of each core from bark to pith was measured to the nearest 0.01 inch immediately after extraction.

After the trees had been felled, pulpwood bolts (5 feet 3 inches) were cut progressively from the stump to a minimum top diameter of approximately 4 inches. Complete cross sections about $1\frac{1}{2}$ inches thick were cut from the top end of each pulpwood bolt. No sample was taken at the butt end of the first bolt.

LABORATORY PROCEDURE

All disks were soaked for at least 24 hours upon arrival at the Forest Products Laboratory to insure accurate green volume determinations. Following the soaking period, the bark was removed from the disks, the diameter (d.i.b.), age (breast height section only), and green volume (by water immersion) were determined. The samples were then ovendried at 105° C. in a forced draft oven and their ovendry weight determined. Specific gravity of the disks was calculated from the ovendry weight and green volume of the sample.

The increment cores were handled differently from the disks. Increment core length from bark to pith was measured to the nearest 0.01 inch in the field. Following a soaking period, the cores were segmented into three approximately equal lengths, remeasured to the nearest 0.01 inch, and then dried to an ovendry condition. The diameter of each increment core or core segment was the caliber of the cutting edge of the increment borer determined to the nearest 0.001 inch. Micrometer measurements of individual cores substantiated the borer caliber.

Specific gravity values were determined for each core segment, and thus made available the following gravity combinations for each core:

Complete core gravity
Complete weighted core gravity
Outer 1/3 core gravity
Outer 2/3 core gravity

Complete weighted core gravity was determined by weighting the segment gravities by the cross sectional areas the segments represented.

The average specific gravity of each bolt was computed as the mean gravity of its terminal disks (except that a single disk was used *to* estimate the specific gravity of the butt bolt). The average specific gravity of the tree was determined by weighting the average bolt gravity by bolt volume. Formulas for the above computations are shown in the Appendix.

DATA ANALYSIS

The relationships analyzed in this study are as follows, with *tree* specific gravity as the dependent variable in each case:

Simple Regression Analysis

(1) Tree specific gravity on the specific gravity of a single increment core, and on the average specific gravity of two, three, and four increment cores taken at breast height.

(2) Tree specific gravity on the specific gravity of a single weighted increment core, and on the average specific gravity of two, three, and four weighted increment cores.

(3) Tree specific gravity on the specific gravity of the outer one-third of a single increment core, and the average specific gravity of the outer one-third of two, three, and four increment cores.

(4) Tree specific gravity on the specific gravity of the outer two-thirds of a single increment core, and the average specific gravity of the outer two-thirds of two, three, and four increment cores.

(5) Tree specific gravity on the reciprocal of specific gravity of a single increment core.

Multiple Regression Analysis

In addition to the simple relationships above, measurable tree characteristics were used with single and multiple core gravities in a multiple regression analysis to predict average tree specific gravity. The variables included in the analysis were as follows:

Y = tree specific gravity

X_1 = single increment core specific gravity

X_2 = average weighted specific gravity of cores 1 and 3

X_3 = diameter breast height (dbh)

X_4 = dbh/age

X_5 = age

X_6 = 1/age

X_7 = volume/age

X_8 = total height

X_9 = total height/age

DISCUSSION OF RESULTS

Simple Regression Analysis

In the linear regression analyses on the tree and increment core specific gravity relationships, correlation coefficients and standard errors of estimate were determined for each individual increment core extracted from each tree. These values are shown in table 2 for both longleaf and slash pine.

In comparing the correlation coefficients and standard errors of the single untreated increment cores of longleaf pine with the results obtained for the weighted increment core group, and the two-thirds increment core group, one finds only minor improvements in the correlations and standard errors. Where a single increment core accounts for about 55 percent of the variation, a weighted core accounts for about 63 percent of the variation--an increase of 8 percent--and the two-thirds core accounts for only 60 percent of the variation, or an increase of 5 percent. The reciprocal of core specific gravity showed no improvement over a single increment core, and the outer one-third core gave the poorest correlation of all treatments, accounting for only 43 percent of the variation.

The results obtained for slash pine do not coincide in all cases with those obtained for longleaf pine. The correlation coefficients and standard errors for the single untreated slash pine cores are the only results that compared favorably with results obtained for longleaf pine. Unlike the correlation coefficients in longleaf pine, which increased, the correlation coefficients for weighted slash pine cores and the two-thirds cores decreased slightly. Untreated single cores on the average accounted for about 57 percent of the variation, whereas the weighted cores accounted for about 55 percent of the variation and two-thirds cores accounted for about 49 percent of the variation. Reasons for these differences between slash and longleaf are not apparent. The reciprocal of core specific gravity also showed a minor decrease in the correlation coefficient. The one-third core, as in the longleaf pine, had the lowest correlation and accounted for only 36 percent of the variation.

