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Site Index for Loblolly Pine in the Atlantic Coastal Plain of the Carolinas and Virginia

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This paper presents site index curves for natural stands of loblolly pine in the Atlantic Coastal Plain of Virginia, North Carolina, and South Carolina.[1] The curves were developed from stem analysis and allow for varying curve shapes on sites of differing quality.

[1]The North Carolina and Virginia portions of the study were conducted in cooperation with Union Camp Corp., Franklin, Virginia.

Site Index for Loblolly Pine in the Atlantic Coastal Plain of the Carolinas and Virginia

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Site index, the height of the dominant stand at a selected index age, is a useful indicator of relative yield potential for even-aged stands. It is the most direct and probably the best tool now available for evaluating productivity.

Height measurements for determination of site index were made at 5-year intervals over a period of 15 years on a series of permanent growth plots of loblolly pine (*Pinus taeda* L.) in the middle Coastal Plain of Virginia and the lower Coastal Plain of South Carolina. The measured height-growth trend on these plots did not conform to several existing site curves for natural stands (USDA Forest Service 1929; Coile 1952; Schumacher and Coile 1960). In general, the measured rate of growth was more rapid than the rate depicted by the site curves. Consequently, when the existing site curves were applied to the measured values, the stands appeared to be increasing in site index as they increased in age.

Many possible weaknesses of the conventional methods of preparing harmonic site index curves could lead to disagreement between site curves and measured growth trends, as has been thoroughly discussed by Spurr (1952, 1956). Recent studies have shown that these weaknesses may contribute to major errors in estimating site index (Curtis 1966; Beck 1971). It is possible to avoid many of the pitfalls by using data developed from stem analysis or periodic remeasurement of stands on permanent plots. Curves constructed from such data would show true growth trends for given sites.

This paper presents site index curves for natural stands of loblolly pine in the Atlantic Coastal Plain of Virginia, North Carolina, and South Carolina.[1] The curves were developed from stem analysis and allow for varying curve shapes on sites of differing quality.

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FIELD PROCEDURES

Twenty-two 2-tree plots were located in stands 50 years old or older. The trees ranged from 70 to 120 feet in height at age 50. The criteria set for choosing and accepting a sample tree were that the tree (a) was a dominant or codominant in the stand, (b) showed no evidence in the increment core of prior suppression, (c) did not show evidence of heart rot along the bole, and (d) showed no evidence of past damage to the crown or leader. If no physical evidence to disqualify it was found, the tree was felled.

After felling, total height was measured and the tree was cut into 6-foot bolts if it was in site index class 60 to 70, 8-foot bolts if it was in class 80 to 90, or 10-foot bolts if it was in class 100 to 120. Increment cores were taken at the 1-foot height to determine total age and at each cut to determine at what ages the tree reached intermediate heights. Exact height of the tree at these intermediate ages was determined by locating the nearest primary whorl[2] below the increment core and measuring height to this point. In the lower part of the bole where branch knots were overgrown, the bolt was split to expose all branch whorls at the pith. This field procedure furnished 12 to 16 height/age measurements per tree.

LABORATORY PROCEDURES

In the laboratory, all increment cores were sliced and the annual rings were counted. Two independent age counts were made, and differences were settled by close inspection and recounting. Total tree age was the age determined at the 1-foot height plus 1 year. The ages corresponding to the primary whorls below each increment core were calculated as total tree age minus the age count of that particular core.

ANALYSIS AND RESULTS

Site index curves for index ages of 25 and 50 years were developed from the data on stem analysis by (a) fitting for each tree a mathematical curve to the height/age data by means of a least squares estimation technique, (b) determining if and how the pattern of growth varied among trees from plots of varying site index, and (c) providing for change in curve shape in the model, if needed.

When loblolly pine grows under favorable environmental conditions and in the absence of extreme competition from its neighbors, one expects the rate of height growth to increase in early years and decrease thereafter, approaching zero as the tree grows old. The sigmoid growth model described by Richards (1959) provided an adequate description of the growth of the trees in this study when it was fit to the data with a nonlinear least squares technique (Middleton 1969). This extremely flexible growth

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[2]Observations by the senior author indicate that loblolly pine annually produces about three growth flushes, at least in its first 20 to 25 years. The initial spring flush, with the primary whorl at its base, is the longest, and the last flush in the growing season is the shortest. In the tops of the mature pines on the study plots, only one flush of height growth occurred.

model has been used to describe the height growth of a number of species in recent years (Brickell 1966, 1968; Lundgren and Dolid 1970; Beck 1971). The form of the equation used in this study is

$$H = A \left[1 - e^{-Bt}\right]^{\frac{1}{1-m}} \qquad (1)$$

where H equals the height of trees at age t and A, B, and m are parameters to be estimated.

Fitting equation 1 to the height/age data for each tree individually resulted in 44 sets of estimates ($\hat{A}_i$, $\hat{B}_i$, $\hat{m}_i$, $i=1, 2, \ldots, 44$) of the three growth function parameters. Because the heights of the two trees measured on a plot were not generally observed at the two index ages of 25 and 50 years, site index (S) was taken to be the predicted height at index age from an estimated form of equation 1 with estimates of the parameters obtained by using both trees on a plot. The success of our approach to introducing site index into the model depended on the existence of a relationship between at least one of the growth function parameters and site index. We looked only at those functions

$$A = f_1 (S) \qquad (2)$$

$$B = f_2 (S) \qquad (3)$$

$$m = f_3 (S) \qquad (4)$$

that were linear in the parameters. We then used nonlinear least squares estimation on the model

$$H = f_1(S) \left[1 - e^{-f_2(S)t}\right]^{\frac{1}{1-f_3(S)}} \qquad (5)$$

to obtain estimates of the parameters in the equations f_1, f_2, and f_3. Although equation 1 provided a good fit with the height/age data on individual trees, four of the 44 trees appeared to have parameter/site index relationships different from the other 40 trees, especially for parameter A. The following tabulation of R^2 values for the equations

$$f_1(S) = b_1 + b_2S \qquad (6)$$

$$f_2(S) = b_3 + b_4S + b_5S^2 \qquad (7)$$

$$f_3(S) = b_6 + b_7S + b_8S^2 \qquad (8)$$

shows how they were changed when the four problem trees were deleted:

Parameters	Index age (Years)	Fit for data set 1* (R^2)	Fit for data set 2 ** (R^2)
A	25	0.01	0.35
	50	.02	.49
B	25	.55	.49
	50	.46	.37
m	25	.25	.13
	50	.27	.13

*Data set 1 includes all observations.
**Data set 2 does not contain the four problem trees.

Because of (a) the increased R^2 for f_1, (b) the small difference in curve shape between the problem trees and the others, and (c) the relatively small number of problem trees (9 percent), we decided to estimate the parameters of equation 5 by using the reduced data set of 40 trees. The resulting parameter estimates for both index ages are

Parameter	Estimate for index age 50	Estimate for index age 25
b_1	6.31415×10	8.30075×10
b_2	6.35080×10^{-1}	6.57918×10^{-1}
b_3	6.43041×10^{-3}	1.57700×10^{-2}
b_4	1.24189×10^{-4}	-4.72909×10^{-5}
b_5	1.62545×10^{-6}	5.31718×10^{-6}
b_6	1.72741×10^{-1}	3.53269×10^{-1}
b_7	-2.91877×10^{-3}	-9.36396×10^{-3}
b_8	3.10915×10^{-5}	1.05419×10^{-4}

Tables 1 and 2 present the absolute values for the deviations of predicted from observed site index when all trees were included, that is, the problem trees were used in the construction of these tables even though they were not used in the estimation of parameters in equation 5. Although not presented in this paper, similar tables were calculated from equation 5 in which the parameters were estimated by using all 44 trees. The predictions were much more aberrant when all the trees were used in estimating the parameters, with some differences between observed and

Table 1.--Deviations of predicted from observed site index at index age 50 years

Stand age (years)	Deviation in feet at age 50				Observations of height/age
	±0.0 to 2.5	±2.6 to 5.0	±5.1 to 7.5	±7.6 to 10.0	
	Percent of the deviations				No.
10	32	23	32	13	22
20	41	50	9	--	22
30	73	27	--	--	22
40	100	--	--	--	22
50	100	--	--	--	22
60	95	5	--	--	22
Average or total	74	17	7	2	132

Table 2.--Deviations of predicted from observed site index at index age 25 years

Stand age (years)	Deviation in feet at age 25			Observations of height/age
	±0.0 to 2.5	±2.6 to 5.0	±5.1 to 7.5	
	Percent of the deviations			No.
10	64	23	13	22
20	100	--	--	22
30	100	--	--	22
40	100	--	--	22
50	73	27	--	22
60	55	41	4	22
Average or total	82	15	3	132

predicted site index being greater than 20 feet. The heights for the predictions in tables 1 and 2 were obtained from the average height growth curves for each of the 22 plots at the ages given in the tables. Notice that, for the predictions made from the curves for index age 50, 91 percent of the predicted values were within 5 feet of the observed site index; and, for the predictions made from the curves for index age 25, 97 percent were within 5 feet of the observed site index. As one would expect, tables 1 and 2 show that the further the age of a stand is from the index age at the time the prediction is made, the more aberrant the site index predictions will be. It follows that a set of site index curves with index age near the average age of the stands to be predicted should generate the most accurate predictions. For example, if rotation age for a forest property is 50 years or less, curves for index age 25 are preferred. If, however, the rotation is longer, curves for index age 50 might be preferable.

Equation 5, along with the estimates of the b_i ($i=1, 2, \ldots, 8$) substituted in it, were used to calculate curves for selected site indices, as shown in figures 1 and 2. As noted by Lundgren and Dolid (1970), the height-age function used does not specify that the height at age 50 must be exactly equal to site index, but only that it be proportional to it. However, the error in predicted height at age 50 is usually small, and the curves in figures 1 and 2 have been adjusted to pass through the indicated site index at age 50 and 25.

In order to determine the deviations of site index predicted by our curves from observed site index, the stands were grouped into 7-foot site classes for index age 25 and 10-foot site classes for index age 50, and the deviations were plotted over the age at which the predictions were made. Where three or more plots were available in a site index class, there did not appear to be any trend in the deviations over the age at prediction.

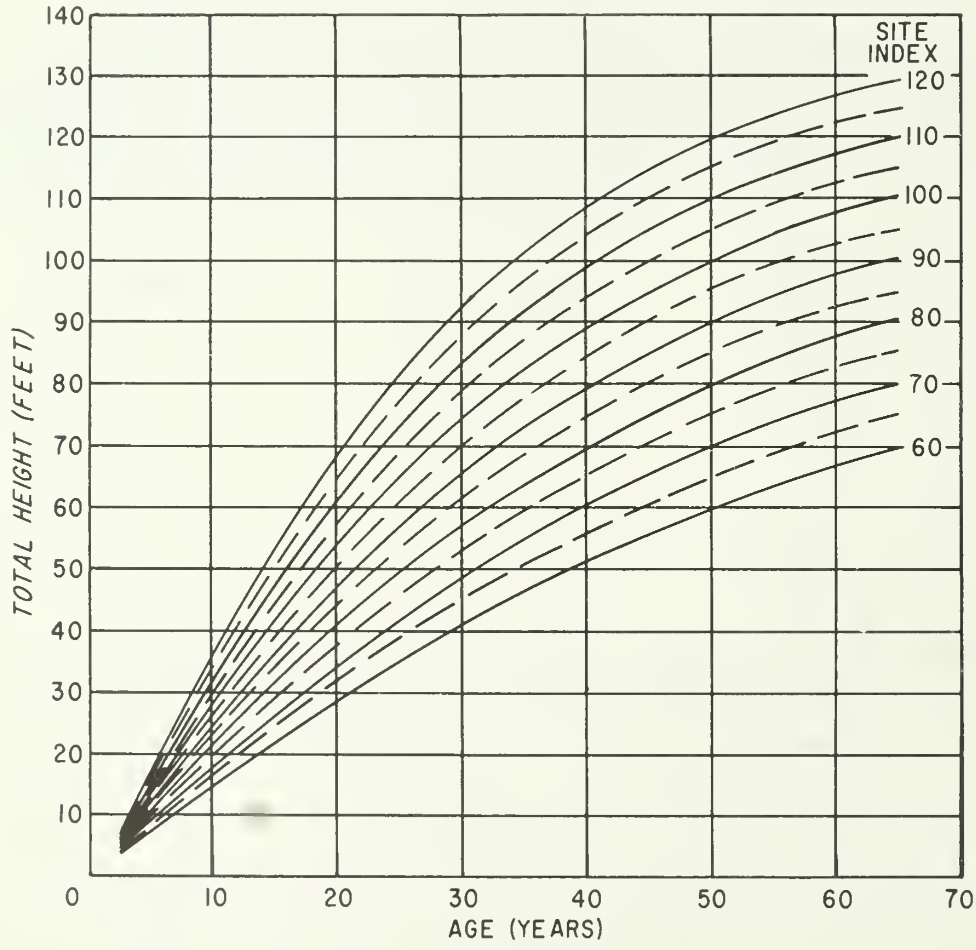

Figure 1.--Site index curves for loblolly pine at index age 50 years in the Coastal Plain of Virginia, North Carolina, and South Carolina. (These curves are based on stem analysis of 40 dominant trees in the middle and lower Coastal Plain.)

Notice that, because equation 5 cannot be solved for S in terms of H and t, it is necessary to use an iterative technique to calculate site index ($\hat{S}_0$) from stand age and sample mean height (t_0, H_0) of a particular plot. For further explanation of this procedure, see the Appendix. For practical purposes, site index may be estimated by using either figure 1 or figure 2.

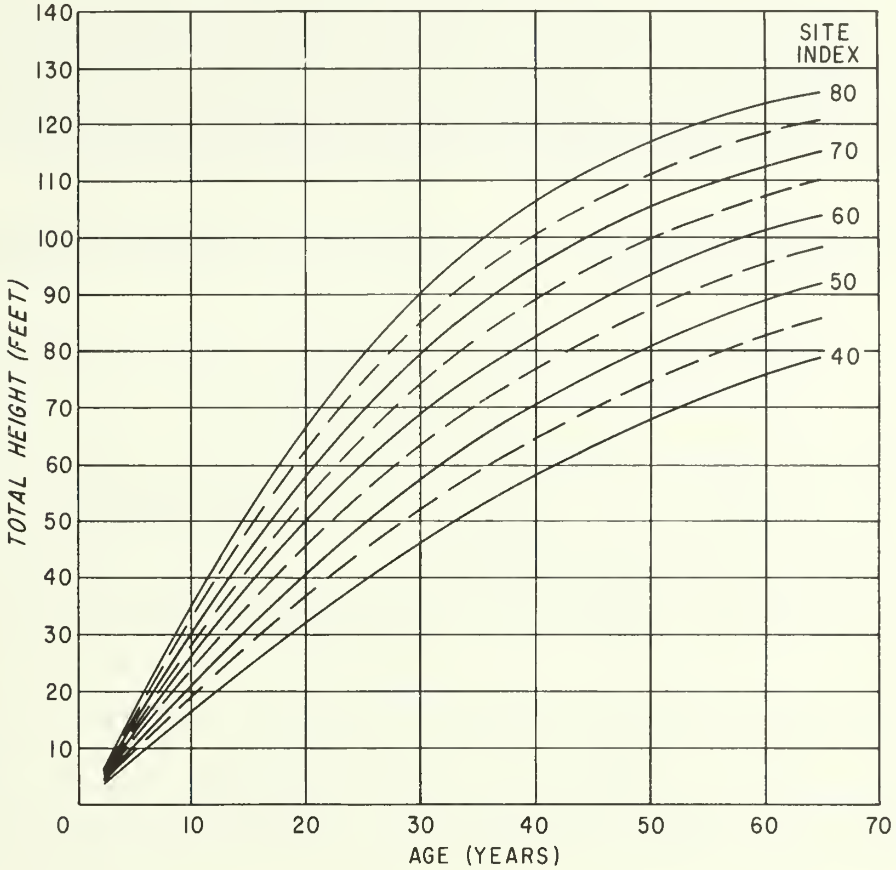

Figure 2.--Site index curves for loblolly pine at index age 25 years in the Coastal Plain of Virginia, North Carolina, and South Carolina. (These curves are based on stem analysis of 40 dominant trees in the middle and lower Coastal Plain.)

TEST AND COMPARISON OF SITE INDEX CURVES

Seventy-four permanent growth plots in another study provided independent data for testing our new site index curves with those of Schumacher and Coile (1960). We chose the Schumacher-Coile curves for purposes of comparison because they are widely used in estimating growth and yield of loblolly pine in the Southeastern Coastal Plain. When the growth plots were established in 1949, they ranged in age from 16 to 50 years and in site index (age 50) from 63 to 119 feet. Measurements of these 74 plots at 5-year intervals for a 20-year period furnished 364 separate estimates of age and height.

In our test of each curve, we wished to determine if site index estimates changed with age and if this relationship varied by broad site classes (that is, low, medium, and high sites). The grouping of the plots was as follows: low sites included site indices 63 to 89 (age 50); medium site included indices 90 to 104; and high sites included indices 105 to 119. The regression model used for these tests was

$$Y = a + bx + \epsilon$$

where Y equals site index and x equals age when site index was estimated. Separate regressions were computed for our new curves on the basis of low (Y_1), medium (Y_2), and high (Y_3) site groupings and for the Schumacher-Coile curves also on the basis of low (Y_4), medium (Y_5), and high (Y_6) site groupings.

The regressions of x and Y_1, Y_2, and Y_3 for our new site index curves were nonsignificant:

$$Y_1 = 83.3793 - 0.0303\,x \; ; \; R^2 = 0.3 \text{ percent}$$

$$Y_2 = 96.3655 + 0.0827\,x \; ; \; R^2 = 3.9 \text{ percent}$$

$$Y_3 = 107.7456 + 0.0235\,x \; ; \; R^2 = 0.4 \text{ percent}$$

However, the regressions of x and Y_4, Y_5, and Y_6 for the Schumacher-Coile curves were all highly significant:

$$Y_4 = 60.7662 + 0.4098\,x \; ; \; R^2 = 36.2 \text{ percent}$$

$$Y_5 = 77.5144 + 0.4335\,x \; ; \; R^2 = 53.3 \text{ percent}$$

$$Y_6 = 88.8352 + 0.3814\,x \; ; \; R^2 = 44.6 \text{ percent}$$

The slopes of the regressions for the Schumacher-Coile curves were not significantly different.

These tests and comparisons of the two site index curves show that site index estimates of remeasured plots do not change with increasing ages when our new curves are used but that the estimates do change when the Schumacher-Coile curves are used. The changing estimates generated by the latter curves indicate that the curves are biased. We therefore conclude that our new curves give unbiased estimates of site index that are consistently better than those generated by the Schumacher-Coile curves.

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APPENDIX

The least squares fit of equation 5 is

$$H = (\hat{b}_1 + \hat{b}_2 S) \left[1 - e^{-t(\hat{b}_3 + \hat{b}_4 S + \hat{b}_5 S^2)}\right]^{\frac{1}{1 - \hat{b}_6 - \hat{b}_7 S - \hat{b}_8 S^2}} \qquad (1A)$$

where the $\hat{b}_i$ $(i=1,2,\ldots,8)$ are the nonlinear least squares estimates of the model parameters. We want to obtain the value of site index (S^*) for particular values of height (H^*) and age (t^*) observed in some stand. However, equation 1A can <u>not</u> be solved for S in terms of H and t, and, therefore, it is necessary to find by iterative, numerical methods an approximation to S^*.

Equation 1A satisfies the mathematical properties necessary for the following procedure to work. Consider the equation in site index (S)

$$g(S) = 0 = H^* - \hat{f}_1(S) \left[1 - e^{-t^* \hat{f}_2(S)}\right]^{\frac{1}{1 - \hat{f}_3(S)}} \qquad (2A)$$

where H^* and t^* are numbers, that is, observed values of height and age from some stand. We want to find a value of site index (S_i) that is "close" to the value of site index (S^*) which satisfies equation 2A above, that is

$$g(S^*) = 0.$$

In other words, S^* is the predicted value of site index that would be obtained if equation 1A could be solved for S in terms of H and t. Start with an initial guess of site index, say S_0. Compute

$$D_0 = \frac{g(S_0) - g(S_0 + h)}{h} \qquad (3A)$$

where h is some small number, say $h = 0.001$. The quantity D_0 is an approximation to the value of the derivative function of g evaluated at $S = S_0$. One could find the derivative function, but this process is rather complicated. Then compute

$$\delta_0 = - \frac{g(S_0)}{D_0} \qquad (4A)$$

and test whether

$$|\delta_0| \leq \Delta \qquad (5A)$$

where Δ equals some small, positive number, such as $\Delta = 0.00005$. If 5A is not true, then set

$$S_1 = S_0 + \delta_0$$

and compute

$$\delta_1 = -\frac{g(S_1)}{D_1}$$

where

$$D_1 = \frac{g(S_1) - g(S_1 + h)}{h}$$

Now test if

$$|\delta_1| \leq \Delta . \qquad (6A)$$

Continue computing δ_i's until the statement

$$|\delta_i| \leq \Delta \qquad (7A)$$

is true. When 7A is true for some small Δ, then δ_i is a good measure of how close S_i is to the unknown S^*.

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1974. Site index for loblolly pine in the Atlantic Coastal Plain of the Carolinas and Virginia. Southeast. For. Exp. Stn., USDA For. Serv. Res. Pap. SE-115, 11 pp.

Polymorphic site index curves for natural stands of loblolly pine (*Pinus taeda* L.) in the Atlantic Coastal Plain were developed from data on stem analysis by using a sigmoid growth model. These new curves give unbiased estimates of site index that are consistently better than those generated by existing curves.

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The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

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Appalachian Trail Users in the Southern National Forests:

Their Characteristics, Attitudes and Management Preferences

by
Judith Buckley Murray

A 2,000-mile footpath running from Maine to Georgia, primarily along the crestline of the Appalachian Mountains, the Appalachian Trail is within a day's drive of 60 percent of the American public. Eight hundred and sixty-six miles of the trail are located, with permission of the owners, on private land. The remainder is on State and Federal land, passing through eight National Forests and two National Parks. Eight hundred and thirty-two miles are within the exterior boundaries of the National Forests; 680 of those are in the Southern Region. By virtue of its location and numerous access points, the trail plays a significant role in hiking in eastern America.

A volunteer citizens' project, construction of the trail began in 1921, and in 1925 the Appalachian Trail Conference, comprised of Appalachian Trail clubs and interested individuals, was organized to coordinate the efforts of those who were building and marking the trail. The Appalachian Trail Conference, in cooperation with State and Federal agencies, continues maintenance and protection of the trail.

Although the trail had been in existence for nearly 50 years prior to its inclusion in the National Trails System, numerous encroachments forced relocations of many sections. More sections may yet have to be relocated to provide optimum routing. The USDA Forest Service, in cooperation with the Appalachian Trail Conference, is responsible for the planning and design of new sections and the management of the trail on lands under its jurisdiction.

Cover photo: Trailhead in the Nantahala National Forest, North Carolina. (Photo courtesy of Zellie G. Earnest.)

Appalachian Trail Users in the Southern National Forests: Their Characteristics, Attitudes and Management Preferences

by

Judith Buckley Murray

Who can say for sure why a man puts a pack on his back and heads up a trail? To escape the neon-bordered, four-lane highway which he travels daily...to feel the soil under his feet and breathe deeply of the moist woodsy smell...to find some measure of self-reliance in getting through a day quite nicely with simple provisions and few conveniences... to see the mountains stretching out beyond him just as they were before the white man reached the New World. Perhaps the motivations are as many as the hikers.

We may not know just why they do it, but we do know that their numbers are growing. Each year thousands of people are being introduced to trail hiking and are coming back for more.

In response to the Nation's trail needs, Congress in 1968 passed the National Trails System Act, which provided for National Scenic Trails--extended trails passing through nationally significant scenic, historic, natural, or cultural areas--and for National Recreation Trails--shorter trails reasonably accessible to urban areas. The Appalachian National Scenic Trail became an initial component of the national system of trails.

The Appalachian Trail is probably the most famous trail in the United States. Who is using this trail? What kind of experience is he seeking? Effective planning and management of the trail require not only protection of the physical resource and definition of appropriate recreational opportunities, but an understanding of the characteristics and attitudes of the users as well. The study described here was designed to obtain this information through an on-trail questionnaire survey of the hikers themselves. The survey was conducted at various points on the Appalachian Trail in the southern National Forests.

The author is presently serving on the advisory committee to the Forestry School at Virginia Polytechnic Institute. She is currently involved with development plans for a recreation park-environmental study complex and is general co-chairman for the 50th Anniversary meeting of the Appalachian Trail Conference. Her present address is Kingsport, Tennessee.

Research reported here was done as partial fulfillment of the requirements for the degree of Master of Science in the Graduate Program in Ecology, University of Tennessee. Funds and assistance for this research were provided by the USDA Forest Service, the Appalachian Trail Conference, and the University of Tennessee.

SCOPE

Six sampling points were selected in National Forests in Virginia, Tennessee, North Carolina, and Georgia. Three of these locations were considered "easy access, high use" sections of the trail, while the other three were considered "back-country, low use" areas. Sampling took place over 18 weeks from June through October in 1970 and 1971. Every hiker 16 years of age and older was given a questionnaire to fill out on the spot. The survey-taker personally administered the self-fillout questionnaires to hikers along the trail. There were 439 respondents.

DIFFERENTIATION OF USERS

Some people are introduced to the Appalachian Trail by experienced friends; some first encounter it in their Scouting days; some read about it in newspapers and decide to give it a try. A portion of these neophytes find the experience rewarding and return. Others exhibit little or no interest in future trips. Thus, at any given time, hikers with varying degrees of experience can be found on the Appalachian Trail. Hikers encountered in this study ranged from a backpacker en route from Georgia to Maine to a woman who suggested more intensive trailbrushing so that she would not snag her nylon stockings. One might expect some different opinions from these two users. Managers of recreation lands are cautioned to avoid drawing conclusions from "majority" or "average" response without looking for differing opinions from different types of users.