Table 2. --Correlation coefficients, standard errors, and coefficients of determination for various single increment core and tree specific gravity relationships

Relationships	Longleaf pine			Slash pine		
	r	r^2	Standard error	r	r^2	Standard error
Tree specific gravity on:						
Specific gravity, Core No. 1	**0.7316**	0.5352	0.024	0.7256	0.5284	0.024
Specific gravity, Core No. 2	0.7567	0.5725	0.023	0.7307	0.5339	0.024
Specific gravity, Core No. 3	0.7446	0.5544	0.023	0.7625	0.5814	0.022
Specific gravity, Core No. 4	0.7438	0.5532	0.023	0.8058	0.6493	0.020
Average	0.7442	0.5538	0.023	0.7562	0.5718	0.022
Weighted specific gravity, Core No. 1	0.7958	0.6333	0.021	0.6563	0.4307	0.026
Weighted specific gravity, Core No. 2	0.7909	0.6255	0.021	0.7639	0.5835	0.022
Weighted specific gravity, Core No. 3	**0.8119**	**0.6591**	0.020	**0.7319**	0.5357	0.024
Weighted specific gravity, Core No. 4	0.7933	0.6293	0.021	0.8342	0.6958	**0.019**
Average	**0.7980**	0.6368	0.021	0.7466	0.5574	0.023
Specific gravity, outer 2/3, Core No. 1	0.7811	0.6101	0.022	0.5940	0.3528	0.028
Specific gravity, outer 2/3, Core No. 2	0.7715	0.5952	0.022	0.7116	0.5064	0.024
Specific gravity, outer 2/3, Core No. 3	0.8066	0.6506	0.020	0.6967	0.4853	0.025
Specific gravity, outer 2/3, Core No. 4	0.7558	0.5712	0.023	0.7977	0.6363	0.021
Average	0.7788	0.6065	0.022	0.7000	0.4900	0.024
Specific gravity, outer 1/3, Core No. 1	0.6547	0.4286	0.026	0.4805	0.2308	0.030
Specific gravity, outer 1/3, Core No. 2	0.6090	0.3708	0.027	0.7075	0.5005	0.024
Specific gravity, outer 1/3, Core No. 3	0.7087	0.5022	0.024	0.5243	0.2748	0.030
Specific gravity, outer 1/3, Core No. 4	0.6562	0.4306	0.026	0.6938	0.4814	0.025
Average	0.6572	0.4319	0.023	0.6015	0.3618	0.027
$\frac{1}{\text{Specific gravity, Core No. 1}}$	0.7527	0.5665	0.023	0.7208	**0.5196**	0.024

It should be noted in table 2 that within a group of four cores (1 to 4) there is greater variation between correlation coefficients in the slash pine groups than in the longleaf pine. In the single untreated core group, for example, where the correlation coefficients on the average are comparable between species, the longleaf pine shows a maximum spread between values of 0.0251 (between cores 1 and 2) whereas in slash pine the spread is 0.0802 (between cores 1 and 4). Although this 0.0802 appears to be high, a test of significance between cores within this group showed no statistically significant difference between cores.

In view of the relatively slight variation in coefficients between cores taken around the tree, it is reasonable to assume that circumferential position has little to no effect on the relationship. When one considers extracting an increment core from a tree for a specific gravity sample, a core from the east side of a tree should give results equivalent to a core extracted from any other position on the circumference of the tree at breast height, providing that abnormal growth such as compression wood is not present and areas associated with branch whorls are avoided.

Up to this point, single increment core sampling and the effects of weighting the increment core and using only a part of the core have been discussed. The improvements which can be realized by using more than one increment core as a sample can be seen in table 3, where the coefficients of variation, coefficients of determination, and the standard errors are listed for both longleaf and slash pine.