One large source of variation in attitude of Appalachian Trail users may be traced to differences in levels of hiking experience. As in most recreational and sporting pursuits, increased experience and capabilities in hiking may alter opinions about facilities. One of the objectives of this study was to determine if there is a relationship between hiking experience and trail attitudes and preferences.

To test whether trail-related attitudes and opinions were different at different levels of experience, an Experience Score was devised from responses to questions on the following topics:

1. Number of years the respondent had engaged in hiking.
2. Number of days he spent hiking during the 12 months prior to the sampling date.
3. Average distance walked in a day's hiking on the trail.
4. Number of days spent on the longest backpacking trip.
5. Use of an Appalachian Trail shelter.

Responses were weighted according to the author's evaluation of their contribution to one's hiking experience. Points for each factor were then added to give each respondent an Experience Score. Respondents were then divided into three groups as nearly equal in size as possible and classified as low, moderate, and high experience levels. These three levels were cross-tabulated with attitudes, preferences, and user characteristics to examine for significant relationships through the chi-square test.

THE HIKE

Hikers in this study were most often found in the company of friends. Family groups were the second most frequently encountered, but family participation dropped off with increasing hiking experience. Scouts were the next group in frequency, followed by assorted lone hikers, clubs, summer campers, and church groups.

When asked their preferred hiking company, respondents chose friends as the favored company among all levels of hiking experience. Users exhibited a preference for traveling in small intimate parties (table 1). Half of the most experienced hikers stated a preference for hiking alone or with just one companion; more than a third of the entire sample expressed the same preference. Only 2 percent voiced a preference for large parties.

Table 1.--Distribution of preferred hiking company, by experience level

Preferred company	Experience level		
	Low	Moderate	High
	Percent		
Friends	47.9	54.1	41.0
One companion	21.4	25.8	36.9
Family	25.0	11.9	8.2
Alone	4.3	5.7	12.3
Large party	1.4	2.5	1.6
	Number of cases		
Total	140	159	122

Hikers were taking advantage of the virtually limitless hiking opportunities, ranging from afternoon jaunts to 2,000-mile treks. Nearly half of them were to be on the trail for 2 or more days, and more than 70 percent had been on at least one backpacking trip in their hiking careers. Although most of the hikers in the low experience level were on 1-day hikes, most of those in the moderate and high experience levels

Photo courtesy of Paul M. Hutton

Appalachian Trail hikers most often travel in small parties of families or friends.

Photo courtesy of Stanley A. Murray

were out for more than 1 day (table 2). Two-thirds of those with backpacking experience had used a trail shelter--a primitive, three-sided, roofed structure--on at least one occasion.

Thirty-two percent of the hikers said they averaged 5 miles or less in a day's hiking. Shown below is the distribution of trail users (n = 421), by distance hiked per day:

Miles per day	Percent
0 to 5	31.6
6 to 8	26.8
9 to 11	24.5
12 to 15	13.5
More than 15	3.6

The Appalachian Trail offers virtually limitless hiking opportunities, ranging from afternoon jaunts to extended treks. (Photo courtesy of Zellie G. Earnest.)

Table 2.--Distribution of length of trip, by experience level

Days this trip (number)	Experience level		
	Low	Moderate	High
		Percent	
1	77.9	45.5	34.9
2	6.9	28.1	15.1
3 to 4	12.4	18.0	15.1
5 to 7	2.1	6.0	11.9
More than 7	.7	2.4	23.0
		Number of cases	
Total	145	167	126

THE HIKER

Appalachian Trail users range in age from youngsters to retirees. Heaviest representation was from the teenage and young adult population. Age distribution of trail users (n = 435) is shown below:

Age	Percent
16 to 18	20.9
19 to 24	27.4
25 to 34	19.8
35 to 44	16.1
45 to 54	9.2
55 to 64	4.1
Older than 65	2.5

Thirty percent of the hikers encountered were female (n = 435). Half of the hikers were married, a figure not surprisingly low considering the youthful segment of the sample (n = 436). Of those married respondents, only 38 percent had children (n = 218).

Perhaps the most striking characteristic of Appalachian Trail users was their high educational attainment. Educational attainment of the non-student segment of Appalachian Trail users (n = 272) is shown below:

	Percent
High school graduate or less	20.1
College graduate or some college	43.7
Graduate studies	36.2

These figures support findings in studies of other back-country users that point to a relationship between education and user motivation.

Sixty percent of the nonstudents had occupations which they classified as professional or technical. Distribution of the nonstudent portion of Appalachian Trail users (n = 272), by occupation, is listed below:

Occupation	Percent
Professional-technical	60.3
Business	16.7
Housewife	11.7
Skilled and nonskilled wage earners	6.2
Retired	3.5
Other	1.6

Incomes were high, corresponding to the high level of education; however, it should not be concluded that hiking is an expensive pastime. Retirees as well as students with limited incomes participate. Yearly incomes reported below represent the nonstudent portion (n = 272) of the sample:

Yearly combined income of household	Percent
Less than $3,000	5.2
$3,000 to $4,999	4.5
$5,000 to $7,999	10.5
$8,000 to $9,999	13.5
$10,000 to $14,999	22.5
$15,000 to $19,999	27.0
More than $20,000	16.8

Hikers in this study tended to live in large towns or large cities, but rural and small-town hikers were well represented (table 3). Trail users had diverse backgrounds, the environments of childhood being fairly evenly distributed among rural, small town, large town to small city, and large city.

Table 3.--Distribution of childhood and present living environments

Item	Environment				Total cases
	Rural	Small town	Large town-small city	Large city	
	Percent				Number
Childhood	20.9	27.9	26.3	24.9	430
Present	13.9	18.1	36.7	31.3	430

Sampling of Appalachian Trail users was done in four states: Virginia, Tennessee, North Carolina, and Georgia. The entire Appalachian Trail traverses 14 states. Hikers in this study represented 23 states.

Twenty-eight percent of the respondents lived outside the state in which the sampling was done. (States other than Tennessee and North Carolina at the Round Bald and Deer Park Mountain locations, and North Carolina and Georgia at the Rock Gap location were considered out of state. At these points, sampling was very close to state lines.) Sixteen percent of the hikers were from states through which the Appalachian Trail does not pass.

Nearly a fourth of the hikers in the high-use areas and half of those in the low-use areas were from out of state (table 4). These figures might indicate that some hikers will drive long distances to find a remote section of trail.

Table 4.--Distribution of in-state and out-of-state residents at each sampling location

Sampling location	Residence	
	In-state	Out-of-state
	- - - - - - Percent - - - - - -	
High use, easy access		
Cornelius Creek (Va.)	79.4	20.6
Round Bald (Tenn., N.C.)	83.0	17.0
Neel Gap (Ga.)	74.3	25.7
Composite of high-use areas (Number of cases = 278)	77.8	22.2
Low use, back-country		
Monster Rock (Va.)	36.8	63.2
Deer Park Mtn. (N.C., Tenn.)	47.1	52.9
Rock Gap (N.C., Ga.)	53.3	46.7
Composite of low-use areas (Number of cases = 96)	49.0	51.0

Since young people made up a large portion of the sample, it is not surprising that over half of the users had been hiking 5 years or less. Distribution of Appalachian Trail users (n = 437), by numbers of years spent in hiking, is shown below:

Years hiking	Percent
0 to 1	29.4
2 to 5	28.8
6 to 10	19.3
11 to 20	9.9
More than 20	12.6

Fifty-eight percent of the hikers had spent more than 5 days hiking during the 12 months prior to sampling. The following tabulation shows the distribution of Appalachian Trail users (n = 435), by hiking days per year:

Hiking days during previous 12 months	Percent
0 to 5	42.5
6 to 10	23.2
11 to 20	17.0
21 to 30	6.7
More than 30	10.6

TRAIL ATTITUDES AND PREFERENCES

User attitudes and preferences concerning characteristics and facilities of the Appalachian Trail were probed to guide the Forest Service in future selection of route, design of trail and shelters, and management of the trail itself and adjoining lands.

Visual Considerations

Views of undeveloped mountain ranges and pastoral scenes were strongly favored (table 5). Vistas are provided by natural causes such as fire, blowdowns, or rock outcrops or by management practices such as selective thinning and clearing. Although the hikers were enthusiastic about scenic vistas, sentiment was mixed as to whether vistas should be

Table 5.--Distribution of attitudes of Appalachian Trail users toward visual quality

Item	Attitudes[1]					Total cases
	SD	D	N	F	SF	
	Percent					Number
Views of undeveloped mountain ranges	0.5	0.8	4.7	21.8	72.2	385
Views of rural valleys	1.3	2.3	14.2	44.1	38.1	388
Views of industrial valleys	40.6	23.3	24.3	8.8	3.0	387
Occasional tree removal to provide overlooks	6.3	13.0	20.8	47.9	12.0	384
Seeing evidence of recent timber harvesting at close range	34.4	34.9	27.9	2.3	.5	384
Seeing evidence of recent timber harvesting at a distance	22.9	31.4	40.8	3.9	1.0	388
Passing a manmade reservoir	5.8	17.7	54.6	18.5	3.4	379

[1]SD = Strongly dislike, D = Dislike, N = Neutral, F = Favor, SF = Strongly favor.

provided by tree and brush removal (tables 5 and 6). At sampling locations where the trail ran entirely through the forest, the preference for cut overlooks was somewhat higher than the objection (table 6). However, at the Round Bald and Blood Mountain locations, where natural views existed, the stronger reaction was opposition to the practice. In areas where natural overlooks do not exist, most hikers probably would not object to an occasional natural-appearing cut overlook. Natural vistas should be taken advantage of where possible.

Table 6.--Distribution of preference for cut overlooks at each sampling location

Question: Would you favor removal of trees and brush to provide overlooks?

Response	Location						Entire sample
	Cornelius Creek	Monster Rock	Round Bald[1]	Deer Park Mountain	Blood Mountain[1]	Rock Gap	
	Percent[2]						
Yes	53.5	55.5	30.1	46.7	37.4	57.2	41.9
No	38.0	38.9	60.2	40.0	47.7	36.7	46.9
No opinion	8.5	5.6	9.7	13.3	14.9	6.1	11.2
	Number of cases						
Total	71	18	93	15	174	49	420

[1] Locations with natural views.
[2] Chi square = 20.59. Statistically significant at the 0.025 level.

Hikers expressed dislike for viewing from the trail industrial valleys, timber harvesting, and resorts. In the Southern Appalachian Mountains most lakes are reservoirs, cultural rather than natural features. The question of the trail passing by a reservoir did not elicit strong response. As many opposed it as favored it, but the majority were neutral (table 5).

Sounds

Even though a screen of vegetation prevents viewing of autos and chain saws, hikers strongly opposed hearing the sounds of these machines on the trail (table 7).

Table 7.--Distribution of attitudes of Appalachian Trail users toward sounds

Item	Attitudes[1]					Total cases
	SD	D	N	F	SF	
	Percent					Number
Hearing the sound of autos	38.9	38.9	19.4	1.8	1.0	388
Hearing the sound of a train	24.3	30.7	36.2	7.2	1.6	387
Hearing a chain saw	42.3	38.5	18.1	.8	.3	387

[1] SD = Strongly dislike, D = Dislike, N = Neutral, F = Favor, SF = Strongly favor.

Trail Width

Historically the Appalachian Trail has been, where possible, a simple footpath through the woods, sufficiently wide for a single hiker. Some sections of the trail are over old woods roads and provide diversity for the eye and the opportunity to walk beside a companion. Hikers interviewed generally agreed with the current practice. Strongest sentiment favored a trail of single-hiker width, this preference increasing with experience (table 8).

Table 8.--Distribution of trail width preference, by experience level

Trail width	Experience level		
	Low	Moderate	High
	Percent[1]		
Single file	31.8	51.6	55.6
Two abreast	32.6	16.4	14.3
Varying	35.6	32.0	30.1
	Number of cases		
Total	132	159	136

[1] Chi square = 22.67. Statistically significant at the 0.0005 level.

Grade

A wide variety of trail conditions exists in the southern National Forests. Some mountains are ascended by a smooth trail of gentle grade that by switchbacks wends its way to the top. Some mountains extend a challenge to those who climb their steep and sometimes rocky paths.

It is difficult to determine a hiker's true reaction to steep climbs. Many hikers may never have analyzed their feelings and reactions to physical exertion as it relates to their entire trail experience. A variety of questions regarding steep and difficult sections was asked of the hikers.

When asked their attitudes toward what seemed to them a steep climb, 24 percent of the hikers disliked it, 35 percent were neutral, and 41 percent favored it. There was no significant relationship with experience level, but attitudes toward general physical exertion while hiking were related to experience level. The majority of all three levels favored it, and, as experience increased, favorable reaction increased (table 9). Attitudes toward providing side trails to bypass rough or steep sections were related to experience. Fewer of those with high experience favored side trails than those with moderate or low experience (table 10).

Table 9.--Distribution of attitudes of Appalachian Trail users toward physical exertion, by experience level

Experience level	Attitudes[1]			Total cases
	D	N	F	
	Percent[2]			Number
Low	14.4	21.2	64.4	118
Moderate	8.1	24.3	67.6	148
High	5.2	14.7	80.1	116

[1]D = Dislike, N = Neutral, F = Favor.
[2]Chi square = 11.11. Statistically significant at the 0.05 level.

Table 10.--Distribution of attitudes of Appalachian Trail users toward side trails to bypass rough or steep sections, by experience level

Experience level	Attitudes[1]			Total cases
	D	N	F	
	Percent[2]			Number
Low	11.2	37.1	51.7	116
Moderate	12.6	31.8	55.6	151
High	19.1	43.5	37.4	115

[1]D = Dislike, N = Neutral, F = Favor.
[2]Chi square = 10.11. Statistically significant at the 0.05 level.

Responses of hikers when asked if they would like to have trail sections marked as to their difficulty were again related to experience level (table 11). Hikers with the least experience were the most enthusiastic; most respondents in the moderate and high experience levels said the signs "wouldn't matter."

Table 11.--Distribution of preference for marking trail sections as to their difficulty, by experience level

Question: Would you like to have trail sections marked at the access points as to their difficulty?

Response	Experience level		
	Low	Moderate	High
	Percent[1]		
Yes	47.4	40.9	21.3
Wouldn't matter	39.4	45.7	52.7
No	13.2	13.4	26.0
	Number of cases		
Total	137	164	127

[1]Chi square = 24.15. Statistically significant at the 0.0005 level.

Guidebooks providing detailed information on the trail route and shelter facilities are available. How many hikers knew what to expect through benefit of guidebook description, advice of friends, or prior use? As one might expect, those with the least experience had the least foreknowledge (table 12). In some cases, having no prior knowledge about the ease or difficulty of the trail section, they may have found that the trail section proved too difficult for them.

Table 12.--Distribution of knowledge of difficulty of the trail, by experience level

Question: Did you know what to expect as far as difficulty of the trail section on this hike?

Response	Experience level		
	Low	Moderate	High
	Percent[1]		
Yes	26.4	46.3	62.7
Had some idea	41.5	40.9	29.4
No	32.1	12.8	7.9
	Number of cases		
Total	140	164	126

[1]Chi square = 48.52. Statistically significant at the 0.0005 level.

Shelters

Questions pertaining to shelters were restricted to those who had used them. These persons favored shelters to tents 3 to 1 (n = 194). Backpackers who may prefer tents to shelters, however, did not have a voice in this question if they had never used a shelter. In good weather 58 percent of the shelter users preferred sleeping out to using a shelter (n = 200).

Shelter capacity generally ranges from 5 to 12 persons. Most users prefer low-density camping, favoring seven persons or fewer. Listed below is the shelter capacity preference of shelter users (n = 198) when they were asked: What is the maximum number of persons a shelter should accommodate without lessening the enjoyment of your camping experience?

Response	Percent
Fewer than 6	41.4
6 to 7	27.8
8 to 9	16.2
10 to 11	7.6
12 to 16	3.5
More than 16	3.5

Three-sided shelters are found at 7- to 8-mile intervals along much of the Appalachian Trail.
(Photo courtesy of Zellie G. Earnest.)

Over the years, each National Forest in the Southern Region has independently developed its own shelter program. Shelter facilities, therefore, vary from forest to forest, lending a desirable diversity.

Shelters at the sampling locations on the Jefferson and Nantahala National Forests had wood floors upon which the hiker spread his sleeping bag. In the Chattahoochee National Forest there were shelters with wood floors and dirt floors. At the Cherokee and Pisgah National Forest locations, individual wire bunks were constructed in the shelters. The hiker indicated his shelter-style preference but was not given the opportunity to show what other facilities he had experienced. His checking of a category might therefore have been a matter of familiarity rather than of preference, though certainly several backpackers were familiar with more than one style. In general, the wood floor (45.9 percent) and the wire bunk (38.3 percent) met with greatest favor (n = 196). Dirt floors were preferred by only 11.2 percent and all other-type floors by only 4.6 percent.

Most shelters have a source of water and a fireplace, but some may have a picnic table with benches, toilet, garbage pit, register, bulletin board, wall maps, broom, fire rake, axe, and Smokey Bear posters. Shelter users were asked what conveniences they would like at a shelter; the feature in greatest demand was the fireplace (table 13). How much of this response was for cooking purposes and how much for the esthetics of a campfire or warmth was not determined. Nor was it determined how many backpackers carry their own sources of cooking heat. On some sections of the trail, finding enough firewood is a problem.

Table 13.--Shelter facility preferences of shelter users

Question: Which of the following would you like at a shelter?		
Facility	Response	
	Yes	No
	Percent	
Fireplace	77.1	22.9
Table	65.3	34.7
Benches	48.5	51.5
Toilet	41.8	58.2
Bulletin board	20.6	79.4
Tools	16.0	84.0
	Number of cases	
Total	202	

Tables at shelter sites were favored nearly 2 to 1. Some shelters have built-on "stand up" tables that are under the cover of the shelter roof. All tables in the study areas, however, were unprotected picnic-style tables with built-on benches. Preferences for benches were about evenly divided.

More shelter users did not want a toilet at a shelter site than did want one. Some persons may consider the structure an unnecessary intrusion on the back-country environment; others may have found toilets in unpleasant conditions. In some areas, hikers misused them to dispose of garbage. This subject requires further study and an intensive educational program.

Hikers showed little desire for bulletin boards or tools.

The data indicate that most backpackers are not "convenience oriented." Generally, they request only the facilities necessary for their cooking activities, favoring little development of the shelter site.

Horse Use

Horseback riding generally is not prohibited on National Scenic Trails. Footway standards in some areas preclude the practical use of horses. Opinions vary among trail land managers as to the compatibility of hikers and horses on the same trail.

In this study, hikers were first asked whether they had been on a trail in the Southern Appalachian Mountains that had recently been used by horses. If the answer was affirmative, hikers were asked to indicate their opinions of horse use of the Appalachian Trail. There was a significant relationship between experience level and contact with horses as well as opinions on horse use (table 14). Highly experienced hikers objected 2 to 1 to horse use. The data suggest that most hikers begin with neutral feelings toward horse use, but with increased exposure to horses, begin to object to their use of the Appalachian Trail. The question of horse use was posed in another way. Trail users were asked their attitude toward following a horse party. This question was more graphic. While a hiker might say that he had no objections to horses using the trail, he might be forced to admit that he would not personally enjoy following a party of them. Shown below are attitudes of trail users (n = 387) toward following a horse party:

Attitude	Percent
Strongly dislike	42.2
Dislike	33.6
Neutral	20.9
Favor	2.8
Strongly favor	.5

Table 14.--Opinions on horse use on the Appalachian Trail, by experience level

Question: Have you ever hiked on a trail in the Southern Appalachians which had recently been used by horses? If yes, do you object to horse use of the Appalachian Trail?

Response	Experience level		
	Low	Moderate	High
	Percent[1]		
Haven't seen	92.1	64.9	35.2
Have seen, object	3.6	15.6	44.0
Have seen, don't object	4.3	19.5	20.8
	Number of cases		
Total	139	154	125

[1]Chi square = 104.27. Statistically significant at the 0.0005 level.

Hunting

A portion of this study was conducted during the hunting season. Numerous shell cases were found on the trail, and hunters were seen. When asked their attitude toward hunting on the Appalachian Trail, 63 percent of the hikers opposed it, 15 percent favored it, and 22 percent felt neutral (n = 387).

Hiking Density

Hikers were asked their attitudes toward encountering certain numbers of other hikers in the course of a day. Those hikers with more experience expressed stronger preference for low-density hiking (table 15).

Table 15.--User attitude toward encountering other hikers on the trail

Item	Experience level	Attitudes[1]			Total cases
		D	N	F	
		Percent			Number
Encountering as many as 30 hikers in a day[2]	Low	41.0	46.2	12.8	117
	Moderate	48.6	33.8	17.6	148
	High	66.7	19.7	13.6	117
Encountering as many as 10 hikers in a day[3]	Low	9.4	49.6	41.0	117
	Moderate	18.4	46.3	35.3	147
	High	22.4	46.6	31.0	116

[1]D = Dislike, N = Neutral, F = Favor.
[2]Chi square = 21.43. Statistically significant at the 0.0005 level.
[3]Chi square = 8.00. Statistically significant at the 0.01 level.

CONCLUSIONS

Differences among users should be recognized. A new interest in hiking is bringing a wave of young people to the trail, but parents and even grandparents also backpack. The Appalachian Trail users studied did not share a common type of childhood environment, nor are their present living environs similar. Some users prefer to hike with friends, others with family, still others with just one companion. Some prefer to walk slowly and cover little ground while others find satisfaction in pressing on. Some hike out to a scenic spot for the day, returning by the same route. Others find adventure in passing through the diverse zones of forest life as they traverse many miles of Appalachian Trail.

Yet Appalachian Trail hikers do share many common attributes. Whether with son or spouse, friends or family, most hikers prefer to travel in small parties. They often enjoy meeting other small parties but do not enjoy hiking on a crowded trail. For the most part, they are highly educated.

User opinions and attitudes were often related to hiking experience. Experience rating was significantly related to opinions about trail width, physical exertion, side trails to bypass steep sections, stone steps at steep ascents, encountering other hikers, resort development near the trail, marking sections for difficulty, and transistor radios on the trail. In most of these situations, however, there was a trend rather than wide polarization. In general, those with more experience expressed stronger preferences for quiet and solitude, a natural footway, and a minimum amount of development.

Hikers were not significantly stratified in most other opinions. At all experience levels they favored views of mountains and countryside but disliked seeing or hearing industrial valleys, timber harvesting, and roads. They favored cooking trailside meals, drinking from mountain streams, and packing their trash out. They preferred small shelters with few facilities. They favored natural materials to keep the footway dry on wet sections. They considered horse use and hunting incompatible with Appalachian Trail hiking.

Preferences for cutting scenic overlooks and for shelter styles were related to specific sampling locations. Where there were natural views, sentiment was negative toward cutting overlooks; there was more approval in heavily forested areas. With respect to shelter styles, hikers tended to favor the type in the forest where interviewed.

Through questions on attitudes, preferences, motivations, user characteristics, and factual hiking information, this study defined some of the unique attributes which attract the user to the Appalachian Trail--the opportunity to hike for as long as he likes, the physical and mental challenge offered by a mountain trail, the opportunity for back-country and primitive camping, the respite from the civilized world, the esthetic qualities of a natural environment.

The interests of the Appalachian Trail user, then, can best be served by managing the trail and the lands through which it passes to protect these qualities. Where attitude or preference is a function of hiking experience, the views of the more experienced hikers should receive added consideration regarding a management decision. These persons are more dependent upon the unique characteristics of the Appalachian Trail, and for them there are few alternatives, if any, to which they can turn to meet their recreational needs. On the other hand, those persons more desirous of facilities such as wide nature trails, campsites with conveniences, picnic spots or similar developments do have other alternatives.

The Appalachian Trail serves a wide range of users, but it cannot meet the needs of all trail users. Total user satisfaction could be maximized through protection of Appalachian Trail attributes and by the creation of more developed facilities off the trail as they are needed. The convenience-oriented trail user could be served through a more extensive trail network in areas peripheral to or separated from the Appalachian Trail. This system could include easier trails, improved campsites, loop trails, and trails that could connect with the Appalachian Trail. Managers could best meet the needs of all trail users through regional planning which would take advantage of the broad spectrum of environmental opportunities.

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Murray, Judith Buckley
1974. Appalachian Trail users in the southern National Forests: their characteristics, attitudes, and management preferences. Southeast. For. Exp. Stn., USDA For. Serv. Res. Pap. SE-116, 19 p.

Questionnaires filled out by a sample of Appalachian Trail users reveal that preferences for solitude, a natural footway, and minimum development increase with degree of hiking experience. Most hikers travel in small groups and prefer not to encounter large groups. Most Appalachian Trail users are highly educated.