Table 3. --Correlation coefficients, standard errors, and coefficients of determination for various multiple increment core and tree specific gravity relationships

Relationships	Longleaf pine			Slash pine		
	r	r^2	Standard error	r	r^2	Standard error
Tree specific gravity on:						
Specific gravity, Cores 1 + 3	0.7814	0.6105	0.022	0.8132	0.6613	0.020
Specific gravity, Cores 1 + 2 + 3	0.7899	0.6239	0.021	0.8178	0.8688	0.020
Specific gravity, Cores 1 + 3 + 4	0.8014	0.6422	0.021	0.8490	0.7208	0.018
Specific gravity, Cores 1 + 2 + 3 + 4	0.8030	0.6448	0.021	0.8401	0.7058	0.019
Weighted specific gravity, Cores 1 + 3	0.8582	0.7365	0.018	0.8003	0.8405	0.021
Weighted specific gravity, Cores 1 + 2 + 3	0.8661	0.7501	0.017	0.8399	0.7054	0.019
Weighted specific gravity, Cores 1 + 3 + 4	0.8730	0.7621	0.017	0.8736	0.7632	0.017
Weighted specific gravity, Cores 1 + 2 + 3 t 4	0.8783	0.7714	0.017	0.8798	0.7740	0.016
Specific gravity, outer 2/3, Cores 1 + 3	0.8514	0.7249	0.018	0.7612	0.5794	0.022
Specific gravity, outer 2/3, Cores 1 + 2 + 3	0.8636	0.7458	0.017	0.8009	0.8414	0.021
Specific gravity, outer 2/3, Cores 1 + 3 t 4	0 8649	0.7480	0.017	0.8458	0.7154	0.018
Specific gravity, outer 2/3, Cores 1 + 2 + 3 + 4	0.8742	0.7642	0.017	0.8473	0.7179	0.018
Specific gravity, outer 1/3, Cores 1 + 3	0.7893	0.5918	0.022	0.6129	0.3756	0.027
Specific gravity, outer 1/3, Cores 1 + 2 + 3	0.7823	0.6119	0.022	0.7337	0.5383	0.024
Specific gravity, outer 1/3, Cores 1 t 3 + 4	0.7853	0.6167	0.021	0.7297	0.5325	0.024
Specific gravity, outer 1/3, Cores 1 + 2 + 3 t 4	0.7998	0.6397	0.021	0.7921	0.6274	0.021

The effect of increasing sample size from two to four cores on these relationships is readily apparent within each of the specific gravity groups listed above. The correlation coefficients consistently increase with increase in the number of cores used in the sample. The improvement realized by taking more than two cores is rather small, and for a number of sampling purposes two increment cores will serve as well as three or four cores. In the longleaf pine, for instance, the largest improvement in total variation explained by increasing the sample from two to four cores was only 4 percent. The standard errors in each group either remain the same or change very little with increase in the number of cores, so the relative precision is affected but little.

Since the response to change in sample size is the same for both species and all treatments, and the magnitude of change from a 2-core sample to a 4-core sample is small, the remainder of this discussion on multiple core sampling will for purposes of simplification be restricted to the 2-core samples.

In the multiple core sampling groups of longleaf pine, weighting the two increment cores or using only the outer two-thirds of the cores shows an improvement over the average of two untreated increment cores. The magnitude of this improvement is an increase of about 11 percent in total variation explained. This increase is only slightly better than the 8-percent increase in total variation explained when one untreated core is compared to a single weighted increment core.

When treatments are compared, the slash pine multiple core samples reacted in the same manner as the single core samples did. Weighting two increment cores or using only the outer two-thirds showed either no improvement or a slight decrease in correlation coefficients. Use of only the outer one-third of two increment cores resulted in the poorest correlation for the multiple core sampling groups. It should be noted that the correlation coefficient (r = 0.7693) for the outer one-third of two increment cores of longleaf pine is about equal to the correlations obtained for the single unweighted increment cores.

Table 4 shows a comparison of single increment core relationships with multiple core relationships (the average of two cores, 1 and 3). The correlations for the single increment cores are the averages of the four determinations that were listed in table 1.

In the longleaf pine listing it can be seen that very little improvement is realized if two cores are taken instead of one. The increase in percent of variation accounted for by taking two cores amounted to about 6 percent and is equivalent to that obtained by taking one core and weighting it or taking the outer two-thirds of a single core. A reasonably good improvement can be observed, however, when two weighted cores are compared to one core only. In this case there is an increase of 18 percent in total variation explained, and a reduction in the standard error from 0.023 to 0.018. The outer one -third of two cores is equivalent to what one can obtain with a single increment core and is certainly better than one sample of a one-third core.

Table 4. --Correlation coefficients, standard errors, and coefficients of determination for single increment core-tree specific gravity relationships and multiple increment core-tree specific gravity relationships

Relationships	Longleaf pine			Slash pine		
	r	r^2	Standard error	r	r^2	Standard error
Tree specific gravity on:						
	Single increment core sample					
Specific gravity, 1 core	0.7442	0.5538	0.023	0.7562	0.5718	0.022
Weighted specific gravity, 1 core	0.7980	0.6368	0.021	0.7466	0.5574	0.023
Specific gravity, outer 2/3 of 1 core	0.7788	0.6065	0.022	0.7000	0.4900	0.024
Specific gravity, outer 1/3 of 1 core	0.6527	0.4319	0.023	0.6015	0.3618	0.027
	Multiple increment core sample					
Specific gravity, Cores 1 + 3	0.7814	0.6105	0.022	0.8132	0.6613	0.020
Weighted specific gravity, Cores 1 + 3	0.8582	0.7365	0.018	0.8003	0.6405	0.021
Specific gravity, outer 2/3, Cores 1 + 3	0.8536	0.7249	0.018	0.7612	0.5794	0.022
Specific gravity, outer 1/3, Cores 1 t 3	0.7693	0.5918	0.022	0.6129	0.3756	0.027

In the slash pine sample, there was an increase in the total explained variation when two increment cores were used instead of one. This amounted to about 9 percent, which was slightly higher than that realized in the longleaf pine. Slash pine differed from longleaf, in that no improvement in the correlation coefficient was realized by weighting the two cores or by taking the outer two-thirds of two cores. There was also very little change realized in the reduction of the standard errors. Regression equations for the various simple regressions discussed are in table 8 and 9 of the Appendix.

Multiple Regression Analysis

The multiple regression analysis in this study was made to see whether or not such factors as dbh, age, total height, dbh/age, l/age, volume/age, total height/age, made an improvement in the simple relationships of tree specific gravity to the specific gravity of a single increment core and to the average weighted specific gravity of two increment cores. Using the Forest Products Laboratory IBM 1620 Regression Program, we made a stepwise multiple regression analysis using the independent variables listed above. Multiple correlation coefficients and standard errors for both longleaf and slash pine for the best two, three, and four variable regressions are shown in table 5.

Table 5 shows only three cases where the "best" regressions for the two species involve the same variables, and these are in the two variable regression groups. In the case of the unweighted single increment core, dbh and dbh/age both appear in the "best" regression for the two species. In the weighted specific gravity of two cores, dbh/age appears in both species. In all other cases the combination of variables differs.

Table 5. --Correlation coefficients, standard errors, and coefficients of determination for the best two, three, and four variable regressions for longleaf and slash pine tree specific gravity relationships

Relationships	r	r^2	Standard error
Longleaf pine tree specific gravity on:			
Specific gravity of 1 increment core	0.7442	0.5538	0.023
Weighted specific gravity of 2 increment cores	0.8582	0.7365	0.018
2 variables			
Specific gravity of 1 core + dbh	0.7984	0.6374	0.021
Specific gravity of 1 core + $\frac{\text{dbh}}{\text{age}}$	0.8009	0.6414	0.021
Weighted specific gravity of 2 cores + dbh	0.8894	0.7910	0.016
Weighted specific gravity of 2 cores + $\frac{\text{dbh}}{\text{age}}$	0.8914	0.7946	0.016
Weighted specific gravity of 2 cores + $\frac{\text{volume}}{\text{age}}$	0.8979	0.8062	0.015
3 variables			
Specific gravity of Core No. 1 + dbh t $\frac{1}{\text{age}}$	0.8141	0.6628	0.020
Specific gravity of Core No. 1 + $\frac{\text{dbh}}{\text{age}}$ + age	0.8153	0.6647	0.020
Weighted specific gravity of 2 cores + $\frac{\text{dbh}}{\text{age}}$ + $\frac{1}{\text{age}}$	0.9015	0.8127	0.015
Weighted specific gravity of 2 cores + $\frac{\text{volume}}{\text{age}}$ + $\frac{\text{height}}{\text{age}}$	0.9010	0.8118	0.015
Slash pine tree specific gravity on:			
Specific gravity of 1 increment core	0.7562	0.5718	0.022
Weighted specific gravity of 2 increment cores	0.8003	0.6405	0.021
2 variables			
Specific gravity of 1 core + dbh	0.7653	0.5857	0.022
Specific gravity of 1 core + $\frac{\text{dbh}}{\text{age}}$	0.7696	0.5923	0.022
Weighted specific gravity of 2 cores + $\frac{1}{\text{age}}$	0.8208	0.6737	0.020
Weighted specific gravity of 2 cores + $\frac{\text{dbh}}{\text{age}}$	0.8316	0.6915	0.019
3 variables			
Specific gravity of 1 core + dbh + height	0.8083	0.6533	0.021
Specific gravity of 1 core + $\frac{\text{dbh}}{\text{age}}$ + $\frac{\text{height}}{\text{age}}$	0.8014	0.6422	0.021
Weighted specific gravity of 2 cores + $\frac{\text{dbh}}{\text{age}}$ + height	0.8391	0.7041	0.019
Weighted specific gravity of 2 cores + dbh + $\frac{1}{\text{age}}$	0.8391	0.7041	0.019
4 variables			
Specific gravity of 1 core t dbh + $\frac{1}{\text{age}}$ + $\frac{\text{height}}{\text{age}}$	0.8219	0.6755	0.020
Specific gravity of 1 core + dbh + $\frac{1}{\text{age}}$ + height	0.8213	0.6745	0.020
Weighted specific gravity of 2 cores + $\frac{1}{\text{age}}$ + $\frac{\text{volume}}{\text{age}}$ + $\frac{\text{height}}{\text{age}}$	0.8461	0.7159	0.019