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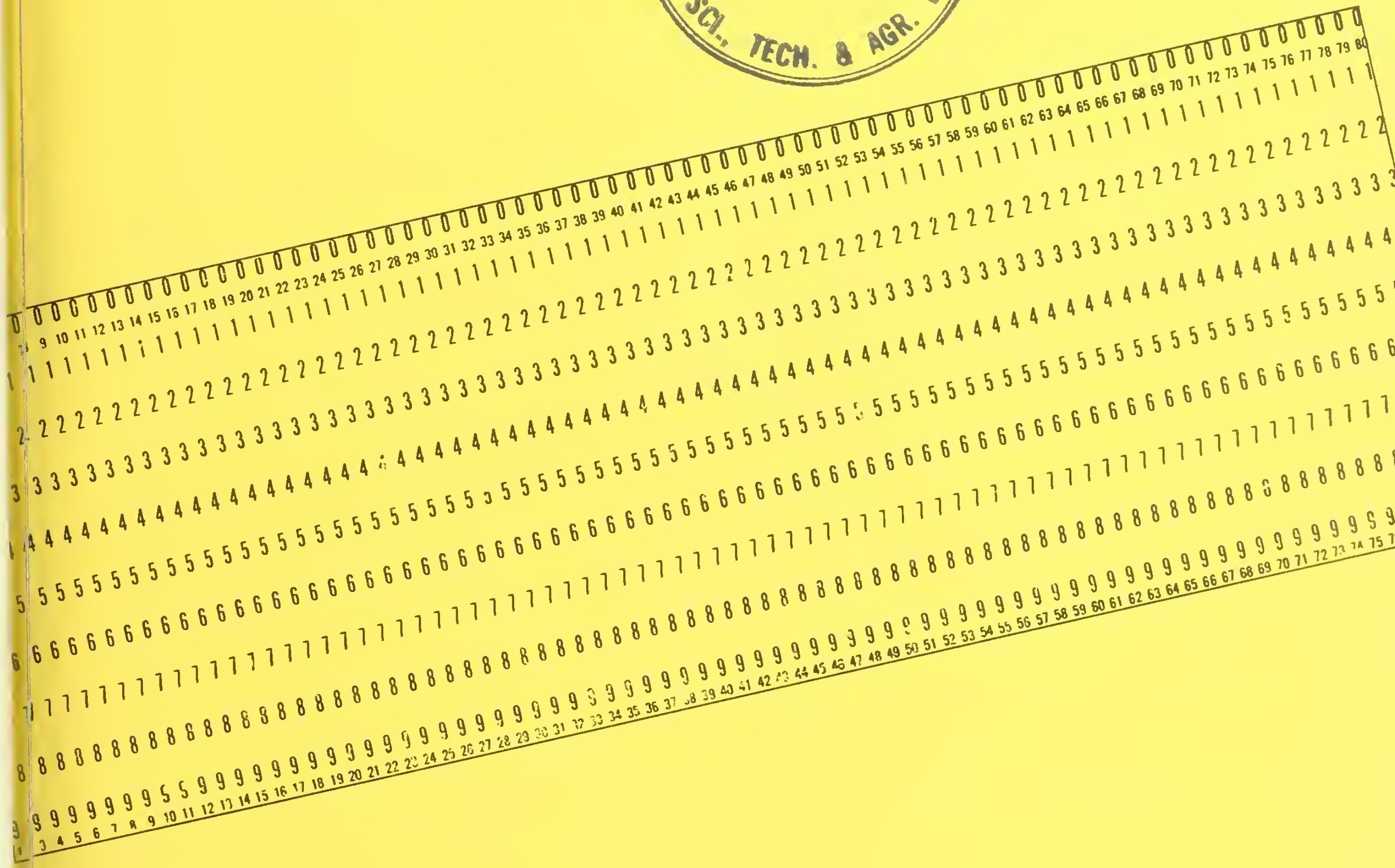
U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

USDA Forest Service Research Paper SE-117 August 1974

STX 3-3-73: Tree Content and Value Estimation Using Various Sample Designs, Dendrometry Methods, and V-S-L Conversion Coefficients

by
L.R. Grosenbaugh



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CONTENTS

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STX 3-3-73: Tree Content and Value Estimation Using Various Sample Designs, Dendrometry Methods, and V-S-L Conversion Coefficients

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================================ SUMMARY ================================

Program STX 3-3-73 (written in '66 ANSI Fortran) processes trees selected with equal or unequal probability by a wide variety of individual-tree or geometric cluster-sampling designs (single-stage strip, plot, line, point, list, 3P or multi-stage combinations thereof along with photo or remote-sensed information). Selected trees may be measured by mechanical calipers and/or tape or by any of the available standing-tree dendrometers (short-base rangefinder, variable-base rangefinder-caliper, etc.). Input consists of stem measurements or a trio of readings from a dendrometer, along with visible quality and defect assessments, plus whole-tree conversion coefficients obtained from felled-tree studies if appraisal information is desired. Results are expressed in primary units of measure (volume, surface, length with or without bark) by various tree, quality, and defect classes so that product-outturn and realization values may be obtained efficiently.

Options allow projecting stem and/or bark beyond the last actual measurement by several extrapolative techniques (linear, asymptotic, etc.). Dummy subroutines for dendrometry and extrapolation permit users to employ dendrometry or projective techniques in addition to those already programmed.

Either U.S. or S.I. (metric) units of measure are accepted as input. The user may specify that output summaries are to be in the same units as input, or that U.S. inputs are to be converted to S.I. output summaries, or vice versa.

An option called "frequency-balancing" has been newly incorporated into the program. It provides for least-squares adjustment of 3P estimates of individual sample-tree frequency so that the sum of adjusted estimates equals the population count, a first-stage sample estimate thereof, or some arbitrary count. This frequency adjustment is achieved with no change in the sample estimate of aggregate KPI or aggregate tree volume.

The current version of the program contains its own Fortran sort/merge and requires only 45 K words (180 K bytes) if the designed overlay structure is used. The program will require considerably more storage if overlay is not used, and will run less efficiently if virtual storage is used.

Input data format has remained essentially unchanged since the initial version of the program. 3 blank control cards must now be appended to the 5 control cards needed for the 1-10-64 and 5-1-67 versions. 2 blank control cards must now be appended to the 6 control cards needed for the 1-1-71 and 2-22-72 versions under major input option 1; calculation of control cards 3 and 4 (now supplemented by control cards 7 and 8) under major input option 2 is considerably different, however. Tree and dendrometer card formats have remained unchanged since 5-1-67.

============= FREQUENCY, PROBABILITY, SAMPLE STRUCTURE, COMPUTATION ===========

No matter how many stages are involved in the design of a probability sample, each tree ultimately selected for measurement represents some estimated number of trees in the population. This real number will be called FREQ (for estimated frequency). Its computation by STX 3-3-73 depends on certain quantities or symbols input on control cards and individual tree cards, and these depend on sample structure and value of probabilities assigned.

Two integers separated by a blank or a plus sign and appearing on the right-hand portion of control card 2 specify major design parameters applicable to all strata of a given data set. If the separator (called JZ) in column 65 is a blank, all input must be in US units of measure, but if it is the plus symbol (+), input must be in SI (metric) units of measure. The first of the two integers (called IQ) must appear in columns 56-64 of control card 2, and it is understood to be positive unless explicitly preceded by a minus sign. Blank or zero IQ will be program-transformed to unity. The second of the 2 integers (called LS1) must appear in column 66 of control card 2. It should be a positive integer--1, 2, 3, or 4. Blank or zero LS1 will be program-transformed to unity, and any digit greater than 4 will be program-transformed to 4.

Frequency computations are also affected by control cards 3 thru 8 (henceforth called CC3-CC8). These each contain nine 8-digit numbers (one for each of 9 possible strata) that can vary by stratum. CC3 and CC4 contain integers, while CC5-CC8 contain real numbers. To avoid subscripts, future discussion of CC3-CC8 will assume that there is only a single number for a single stratum on each card, but extension to the case with more than 1 stratum is obvious.

Lastly, frequency computations are affected by quantities on tree cards--a separate card should be input (at least initially) for each tree individually considered in the sampling or measuring process. Six quantities on each tree card will be discussed--KPI, LST, CERT, DBH, XTRA, XTRB. The first 3 are integer, while the last 3 are real.

The above inputs must be supplemented by program-executed counts and aggregations separate for 3 sampling classes (CERT may contain =, *, or blank) and possibly 9 strata (LST may contain digit 1 thru 9). The symbol = denotes pre-3P selections (called sure-to-be-measured trees), the symbol * denotes 3P selections (called 3P-measured trees), and the symbol blank denotes 3P rejections (called 3P-predicted-only trees). Program-computed tree volumes are also needed in frequency calculations if frequency-balancing has been specified by inputting LS1 = 3 or 4, but volume will not be discussed here.

IQ is a major parameter that specifies whether or not point-sampling has been employed in the design. A positive IQ causes CC6 and XTRB each to be program-transformed to unity, regardless of their input value; this is convenient for pure 3P designs or simple point-3P designs (no prior stages), but not for multistage designs. A negative IQ allows specification of CC6 and XTRB values on input, and is appropriate not only for pure and simple designs, but for a wide variety of multistage, cluster-sample designs. An IQ that is blank or zero will be program-transformed to a positive unity. Whenever IQ is plus or minus one, a derived constant factor QI is set to 1.0 by the program, as is the derived tree-variable divisor PBI. Hence, when IQ is ±1, QI/PBI will constantly be 1.0, a value appropriate to a wide variety of designs that do not employ horizontal point-sampling with an angle gauge. Whenever IQ is something other than plus or minus one, the derived constant factor QI is program-computed as the absolute value (IQ/100) if input is in US units (JZ blank) or as the absolute value (IQ/1000) if input is in metric units (JZ+). The derived tree-variable divisor PBI is program-computed as tree basal area (BA) in sq. ft. or sq. meters (depending on JZ), so that QI/PBI becomes QI/BA, appropriate for horizontal point-sampling if QI is unity, gauge basal area factor, or that factor multiplied by acres or hectares per point.

As was noted earlier, LS1 must be either 1, 2, 3, or 4. When LS1 is 1, tree cards must be input for 3P-rejected as well as 3P-selected trees to obtain an adjusted 3P estimate. CC3, CC4, CC7, CC8 will be ignored and can be left blank, although appropriate values for these cards will be calculated and output for possible future use when LS1 is changed to 2 or 4.

When LS1 is 2, no tree cards for 3P-rejected trees should be input, but counts and aggregate KPI for such trees must be included with similar counts and aggregate KPI of sure-to-be-measured and 3P-selected trees on CC3, CC4. Unless IQ is 1, some estimate of population aggregate PBI*KPI/QI must also appear on CC8; this estimate can be the program output of an earlier run with LS1=1, or it can be based on arbitrary but presumably better information obtained from an earlier complete enumeration or independent sample. Large difference in date or subjective bias in assignment of KPI would cause many independent estimates to be of doubtful value, since the new estimate of population aggregate PBI*KPI will be forced to equal QI*CC8.

When LS1 is 3, input and processing are the same as when LS1 is 1, but in addition, estimated frequencies for individual 3P sample trees are adjusted so that their sum balances the complete enumeration or pre-3P estimate of population frequency, without changing estimates of population aggregate PBI*KPI or aggregate volume.

When LS1 is 4, the same processing occurs as when LS1 is 2, but in addition, estimated frequencies for individual 3P sample trees are adjusted until their sum balances QI*CC7 without changing estimates of population aggregate PBI*KPI or aggregate volume. This is the only situation where CC7 actually is used in frequency computations--it can be left blank if desired when LS1 is 2, although it is good practice to input whatever program-computed values for CC7 were output from initial run where LS1 was 1.

Although parameters PRBS (or KZ) and KQ for the random integer generator and NSTR denoting maximum number of strata allowed also appear on control card 2, they are used only to edit input data and do not enter directly into frequency computations. If PRBS is needed in specification of an unadjusted 3P sample design, it must be included with any other needed factors whose product is input as CC6.

Since CC6 is so important (although only available when IQ is negative), it will be discussed next. It specifies a factor constant for all trees in a given stratum (but possibly varying by stratum) that appears in frequency computations whether or not point sampling is involved. In fact, when IQ=-100 (US) or -1000 (metric), QI is 1.0 so all point-sampling factors must be multiplied together and input as CC6. In other situations CC6 can specify blowup factors for plot sampling, KZ for unadjusted 3P sampling, gauge-factors for line-sampling, acres-per-point or acres-per-chain factors, correction factor for exact QI or for double sample, conversion factors in multistage sample to transform relative probabilities to absolute probabilities (allowing use of relative probabilities in XTRB on tree cards), or products involving these quantities. A negative CC6 for the first stratum specifies that this negative value be converted to a positive value and input as CC6 constant for all strata. Otherwise negative, zero, or blank values of CC6 will be program-transformed to unity, as will any value of CC6 when IQ is positive.

Tree-card quantities KPI, LST, CERT, DBH, XTRA, XTRB will be discussed next, because the remaining control cards involve multipliers, counts, ratios, products, or aggregates of these variable in various combinations.

KPI appears in columns 6-9 of each tree card, and is an integer divisor program-transformed to real in frequency computations involving a 3P-selected tree (*). If 3P-rejected trees (sample class blank) are input, their KPI and other tree-card variables must be input, but they are only aggregated and no frequency is computed for the rejected tree. Except for pre-3P selection (=), KPI may be regarded as the relative probability of selection in the last sampling stage. Trees subjected to the 3P sampling process are rejected when a random number (drawn subsequent to KPI assessment) exceeds KPI. KPI should never be used in selection of sure-to-be-measured trees (=), and if recorded will merely be aggregated. KPI may vary by tree, cluster, or stratum. It is usually a subjective tree volume or value estimate when IQ is ± 1; otherwise, it is usually an estimate proportional to total or merchantable height, since point-sampling is involved and effective PBI*KPI will be proportional to the product (D squared times H). A preliminary KPI may be multiplied by some integer before being recorded and compared with an appropriate random integer. This allows using a single random number list but sampling trees proportional to value rather than volume. Where this technique is used, each different value factor is applicable to a particular stratum and must be input on CC5. Each tree should be assigned to the stratum with which its value factor is associated. Where sampling with equal probability, all KPI in a given stratum must be identical, but CC5 and KPI can vary by strata. KPI must be at least unity and it cannot exceed KZ-1, but usually the upper limit (KQ) is set at some lower figure.

As was noted, LST in column 10 of the tree card is an integer identifying to which of 9 strata the tree belongs. Blank or zero LST is program transformed to unity.

CERT in column 11 of the tree card contains symbols rather than numbers, and indicates to which of 3 previously described sample classes the tree belongs. The program will not accept any sample class other than pre-3P-selected (=), 3P-selected (*), or 3P-rejected (blank).

DBH is real tree diameter at breast height (in inches or centimeters) appearing in columns 17-21 of the tree card. If point-sampling is involved, all 3 classes of sample tree <u>must</u> have DBH input, since squared DBH is needed for program-computation of the real divisor PBI, which is tree basal area (in square feet or meters). When no point-sampling is involved (IQ=±1), DBH may be omitted though this is undesirable; the second set of dendrometry measurements will be used in its stead.

XTRA is a real factor appearing in columns 42-56 of tree cards. It may vary by tree, cluster, or stratum, and may be the product of several factors acting together, such as slope and slopover correction factors in point-sampling. When IQ=-1, XTRA may be used for the direct input of population frequency represented by the sample tree (from earlier computations); this is especially useful when analyzing growth from repeated measurements of a permanently monumented sample tree. When LS1=2 or 4 and IQ is negative, XTRA may be used to input individual blowup factors for individual clusters (areas or points) subsampled by 3P technique. A prerequisite for this is a preliminary run with LS1=1 before cluster blowup factors have been punched in XTRA so that CC3, CC4, CC7, CC8 will be program-computed. Furthermore, unless special provisions in the design prevented the occurrence of zero samples in any cluster, both runs should employ cluster divisors of (1-PO) for all except sure-to-be-measured trees, where PO is the absolute probability that zero 3P samples might have been selected from the cluster. As will be seen below, it will usually be easier to include (1-PO) as a factor of XTRB than to include its reciprocal in XTRA. Where PO is nearly zero, it can be ignored. Blank or negative XTRA is positive unity.

XTRB is a real divisor appearing in columns 57-71 of tree cards. It may vary by the tree, cluster, or stratum, and may be the product of several divisors acting together, such as a series of pre-3P relative selection probabilities and the (1-PO) term discussed above. For each relative probability, a corresponding factor must be present in CC6 to convert relative probabilities to absolute. Thus, when a tree is a member of 3 nested clusters selected at progressively later stages, XTRB might be the product PI*PII*PIII* (1-PO), while CC6 would be $\sum$PI* $\sum$PII* $\sum$PIII/(N1*N2*N3), where PI, PII, PIII are relative probabilities of selection for each of the nested pre-3P clusters to which a given tree belongs, and $\sum$PI is the total sum of relative probabilities (rejected as well as selected) in the first stage, while N1 is the actual number of clusters selected in the first stage, etc.

A temporary set of symbols may help to describe counts and aggregations input on CC3, CC4, CC7, CC8. Let M denote the population of trees in a single stratum, or a real estimate of this integer. When every tree in the stratum is visited and the sampling is pure adjusted 3P, M will be the integer sum of NN pre-3P-selected trees (sure-to-be-measured) plus NS 3P-selected trees plus NR 3P-rejected trees. Where some form of pre-3P sampling takes the place of complete visitation, M=NN+NU+NS+NR, with NU being a usually unknown number of trees rejected by the pre-3P sample (e.g., a point-sample). Note that the NN are not automatically "sure"--they are only sure after being selected by all pre-3P stages, hence they require blowup except in a pure-3P sample. Note also that unless full tree-card information itemized above is recorded for the NR 3P-rejected trees, only unadjusted 3P subsample estimates are possible (whose blowup factor would be KZ, which must be input in CC6).

A brief summary of the major quantities or symbols affecting frequency calculations and where they may be input appears below. All 8 control cards must be input even when some are blanks. The last tree or dendrometer card must be followed by at least one card punched 9999 in columns 1-4.

CC1 merely inputs alpha-numeric identification of the problem

CC2 inputs IQ, JZ, LS1, (also NSTR, KZ, KQ).

CC3 inputs $\sum^{3}$(NN+NS+NR)

CC4 inputs $\sum^{NN}$KPI + $\sum^{NS}$KPI+ $\sum^{NR}$KPI } if LS1=2,4.

CC5 may input relative value factor, if sampling is proportional to value.

CC6 may input blowup or correction factor if IQ is negative

CC7 inputs estimate of M/QI if LS1=4.

CC8 inputs estimate of ($\sum^{M}$KPI*PBI)/QI if LS1=2,4.

Tree cards input KPI, LST, CERT, DBH, XTRA, XTRB (DBH may be blank if IQ=±1, CC7-CC8 may be blank if IQ=+1).

Note that CC3, CC4, CC7, CC8 should be blank when LS1=1 or 3. However, the program will compute estimates of these quantities from pre-3P sample stages and print them out on page 2 or subsequently for possible later use with LS1=2 or 4.

Program-computed values for CC3, CC4 when LS1=1,3 are simply unweighted counts and sums of KPI by stratum regardless of sample class, while values for CC7, CC8 are program-computed as follows:

$$\text{CC7}=\text{CC6}*\left[\sum^{NN}\frac{\text{XTRA}}{\text{XTRB*PBI}}+\sum^{NS}\frac{\text{XTRA}}{\text{XTRB*PBI}}+\sum^{NR}\frac{\text{XTRA}}{\text{XTRB*PBI}}\right]$$

$$\text{CC8}=\text{CC6}*\left[\sum^{NN}\frac{\text{XTRA*KPI}}{\text{XTRB}}+\sum^{NS}\frac{\text{XTRA*KPI}}{\text{XTRB}}+\sum^{NR}\frac{\text{XTRA*KPI}}{\text{XTRB}}\right]$$

The frequency of a pre-3P-sample tree (sure-to-be-measured or =) is always:

$$\text{FREQ}=\text{QI*CC6*}\frac{\text{XTRA}}{\text{XTRB*PBI}}$$

, without regard to KPI, if any was input.

The frequency of a 3P-sample tree (*) when LS1=1 is always:

$$\text{FREQ}=\text{QI*CC6*}\frac{\text{XTRA}}{\text{XTRB*PBI}}*\boxed{\sum^{NS}\frac{\text{XTRA*KPI}}{\text{XTRB}}+\sum^{NR}\frac{\text{XTRA*KPI}}{\text{XTRB}}}\bigg/\left[\text{KPI*}\sum^{NS}\frac{\text{XTRA}}{\text{XTRB}}\right]$$

The frequency of a 3P-sample tree (*) when LS2=2 is always:

$$\text{FREQ}=\text{QI*CC6}\quad*\quad\frac{\text{XTRA}}{\text{XTRB*PBI}}\quad*\quad\boxed{\frac{\text{CC8}}{\text{CC6}}-\sum^{NN}\frac{\text{XTRA*KPI}}{\text{XTRB}}}\bigg/\left[\text{KPI}*\sum^{NS}\frac{\text{XTRA}}{\text{XTRB}}\right]$$

Note that $\sum^{NS}$FREQ*PBI*KPI always equals QI*CC6* $\boxed{\text{boxed element}}$, which may involve an unadjusted 3P estimate, a 3P-adjusted 3P estimate, or an arbitrarily adjusted 3P estimate. Furthermore, after CC8 has been computed in the usual way with LS1=1, individual cluster 3P blowup factors can be hand-computed and incorporated into XTRA of each 3P-sample tree. A second run with LS1=2 and without tree cards for 3P-rejected trees (blank CERT) will now result in individual 3P blowup of these clusters, since the ratio of boxed to bracketed expressions will merely be 1/KPI. Where the probability of failing to obtain a 3P sample from each of these clusters is not negligible, (1-P0) should be incorporated into XTRB on both initial and subsequent runs. Cards 258-260 in subroutine ST22 must be temporarily deleted or "commented" to prevent every 3P sample tree from being listed as "suspicious".

The above-described procedure for individual cluster 3P blowup using augmented XTRA on a second run is an alternative to the standard procedure which relies on a pooling to obtain a single constant multiplier for 1/KPI (the pooling process is explicitly visible in the normal ratio of boxed to bracketed expressions). However, the standard procedure is quite satisfactory for multistage 3P designs where stages preceding the 3P or point-3P stages involve equiprobable selection criteria, and it may sometimes be adopted in other situations for reasons of simplicity. The standard procedure must <u>not</u> be used where a cluster has been subsampled by some method that is <u>not</u> equivalent to use of a single KZ-generated list of random numbers for a given stratum. The standard procedure would be inappropriate where a fixed number of samples (one,say) was selected with probability proportional to height from a cluster of point-selected trees; the alternative procedure <u>must</u> be used here.

When LS1 is 3 or 4, the same calculations of FREQ occur as when LS1 is 1 or 2, but in addition a giant vector of individual-tree frequency-balancing factors is computed (a different factor for each 3P-sample tree), subject to 3 constraints: estimates of population aggregate KPI*PBI and of population aggregate volume must not be changed, while the estimate of population frequency after balancing must equal pre-3P estimates or QI*CC7 (depending on whether LS1 is 3 or 4). Frequency-balancing results in a least-squares adjustment--the sum of squared individual-tree balancing factors is at a minimum--but there are an infinite number of alternative adjustment vectors that satisfy the 3 constraints. Occasionally, when 3P samples differ greatly from expectation, the least-squares adjustments result in negative frequencies for a few small trees. In this case, it would be desirable to be able to impose the additional constraint that no adjustment factor be as negative as -100%. The author has been unable to find or devise an algorithm that would guarantee finding the shortest solution vector satisfying all 4 constraints, although heuristic methods usually can find at least one such vector (not necessarily the shortest).

In general, frequency-balancing tends to utilize 3P sample information more completely, and to adjust a sample that departs from expectation so that its balanced frequencies more closely approximate KPI distribution of the population from which it was drawn, except when negative frequencies are obtained. Frequency estimates are definitely improved, while estimates of aggregate volume and aggregate KPI*PBI are unaffected by the balancing process.

Careful study of the 3 broadly applicable formulae for FREQ discussed earlier should result in identifying suitable input slots for design specifications appropriate to most multistage probability-sampling designs with equal or varying probabilities. IQ can be specified to ensure QI/PBI=1.0

for designs without point sampling, or QI/PBI=QI/BA with point sampling. CC6*XTRA/XTRB can be specified to describe the joint implications of all but the point-3P stages of most multistage probability-sample designs, and may even help specify elements of point or 3P sampling. KPI and either CC8 or tree cards containing information on 3P-rejected trees can be specified to describe 3P portions of the design, supplemented by augmented XTRA if individual cluster 3P-blowup is deemed necessary. Finally CC5 can specify multipliers used in assigning KPI so that different 3P sampling intensities prevail in different strata, although only a single list of random numbers is employed.

When arbitrary adjustment of estimates is desired with LS1=2 or 4, users should understand that CC6 directly affects estimates of frequency of sure-to-be-measured trees, but CC6 affects 3P-sample trees only in a complementary or residual fashion unless CC8 is appropriately modified. In an extreme situation where there are no sure-to-be-measured trees, frequency of 3P-sample trees is completely unaffected by CC6 when LS1=2 or 4. Of course, when LS1=1 or 3, changing CC6 affects sure-to-be-measured and 3P sample-trees identically.

Considerable insight into how various control card and tree card quantities affect individual and aggregate frequency and basal area estimates may be obtained by postulating a small set of tree cards that might reasonably be expected to have been drawn from a hypothetical population by a specific sample design. If each tree card is terminated by an asterisk in column 72, no dendrometer cards need be supplied. Appendix B, pp. 64-71, illustrates control cards, tree cards, and abbreviated output for a number of different sampling designs applied to a small population of trees on 1 acre. There are 3 non-point-sampling designs illustrated in IQ-1 (plot, line, pure 3P), 3 designs involving point-samples in IQ-C (all with QI=1.0 so that basal area factor and acres-per-point must be input as CC6), 2 point-3P designs in EK (both with LS1=2, one using program-computed CC8, the other using arbitrary CC8 known to be better than the previous program-computed value), 2 point-3P designs in EKFR (both with LS1=4 and frequency balancing but otherwise parallelling EK, one using program-computed CC7, the other using arbitrary CC7 known to be better than the previous program-computed CC7). Both EK and EKFR need dendrometer cards as well as tree cards, since frequency-balancing involves a volume constraint.

The hypothetical tree population was 110 trees on a single acre, with 60 being 16-ft. 6-inch trees, 40 being 24-ft. 12-inch trees, and 10 being 64-ft. 18-inch trees.

All examples labelled IQ-1 had IQ= -1 (no point sampling, QI=1.0, CC6 and XTRB available for use) and LS1=1 (no control card input of aggregates). XTRA has been used to input the number of trees having identical characteristics. This is generally a poor practice, since the preliminary report counts cards and ignores XTRA, but all subsequent blowup is correct, and in this situation the reduction in number of input cards helps make the illustrations more easily visualized.

In PLOT, 3 one-thirtieth-acre plots selected 11 sure-to-be-measured trees (=). CC6 specifies individual plot blowup factor times acres per plot = 30*1/3=10. There was no need to use XTRB or KPI.

In LINE, 3 chains of line through the acre using an angle gauge with horizontal line factor = 180 selected 17 sure-to-be-measured trees (=), with probability proportional to their DBH. Hence, diameter had to appear as XTRB. CC6 specified HLF* acres per chain = 180* 1/3=60. KPI was not needed.