In the single unweighted increment core group, the addition of dbh or dbh/age to the regression only increased the explained variation by about 8 percent in longleaf pine and about 1 percent in slash pine. Although this may not be a great increase in the total explained variation, it is equivalent to results obtained by weighting a single increment core or taking the outer two-thirds of a single core in the longleaf pine. Slash pine, which showed little or no improvement from the weighting of single increment cores, did no better when other variables were added to the regression equation. The addition of a third variable to the equation added very little improvement, increasing the total variation explained from about 64 percent to 66 percent for longleaf pine, and from about 59 percent to 65 percent for slash pine. In longleaf pine, no four variable equations were listed, since no improvement was gained by the addition of a fourth variable. In slash pine the addition of a fourth variable improves the relationship an insignificant amount.

In considering the improvement realized for the multiple core sample (average of cores No. 1 and No. 3), the same relative trend can be observed by the addition of 2, 3, or 4 variables into the multiple regression equation. In longleaf pine, the improvement in reduction of the total unexplained variation realized by the use of three independent variables in the equations over a simple weighted average of two increment cores is only 7 percent. In slash pine the same improvement (7 percent) *is* realized *in* the "best" four variable regressions. The multiple regression equations for each of the relationships discussed above are shown in tables 8 and 9 of the Appendix.

SUMMARY AND CONCLUSIONS

The data have shown that for longleaf pine some improvement in the relationship between tree specific gravity and increment core specific gravity can be realized by various treatments such as weighting segments of an increment core by the cross sectional area they represent or by taking only the outer two-thirds of an increment as an estimator of tree gravity. These treatments, however, make only rather minor improvement in the relationships and the precision of estimating tree specific gravity from an increment core.

A comparison of multiple core sampling with single core sampling shows that two cores give little better results than one. However, if the two cores are weighted or only the outer two-thirds of two cores are used as an estimator, considerable improvement in the relationship and precision is realized over a single untreated increment core. In longleaf pine, the single increment core explains only 55 percent of the variation, and the standard error about the regression line is 0.023, whereas the average of two two-thirds cores accounts *for* about 73 percent of the variation and has a standard error of 0.018. Taking more than two increment cores, that is, three or four cores as a sample, adds very little to the improvement of the relationship or the precision of the estimator and certainly will not justify the additional cost or time.

Slash pine did not respond to treatments in the same manner as the longleaf pine. Weighting or taking only two-thirds of the core showed extremely small improvement in the relationship or none at all. There is no reason for the difference which occurs here except that attributed to species, When multiple samples were extracted from slash pine, an additional 9 percent of the variation could be accounted for when a one core sample is compared with a two core sample. This response is similar to that in the longleaf pine when multiple core samples are compared to a single core.

In the multiple regression analysis, the addition of such independent variables as diameter at breast height, total height, age, volume, and their various other functions showed that some improvement can be realized by including them in the analysis. In longleaf pine, for instance, a single, untreated core accounts for only 55 percent of the variation, whereas including dbh or dbh/age in the regression, increases the percent of explained variation to 64, or about 9 percent. The best three variable regressions only account for 66 percent of the variation. In the slash pine multiple regressions there was an extremely minor improvement in the relationship with two variables, and only about a 10 percent increase in the total amount of variation explained with the best 4 variable regression equations. The improvement realized by incorporating these various tree parameters into the predicting equation is equivalent to results obtained with a single weighted core, or the outer two-thirds core, or with multiple core sampling.

The multiple regressions with the multiple core sample as one of the independent variables also showed very little improvement over two weighted increment cores in both species. The longleaf pine multivariate equations which contained the specific gravity of the weighted core samples as one of the variables accounted for the greatest amount of the variation. In this case two equations each explained as high as 81 percent of the variation.

All of the sampling schemes analyzed in this study should be considered on the basis of the precision they offer and simplicity with which the sample can be taken, as well as the facilities one has for computation. A single untreated core, for instance, is reasonably well correlated with tree specific gravity, but the precision with which one could predict the gravity of an individual tree is rather low. A single core would, therefore, not be the most desirable estimator to use when one wishes to predict gravities of individual trees. On the other hand, it could be used where large samples of a large population are being taken for the purpose of predicting the average gravity for the population.

When precision is desired, the best prediction equation would result from a multiple regression analysis of a weighted multiple core sample and the various tree parameters mentioned earlier. Table 6 is a summary of 1, 2, 3, and 4 variable prediction equations in the order of their relative precision. Only 2-core multiple sampling is considered in this listing because of the minor improvements realized by more than two cores.

Table 6.--Regression equations for predicting tree specific gravity of longleaf and slash pine, and their correlation coefficients and standard errors

Regression equations	r	r^2	Standard error
Longleaf pine			
$Y = 0.11702 + 0.77480(\text{sp. gr., weighted, 2 cores}) - 0.08644(\frac{\text{dbh}}{\text{age}}) + 0.37664(\frac{1}{\text{age}})$	0.9015	0.8127	0.015
$Y = 0.10722 + 0.79072(\text{sp. gr., weighted, 2 cores}) - 0.03507(\frac{\text{volume}}{\text{age}})$	0.8979	0.8062	0.015
$Y = 0.10900 + 0.75893(\text{sp. gr., weighted, 2 cores})$	0.8582	0.7365	0.018
$Y = 0.10234 + 0.76658(\text{sp. gr., outer 2/3 of 2 cores})$	0.8514	0.7249	0.018
$Y = 0.31782 + 0.51456(\text{sp. gr., 1 core}) - 0.11028(\frac{\text{dbh}}{\text{age}}) - 0.00104(\text{age})$	0.8153	0.6647	0.020
$Y = 0.32008 + 0.44953(\text{sp. gr., 1 core}) - 0.09238(\frac{\text{dbh}}{\text{age}})$	0.8009	0.6414	0.021
$Y = 0.16439 + 0.66280(\text{sp. gr., weighted, 1 core})$	0.7958	0.6333	0.021
$Y = 0.15398 + 0.67815(\text{sp. gr., outer 2/3 of 1 core})$	0.7811	0.6101	0.022
$Y = 0.20267 + 0.60073(\text{sp. gr., 2 cores})$	0.7814	0.6105	0.022
$Y = 0.16733 + 0.63747(\text{sp. gr., outer 1/3 of 2 cores})$	0.7693	0.5918	0.022
$Y = 0.78381 - 0.13717(\frac{1}{\text{sp. gr., 1 core}})$	0.7527	0.5665	0.023
$Y = 0.26501 + 0.48587(\text{sp. gr., 1 core})$	0.7316	0.5352	0.024
$Y = 0.23242 + 0.52690(\text{sp. gr., outer 1/3 of 1 core})$	0.6547	0.4286	0.026
Slash pine			
$Y = 0.16613 + 0.69693(\text{sp. gr., weighted, 2 cores}) - 1.07870(\frac{1}{\text{age}}) - 0.03492(\frac{\text{volume}}{\text{age}}) + 0.01544(\frac{\text{height}}{\text{age}})$	0.8461	0.7159	0.019
$Y = 0.16810 + 0.73824(\text{sp. gr., weighted, 2 cores}) - 0.00240(\text{dbh}) - 0.66557(\frac{1}{\text{age}})$	0.8391	0.7041	0.019
$Y = 0.12634 + 0.76934(\text{sp. gr., weighted, 2 cores}) - 0.07029(\frac{\text{dbh}}{\text{age}})$	0.8316	0.6916	0.019
$Y = 0.13575 + 0.73268(\text{sp. gr., 2 cores})$	0.8132	0.6613	0.020
$Y = 0.20893 + 0.57112(\text{sp. gr., 2 cores}) - 0.00659(\text{dbh}) + 0.00134(\text{total height})$	0.8083	0.6533	0.021
$Y = 0.08386 + 0.80213(\text{sp. gr., weighted, 2 cores})$	0.8003	0.6405	0.021
$Y = 0.26401 + 0.55426(\text{sp. gr., 1 core}) - 0.07957(\frac{\text{dbh}}{\text{age}})$	0.7696	0.5923	0.022
$Y = 0.11113 + 0.74875(\text{sp. gr., outer 2/3 of 2 cores})$	0.7612	0.5794	0.022
$Y = 0.22410 + 0.57789(\text{sp. gr., 1 core})$	0.7256	0.5265	0.024
$Y = 0.83868 - 0.16224(\frac{1}{\text{sp. gr., 1 core}})$	0.7208	0.5195	0.024
$Y = 0.22108 + 0.56652(\text{sp. gr., weighted, 1 core})$	0.6563	0.4307	0.026
$Y = 0.22966 + 0.52798(\text{sp. gr., outer 1/3 of 2 cores})$	0.6129	0.3756	0.027
$Y = 0.25483 + 0.50348(\text{sp. gr., outer 2/3 of 1 core})$	0.5940	0.3528	0.028
$Y = 0.34111 + 0.34103(\text{sp. gr., outer 1/3 of 1 core})$	0.4805	0.2308	0.030