In SS3P, a pure, single-stage adjusted 3P sample was taken with all 110 trees visited and each assigned a KPI that was recorded, so that probabilities could be input for 99 3P-rejected trees (blank CERT) as well as for 11 3P-selected trees (*). KPI was guessed D^2H, with D expressed in feet and H as number of 4-foot bolts. The random number generator has KZ=60, but this was not needed in frequency calculation. CC6 and XTRB were not needed and where left blank were implicitly unity.

All 3 examples labelled IQ-C had IQ=-100 (point-sampling, QI=1.0, CC6 and XTRB available for use) and LS1=1 (no control card input of aggregates). XTRA is again used to indicate the number of identical trees.

In PTEQ, 3 point-samples using an angle guage with BAF=1.9635 point-selected 93 trees. All trees were given an equiprobable KPI=8 and compared with a random number list generated by KZ=24, which resulted in 31 3P-selected trees (*) and 62 3P-rejected trees (blank CERT) whose indivudual probabilities could be input. Thus, this is a point-sample subsampled by an equiprobable 3P sample, CC6 is BAF* acres per point, and the adjusted 3P portion of the design is program-computed by aggregating KPI for both 3P selection and 3P rejections, and dividing by KPI*NS. CC6 is BAF* acres per point=1.9635*1/3=.654498. XTRB is not needed.

In PT3P, 3 point samples using an angle gauge with BAF=5.8905 point-selected 31 trees, all of which were assigned KPI= height and compared with random number list generated by KZ=24, which resulted in 11 3P-selected trees (*) and 20 3P-rejected trees (blank CERT). CC6 is BAF* acres per point= 5.8905*1/3=1.96350. Program-computed values for CC7 and CC8 will be given here, since they will be used in the second portion of EK and EKFR. CC7=110, and CC8=518.363 (exact value would be $660*\pi/4$).

In APT3, the acre has been subdivided into 3 equal areas and a photo guess of cubic volume on each has been recorded (guesses were 1000, 1000, 2000). Two sample areas were list-selected with probability proportional to guess (1000, 2000 were selections). A single point-sample using gauge with BAF=1.47263 selected 31 trees from one area, 62 from the other. These trees were 3P subsampled proportional to H using random numbers generated by KZ=24. On one area, 11 trees were 3P-selected, 20 3P-rejected. On the other area 22 trees were 3P-selected, 40 were 3P-rejected. CC6 was BAF* acres per point $*\sum$photoguesses/ number of sample areas=1.47263* (1/3)*(4000/2) = 981.75, with XTRB on selected trees and on rejected trees being the photoguess corresponding to where they were located.

The APT3 example above uses standard pooled 3P blowup with LS1=1. However, program computed CC3=16, CC4=168, CC7=110.000, CC8=518.364, and these could be used on a second run to individually blow up clusters (areas) selected with unequal probability; areas would still govern blowup computation if there were more than a single point on an area. The first individual area 3P-blowup factor is $\sum^{31}$H/11=264/11=24, and the other is $\sum^{62}$H/22=24. Since they are the same, individual cluster blowup would not change the estimate. However, if LS2 were set to 2, if cards for 3P-rejected trees were deleted from the deck, and if XTRA of remaining 3P-selected trees were multiplied by their appropriate blowup (24 for both areas), the alternate individual blowup would occur. 1-PO differs from unity only in the 8th decimal place and beyond for either area, so it can be ignored. If used, appropriate 1-PO should be multiplied by existing XTRB and used on both runs.

EK and EKFR each contain 2 illustrations, and have design parameters identical with PT3P given earlier, except for LS1 which is 2 in EK and 4 in EKFR to allow input of arbitrary aggregates on control cards and deletion of 3P-rejected tree cards. A somewhat less representative sample has been postulated (2, 3, 8, instead of 1, 4, 6) to illustrate the beneficial effect of using a better value for CC8 in EK, and better values for both CC7 and CC8 in EKFR. In the latter case, the improvement is much more evident in estimates of frequency, surface, and length than in estimate of basal area. Of course, volume remains unchanged.

1/ For a full discussion of horizontal point and line sampling see references (*2) and (*10). For a discussion of 3P and list sampling, see references (*4), (*5), and (*9). Simple two-stage point-3P sampling combines methodologies by dendrometering only a 3P subsample (selected with probability proportional to measured or guessed height) of point-selected trees (selected with probability proportional to squared DBH or basal area), so that dendrometered trees will have been selected with probability proportional to D^2H. The author was the first to exploit this very efficient but simple technique in STX 1-11-71.

1/ Numbers in parentheses preceded by an asterisk refer to literature cited, page 38

================================== DATA INPUT ==================================

Let us assume that STX has been compiled with constants appropriate to the installation and job in block data subprogram BLD (these are discussed later in the section called "Usage and Output"), and that appropriate conversion coefficients have been inserted in subroutine ST44 (these are discussed later in the section called "V-S-L Conversion").

Input data must directly follow the card or instruction that invokes execution of STX. Although currently such input is format-oriented, when extended Fortran standards are promulgated and implemented, the program can easily be modified to accept list-oriented, free-form input (field sequence and separation by blanks or commas will make columnar placement of field irrelevant).

Eight control cards discussed briefly in the previous section must precede all tree and dendrometry cards, and these in turn must be followed by one or two cards punched 9999 in columns 1-4. One such card serves to separate each job in a stack of several jobs, and a pair of such cards terminates program execution and returns control to the system monitor.

The 8 control cards are illustrated in figures 1 thru 3 of Appendix A. Columns 1-4 of CC1 and CC2 should be blank. Column 5-68 of CC1 can be used for alphanumeric description of the job, while column 73-76 is useful to input a brief alphanumeric job identifier that will label each page or card of output. It is wise to use columns 77-80 for sequencing the 8 control cards, but this is not mandatory.

Column 5-16 of CC2 should contain the initials of the person responsible for processing the job and the date processing started.

Figures 1-3 are self-explanatory when coupled with the previous section and the formats and lists shown in figure 3, except for dendrometer parameters (B, Q, U, G), 3P sample parameters (PRBS, KQ), and job options (LS1 thru LS6). These will be discussed below.

B is the short-base-rangefinder dendrometer optical base in inches or centimeters.

Q is the sine of 1/2 the maximum deflection caused by counter-rotation of short-base-rangefinder dendrometer prisms away from neutral position.

U is the constant amount of deflection (in degrees) built into a given short-base-rangefinder dendrometer and algebraically added to the variable deflection caused by prisms' counter-rotation.

G is the refractive index of the glass used in the counter-rotating prisms.

B, Q, U, G may be left blank if no short-base rangefinders are employed.

PRBS (or KZ or K+Z) is the total number of opportunities for selection or rejection specified by the last-stage 3P or list sample design (maximum is 9999 if output overflow is to be avoided).

KQ is the largest assignable relative sampling probability in a last-stage 3P or list sample design (equivalent to the integer number of non-null opportunities specified by the design); KQ must be a positive integer greater than 0 but less than KZ.

PRBS and KQ may be left blank if no last-stage 3P or list sample is employed (i.e., if all measured trees are sure-to-be-measured (=)).

Values for B, Q, U, and G used in examples in the appendices have been derived by the author from rather cryptic design parameters provided by the manufacturer of the only commercially available shortbase-rangefinder dendrometer (instead of from empirical calibration procedures). Values are B=8.000 inches, Q=.01964673, U=-1.1905 degrees, and G=1.5658. If metric input is specified, B=20.320 centimeters but Q, U, G are the same.

Dendrometry theory and trigonometry are discussed in considerable detail in reference (*3).

The 6 job options (LS1 thru LS6) specified in columns 66-71 of CC2 provide the following alternatives:

FIRST (66)	0 or 1	Input cards must be punched for all trees (including nonmeasured trees assigned predictions only), and CC3, CC4, CC7, CC8 should be left blank.
	2	Input cards must be punched only for measured trees, but CC3, CC4, CC7, CC8 must contain aggregates as specified on page 6.
	3	Like 1, but specifies frequency-balancing in addition.
	4 or 4+	Like 2, but specifies frequency-balancing in addition.
SECOND (67)	0 or 1	Processing will cease after ST11 has calculated and printed preliminary report.
	2 or 2+	Processing will continue beyond ST11 if no fatal errors occur.
THIRD (68)	0 or 1	No individual tree detail will be printed.
	2	Individual tree detail will be printed.
	3 or 3+	Individual log and tree detail will be printed.
FOURTH (69)	0 or 1	No detail cards will be punched as part of output.
	2	Tree detail cards will be punched as part of output.
	3 or 3+	Log detail cards will be punched as part of output.
FIFTH (70)	0 or 1	No log and tree detail will be written on tape JX for later grade-yield and realization processing by PROD.
	2	Log and tree detail will be written on tape JX and will be processed by PROD if no fatal errors have occurred, but only class-grade subtotals of the full log sort will be printed.
	3	Like 2, but prints full sorted log detail prior to class-grade subtotals.
	4	Like 2, but prints within-tree sorted subtotals prior to class-grade subtotals.
	5	Like 3, but prints within-tree sorted subtotals prior to full sorted log detail.
	6 or 6+	Prints within-tree sorted subtotals but omits full log sort.
SIXTH (71)	0	No further processing by PROD or ST44.
	1 thru 9	Conversion coefficient matrices in ST44 will be used to convert V-S-L to product outturn and realization values, but search for appropriate species matrix never extends beyond number of matrices specified in column 71.

Actual data input following the 8 control cards involves only 2 card forms--tree cards and dendrometer cards. A special form of tree card that is blank except for tree number punched 9999 is used as a job-end card for each of a group of similar jobs and also as a final signal for termination exit of the program (no more jobs or sets of data to process). Obviously, no tree number higher than 9998 can be assigned to real trees. Each tree card must be immediately followed by its own dendrometer cards (if any are required), starting with the lowest (or stump) measurement.

Tree input card shown in Figure 4 of Appendix A is largely self-explanatory. Column 11 denotes tree sampling class. Thus, a blank column implies a 3P-predicted-only tree, (*) indicates a 3P-sample tree, and (=) flags a sure-to-be-measured tree.

The three tree-options on each tree-card are specified by punching of columns 23-25, thus--

FIRST (23)	0 or 1	Tree measured by short-base-rangefinder and SBRD (1 causes coded SINELV to be reduced by unity).
	2	Tree measured by linear devices and DLIN.
	3	Tree measured by optical calipers and OPCL.
	4	Tree measured by optical fork (OPFK NOW A DUMMY).
	5 or 5+	Tree measured by other device (OTHR NOW A DUMMY).
SECOND (24)	0 or 1	Constant ratio (D.I.B.)/(D.O.B.) assumed = (D.B.H.I.B.)/(D.B.H.O.B.).
	2	Hyperbolic ratio (D.O.B. - D.I.B.)/(D.O.B.) assumed = QUAN/ (DENO-D.O.B./D.B.H.O.B.) all multiplied by (D.B.H.O.B. - D.B.H.I.B.)/(D.B.H.O.B.).
	3 or 3+	Hyperbolic ratio (D.I.B.)/(D.O.B.) assumed = (first bark option)*9./(10.-D.O.B./D.B.H.O.B.).
THIRD (25)	0 or 1	Unseen but usable material above last measured section of tree estimated by convex-conic-concave projections depending on computer analysis of taper behavior.
	2	Unseen but usable material above last measured section of tree computed from guessed conic taper rate, length.
	3 or 3+	Unseen but usable material above last measured section of tree estimated from user-supplied functions FFH3, FFS3, FFV3.

The value of the integer in the first tree option (called METH) specifies what method of dendrometry has been used to measure the tree. A Barr and Stroud FP-9 or FP-12 is implied by blank or zero, although such default value could just as easily be reassigned to the FP-15 (on card ST11 127) if no FP-9 or FP-12 instruments are used. A Barr and Stroud FP-15 (which has a coded SINELV scale increased by unity) is implied by '1'. Linear measurements (tape or caliper) are implied by '2'. A variable-base rangefinder-caliper (Zeiss Teletop, Breithaupt Todis, etc.) is implied by '3', although subroutine OPCL must be modified if SINELV is not input as 100 plus degrees and tenths, with explicit decimal. Dummy subroutine OPFK is implied by '4', and dummy subroutine OTHR by '5'. A user can easily expand these dummy subroutines to handle various types of optical fork or even volume regressions or volume-table lookups (though the last two are backward steps).

The value of the integer in the second tree option (called MBK) specifies how bark thickness is to be projected from measured or assumed bark thickness at breast height. The default option (blank, zero, or '1') implies that bark thickness is a constant proportion of DOB throughout the length of the tree. A '2' implies that the proportion of bark diminishes hyperbolicly up the tree. A '3' implies that the proportion of bark increases hyperbolicly up the tree. If the sum of single-bark thicknesses punched in BKA and/or BKB is negative, no reduction for bark is made and the bark projection options are ignored. If no bark thickness is punched in BKA, double-bark thickness is assumed to be (1.0-RDE)*DBH. Otherwise, double-bark thickness at breast height is calculated as twice single-bark thickness if only BKA or BKB is input, or the sum of BKA + BKB if both are input. The value of RDE (set in block data subprogram BLD) is currently .90, but may easily be changed. QUAN and DENO (currently 1.0 and 2.0) may also be reset in BLD--they specify the asymptotes of the right hyperbola in the second bark projection. To change asymptotes of the third bark projection, substitute different literals for 9.0 and 10.0 in function FFB3. If desired, the user could reprogram function FFB3 to implement some other method of bark projection. Note that for projections '2' and '3', the second hyperbolic parameter should be one greater than the first, though they need not be integers. In Appendix B (example XMPL), tree numbers 3, 223, 233 illustrate the different effect on the same tree of having MBK=1, 2, 3, while tree 203 illustrates the effect of punching negative bark thickness when inside bark measurements have been input (no reduction for bark occurs).

The value of the integer in the third tree option (called MUL) specifies what method of extrapolation will be used to project the stem for unseen length beyond the last measured diameter and height, if called for. However, no projection will occur unless a fictitious terminal FGRADS value of -999 immediately follows the last measured (positive) FGRADS value on the dendrometer card. Tree number 1113 in Appendix B (example XMPL) illustrates such a projection. When METH=0 or 1, an additional way of invoking stem projection is available--making terminal TGRADS and SINELV equal to preceding TGRADS and SINELV with terminal FGRADS equal to terminal TGRADS. Tree 285 in Appendix B (example XMPL) illustrates such a projection.

If MUL is blank, zero, or '1', the appropriate terminal FGRADS will invoke the convex-conic-concave projection. A '2' will invoke the conic projection, and a '3' will invoke whatever method the user wishes, but he must first expand dummy functions FFH3, FFS3, and FFV3 to appropriately compute unseen length, surface, and volume.

Theory and computational aspects of the convex-conic-concave projection are discussed in reference (*6). Exact volume and surface integrals are used for all projections. The convex projection uses a data-derived, 2-parameter hyperbola, and the concave projection uses a data-derived, 2-parameter parabola. The convex-conic-concave projection requires at least 4 measured heights and diameters before it can be invoked.

The fields labelled UMAXL and UDORT on the tree input card are left blank unless a fictitious set of dendrometer readings implying unseen, usable material has been recorded. Then, if the third tree option is punched '1', the program will compute uppermost unseen D.O.B. in inches or centimeters as (UDORT)*(DBH). If the third tree option is punched '2', the uppermost unseen D.O.B. is computed by converting UDORT*UMAXL to inches or centimeters and subtracting from the uppermost measured D.O.B. Such a conic projection treats UMAXL as unseen length in feet or decimeters and UDORT as the rate of taper in inches per foot or decimeters per decimeter of length. If UMAXL is left blank or zero when the third option is punched '1', the projection terminates only when calculated uppermost D.O.B. is reached; a positive, nonzero value for UMAXL, however, would be treated as an additional length limitation, and the projection would terminate when either the limiting length or the calculated uppermost D.O.B. was reached (whichever occurred first). If UDORT has been left blank despite the fact that dendrometer readings imply unseen material above last measured section, UDORT will be set equal to UDTRO, a parameter currently set at .45 but easily changed by recompiling BLD. Note that UMAXL should not be left blank if the conic projection has been specified--it would imply zero additional length. A conic projection may be made from a single measured diameter.

Triply forked tree number 264 in Appendix B (example XMPL) illustrates the first or standard option for handling unseen length. Tree number 274 illustrates the second option for handling unseen length, where the user specifies length and rate of taper for a simple conic projection; the tree is the same triply forked tree.

Two other fields on the tree card have default values that are occasionally convenient. If the column for total number of strata on the second control card is left blank or punched zero, it will be considered to be the same as having a (1) punched. Similarly, if the value stratum of the tree card is left blank or punched zero, it will be considered to be in stratum (1). Thus, where sampling is to be proportional to volume (rather than value), no stratification is needed and all value strata fields can be ignored or left blank. A maximum of 9 value strata may be used in column 10 to facilitate varying sampling intensity, but stratification for summarizations in columns 12-15 of the tree input card is practically unrestricted.

If IQ is blank, zero, or plus or minus one, a blank DBH field on a tree card will cause an estimate of D.B.H. to be supplied from the second set of dendrometer readings (the set next above the stump set), and the number of the tree will be recorded in the list of suspicious trees--also, the tree card punched for this tree will show zero basal area. When IQ implies point-sampling, omission of DBH is a fatal error.

After a tree card has been punched, with the column following the tree number either punched zero or left blank, up to 9 dendrometer cards (numbered sequentially in the column following tree number) may follow. The illustration in figure 5 of Appendix A is for observations made with a short-base-rangefinder dendrometer (FP-15). Tapes, mechanical calipers, optical calipers, and optical forks would use the same fields (some fields might be left blank), but variables would be interpreted differently. Dendrometer readings for each tree are processed by whichever one of the five subroutines is appropriate to the method used to measure the tree (SBRD, DLIN, OPCL, OPFK, OTHR), with coded SINELV being program-reduced by 1 if METH=1, and by 100 if METH=3.

The dendrometer card repeats the tree number and follows it with a within-tree card sequence number starting with 1 but never progressing higher than 9. Trios of dendrometer readings (TGRADS, FGRADS, SINELV) are then recorded, starting at the stump (or base) of the tree. The second trio of readings should measure D.B.H. Reference (*3) explains the meaning of these terms for short-base-rangefinder dendrometers. Readings progress upwards--note that this is opposite to the direction specified in the small exploratory computer program outlined in reference (*3). Associated with each trio of readings is a 2-character field (denoted as GAMATH in figure 5 and as GR in figures 6, 7) useful for describing external quality and defect between a particular diameter and the diameter next below it.

Dendrometer measurement of the two lowest diameters of a tree (usually stump and D.B.H.) is often made difficult by intervening brush. When initial TGRADS is recorded as a fictitious -999, SBRD and OPCL interpret initial FGRADS to be tape-measured stump diameter in inches or centimeters and tenths, and initial SINELV to be distance (in feet or meters with explicit decimal point) upwards to next tape measurement. Second TGRADS is ignored while second FGRADS is interpreted to be next tape-measured diameter (usually D.B.H.) in inches or centimeters and tenths, and second SINELV is interpreted to be distance upwards (in feet or meters with explicit decimal point) to place where dendrometer measurements can start.

Another feature solves a different problem. It is sometimes possible to sight a dendrometer at the tip of the tree and obtain a SINELV reading for SBRD or OPCL without being able to get TGRADS and FGRADS for the tip, yet an estimate of volume to the tip is desired. Volume, surface and length of the portion of the tree between this tip (given a nominal D.O.B. of .1 inch or centimeter) and the highest actually measured diameter will be computed if the terminal trio of dendrometer readings is recorded as -999, -999, SINELV to tip.

The two capabilities just discussed are both illustrated in Appendix B (example XMPL) by tree number 243 using SBRD, and by tree number 253 using OPCL.

Of the 3 dendrometry subroutines currently implemented, SBRD is by far the most complicated. When METH=0, it will process FP-9 and FP-12 short-base-rangefinder dendrometry data, and when METH=1 it will process similar FP-15 data. TGRADS is the amount of prism rotation (in grads and tenths, omitting decimal point) needed to obtain true coincidence, FGRADS is a similar rotation needed to obtain false coincidence, while SINELV is the signed sine of the elevation angle at the point where TGRADS and FGRADS were read if METH=0, or 1+SINE if METH=1. The decimal point can be omitted from instrumental readings if the implicit formats (see figure 5 in Appendix A) are appropriate. Tree number 1113 in Appendix B (example USMT) illustrates METH=0, while tree 2 in the same example illustrates METH=1.

When METH=2, subroutine DLIN will process linear diameter and length measurements made with mechanical or optical calipers and tape. Trees thus measured may be standing or felled, and TGRADS is always ignored. FGRADS is interpreted to be diameter in inches or centimeters and tenths, and SINELV is interpreted to be distance (in feet or meters with explicit decimal point) downwards to next diameter below. SINELV must be 0.0 for stump and bottom of each fork. The usual bark and unseen length projections are available. However, if it is desired to use measured D.I.B.'s without any hypothesis as to bark behavior, this can be done by the usual device of punching a fictitious negative bark thickness. Tree number 203 in Appendix B (example XMPL) illustrates DLIN with D.I.B.'s and negative bark for inside-bark volumes, while tree number 1113 in the same example shows the same tree with DOB reduced to DIB by measured positive bark. A negative bark punched for tree 1113 would have caused outside bark volumes to be computed.

When METH=3, subroutine OPCL will process readings made by a variable-base rangefinder dendrometer coupled with a hypsometer. Hence, it is appropriate for use with the Zeiss Teletop or the Breithaupt Todis, although currently SINELV is expected to be input as elevation angle in degrees and tenths (with explicit decimal point) plus 100 degrees. Reference (*11) discusses use of a modified Zeiss Teletop as a dendrometer. TGRADS must be slant range in feet and tenths or in decimeters and tenths. FGRADS must be diameter in inches or centimeters and tenths. The same bark, unseen length, stump, and tip options are available in OPCL as in SBRD.

Obviously, in addition to substituting appropriate subroutines for dummies OPFK and OTHR with METH=4 and METH=5, other subroutines could be inserted that would be invoked by METH=6, 7, 8, and 9, but the program would need to be appropriately modified.

If column 72 is left blank on a dendrometer card, it implies that the card is completely filled with 4 trios of dendrometer readings, and that the particular tree is being continued on a following card.

If column 72 is punched with an asterisk (*), it means that the last set of dendrometer readings occurs somewhere on that particular card, and that the next card should be a tree card for a new tree, or a terminating 9999.

If column 72 is punched with a plus sign (+), it means that a truncating set of dendrometer readings occurs somewhere on that particular card, but that more material for the same tree starting from a new 'bottom' (which might, however, be the same point on the tree as the previous truncation point) will occur on the very next card. This device allows changing position once uphill or downhill for better visibility during the measurement of a single-stemmed tree--here the first measurements from the new viewpoint recorded on the card following the card with the truncating plus sign should be of the same diameter on the tree as that which truncated the previous card when measured from the old viewpoint. The heights of diameters after truncation will all be measured above the new 'bottom' to which will be added the truncating height on the card with the initial plus sign. Tree number 243 in Appendix B (example XMPL) illustrates such a change of viewing point. When viewpoint is changed along the contour (with no change in base elevation), the truncation and plus procedure is unnecessary--the user goes right on up the tree as though he had not moved.

Trees with any number of forks above breast height can be handled by the truncation procedure. The single portion of the stem is truncated with the plus sign, then each fork except the last is measured and truncated with a plus sign. The tallest fork should ordinarily be left till last and should be terminated with an asterisk rather than a plus sign to show that no more material in that tree will be measured. Forked trees are flagged by an asterisk on printed or punched tree-total records. Tree numbers 264 and 274 in Appendix A (example XMPL) each have a triple fork above DBH.

Some users have found it desirable to be able to process nonconvertible, nondendrometered trees (such as culls) along with merchantable, measured trees, though of course such trees must be assigned to a separate stratum. STX can handle this quite easily. Where a cull stratum (or strata) has been specified, each cull must have a nonzero KPI, which can be fictitious or constant, but it cannot be omitted unless the cull is classed as sure-to-be-measured. Any sure-to-be-measured cull or cull qualifying according to 3P procedure must have a tree card containing at least stratum, sampling category, KPI, species, and D.B.H., with an asterisk in column 72. Tree numbers 302 and 3002 in Appendix B (example XMPL) illustrate this method of handling cull trees, but the method is also convenient for exploring sample designs by inputting expected numbers and sizes of trees that might have been selected for dendrometry by a proposed design; this is illustrated in Appendix B by examples IQ-1 and IQ-C. Unless an asterisk is punched in column 72, any tree card in sample class (=) or (*) must be followed by at least 1 dendrometer card, however.

Figure 6 in Appendix A illustrates a tally form suitable for recording 3P-predicted-only tree data, sample-measured or sure-to-be-measured tree data, and dendrometer data in the field.

Figure 7 in Appendix A illustrates a punched-card form convenient for inserting tree or dendrometer data into a computer for processing by program STX.

========================= INPUT ERRORS AND DIAGNOSTICS ========================

Certain errors or inconsistencies may be detected when subroutine ST11 edits input data (it skips over dendrometer cards and scans only tree cards). Commonly detectable tree card faults and their printout codes are illustrated in figure 11 of Appendix A. Tree cards subsequent to a detected fault will be scanned for additional errors or inconsistencies, but no further processing of the data is permitted. The tree card immediately following the error will be skipped in order to allow the scan to locate a valid starting point for resumption of editing.

Detection of invalid characters and resultant printout must be handled by the computer operating system, since ANS Fortran does not yet allow ERR= on READ statements.

If ST11 processes all data without encountering errors, and if the 2nd job option on CC2 has been punched 2 or more, further editing of the data occurs, together with processing of individual tree frequencies and dendrometry by subroutine ST22. Error printouts by ST22 are shorter and slightly less cryptic than those for ST11. The form of message and 7 types of errors that may be detected are illustrated in figure 12 of Appendix A. After finding an error, the subroutine will skip tree and dendrometer cards until an asterisk can be found in column 72. Subsequent trees are edited for additional errors or inconsistencies, but no further summarization is done except for data-processing statistics on page 0.