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APPENDIX

1. Bolt volume was computed by the following formula:

$$V = (d.i.b.)^2 \times 0.0054542 \times \text{length in feet}$$

2. Specific gravity of each disk was computed by the following formula:

$$\text{Disk specific gravity} = \frac{\text{ovendry weight of disk}}{\text{displaced volume of disk}}$$

3. Increment core specific gravity was computed with the following formula:

$$\text{Increment core specific gravity} = \text{ovendry weight (grams)} \div \frac{(\text{core diameter})^2 \times 0.7854 \times \text{core length (inches)}}{0.061}$$

Table 7. --Data on sample trees

Location in Georgia	Stand type	Trees sampled	Tree age class	Diameter breast height			Merchantable height			Total height		
				Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
		Number	Years	- - - Inches - - -			- - - Feet - - -			- - - Feet - - -		
LONGLEAF PINE												
Ware County	Second growth	45	7-45	9.8	4.6	15.6	41.6	17.3	62.4	58.1	28.3	80.4
Brooks County	Second growth	44	21-31	8.3	4.3	12.2	41.6	15.6	60.1	55.1	32.9	69.1
SLASH PINE												
Ware County	Second growth	47	14-50	9.3	5.1	15.9	44.1	16.8	65.6	59.3	32.8	78.8
Brooks County	Second growth	43	B-38	8.3	5.5	12.7	43.9	20.7	58.8	54.7	29.8	69.5

Table 8. --Linear regression equations and best multiple regression equations for estimating tree specific gravity of longleaf pine

Regression equations	Correlation coefficient	Standard error
1 variable		
Y = 0.26501 + 0.48587 (sp. gr., 1 core)	0.7316	0.024
y = 0.16439 + 0.66280 (sp. gr., weighted, 1 core)	0.7958	0.021
Y = 0.15398 + 0.67815 (sp. gr., outer 2/3 of 1 core)	0.7811	0.022
Y = 0.23242 + 0.52690 (sp. gr., outer 1/3 Of 1 core)	0.6547	0.026
Y = 0.20267 + 0.60073 (sp. gr., 2 cores)	0.7814	0.022
y = 0.10900 + 0.75893 (sp. gr., weighted. 2 cores)	0.8582	0.018
Y = 0.10234 + 0.76658 (sp. gr., outer 2/3 of 2 cores)	0.8514	0.018
Y = 0.16733 + 0.63747 (sp. gr., Outer 1/3 of 2 cores)	0.7693	0.022
Y = 0.78381 - 0.13717 $\left(\frac{1}{\text{sp. gr., 1 core}}\right)$	0.7527	0.023
2 variables		
Y = 0.32006 + 0.44953 (sp. gr., 1 core) - 0.09238 $\left(\frac{\text{dbh}}{\text{age}}\right)$	0.8009	0.021
Y = 0.26105 + 0.56416 (sp. gr., 1 core) - 0.00415 (dbb)	0.7984	0.021
y = 0.10722 + 0.79072 (sp. gr., weighted, 2 cores) - 0.03507 $\left(\frac{\text{volume}}{\text{age}}\right)$	0.8979	0.015
Y = 0.16508 + 0.70551 (sp. gr., weighted, 2 cores) - 0.06956 $\left(\frac{\text{dbh}}{\text{age}}\right)$	0.8914	0.016
y = 0.11105 + 0.80348 (sp. gr., weighted, 2 cores) - 0.00290 (dbh)	0.8894	0.016
3 variables		
Y = 0.31782 t 0.51456 (sp. gr., 1 core) - 0.11028 $\left(\frac{\text{dbh}}{\text{age}}\right)$ - 0.00104 (age)	0.8153	0.020
Y = 0.31465 + 0.50816 (sp. gr., 1 core) - 0.00472 (dbh) - 0.41900 $\left(\frac{1}{\text{age}}\right)$	0.8141	0.020
y = 0.11702 + 0.77480 (sp. gr., weighted, 2 cores) - 0.08644 $\left(\frac{\text{dbh}}{\text{age}}\right)$ + 0.37664 $\left(\frac{1}{\text{age}}\right)$	0.9015	0.015
Y = 0.13254 + 0.76377 (sp. gr., weighted, 2 cores) - 0.03 $\left(\frac{\text{volume}}{\text{age}}\right)$ (- 0.00507 $\left(\frac{\text{height}}{\text{age}}\right)$	0.9010	0.015