These statistics are helpful in locating where ST22 found the first error, if any errors occurred. Currently, editing ceases and the program terminates when more than 25 errors are found by ST22, but the maximum can easily be raised or lowered by modifying card ST22 377.

Quite a few specific messages diagnose situations of which the user should be aware.

NORMAL TERMINATION EXIT means that the second of two consecutive 9999 cards terminating data input has been read by the program, although it might have been reached by scanning and skipping over numerous cards during editing.

INPUT INVOLVES INAPPROPRIATE UNITS OF MEASURE OR CODE means that one of the 3 following error conditions was found: JY in block data was 1, but JZ on CC2 did not contain +; JY in block data was 2, but JZ on CC2 was not blank; JY in block data was neither 1 nor 2.

NO BALANCE POSSIBLE FOR STRATUM I means that 3P frequencies of trees in the Ith stratum could not be balanced as called for by job input option 3 or 4, usually because the constraint matrix had rank less than 3. Raw 3P frequencies for the Ith stratum would be left unadjusted in this case.

STRATUM I HAS LESS THAN 2 SAMPLES warns that no calculation of error (and maybe no calculation of sample total) is possible. Sample estimates that are thus incalculable will be set arbitrarily to zero. This message is also output when no dendrometer cards have been input for the Ith stratum (measured trees all terminated by asterisk in column 72 of the tree card).

Page 0 will show the number of fatal input flaws (if any) that blocked processing. This count includes not only actual error cards, but total misarrayed cards and cards that were skipped to allow proper reinitialization of the editorial scan. An additional number of suspicious trees may be shown. This count includes all trees exhibiting taper anomaly (i.e., reverse taper) of more than .5 inches (or 1.3 centimeters) plus the number of non-point-sampled trees with zero or negative DBH, plus the number of 3P-measured trees that represent fewer trees than their pre-3P frequency (e.g., with pure 3P sampling, they would have to represent less than 1 tree).

Page 0 also shows the number of input cards read before any fatal flaw. Number of measured tree cards read on the first pass must agree with the number read on the second pass or a machine error has occurred. A count of cards punched by the program (tree or log) is also given, and must agree with punched output actually received.

There are two input data limitations which cause messages to be printed if exceeded.

MORE TREE SECTIONS THAN 5998 -- NO SORT POSSIBLE EXCEPT WITHIN TREE is self-explanatory. The number 2998 may replace 5998 at installations that can't provide the user with 45K words of core, but this involves a number of additional modifications in STX and in subroutine PREP.

NO SUBTOTALLING POSSIBLE BECAUSE NUMBER OF CLAS-GR EXCEEDS 100 applies only to the product-conversion phase. Nine species groups are currently allowed with 11 quality-defect classes in each. The user can modify the program (the redimensioning is fairly complicated) to handle some combination other than 9*11, but if the product or number of subtotals exceeds 100, program modification would be much more difficult.

Several major checks to detect machine errors are available to the user. First, on the last page of the preliminary report, QI*CC8 should agree with total effective KPI for the stratum (this is total (KPI*BAI) where IQ implies point-sampling). Second, total cubic volume, surface, length for all strata should agree with corresponding totals after the among-tree sort and after the within-tree sort. Last, the total cubic volume for all strata should agree with the sum of volume paired with yield coefficients, plus volume subtotals that were not paired with yield coefficients (all nonpaired conversion values will be zero, but the original nonpaired cubic volumes can be looked up in the table of post-sort subtotals). Different paths of calculation with different rounding errors make agreement beyond the 3rd or 4th significant digit unlikely, and minor differences may occur even there where few trees are involved.

============================== V-S-L CONVERSION ===============================

V-S-L (volume, surface, length) summaries by quality-defect class within tree class contain considerable information about mean size of material and distribution of wood relative to the mean size of material. This is because the volume of a solid of revolution is an analog of the second moment of size about zero, surface is an analog of the first moment about zero, and length is an analog of the zeroth moment about zero. Most size-related phenomena (weight, value, cost of manufacture, product outturn, etc.) can be explained in terms of aggregate volume, aggregate surface, and aggregate length (to some minimum threshold or cutoff point), without need to stratify by size class. Stratification into product, quality, and defect classes then becomes much more feasible. Dendrometry should then select measurement points so that the stem is partitioned into reasonably homogeneous segments characterized by rate of taper, quality, and defect. When appropriate conversion coefficients have been obtained from felled tree studies, they can be applied to V-S-L--the primary units of measurement--of standing trees as discussed in (*7).

Sawdust, trim, slabs-edgings, unusable lumber per tree--all in cubic feet--have been chosen as dependent variables to illustrate outturn items in Appendix B, along with board feet of usable lumber and lumber value per tree. Quantity per tree in each lumber grade might have been computed just as easily. However, excessive tabular detail formerly essential to the appraisal process is no longer necessary and would merely tend to complicate a relatively simple and clear outturn picture. Realization value is obtainable directly in dollars from volume, surface, and length. Separate computations by log size class have been made unnecessary, since volume, surface, and length for a whole tree contain better information about sizes of the component logs than do individual scaling diameters and lengths.

Conversion coefficients for a given species group are best obtained by 3P or point-3P selection of 50 or 60 trees from the population of interest. After the selected trees have been dendrometered so as to partition the stem into meaningful homogeneous portions, the trees should be felled, measured additionally if log scale or weight is of interest, and processed. Any dendrometered portion not utilized or any utilized portion not dendrometered should be measured and recorded without changing any dendrometry classification already assigned. Eleven possible categories of quality and defect per species group have been found useful in relating outturn to V-S-L on an individual tree basis (rather than log by log). Quality class A might be defined as having no exterior indication of overgrown knots or scars; quality class B might have visible overgrown knots or scars; and quality class C might have protruding limbs, scars, or wounds not yet overgrown. Defect class A might have no indication of deformation or unsound material; defect class B might be visibly sound but not straight (i.e., crooked or sweepy); and defect class C might have usable material but indications of unsound material (i.e., rot, fruiting bodies, holes). These 9 quality-defect categories (AA thru CC) must be supplemented by 2 others: UU to categorize unseen material when stem projection extends dendrometry, and XX to categorize material deemed totally worthless by the dendrometrist.

If some of the 11 categories are unlikely to be sampled, the dendrometrist might arbitrarily measure a few trees that contain such material to help plug possible gaps in his conversion coefficients later.

A 33-variable (or smaller) regression of whole-tree yield on utilized V-S-L by category can usually be fitted when at least 34 trees in a given species group are available and when each of the 11 categories of material are observed in at least one tree. All of the regression coefficients thus obtained must be multiplied by an appropriate utilization factor (the ratio of aggregate utilized V, S, or L to aggregate dendrometered V, S, or L). Most such ratios will be unity, except for C quality material in the upper stem (utilization may exceed or fall short of dendrometry), C defect (hidden defect may cause it to be left unutilized), and XX (some of it is occasionally utilized). When moment matrices are of less than full rank, pooling V-S-L in 2 or more categories will be necessary, unless the deficient categories can be supplied by some of the arbitrarily selected trees assigned a minimum frequency merely for conversion purposes.

Multivariate regression program REX (*8) was designed especially to simplify obtaining multiple-product conversion coefficients discussed above. Examples XMPL, USMT, and MUST in Appendix B illustrate the mechanics of input to and output from program STX with hypothetical dendrometry and hypothetical conversion coefficients. References (*12) and (*15) give examples of conversion coefficients derived from actual dendrometry followed by an actual mill scale study.

Obviously, the technique for converting V-S-L to related variables of interest is just as applicable to estimation of biomass, energy production, stemflow, transpiration, wildlife populations, etc., as it is to timber appraisal and inventory.

No conversion of V-S-L will be possible if column 70 (LS5) of the second control card has been left blank or punched '0', '1', or '6'. Punching '2', '3', '4', or '5' in this field will initiate sorting of individual log data, unless some fatal error is encountered that blocks complete processing. The rearrayed individual log and parent tree data will be printed out with class subtotals when '3' or '5' is punched in column 70. Only subtotals will be printed when '2' or '4' is punched in column 70. No more than 100 log-and-tree classes can be subtotalled by current version of subroutine SUBT. Setting LS5 equal to 4, 5, or 6 will cause within-tree sorting and subtotalling by quality-defect category, which facilitates preparing input heeded by REX in deriving conversion coefficients.

If, however, column 70 of CC2 contains any of the digits 2 thru 5, if column 71 (LS6) contains an integer from 1 through 9, and if subroutine ST44 has been recompiled to incorporate the necessary sets of appropriate conversion coefficients, then an attempt will be made to convert log class subtotals of volume, surface, and length to product yields and realization values. In general, one matrix or set of conversion coefficients must be provided for each species group included in the input. Search for matrix label matching subtotal label will be limited to the number of matrices indicated by the digit punched in column 71 of CC2. A maximum of 9 conversion coefficient matrices (or species groups) can be incorporated into subroutine ST44 at any one time. Present versions of subroutines PROD, SUBT, and ST44 can convert 9 species with 11 log classes into 6 end-products. The user can easily change the format of the table headings.

The conversion coefficient matrices in subroutine ST44 must be input by data statement. For a given tree class (or species), a given quality and defect class (grade), and a given end product, a minimum of 3 coefficients are needed to convert volume, surface, and length to the desired entities. More complicated functions of volume, surface, length, or other agregated variables may, of course, require additional coefficients, but subroutine modification to achieve this is quite simple.

Labels used for species and grade in ST44 matrices must correspond with codes used on input data. Also, matrices and grade vectors should be arrayed and subscripted with labels in logical ascending order that will collate with sorted logs. Failure to do this will result in nonconversion of offending class. Where logical IF is handled incorrectly by Fortran compilers (CDC, Univac, etc.), it is necessary for species label and grade label to begin with an alphabetic character. In general, where no coefficient labels can be found to match tree class or log class labels, (.00) is printed for all affected conversions, as illustrated in Appendix B (example XMPL) by label ZP in the DFIR species-group and by the entire DNDR species-group.

The DFIR matrix appropriate to converting US V-S-L to products in example XMPL was already contained in subroutine ST44 initially. In Appendix B immediately following the printout for XMPL, however, is an illustration of the modifications and recompilations needed to replace the U.S. DFIR matrix with one appropriate to metric V-S-L, including a few format changes more appropriate to metric field requirements. The single matrix has 1 species label, 11 grade labels, and 198 real values (V, S, L coefficients for each of 6 products from each of 11 quality-defect classes). For a second species group, the subscript 1 in columns 20 and 30 of the first card of each submatrix data statement would be replaced by 2, and the matrix label DFIR in the first card would contain the name of the second matrix and be subscripted 2 in column 20.

================================ USAGE AND OUTPUT ================================

To fully exploit STX 3-3-73 capabilities, the user must establish or have access to a library of source and object modules containing 4 programs (RN3P 1-10-69, REX 9-20-71, USMT 3-3-73, and STX 3-3-73), each written in ANS Fortran. Although it is good practice to store 4 elements of test data with the 4 programs, this is not done in the current illustration, since an explicit listing of each data input will help illustrate how the programs are used.

RN3P generates pseudo-random integers in accordance with 3P or other sample specification (some rectangular distribution of consecutive integers with a rational proportion of nulls). Comment cards preceding the program explain how to use it.

REX provides capability for a variety of multivariate regression, correlation, or covariance analyses. Its options allow transgeneration, transformation, rearrangement, grouping, weighting, combinatorial screening, fitting best or specific regressions, comparison of observed and predicted values, plots of residuals, etc., for as many as 50 variables, 8 of which can be dependent. Use of program is explained in reference (*8) except for options allowing plot of residuals, which are explained in comment cards preceding subroutine RSID.

USMT converts STX control cards and data decks whose quantities are expressed in U.S. units of measure to equivalent decks with quantities expressed in SI (metric) units of measure and vice versa. Comment cards preceding the program explain how to use it.

STX estimates individual tree and aggregate V-S-L by quality-defect category from various types of dendrometry applied to sample trees selected by a wide variety of sample-designs. V-S-L by category can be program-converted to any related variable of interest (products, realization values, costs, weights, etc.) How to use the program is explained in this and earlier sections.

The programs will run on any computer possessing an ANS Fortran compiler, adequate storage, word length of at least 32 bits, and capability for performing integer arithmetic modulo (N) or (N-1) (N = word-length in bits). However, library establishment and update are much more awkward under some systems than others, and efficiency deteriorates unless overlay rather than virtual storage is employed.

One of the better systems (Univac EXEC 8) requires little if any change in control language from installation to installation. Since it allows library update as well as temporary modifications with a minimum of user effort, it has been selected to illustrate library establishment and usage in Appendix B.

The 4-program library will be called GROSENBAUGH*DNDR3P, though use of any other name would require changing only the @ASG card and the @USE card. It contains only source modules, relocatable modules, and MAP or linkedit instructions. If the unmodified programs were to be used heavily, absolute or linkedited modules could also be included, as well as 4 elements of test data mentioned above. The direct-access storage device used to contain the library can be either disk or drum. Each element in the library will be available to compiler, linkeditor, or loader by element name if the partitioned data set has been processed by an @PREP control card.

Initially, the source elements are rolled into the library from a tape called SOURCE (reel W41). The source elements are modified, recompiled, and new source and relocatable elements together with linkedit instructions are stored in the user's temporary file TPF$, where index and entry-point tables are constructed before copying the entire updated file back into GROSENBAUGH*DNDR3P. This destroys the unmodified versions rolled in from tape. The new file is catalogued public, read-only and can be accessed by anyone.

To use the library, 2 sequential scratch files must be assigned, corresponding to Fortran files 4 and 8. It is assumed that normal system input, output, and punch files are desired; that they are implicitly available to any job without requiring @ASG cards; and that they correspond to Fortran files 5, 6, 1.

Besides assigning the library file and 2 scratch files, the user initially establishing the library must see that the programs are compiled with appropriate internal I/O unit values. This can be done by appropriate data statements in USMT and RN3P, and in block data subprograms BLD for STX and BLRM for REX. Fortran names JW, JX should be set to integer values 4, 8, and Fortran names MRE, MPR, MPU should be set to integer values 5, 6, 1. In this case, where MPR is equated to system print file, MEOF (and MEF in BLD) must be set to 0; if a user print file had been specified, any nonzero value of MEOF and MEF would ensure writing end-of-file and rewinding or initializing. A nonzero value of 99 should never be used for MEF, however.

RN3P must have IMX set to the largest positive integer that can be represented in one word of storage, while MWL must be set to the number of bits needed to represent that integer in binary notation (31 bits, 35 bits, 47 bits, etc., depending on computer).

STX has 3 parameters in block data subprogram BLD that specify what units of measure must be used for input and whether conversion to other units is desired prior to summarization of V-S-L by stratum or by species-quality-defect category. First, JY must be equated to 1 if input is in SI (metric) units, or to 2 if in U.S. units. If N3 and NP are zero, summarization of V-S-L by stratum and species-quality-defect category will be expressed in the same units as input. If N3 is 1, stratum summaries will be converted from SI to US units or vice versa before being printed. If NP is 1, species-quality-defect summaries of V-S-L will undergo similar conversion before being printed and paired with appropriate conversion coefficients in ST44.

BLD also contains some default parameters involving bark projection, stem projection, and sorting. RDE (currently set at .90) is the DIB/DOB ratio at breast height assumed if no bark measurement is input. QUAN and DENO (currently set at 1.0 and 2.0) specify an asymptote of an upward-diminishing right-hyperbolic bark projection (used when MBK = 2). UDTRO (currently set at .45) is the value of UDORT that will be assumed if no value is input on the tree card, yet stem projection is revoked. MULL should be set to the most negative integer possible if logical IF's are correctly implemented on the system compiler, otherwise it should be set to 0 (currently CDC and UNIVAC compilers generate faulty code for logical IF).

Finally, whatever linear function of V-S-L (in STX) the user wishes to compare with his prediction (KPI) must be specified by establishing the values for BORD, SLAB, CLFT, since 3P error computations will analyze variation in the ratio (V*BORD + S*SLAB + L*CLFT)*CC5/KPI per tree. BORD, SLAB, CLFT are currently set at 1.0, 0.0, 0.0, so that variation in the ratio (cubic volume * CC5/KPI) would be computed. The coefficients can easily be changed to 8.956, -.6954, .04145 which correspond closely to International board feet with 1/4-inch kerf and .3 foot trim per 16.3 feet; other log rule coefficients for V-S-L may be found in reference (*1). Whatever units of measure are appropriate to the linear compound should be inserted as Hollerith strings in array BCDEF.

All of the data statements for STX discussed above occur in block data subprogram BLD, cards 9-14. Additional data statements establishing a matrix of conversion coefficients deemed suitable for a species-group labelled DFIR are included in subroutine ST44, along with another matrix containing identical coefficients for a second species group labelled PPIN. The second matrix is not used in any of the examples in this publication, but is included in the ST44 source deck to illustrate how additional matrices can be input, and to allow running test problem APPR used with the 5-1-67 version of STX. The technique for replacing such matrices in ST44 is illustrated in Appendix B between output for STX example XMPL and input to example USMT.

Illustrations of appropriate input and resultant output will be discussed on the assumption that the library DNDR3P has been initially compiled with appropriate Fortran I/O integers; that library DNDR3P and 2 scratch I/O files have been assigned to the job; that BLD specifies JY, N3, NP to be 2, 0, 0 and BORD, SLAB, CLFT to be 1., 0., 0., and BCDEF to be cubic feet inside bark; and that ST44 currently includes the matrix of conversion coefficients for DFIR discussed above.

A detailed explanation of how to use REX appears in reference (*8), along with examples, so in the interest of brevity it has been omitted from the current discussion.

To use RN3P to generate lists of pseudo-random integers for sampling purposes, 2 data cards must be input for each list desired. The first must be blank in columns 1-4, with alphanumeric job identification in columns 5-64, and a briefer identifier in columns 73-76 that will appear at the foot of each column of numbers. Usually this same label should appear on the first STX control card of the job for which the numbers were generated. The second card must be blank in column 1, with any arbitrary decimal integer in columns 2-10 (to be used to compute a starting number for the generator). Column 14-20 contains the number of integers desired, rounded upwards to the next multiple of 500 if not a multiple already. Columns 24-30 contain K (called KQ in STX)--the largest nonnull integer desired--and columns 34-40 contain KZ (called PRBS in STX)--the aggregate amount of KPI which will, on the average, trigger selection of a 3P sample. Many pairs of cards such as the above may be stacked together to generate different lists. The last such pair should be followed by a card punched 9999 in columns 1-4. Other capabilities and limitations are discussed in comment cards at the start of the program listing.

RN3P examples SS3P (single-stage 3P sampling) and XMPL (exemplifying dendrometry with point and point-3P sampling) illustrate the 2-card inputs suitable for generating 2 different lists of 500 numbers each. The list labelled SS3P will contain integers ranging from 1 thru 60 (with no nulls). These integers were used to 3P-select sample trees for the third stratum in example IQ-1 and for the only stratum in example SS3P. The list itself has been omitted, since it is easily visualized. All other examples in Appendix B use the list of integers labelled XMPL, which is shown in Appendix B and consists of a rectangularly distributed set of integers from 1 thru 21 plus 3 nulls. A null (meaning that the associated tree is rejected as a sample) is symbolized by -99999 in the list of integers. Out of 500 integers, 437 are nonnull with sum 4679. Expectation is 437 with sum 4807. Comparison of actual with expected permits the user to discard in the office any sheets that deviate excessively from expectation.

There are 8 examples of different uses of STX in Appendix B. IQ-1 gives simple illustrations of plot sampling, line sampling and single-stage 3P sampling. IQ-C illustrates point-sampling subsampled with equal probabilities, point-3P sampling, and area-point-3P sampling. EK illustrates point-3P sampling using both a poor and a good estimate of aggregate KPI. EKFR is identical except that, in addition, poor and good estimates of total number of trees are also used with frequency-balancing. SS3P illustrates single-stage list sampling or pure 3P sampling. XMPL illustrates point-3P sampling and point sampling subsampled with equal probabilities (different probabilities in different strata). Also, XMPL illustrates all of the various dendrometric techniques (including stem and bark projection, forked trees, etc.) and V-S-L conversion to products and value. Example USMT shows how STX input in U.S. units of measure can be program-converted to metric outputs, while example MUST shows how metric measurement of the same sample trees can be input to produce metric outputs.

The hypothetical population of trees from which samples have been drawn is identical for all examples (except for strata 2 and 3 in XMPL). The hypothetical population consists of 110 trees (10 large trees, 40 medium trees, 60 small trees). "Large" implies D.B.H. = 18 inches, H = 16 4-foot sections; "medium" implies D.B.H. = 12 inches, H = 6 4-foot sections; and "small" implies D.B.H. = 6 inches, H = 4 4-foot sections. For clarity, the examples postulate that the number of samples selected is the same as that expected for the stipulated sample design, except for examples EK, EKFR, and stratum 2 of XMPL, where moderate deviations from expectation have been postulated to illustrate the effect of frequency-balancing or to avoid fractional selections.

Examples IQ-1, IQ-C, EK, and EKFR have been discussed in earlier sections. Example SS3P involves complete visitation of all 110 trees in the population, with a tree card punched for 3P-rejected as well as 3P-selected trees; input would be identical if list sampling were feasible. Each tree is assigned KPI = D^2H (with D guessed as square feet, H guessed as number of 4-foot bolts). The 3P random number list labelled SS3P selected 6 large, 4 medium, 1 small tree, and they were either climbed or pole-calipered, so parameters B, Q, U, G could be left blank. Since no bark thickness was measured, the default assumption is D.B.H.I.B./ D.B.H.O.B. = .90. Since no bark projection was specified, the default assumption is that the ratio remained constant throughout each tree. The default assumption as to number of strata is unity. Tree summaries only (no log detail) are desired, and no cardpunching, sorting, or product conversion are desired. No stem projection has been invoked on any tree, although the last section of tree number 1113 has been classed as UU to provide parallelism with later example XMPL.

The output for SS3P starts with a preliminary report on the 3P sample itself, showing number of 3P-selected trees and their aggregate KPI (11 trees with aggregate KPI = 241). Expectation for these values is given, as well as their standard errors. This preliminary report is meaningful only when 3P sampling has been employed, and only if a tree card has been input for every 3P-selected or sure-to-be-measured tree. When tree cards for 3P-rejected trees are omitted but aggregates are input on CC3-CC4, CC7-CC8, the 3P statistics are derived from sample estimates, since only 2 of the necessary population parameters can be inferred.

Immediately following the preliminary report on the 3P phase of the sampling is a sheet showing inputs on cards CC3-CC8 if aggregates were input. Otherwise, inputs on cards CC5-CC6 are printed, along with appropriate aggregates for CC3-CC4, CC7-CC8 computed from inputs of pre-3P-selected trees, 3P-selected trees, and 3P-rejected trees. Inputting such computed values on future runs allows omission of all 3P-rejected tree cards. In addition to information about CC3-CC8, this sheet of the preliminary report gives values for frequency adjustment coefficients if frequency-balancing has been specified. In example SS3P, aggregate number of trees input is 110, while aggregate KPI is 660. Since IQ = 1, single-stage 3P is implied; CC7-CC8 would be the same as CC3-CC4, but they could be left blank.

A sheet summarizing information about each measured tree is next, and its fields are explained in detail in figure 10 of Appendix A. Ordinarily the 11 trees would each have different numbers, but to simplify the illustration, 4 medium sample trees have been numbered identically and 6 large sample trees have been numbered either 3 or 1113, depending on which of 2 different assignments of quality-defect classes occurred. Generally, use of identical tree numbers is bad practice, since all material from contiguous identical numbers would have been aggregated together if a within-tree sort had been specified. Measured tree numbers should never be left blank, or contiguous blank material would also be aggregated together in a within-tree sort, just as though only a single tree were involved.

A stratum summary sheet follows the tree summaries and is self explanatory, except that it should be understood that the standard error (expressed as a percent of the stratum total aggregate linear compound of V-S-L specified by BORD, SLAB, CLFT) is merely that part of total sampling error attributable to last-stage variation in individual-sample-tree ratio of compound divided by KPI. Variance and covariance of earlier-stage sampling, if any, must be hand-computed and appropriately combined with this variance. However, in example SS3P, the design involved only pure 3P sampling without any earlier stages, so the 2.5 percent sampling error (ignoring a usually trivial correction for finite population) is appropriate for the 1337 cubic foot estimate of total volume.

A summary for all strata follows the individual stratum summaries, and contains nothing new. However, if several strata had been involved and different value factors had been specified on CC5, estimates of manufactured units and aggregate weighted value of manufactured units would not be the same, nor would their standard errors.

A final sheet (paginated 0) reports number of flawed input cards encountered during editing, including any possibly valid cards skipped while reorienting after encountering an error. Tree numbers of trees deemed suspicious are also listed. The major cause for suspicion is anomalous (or reverse) taper, where the upper of two successive diameter measures is more than .5 inch or 1.3 centimeters larger than the lower. The tolerable anomaly can be easily modified to suit the user. It is almost impossible to make a serious error in measuring or recording diameter without causing the tree to be flagged as suspicious. Too large a stump measurement or too small a terminal measurement are the only situations where a blunder in diameter measurement could not be detected. Other causes for suspicion are omission of D.B.H. measurement (fatal when point-sampling), or a 3P frequency estimate (after frequency balancing, if specified) that is smaller than the frequency would have been had the tree been classed as sure-to-be measured.

Input read before flaw and processing done before flaw serve as useful checks for known number of input records and punched output delivered to the user. Unless data errors or machine errors have occurred, the number of cards with measured tree information on first and second pass should always agree with each other and with number of measured trees processed (11 in the case of SS3P).

The final check of input aggregates with expanded 3P sample is ordinarily useful only in the case of a single-stage, pure 3P sample where a tree card has been input for every measured tree. In this case, sample estimate of total KPI should closely check with aggregate predictions input (660 in the case of SS3P). If, in addition, LS1 had been specified as 3 (invoking frequency-balancing), the sample estimate of total number of trees should closely check with aggregate number of trees input (110 does check, but it is accidental because LS1 is 1 rather than 3). The standard error of estimated number of trees is useful in judging the seriousness of difference between last-stage 3P frequency estimates and earlier-stage estimates of frequency, but it does not include any of the sampling error attributable to earlier-stage sampling.

Input for example XMPL immediately follows that for SS3P in Appendix B. Parameters B, Q, U, G must now be specified on CC2 because short-base-rangefinder dendrometry has been employed. The sample design involves horizontal point sampling using an angle gauge with a nominal basal area factor of 5.89 sq. ft. per acre per tallied tree; specifying IQ = -589 will indicate this and allow use of CC6 and XTRB. Since gauge calibration disclosed an actual basal area factor of 5.8905, a correction factor of 1.000086 should be incorporated into CC6.

The standard hypothetical acre involving 60.9 sq. ft of basal area will comprise stratum 1, sampled by 3 point samples using the above gauge. Point-selected trees (all classed as DFIR) will be subjected to 3P subsampling comparing KPI = guessed H with a random integer from the list previously labelled XMPL.

Stratum 2 of XMPL consists of another acre containing 10 medium trees and 27 large trees, with total basal area of 55 sq. ft. All trees are classed as DNDR. These, too, will be sampled by 3 point samples using the above gauge, but large point-selected trees will be subsampled with equal probability (KPI = 21 for each) using the random number list labelled XMPL. Medium trees are strangely unlike medium trees in stratum 1, and will be classed as sure-to-be measured (=) if point-selected. A unit volume in stratum 2 is deemed twice as valuable as a unit volume in stratum 1, as is indicated by the figures 1.0 and 2.0 on CC5. No field multiplication of guessed H by CC5 is necessary, however, since KPI = 21 is an arbitrary constant for stratum 2 that adequately reflects higher value.

Stratum 3 of XMPL consists of another acre containing 30 medium trees with a total basal area of 23.6 sq. ft, all trees being classed as CULL (worthless). CC5 shows a blank for stratum 3, which implies a default value of unity. Since no cull tree is allowed to generate any volume (an asterisk in column 72 of the tree card indicates there is no dendrometry), the value factor is meaningless anyway. Stratum 3 is also sampled by 3 point-samples, but at 1 of these points a narrower angle-gauge is used than the one used at all other points -- its basal area factor is 1/2 that of the gauge specified by IQ and CC6. All point-selected trees will be subsampled with equal probability (KPI = 12 for each) using the random number list labelled XMPL.

There were 31 point-selected trees in stratum 1, of which 11 were 3P selected (1 small, 4 medium, 6 large). There were 28 point-selected trees in stratum 2, of which 21 large trees were randomly selected with probability equal to 7/8, and

4 medium trees were classed as sure-to-be-measured. There were 16 point-selected medium culls in stratum 3, of which 8 were randomly selected with probability equal to 1/2.

Since a correction factor of 1.000086 is needed for IQ by all 3 strata, and since acres per point in each stratum is 1/3, CC6 can be input as -.333362 (=1.000086/3), with the minus sign implying that the same CC6 factor is valid for all strata. Since 1 point in stratum 3 was sampled with a gauge having half the basal area factor (twice the probability of selection for any given tree), tree number 3002 tallied at that point should have XTRB = 2.0.

Values for CC3-CC4 and CC7-CC8 were obtained from a previous run. Since both the current run and the previous run used XTRA to input the number of identical trees rejected and the number of identical trees measured (in order to shorten the listing of input data), the preliminary report on the 3P sample is not meaningful. Tree cards for 52 3P-selected trees and for 23 3P-rejected trees would have been necessary to obtain a meaningful preliminary report.

The detailed log and tree report in example XMPL is called for by LS3=3, and is largely self-explanatory. In addition to tree summaries explained by figure 10 of Appendix B, detailed stem measurements outside bark are shown under TGRADS, FGRADS and SINELV, while quality-defect category of each tree section is shown under LOG CODE. Diameter inside bark (inches) at upper end, length downward (feet), and volume, surface, length of each section appear successively on the left. Since trees were measured with calipers and tape in stratum 1, no values for TGRADS occur until stratum 2 trees are reached.

The 14 tree cards actually input illustrate nearly all of the capabilities of the dendrometry subroutines that have been discussed in the earlier section called "Data Input". In particular, the effect of different bark projections can be visualized from trees 3, 223, and 233 which had identical outside bark dimensions, while tree 203 illustrates input of inside bark measurements and tree 285 illustrates inclusion of both bark and wood in volume and surface computations.

Trees 264 and 274 provide a comparison of convex-conic-concave projections on a triply forked tree with a simple conic projection applied to the same tree.

Finally, tree 285 exhibits anomalous taper, the rare phenomenon of "front" instead of "back" coincidence (discussed in reference (*3)), and an uncommon method of invoking a stem projection for unseen length available only with short-base rangefinders.

Since individual cards were not input for each measured tree, the error calculations for individual strata and for all 3 strata are meaningless even for the 3P portion of the sample. The only useful check on page 0 is that 14 measured tree cards were read on first and second pass, and that dendrometry for 14 trees was processed without encountering a flaw. The fact that tree 285 was listed as suspicious called attention to the taper anomaly, which in practice would almost certainly have been attributable to an instrument error, a recording error, or a punching error. If so, and if a rational correction could not be deduced, tree number 285 would have been deleted without diminishing the number of trees or aggregate KPI, and the data would have been processed again.

Since LS5=2, a summary of V-S-L by species group and quality-defect category follows. The totals should closely approximate the totals in the summary of all strata.

Since LS6=1, an attempt is made to match tree species-quality-defect with the first set of conversion coefficients in ST44. This causes all DFIR quality defect except ZP to be converted, but fails to find a match for any DNDR labels. A match is found for 1198.84 cubic feet, and unmatched DFIR ZP involves another 138.19 cubic feet, so that 1337.03 cubic feet of DFIR in stratum 1 has been accounted for, which checks previous totals. It is known that no ZP coefficients were present in ST44, nor were any DNDR coefficients.

The next example is USMT, and it requires recompiling block data subprogram BLD so that JY, N3, NP are 2, 1, 1. This expects U.S. input, but will convert V-S-L summaries by stratum and by species-quality-defect category to SI (metric) prior to pairing with conversion coefficients. Hence, the DFIR matrix in ST44 must be replaced by an appropriate metric DFIR matrix. At the same time, it is desirable to redefine a few formats in ST33 and PROD so that the decimal points are more suitable for metric output, given a fixed total field width. Though not theoretically necessary, this preserves some significant digits that might otherwise be lost.

The small data deck for USMT involves essentially the same sampling design as for stratum 1 of XMPL, but acres-per-point (1/3) has been incorporated into negative IQ. However, this results in QI = 1.96 instead of the 1.9635 needed, so a correction factor of 1.00178 is needed in CC6. Actually, in the current situation where aggregates are input by control card and there are no sure-to-be-measured trees, the value of CC6 has absolutely no effect on frequency computations. The quantities in CC3, CC4 are the same as for stratum 1 of XMPL, but CC7, CC8 differ due to different IQ. However, it should be noted that QI*CC7 and QI*CC8 for stratum 1 of XMPL is almost identical with USMT, indicating that population estimates will be almost identical. Of course, since XTRA is used in both examples to indicate the number of identical trees measured instead of punching cards for all measured trees, the 3P preliminary report and 3P error approximations are invalid.

USMT dendrometry has been carefully constructed to measure the same trees as in stratum 1 of XMPL, but to do so by using METH = 0, 1, 2, 3 instead of having METH = 2 always, and to project stem by MUL = 1, 2 instead of only the latter. Also, direct measurement of stump and DBH and the projection to a tip coincident with the previous SINELV have been specified. Finally, inside bark dimensions with negative bark have been specified, as has a single truncation or change of reference plane, with the new reference plane identical with the plane of truncation. This variety of input enables the small 4-tree USMT data deck to illustrate almost all dendrometry techniques except MBK = 2, and results, except for minor rounding errors, should be comparable to stratum 1 of XMPL. Of course, the current example will have summaries in metric rather than U.S. units.

It can be seen from the stratum summary (which is metric) that the metric conversion has been neatly achieved, although of course KPI and manufactured products remain in whatever units they were input. Additionally, LS5=5 has specified a within tree sort and summary (useful for summarizing independent variable input to REX) and an among-tree sort (for which both individual log and tree detail are printed as well as summary by quality-defect category). Figure 13 in Appendix A identifies the log and tree variables shown on the sorted log and tree detail printout. Parent tree information is furnished for each log, so that it can be used in variance and covariance calculations if desired.

There are ample checks both for the U.S. and SI outputs. Finally, the product yield summary is given, with all except quality-defect category ZP being paired with yield coefficients.

The next example illustrates how interconversion program USMT processes STX data deck USMT (in U.S. units) followed by a 9999 card and STX data deck MUST (in SI or metric units) followed by two 9999 cards. Two new decks are punched out—one for USMT (now with metric control and data cards), the other for MUST (now with U.S. control and data cards). Numerous decks to be converted can be stacked (whether U.S. or SI is immaterial), each separated by a 9999 card, and the last followed by two 9999 cards. It is important to note that all decks should be successfully input to STX prior to conversion, since no editing is done during the conversion process. Program USMT will facilitate converting earlier sets of measurements of permanent samples into new units of measure whenever it is decided that future field remeasurements will use the new units.

Data deck MUST (converted to metric from the earlier U.S. data deck USMT) provides the final illustration of completely metric processing—metric input data and metric output summaries. In addition to setting JY, N3, NP to 1, 0, 0, a number of formats should be revised to save significant metric digits, and the same metric set of conversion coefficients must be inserted in ST44 that was previously inserted. Comparison of output of this problem with the previous problem provides reassuring checks. There will be some slight differences in metric magnitudes because of rounding errors, but 37.88 cubic meters of total volume checks well with 37.89, and 33.965 cubic meters matched with conversion coefficients checks well with 34.005. Board feet of usable lumber and dollar value are also in reasonable agreement.

Although no example specified any punched card output, if LS4=2 a card will be punched for each measured tree, and if LS4=3, a card will be punched for each measured and graded section of a measured tree. Figures 8 and 9 in Appendix A illustrate the format and content of such card outputs.

Despite the many options and flexibility built into the program, it has been kept as simple as possible, since many will be glad to minimize the output of conventional tables no longer needed. However, references (*13) and (*14) discuss application of the package (using point-3P sampling) to continuous forest inventory (CFI), and describe a number of modifications or additions some users have found useful. Similarly, references (*16) and (*17) discuss application of the package (using point-3P sampling) to the US Forest Service's Forest Survey, while reference (*12) discusses application of the package (using pure-3P sampling) to the appraisal and sale of National Forest timber.

In each application, desired program modifications were easily made, yet it would scarcely have been feasible to incorporate all of them permanently into the programs, considering the need for stability in documentation, the wide and continuing distribution of the programs, and the diversity of user desires.

================================== SAMPLING ERROR ==================================

Regardless of design, STX computes only one portion of the total sampling error—that part attributable to an ultimate stage of adjusted 3P or list sampling. It assumes that aggregate KPI for the population is known without error, that the correction factor needed for sampling without replacement in a finite population is nearly unity, and that the probability of obtaining zero samples is negligible. If design or sampling intensity are such that any of these assumptions are invalid, then the user must carry out hand calculations to supply appropriate correction factors or estimates of additional contributions to sampling error. Such calculations are simple in the case of point-3P designs where pooled blowup has been employed.

Unadjusted 3P sampling involves no bias in estimates of totals nor in estimates of their variances, but it is far less efficient than adjusted 3P or list sampling, which should always be used where knowledge of probabilities for 3P-rejected trees is available. Though a slight bias may be involved in adjusted 3P estimates of frequency, extensive simulations have found that bias has always been negligible where any positive correlation exists between the prediction and the measured variable. The correction for expected bias is exactly equal to the covariance between the actual number of samples and the adjusted estimate, divided by the expected number of samples. By assuming perfect correlation between adjusted estimate and the actual number of samples (and it is always much less than unity), G.M. Furnival established (in a personal communication) an upper bound for possible bias as a fraction of the standard error of the adjusted estimate. This fraction is always much less than the square root of the reciprocal of the expected number of samples, and is zero if the number of samples is fixed, as in appropriately conducted variable-probability list-sampling.

The expected value of the variance of an adjusted 3P sample has not yet been expressed in terms of population parameters, but adequate approximations are available using either population parameters or sample statistics. These approximations can be checked against empirical variances derived from replicated sampling from known populations or from interpenetrating samples. Unfortunately, some erroneous results of such checks have been published that cast doubt on the adequacy of <u>any</u> approximations. Mistakes and inconsistencies in those results imply serious blunders in data handling, programming, simulation, or computing; others have obtained good results from approximate formula (VA) on the next page or closely related formulae.

The superior efficiency of adjusted 3P sampling is most apparent where there is considerable variation in size of individual trees but where the cost of measuring sample trees is nearly independent of size (as is the case where optical dendrometers are used). Although list sampling would be preferable, it is rarely feasible to conduct such sampling free from selection bias. However, if a second visitation to the forest is necessary to conduct dendrometry after initial 3P selection, an equal-probability selection (prior to the second visit) from too many 3P-selected trees can limit dendrometry to some lesser desired number. If the initial 3P selections included too few samples, additional point-3P selections can supply enough well distributed trees to equal some greater desired number.

References (*4), (*5), and (*9) give enough details and theory about 3P sampling so that only a legend and major formulae will be given below.

M = total number of trees in population.

YI = any measured variable associated with the Ith tree.

$\sum^{M}$YI = aggregate YI for population.

KPI = a prediction or arbitrary relative probability assigned to the Ith tree.

TI = YI/KPI

$\sum^{M}$KPI = aggregate KPI for population.

KZ = denominator for relative probability, or amount of KPI represented by each sample tree if aggregate KPI is not known.

N = the number of 3P-selected sample trees.

PO = the probability that not <u>any</u> of the M trees will be 3P-selected.

ESN = the expected number of sample trees if N = 0 is acceptable.
= $\sum^{M}$KPI/KZ

ENZSN = the expected number of sample trees if N = 0 requires resampling.
= ESN/(1-PO)

C^2 = parametric relvariance of YI.

G^2 = parametric relvariance of KPI.

A^2 = parametric relvariance of YI/KPI, each ratio assumed to recur KPI times.

r = parametric correlation between YI and KPI.

W = parametric relcovariance between YI and KPI = r*G*C.

VN = parametric relvariance of N about ENZSN.

$$(1+VN) = (1+1/ESN-(1+G^2)/M)*[1-PO]$$

$$A^2*(1+VN) = (\sum^{M}KPI*\sum^{M}KPI*TI^2/(\sum^{M}YI)^2-1)*[1+VN], \text{ sample-estimated as}$$

$$= \longleftarrow (N/(N-1))*(N*\sum^{N}TI^2/(\sum^{N}TI)^2-1)$$

$$(1+A^2)/ESN = KZ*\sum^{M}KPI*TI^2/(\sum^{M}YI)^2 \longleftarrow \sum^{N}TI^2/(\sum^{N}TI)^2$$

$$(1+C^2)/M = \sum^{M}YI^2/(\sum^{M}YI)^2 \longleftarrow \sum^{N}KPI*TI^2/((\sum^{N}TI)^2*KZ)$$

$$(1+G^2)/M = \sum^{M}KPI^2/(\sum^{M}KPI)^2 \longleftarrow \sum^{N}KPI/(N^2*KZ)$$

$$(1+W)/M = \sum^{M}KPI*YI/(\sum^{M}KPI*\sum^{M}YI) \longleftarrow \sum^{N}YI/(KZ*N*\sum^{N}TI)$$

Unadjusted and adjusted 3P estimators with their unconditional relvariances are given below. Specifying resampling when N=0 is completely taken into account by terms containing PO, so ENZSN should never replace ESN.

$$YU = KZ*\sum^{N}TI*[1-PO]$$

$$YA = (\sum^{M}KPI/N)*\sum^{N}TI*[1-PO]$$

$$VU = ((1+A^2)/ESN-(1+C^2)/M)*[1-PO]-[PO]$$

$$VA \cong (A^2*(1+VN)/ESN)*[1-ESN/M]*[1-PO]$$

Unconditional relvariances are estimated when $((1+A^2)/ESN)$, $((1+C^2)/M)$, or $(A^2*(1+VN))$ are replaced by sample estimates, but ESN in VA should <u>not</u> be replaced by N, as was proposed originally by the author. Until the next revision of STX, program-computed standard errors for volume and frequency should be user-multiplied by the square root of N/ESN. For N greater than 100, the difference would be negligible. When ESN is larger than 10 and ESN/M is smaller than .05, bracketed terms in YA and VA have only a trivial effect; they are always ignored in STX. In example SS3P in Appendix B, program-computed standard error is 2.5 percent with bracketed terms ignored, and 2.4 percent with bracketed terms considered.

Two-stage sampling is a simple extension of single-stage adjusted 3P sampling. The pre-3P stage is usually an equiprobable set of points swept by an angle gauge, with height of each point-selected tree being guessed or measured and used as KPI to allow selection of the ultimate point-3P sample (selected with combined probability proportional to basal area times H). Aggregate effective KPI is the estimated sum of basal area times height for the entire population (program-computed). The relative standard error computed by the program is appropriate when few points have more than one 3P-selected tree, and when the design is appropriate for use of the pooled 3P blowup procedure. If so, the user merely needs to calculate the relvariance for mean sum H, and to add to this the squared program-computed relative error. To this should be added twice the covariance of mean sum H with the mean ratio of volume/(H*BA), although this term is frequently negligible and is often omitted, since it is troublesome to calculate.

Where individual blowup for points or areas has been employed, the user must hand-calculate and sum all 3 quantities: the same relvariance of mean sum H per point, and also the mean relvariance of mean ratios per point, and twice the mean relcovariance of mean ratio per point with sum H per point. If PO for a point is not negligible, XTRB for all point-selected trees associated with that point must include (1 - PO), as has been mentioned earlier.

Whether pooled or individual blowup has been employed, the relative standard error is the square root of the sum of the terms specified as contributing. Usually relvariance of mean sum H is by far the largest and most important term, so the relvariance of mean sum H usually largely determines the standard error of the total.

To illustrate the procedure, consider example XMPL (stratum 1) in Appendix B. Its estimate of relative standard error for the 3P portion of the design would have been 2.5 percent (the same as example SS3P) if tree and dendrometer cards had been input for each of the 11 3P-selected sample trees.

Suppose the 31 point-selected trees had been tallied as follows: at point 1, sum H = 24 for 6 small trees of which 1 was 3P-selected; at point 2, sum H = 96 for 16 medium trees of which 4 were 3P-selected; at point 3, sum H = 144 for 9 large trees of which 6 were 3P-selected. Volume/(H*BA) ratios for the 11 dendrometered trees were 2.932 for the small, 2.760 for the medium, and 2.760 for the large. The reciprocals of 1 - PO for the points were 1.504, 1.010, and 1.000.

Whether pooled or individual blowup is used, relvariance of mean sum H is .3491/2. Squaring program-computed relative standard error is a poor practice here because several points have more than 1 sample tree, but ignoring this to illustrate error approximation, the square of 2.5 percent is .000625. Adding .1746 to .0006 gives .1752, whose square root is 41.9 percent. This ignores covariance, which is usually negligible, although not in this example.

Where individual cluster blowup has been employed in XTRA, (1 - PO) should be included in XTRB, or 1/(1 - PO) should be included in XTRA. Relvariance of mean sum H is unaffected by PO, and it is .3491/2 as above. Relvariance of the mean volume/(H*BA) ratio is .00624/2, and twice the relcovariance of the mean ratio with mean sum H is 2*(-.0590)/2. The total variance is thus .1187, whose square root is ± 34.5 percent. In this case, it would have been unwise to neglect covariance and unwise to use the program approximation for the 3P component of error.

The only other multistage design whose sampling error will be discussed here is a 3-stage photo-point-3P sample. As in 2-stage point-3P sampling, the first stage must generally deal with a highly variable population, but photo-points are relatively cheap and the relvariance from this stage can usually be reduced to desired levels. The real questions are whether a small list-selected subset of these photo-points (selected with probability proportional to photo-guess) can be located precisely enough by ground crews to point-sample essentially what the photo-guess was based upon, and whether that guess proves to be highly correlated with sum H for the point or points. There is little doubt that the subsequent 3P dendrometry of individual trees will complete an efficient sample if there is high correlation between photo-guess and sum H.

There is much to be said, however, in favor of having 2 independent sets of point samples--the first having points located with probability proportional to photo-guess so as to allow conversion of photo-guesses to sum H and the second having points located with equal probability so as not to confound the effect of areal density with tree size. Another advantage of independence is the elimination of several covariance terms in error calculations. A slight overlap or interpenetration of the two sets of samples would not be objectionable.

The relvariance of such a double-barreled estimate would consist of the relvariance of mean photo-guess, plus the relvariance of the mean ratio sum H/photo-guess, plus twice their relcovariance, plus the relvariance of the mean ratio of volume/(H*BA).

Hopefully, photo interpretation or some other remote sensing or measuring technique will be able to generate subjective or objective numbers highly correlated with point-sample sum H (which tends to be strongly proportional to sum D^2H of any forest). This should greatly increase the efficiency of point-3P dendrometry for regional inventories and analyses of growth, harvest, and mortality. A ground analog has already proved very efficient (guessing sum H per acre, but checking guess with an actual point sample only when guess is greater than or equal to random number).

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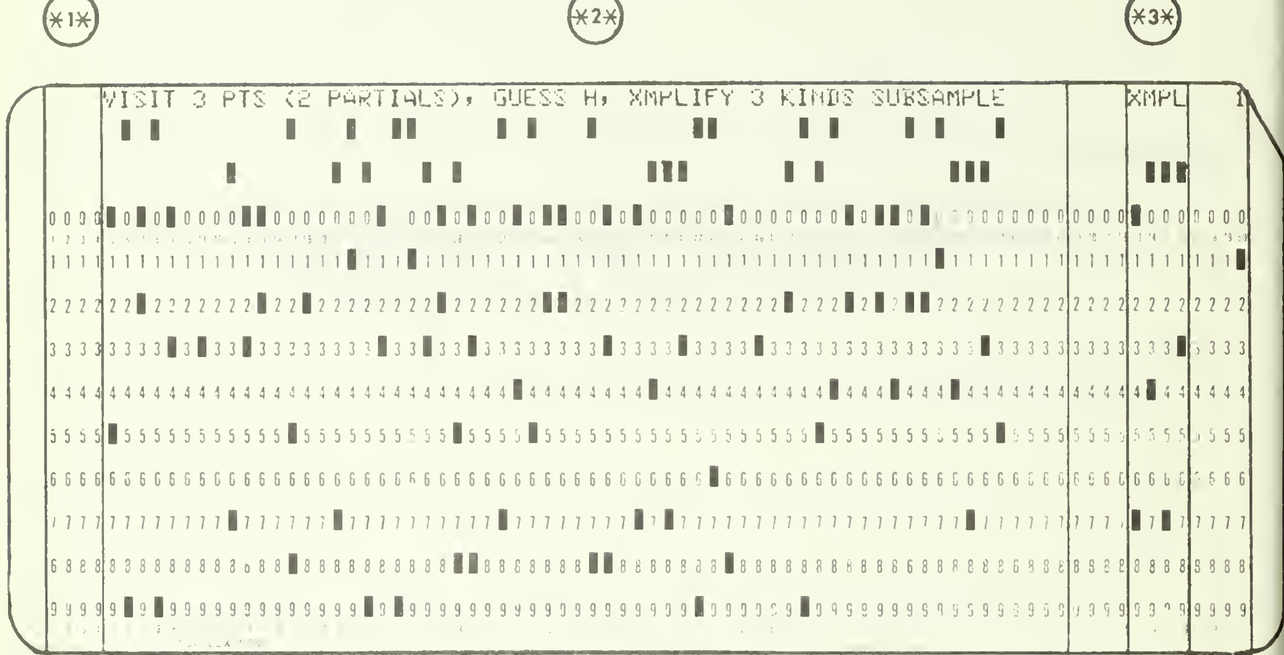
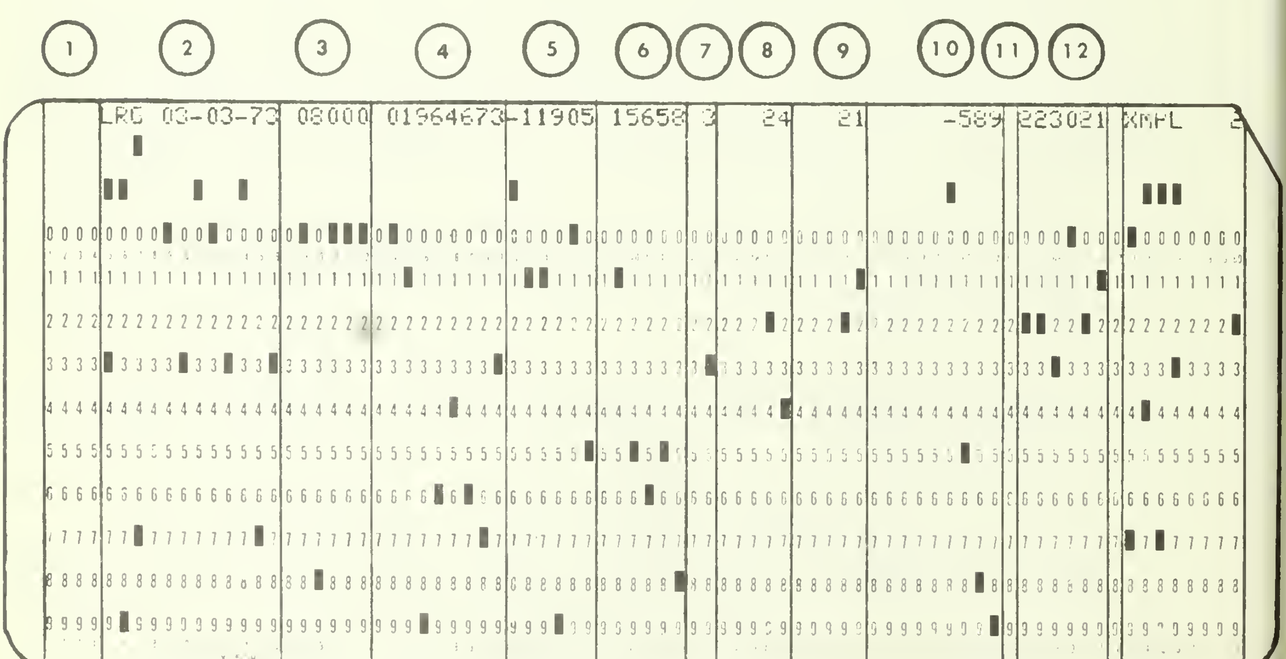
================================ APPENDIX A ================================

LINE FIGURES ILLUSTRATING CARD LAYOUTS AND FORMATS FOR
STX CONTROL CARDS, DATA INPUT AND PUNCHED OUTPUT, PLUS
EXPLANATIONS OF CRYPTIC STX PRINTOUTS
--- INCLUDING CODED ERROR DIAGNOSTICS

FIGURE 1. FIRST AND SECOND CONTROL CARDS.