Table 9. --Linear regression equations and best multiple regression equations for estimating tree specific gravity of slash pine

Regression equations	Coefficient of variation	Standard error
1 variable		
Y = 0.22410 + 0.57789 (sp. gr., 1 core)	0.7256	0.024
Y = 0.22108 + 0.56652 (sp. gr., weighted, 1 core)	0.6563	0.026
Y = 0.25483 + 0.50348 (sp. gr., outer 2/3 of 1 core)	0.5940	0.028
Y = 0.34111 + 0.34103 (sp. gr., outer 1/3 of 1 core)	0.4805	0.030
Y = 0.13575 + 0.73268 (sp. gr., 2 cores)	0.8132	0.020
Y = 0.08386 + 0.80213 (sp. gr., weighted, 2 cores)	0.8003	0.021
Y = 0.11113 + 0.74875 (sp. gr., outer 2/3 of 2 cores)	0.7612	0.022
Y = 0.22966 + 0.52798 (sp. gr., outer 1/3 of 2 cores)	0.6129	0.027
Y = 0.83868 - 0.16224 $\left(\frac{1}{\text{sp. gr., 1 core}}\right)$	0.7208	0.024
2 variables		
Y = 0.26401 + 0.55426 (sp. gr., 1 core) - 0.07957 $\left(\frac{\text{dbh}}{\text{age}}\right)$	0.7696	0.022
Y = 0.21894 + 0.63964 (sp. gr., 1 core) - 0.00323 (dbh)	0.7653	0.022
Y = 0.12634 + 0.76934 (sp. gr., weighted, 2 cores) - 0.07029 $\left(\frac{\text{dbh}}{\text{age}}\right)$	0.8316	0.019
Y = 0.13588 + 0.74391 (sp. gr., weighted, 2 cores) - 0.47210 $\left(\frac{1}{\text{age}}\right)$	0.8208	0.020
3 variables		
Y = 0.20893 + 0.57112 (sp. gr., 1 core) - 0.00659 (dbh) + 0.00134 (total height)	0.8083	0.021
Y = 0.22712 + 0.58832 (sp. gr., 1 core) - 0.16022 $\left(\frac{\text{dbh}}{\text{age}}\right)$ + 0.02050 $\left(\frac{\text{height}}{\text{age}}\right)$	0.8014	0.021
Y = 0.13339 + 0.72069 (sp. gr., weighted, 2 cores) - 0.08094 $\left(\frac{\text{dbh}}{\text{age}}\right)$		
+ 0.00042 (total height)	0.8391	0.019
Y = 0.16810 + 0.73824 (sp. gr., weighted, 2 cores) - 0.00240 (dbh) - 0.66557 $\left(\frac{1}{\text{age}}\right)$	0.8391	0.019
4 variables		
Y = 0.29382 + 0.55937 (sp. gr., 1 core) - 0.00569 (dbh) - 1.36050 $\left(\frac{1}{\text{age}}\right)$ + 0.02031 $\left(\frac{\text{height}}{\text{age}}\right)$	0.8219	0.020
Y = 0.25913 + 0.53568 (sp. gr., 1 core) - 0.00674 (dbh) - 0.43496 $\left(\frac{1}{\text{age}}\right)$		
+ 0.00113 (total height)	0.8213	0.020
Y = 0.16613 + 0.69693 (sp. gr., weighted, 2 cores) - 1.07870 $\left(\frac{1}{\text{age}}\right)$ - 0.03492 $\left(\frac{\text{volume}}{\text{age}}\right)$		
+ 0.01544 $\left(\frac{\text{height}}{\text{age}}\right)$	0.8461	0.019