URE 1 (CONTINUED).

FIRST CONTROL CARD

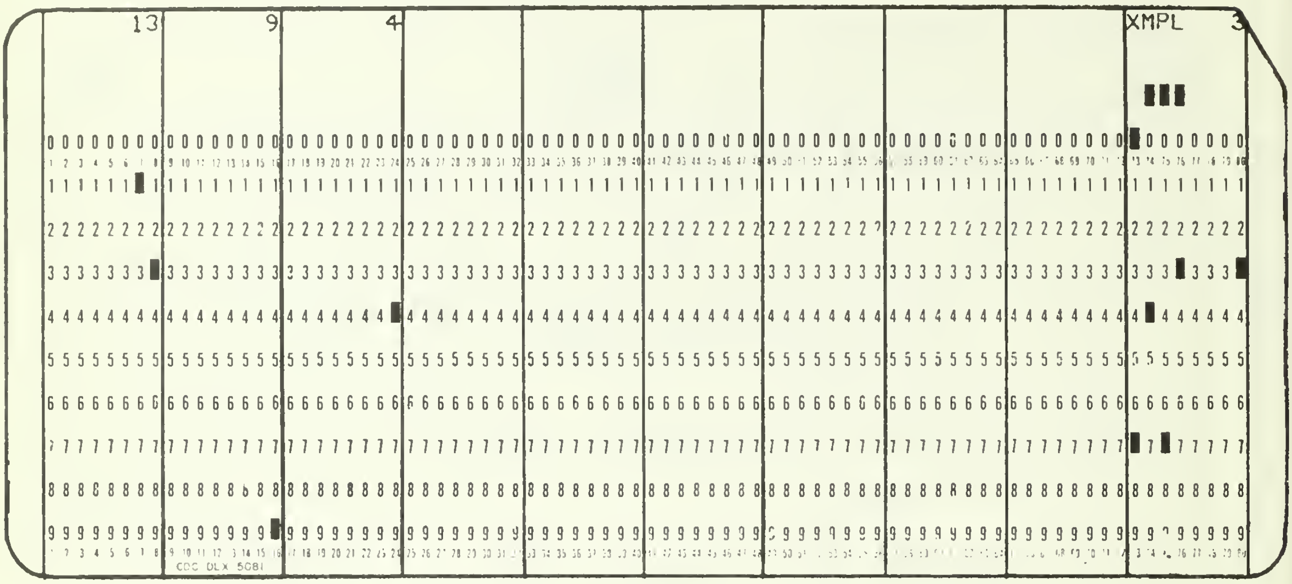
```
*1*=KREENO= ALWAYS BLANK.

*2*=ALFATH= NAME OF SALE, AREA, OR JOB.

*3*= CDID = BRIEF JOB IDENTIFIER.
```

SECOND CONTROL CARD

```
 1 =KREENO= ALWAYS BLANK.

 2 =ADALFA= INITIALS OF USER AND INPUT DATE.

 3 =   B   = SEE PAGE 12.

 4 =   Q   = SEE PAGE 12.

 5 =   U   = SEE PAGE 12.

 6 =   G   = SEE PAGE 12.

 7 = NSTR = TOTAL NUMBER OF VALUE STRATA USED (9 IS MAXIMUM).

 8 = PRBS = KZ (OR K+Z).  SEE PAGE 12.

 9 =  KQ  = K OR MAXIMUM ALLOWABLE KPI (SAMPLE PREDICTION).

          (=  1, 0, OR BLANK FOR PURE 3P SAMPLE (NO POINT-SAMPLING).
          (= -1 FOR MULTISTAGE DESIGN (NO POINT-SAMPLING).
10 =   IQ (= SEE PAGE 2  FOR CALCULATION IF POINT-SAMPLING IS INVOLVED.
          (= GREATER THAN 1 FOR SIMPLE POINT-3P SAMPLE.
          (= LESS THAN -1 FOR MULTISTAGE DESIGN (WITH POINT-SAMPLING).

11 =   JZ (= BLANK FOR U.S. INPUT DATA.
          (= + SIGN FOR METRIC INPUT DATA.

     (LS1)
     (LS2)
12 = (LS3)= JOB OPTIONS (SEE PAGE 13).
     (LS4)
     (LS5)
     (LS6)
```

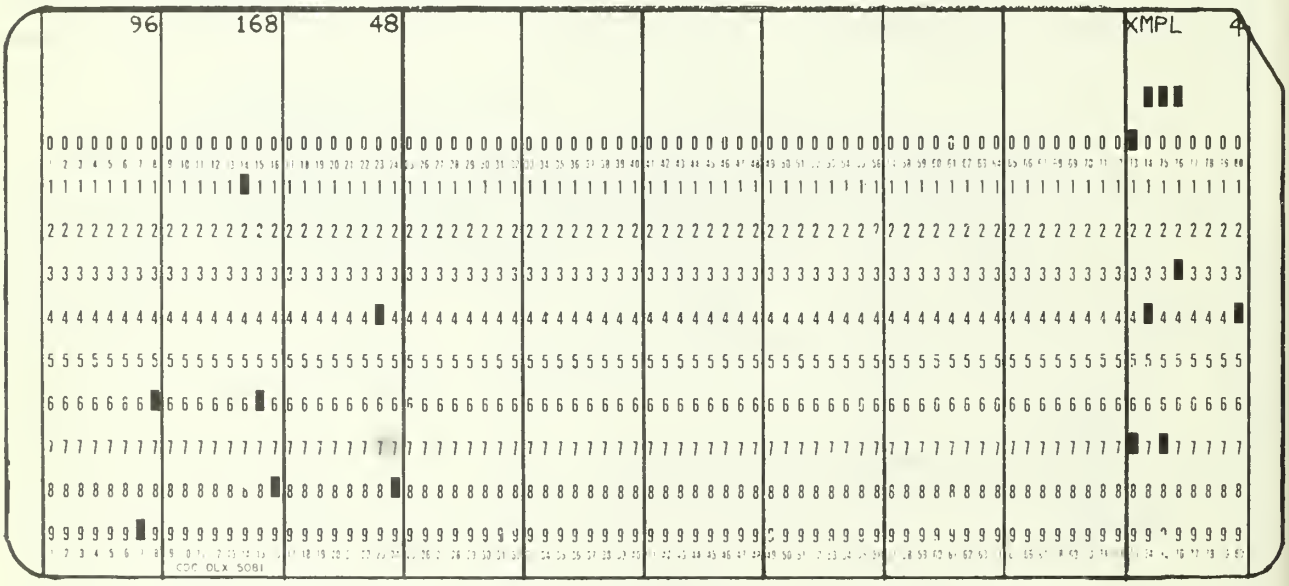
FIGURE 2. THIRD AND FOURTH CONTROL CARDS.

TOTAL NUMBER OF TREES VISITED IN EACH VALUE STRATUM (SURE AND 3P)



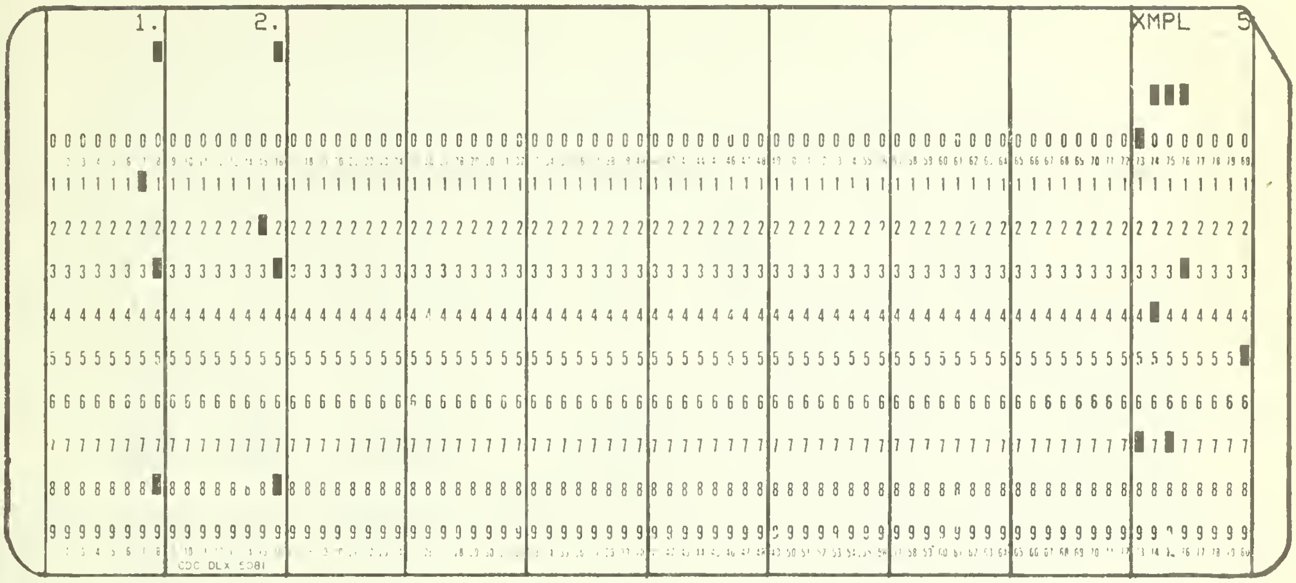
THIRD CONTROL CARD WILL BE BLANK UNLESS FIRST JOB-OPTION IS '2' OR '4'.

AGGREGATE PREDICTIONS FOR ABOVE TREES IN EACH VALUE STRATUM (SURE AND 3P)



FOURTH CONTROL CARD WILL BE BLANK UNLESS FIRST JOB-OPTION IS '2' OR '4'.

FIGURE 3. 5TH THRO 8TH CONTROL CARDS, WITH FORMATS AND LISTS FOR ALL 8 CARDS.

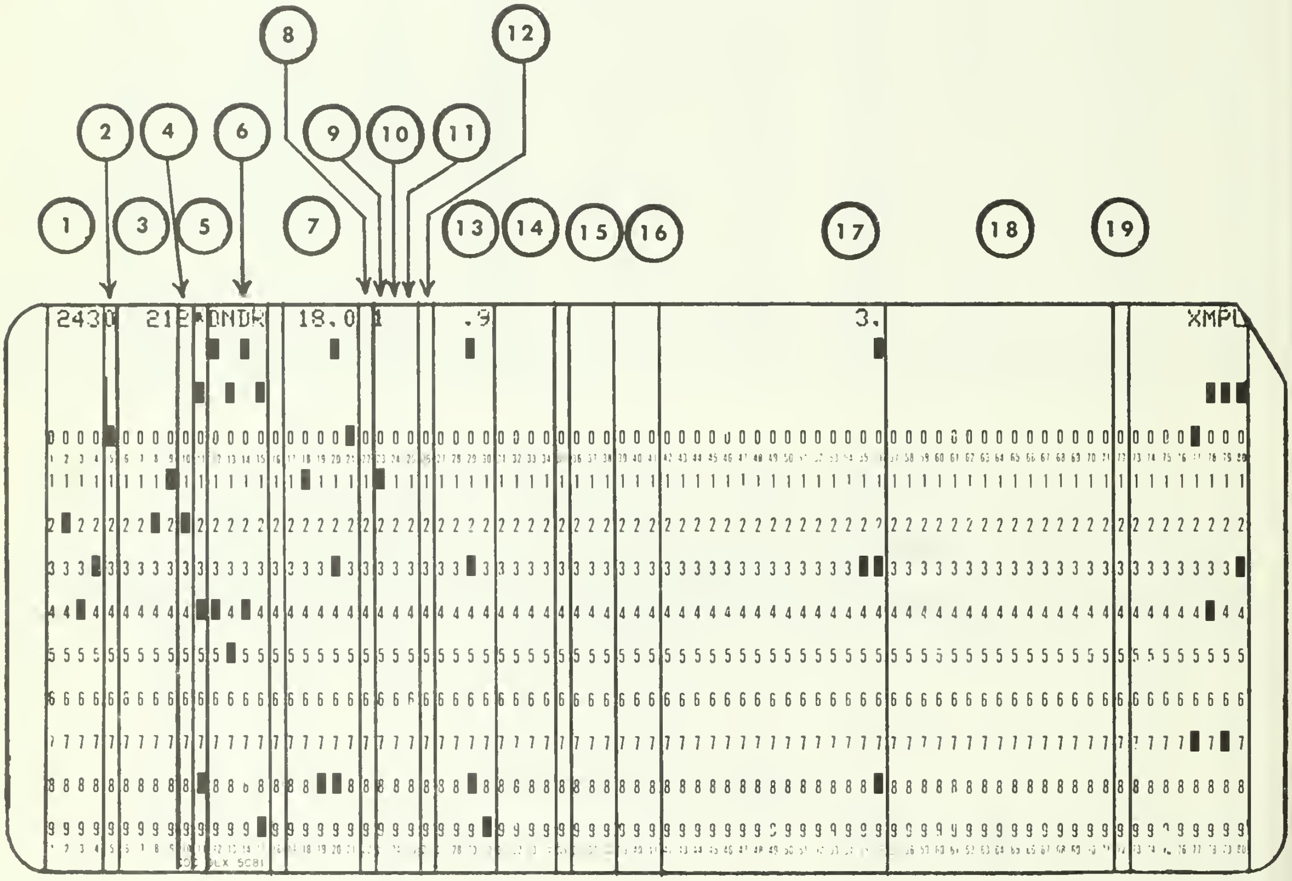


ALL 8 CONTROL CARDS MUST ALWAYS BE PRESENT, ALTHOUGH 3-8 CAN BE LEFT BLANK UNDER MANY CIRCUMSTANCES. THEIR USE IS EXPLAINED ON PAGES 2-10. CC3, CC4, CC7, AND CC8 MUST CONTAIN USER-SUPPLIED VALUES UNDER MAJOR INPUT OPTIONS 2 OR 4, BUT UNDER OPTIONS 1 OR 3 THE PROGRAM WILL COMPUTE APPROPRIATE VALUES FROM SAMPLE STAGES PRIOR TO 3P STAGE. PAGE 2 OF EACH OUTPUT EITHER REPEATS USER-SUPPLIED VALUES FOR CC3-CC8 OR GIVES USER-SUPPLIED VALUES FOR CC5-CC6 AND COMPUTED VALUES FOR OTHERS.

FORMATS AND LISTS

```
    1 FORMAT (I4,16A4,4X,A4)                                              STX    22
    2 FORMAT (4X,3A4,F6.3,F9.8,2F6.4,I2,F5.0,I5,I9,A1,6I1)                STX    23
   23 FORMAT (9I8)                                                        ST11   61
   24 FORMAT (9F8.0)                                                      ST11   62

   91 READ  (MRE,1)             KREENO,ALFATH,CDID                        STX    33
   920READ  (MRE,2)             ADALFA,B,Q,U,G,NSTR,PRBS,KQ,IQ,JZ,        STX    35
     1LS1,LS2,LS3,LS4,LS5,LS6                                             STX    36
      READ  (MRE,23)           (JN(I),I=1,NSTR)                           ST11   87
      READ  (MRE,23)           (KP(I),I=1,NSTR)                           ST11   88
      READ  (MRE,24)           (WV(I),I=1,NSTR)                           ST11   89
      READ  (MRE,24)           (ASX12(I, 9),I=1,NSTR)                     ST11   90
      READ  (MRE,24)           (ASX12(I,11),I=1,NSTR)                     ST11   91
      READ  (MRE,24)           (ASX12(I,12),I=1,NSTR)                     ST11   92
```

FIGURE 4. TREE INPUT CARD.



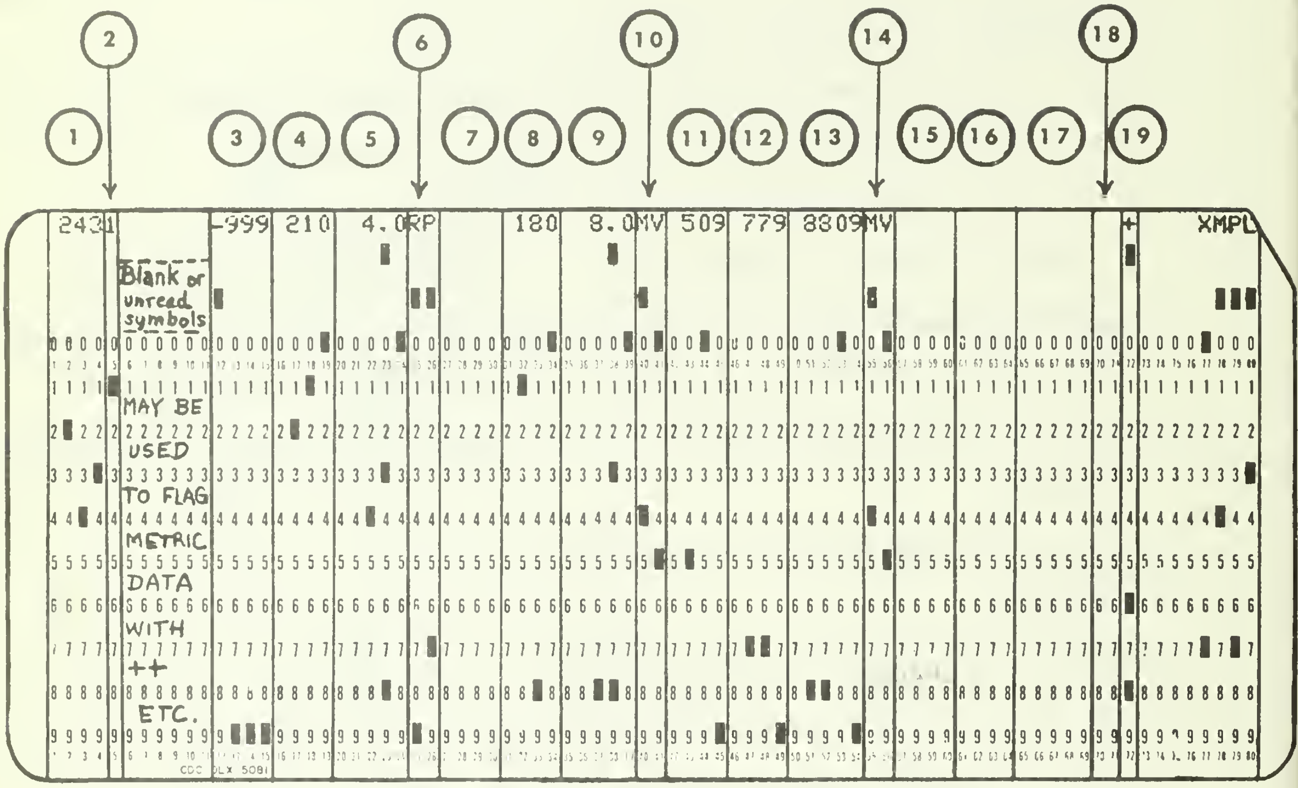
FORMAT AND LIST

```
90 FORMAT(I4,I1,I4,I1,A1,A4,1X,F5.1,A1,3I1,I1,2F4.1,1X,F3.0,F3.3,   ST11   22
 1 2F15.0,A1)                                                       ST11   23

 0 READ  (MRE, 9)        KREENO,JQ,KPI,LST,CERT,BETATH,DBH,JIM,     ST11  105
 1 METH,MBK,MUL,JAM,BKA,BKB,UMAXL,UDORT,XTRA,XTRB,TERM              ST11  106
```

FIGURE 4 (CONTINUED).

```
 1 =KREENO= TREE NUMBER (CANNOT EXCEED 9998).

 2 =   JQ = CARD NUMBER WITHIN TREE (TREE CARD IS ALWAYS BLANK OR 0).

 3 =  KPI = PREDICTION FOR TREE (CANNOT EXCEED 9999).

 4 =  LST = VALUE STRATUM (CANNOT EXCEED NSTR ON CC2).

 5 = CERT = SAMPLING CLASS (=,*, ).

 6 =BETATH= OTHER TREE CLASSIFICATIONS (SPECIES GROUP, SUITABILITY).

 7 =  DBH = BREAST-HIGH DIAMETER O.B. (INCHES OR CENTIMETERS).

 8 =  JIM = MUST AGREE WITH JZ ON CC2 (BLANK FOR U.S., + FOR METRIC).

 9 = METH)
         )
10 = MBK )= TREE OPTIONS (SEE PAGES 14-15).
         )
11 = MUL )

12 =  JAM = DUMMY VARIABLE USED ONLY TO PAD RECORD.

13 =  BKA = FIRST  SINGLE-BARK THICKNESS (INCHES OR CENTIMETERS).

14 =  BKA = SECOND SINGLE-BARK THICKNESS (INCHES OR CENTIMETERS).

15 =UMAXL = SEE PAGE 16.

16 =UDORT = SEE PAGE 16.

17 = XTRA = FACTOR IN TREE OR CLUSTER FREQUENCY (SEE PAGES 5-6).

18 = XTRB = DIVISOR IN TREE OR CLUSTER FREQUENCY (SEE PAGES 5-6).

19 = TERM = ALWAYS BLANK EXCEPT * FOR SAMPLE TREE LACKING DENDROMETRY.
```

FIGURE 5. DENDROMETER INPUT CARD.



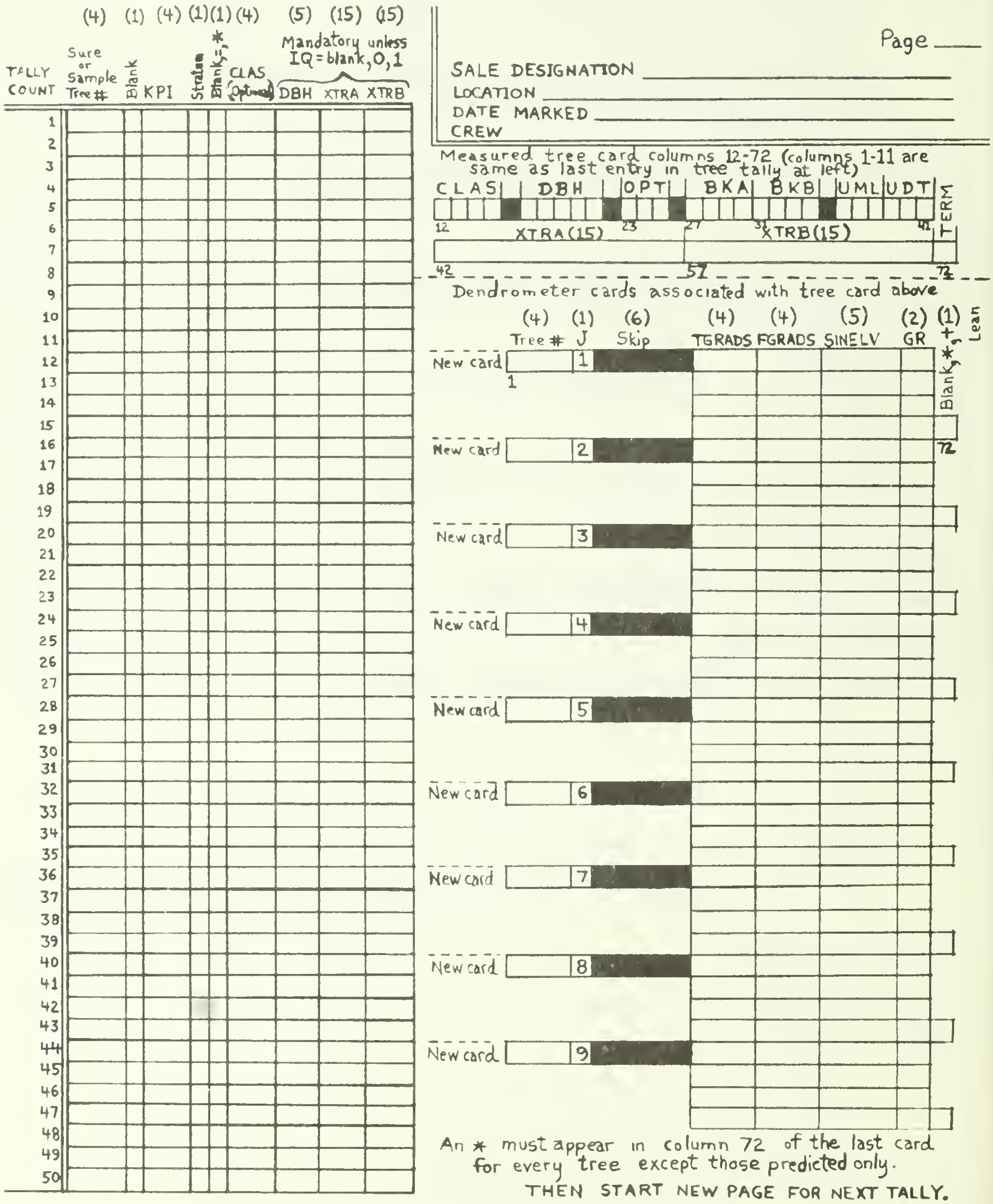
FORMAT AND LIST

```
  10 FORMAT (I4,I1,6X,  4(2F4.1,F5.4,A2),A1)                           ST11   24
1150 READ  (MRE,10)          KREENO,JQ,(TGRADS(I),FGRADS(I),SINELV(I),   ST11  162
    1GAMATH(I),I=1,4),   TERM                                          ST11  163
```

FIGURE 5 (CONTINUED).

```
 1 =KREENO =TREE NUMBER.

 2 =  JQ   =CARD NUMBER WITHIN TREE (MUST BE SEQUENTIAL WITHIN TREE).

 3 =TGRADS)
          )
 4 =FGRADS)= LOWEST PAIR OR TRIO OF DENDROMETER READINGS.
          )
 5 =SINELV)

 6 =GAMATH =GRADE AND DEFECT.

 7 =TGRADS)
          )
 8 =FGRADS)=NEXT DENDROMETER READINGS.
          )
 9 =SINELV)

10 =GAMATH =GRADE AND DEFECT.

11 =TGRADS)
          )
12 =FGRADS)=NEXT DENDROMETER READINGS.
          )
13 =SINELV)

14 =GAMATH =GRADE AND DEFECT.

15 =TGRADS)
          )
16 =FGRADS)=NEXT DENDROMETER READINGS.
          )
17 =SINELV)

18 =GAMATH =GRADE AND DEFECT.

19 = TERM  =* IF NEXT CARD STARTS NEW TREE.
           =+ IF NEXT CARD STARTS NEW REFERENCE PLANE FOR SAME TREE.
           =BLANK IF TREE AND REFERENCE PLANE CONTINUE ON NEXT CARD.
```

FIGURE 6. CONVENIENT TALLY FORM FOR RECORDING FIELD DATA.



IGURE 7. SUGGESTED PRINTED CARD-FORMAT TO FACILITATE PUNCHING EITHER TREE OR DENDROMETER INPUT DATA.

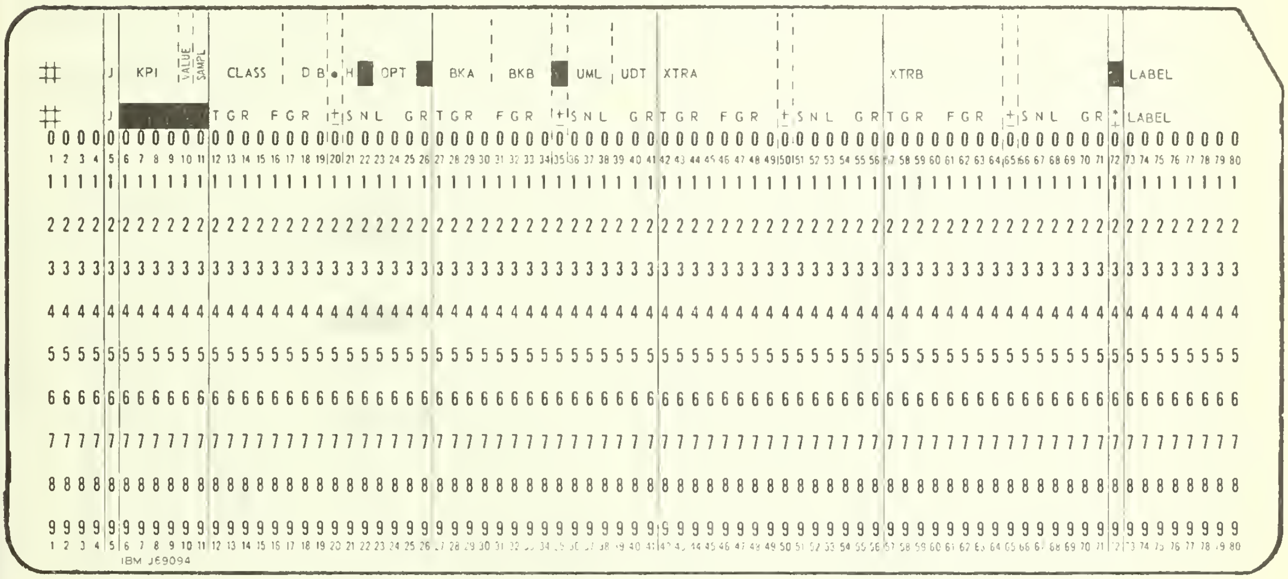
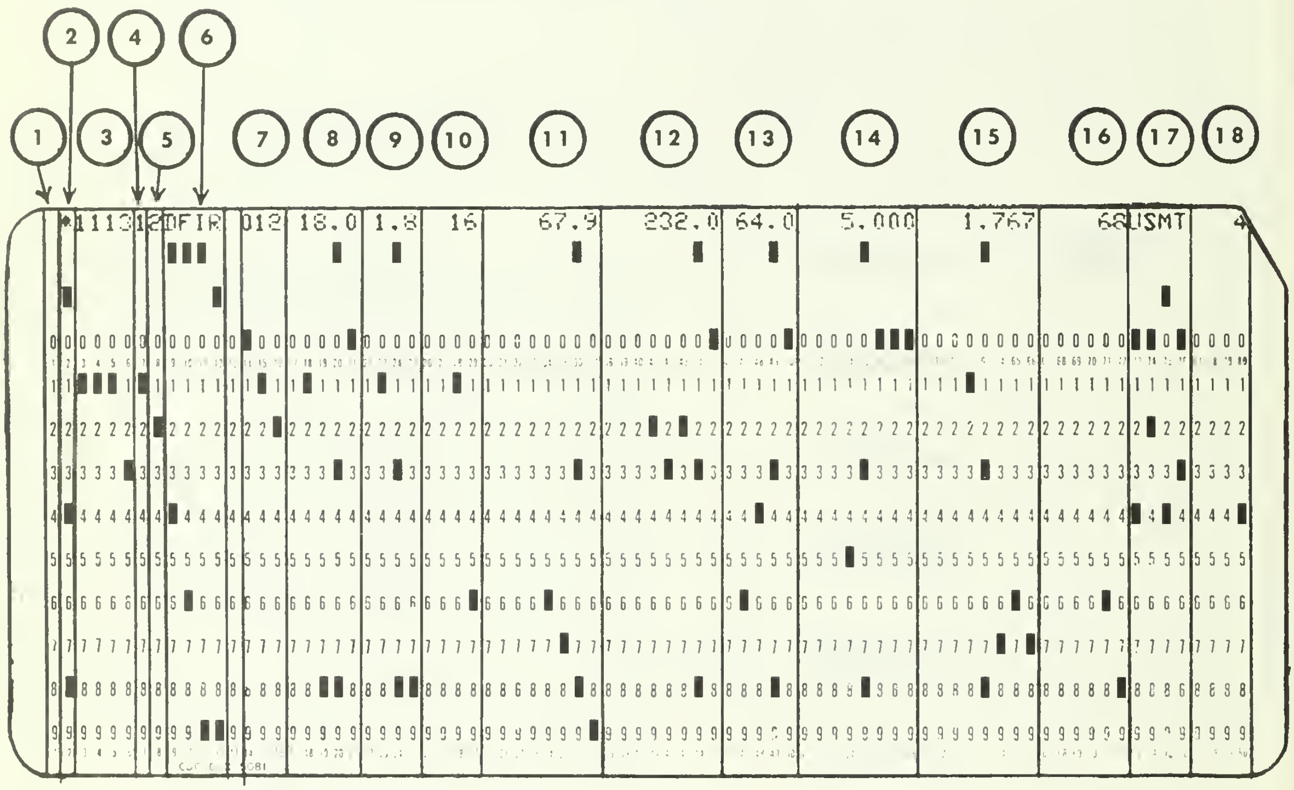


FIGURE 8. TREE OUTPUT CARD (OBTAINED BY PUNCHING '2' IN 4TH JOB-OPTION).



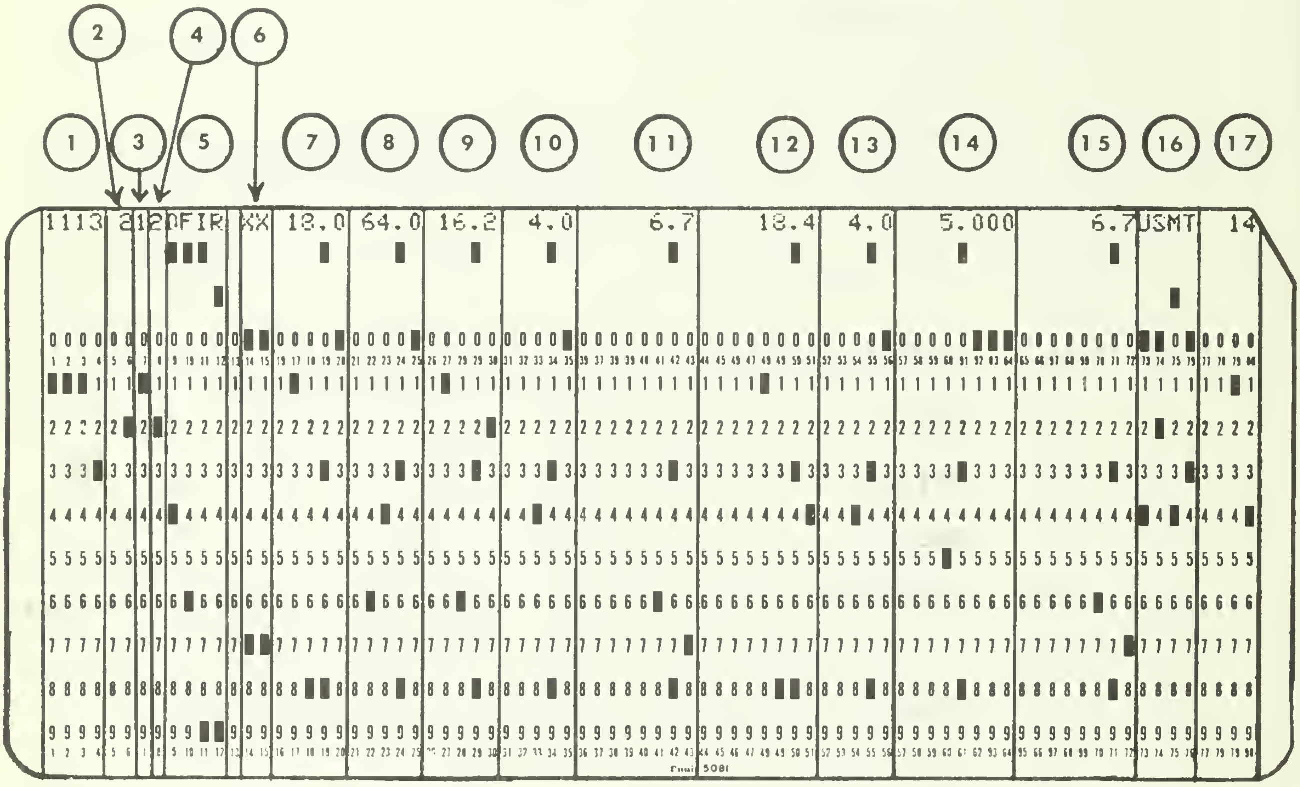
FORMAT AND LIST

```
21 0 FORMAT (2A1,I4,2I1,A4,A1,3I1,F5.1,F4.1,I4,F8.1,F8.1,F5.1,2F8.3,I6, ST22   37
   1 A4,I4)                                                              ST22   38

   0 WRITE (MPU,21)           MX(5),MX(6),KREENO,LST, CERT,BETATH,JZ,    ST22  303
   1 METH,MBK,MUL,DBH,BK,KPI,SUMV,SUMS,SUMH,FREQ,BA,LOUT,CDID,KRDS2      ST22  304
```

IGURE 8 (CONTINUED).

```
  1 = MX(5)= ASTERISK IMPLIES FORKED TREE.

  2 = MX(6)= ASTERISK IMPLIES UNSEEN USABLE MATERIAL.

  3 =KREENO= TREE NUMBER.

  4 =  LST = VALUE STRATUM.

  5 = CERT = SAMPLING CLASS (1=CERTAIN, 2=SAMPLE).

  6 =BETATH= OTHER TREE CLASSIFICATIONS.

     (METH)
  7 =(MBK )= TREE OPTIONS (SEE PAGES 14-15).
     (MUL )

  8 =  DBH = BREAST-HIGH DIAMETER O.B. (INCHES OR CENTIMETERS).

  9 =  BK  = DOUBLE-BARK THICKNESS (INCHES OR CENTIMETERS).

 10 =  KPI = PREDICTION FOR TREE.

 11 = SUMV = CUBIC VOLUME OF TREE (FEET OR METERS, I.B. OR O.B.).

 12 = SUMS = CIRCUMFERENTIAL SURFACE OF TREE (FT. OR M., I.B. OR O.B.).

 13 = SUMH = LENGTH OF MATERIAL IN TREE (FT. OR M., INCLUDING FORKS).

 14 = FREQ = POPULATION FREQUENCY REPRESENTED BY SAMPLE TREE.

 15 =  BA  = BASAL AREA OF TREE (SQ. FT. OR SQ. M.).

 16 = LOUT = LINEAR COMPOUND OF V, S, L OBTAINED FROM TREE (MF. UNITS).

 17 = CDID = BRIEF JOB IDENTIFIER.

 18 = KRDS2= CARD OUTPUT SEQUENCE WITHIN JOB.
```

FIGURE 9. LOG OUTPUT CARD (OBTAINED BY PUNCHING '3' IN 4TH JOB-OPTION).



FORMAT AND LIST

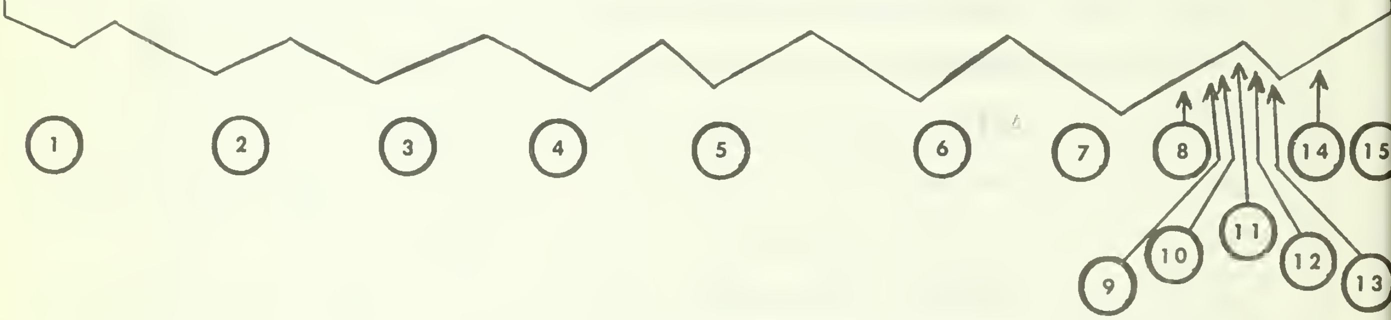
```
22 FORMAT(I4,I2,2I1,A4,A1,A2,2(F5.1,F5.1),2F8.1,F5.1,F8.3,F8.1,A4,I4)ST22   39

 0WRITE (MPU,22)           KREENO,I,LST, CERT,BETATH,JZ,GAMATH(I),  ST22 293
 1DBH,E(N),DR(I),E(I),CC(I),C(I),H(I),FREQ,POUT,CDID,KRDS2           ST22 294
```

FIGURE 9 (CONTINUED).

```
 1 =KREENO= TREE NUMBER.
 2 =   I  = DIAMETER SEQUENCE WITHIN TREE.
 3 =  LST = VALUE STRATUM.
 4 = CERT = SAMPLING CLASS (1=CERTAIN, 2=SAMPLE).
 5 =BETATH= OTHER TREE CLASSIFICATIONS.
 6 =GAMATH= GRADE AND DEFECT.
 7 =  DBH = BREAST-HIGH DIAMETER O.B. (INCHES OR CENTIMETERS).
 8 = E(N) = HEIGHT ABOVE STUMP OF TOPMOST MEASURED DIAM. (FT. OR M.).
 9 =  DR  = UPPER DIAMETER OF LOG (IN. OR CM., I.B. OR O.B.).
10 =   E  = HEIGHT OF UPPER END OF LOG ABOVE STUMP (FT. OR M.).
11 =  CC  = CUBIC VOLUME OF  LOG (FEET OR METERS, I.B. OR O.B.).
12 =   C  = CIRCUMFERENTIAL SURFACE OF  LOG (FT. OR M., I.B. OR O.B.).
13 =   H  = LENGTH OF MATERIAL IN  LOG (FT. OR M.).
14 = FREQ = POPULATION FREQUENCY REPRESENTED BY SAMPLE LOG.
15 = POUT = LINEAR COMPOUND OF V, S, L OBTAINED FROM LOG (MF. UNITS).
16 = CDID = BRIEF JOB IDENTIFIER.
17 = KRDS2= CARD OUTPUT SEQUENCE WITHIN JOB.
```

FIGURE 10. TREE PRINTOUT WITHOUT LOGS (OBTAINED BY PUNCHING '2' IN 3RD JOB-OPTION).

```
VISIT ALL TREES, GUESS H*D**2, MEASURE SINGLE-STAGE-3P SAMPLE    SS3P  PAGE   3
LRG 03-03-73    .000  .00000000    .0000    .0000  1       60.   60          1 122000
                             DETAILED LOG AND/OR TREE REPORT
===================================================================================
TREE/  VOLUME   / SURFACE / LENGTH / D.B.H. /
 NO./  CU.FT.   /  SQ.FT. /   FT.  /  IN.   /
===================================================================================
   1        2.3      21.2     16.0     6.0=D,F=   60.000,    1,   .0 211 DFIR 1
   2       13.0      62.2     24.0    12.0=D,F=   10.000,    6,   .0 211 DFIR 1
   2       13.0      62.2     24.0    12.0=D,F=   10.000,    6,   .0 211 DFIR 1
   2       13.0      62.2     24.0    12.0=D,F=   10.000,    6,   .0 211 DFIR 1
   2       13.0      62.2     24.0    12.0=D,F=   10.000,    6,   .0 211 DFIR 1
   3       67.9     231.8     64.0    18.0=D,F=    1.667,   36,   .0 211 DFIR 1
   3       67.9     231.8     64.0    18.0=D,F=    1.667,   36,   .0 211 DFIR 1
   3       67.9     231.8     64.0    18.0=D,F=    1.667,   36,   .0 211 DFIR 1
1113       67.9     231.8     64.0    18.0=D,F=    1.667,   36,   .0 211 DFIR 1
1113       67.9     231.8     64.0    18.0=D,F=    1.667,   36,   .0 211 DFIR 1
1113       67.9     231.8     64.0    18.0=D,F=    1.667,   36,   .0 211 DFIR 1
```



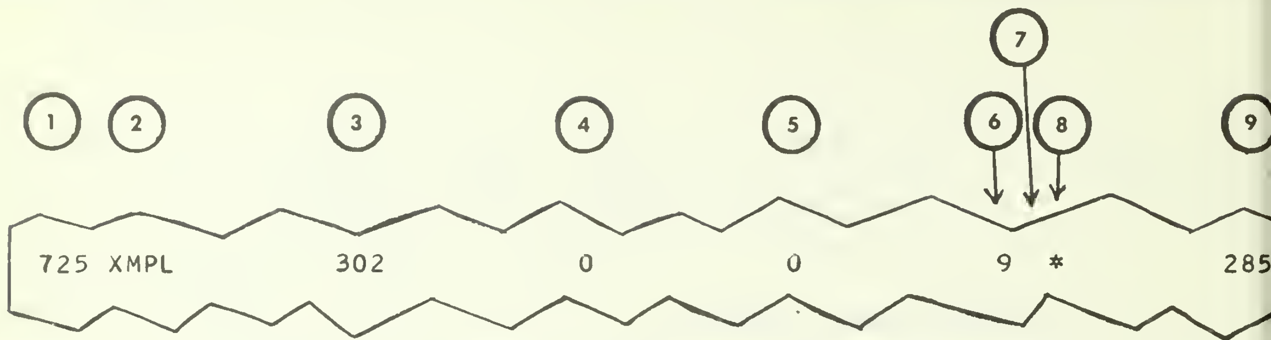
FORMAT AND LIST

```
  190 FORMAT          (1X,I4,F11.1,F10.1,F8.1,F9.1,5H=D,F=,F9.3,1H,,   ST22  35
    1 I5,1H,,F5.1,A1,3I1,A1,A4,1X,I1)                                  ST22  36

 3650 WRITE (MPR,19)          KREENO,SUMV,SUMS,SUMH,DBH,FREQ,KPI,BK,    ST22 283
    1 MX(5),METH,MBK,MUL,MX(6),BETATH,LST                              ST22 284
```

FIGURE 10 (CONTINUED).

```
 1 =KREENO= TREE NUMBER.
 2 = SUMV = CUBIC VOLUME OF TREE (FEET OR METERS, I.B. OR O.B.).
 3 = SUMS = CIRCUMFERENTIAL SURFACE OF TREE (FT. OR M., I.B. OR O.B.).
 4 = SUMH = LENGTH OF MATERIAL IN TREE (FT. OR M., INCLUDING FORKS).
 5 =  DBH = BREAST-HIGH DIAMETER O.B. (INCHES OR CENTIMETERS).
 6 = FREQ = POPULATICN FREQUENCY REPRESENTED BY SAMPLE TREE.
 7 =  KPI = PREDICTICN FCR TREE.
 8 =  BK  = DOUBLE-BARK THICKNESS (INCHES OR CENTIMETERS).
 9 = MX(5)= ASTERISK IMPLIES FORKED TREE.
10 = METH = TYPE OF CENDROMETER (SEE PAGES 14-15).
11 = MBK  = METHOD OF HANDLING BARK DEDUCTION (SEE PAGES 14-15).
12 = MUL  = METHOD OF PROJECTION FOR UNSEEN LENGTH (SEE PAGES 14-15).
13 = MX(6)= ASTERISK IMPLIES UNSEEN USABLE MATERIAL.
14 =BETATH= TREE CLASSIFICATIONS.
15 =  LST = VALUE STRATUM.
```

FIGURE 11. INFORMATION PRINTOUT FOR ERROR ENCOUNTERED BY SUBROUTINE ST11.



1 = NER = TOTAL OF OCTAL CODES PER TREE FOR ERRORS FOUND (SEE BE
2 = CDID = BRIEF JOB IDENTIFIER.
3 =KREENO= TREE NUMBER STORED MOST RECENTLY.
4 = JQ = CARD NUMBER WITHIN TREE.
5 = KPI = PREDICTICN FCR TREE.
6 = LST = VALUE STRATUM.
7 =JCERT = SAMPLING CLASS (=,*,).
8 = TERM = TERMINAL SYMBOL (,+,*).
9 = LKR = PREVIOUS TREE NUMBER.

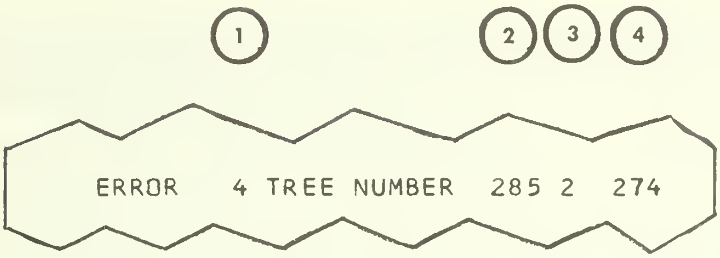
FORMAT AND LIST

```
15  FORMAT (1H ,I3,1X,A4,4I12,1X,2A1,I12)                          ST11
    WRITE (MPR,15)          NER,CDID,KREENO,JQ,KPI,LST,JCERT,TERM,LKR ST11
```

ST11 OCTAL ELEMENT CODE	MULTIPLE ELEMENTS INDICATE MULTIPLE ERRORS
1	DATA DECK JUMBLED OR MISPUNCHED (CERT NE =,*, OR BLANK).
2	DATA DECK JUMBLED OR JQ MISPUNCHED (1ST JQ GT 0) OR PRIOR * OMITTE
3	ERRORS 1 AND 2.
4	TREE STRATUM GREATER THAN MAXIMUM (NSTR) SPECIFIED ON CONTROL CARD
5	ERRORS 1 AND 4.
6	ERRORS 2 AND 4.
7	ERRORS 1, 2, AND 4.
20	DBH OMITTED AND ABSOLUTE VALUE OF IQ GREATER THAN 1.
100	KPI GT KQ, LE 0, OR OMITTED AND CERT NE =.
200	JCERT IS BLANK BUT FIRST JOB INPUT OPTION IS 2 OR 4.
300	ERRORS 100 AND 200.
400	JIM ON TREE CARD DOES NOT AGREE WITH JZ ON CONTROL CARD 2 (US-METR
500	ERRORS 100 AND 400.
600	ERRORS 200 AND 400.
700	ERRORS 100, 200, AND 400.

N.B. --- NER WILL BE OCTAL SUM OF 1-DIGIT, 2-DIGIT, AND 3-DIGIT ELEMENTS FO

FIGURE 12. ERROR MESSAGE PRINTED FOR ERRORS ENCOUNTERED BY SUBROUTINE ST22.




```
1 =  NER  = ST22 ERROR CODE (SEE BELOW).
2 =KREENO= TREE NUMBER.
3 =   JQ  = CARD NUMBER WITHIN TREE.
4 =  LKR  = PREVIOUS TREE NUMBER.
```

FORMAT AND LIST

```
  23 FORMAT (11H     ERROR ,I3,1X,12HTREE NUMBER ,I4,1X,I1,1X,I4)      ST22  40
1011 WRITE (MPR,23)              NER,KREENO,JQ,LKR                     ST22 370
```

ST22 ERROR CODE	SINGLE FATAL ERROR
1	NEGATIVE DIAMETER (FAULTY UNSEEN LENGTH PROJECTION).
2	COLUMN 72 *, +, OR BLANK WRONGLY PUNCHED OR COMPUTER-COPIED OR -READ.
3	NEGATIVE LENGTH (DOWNWARD DENDROMRTRY,FAULTY PUNCHING OR PROJECTION).
4	DATA DECK JUMBLED OR JQ MISPUNCHED (1ST JQ GT 0) OR PRIOR * OMITTED.
5	PRIOR MACHINE FAILURE TO DETECT TREE STRATUM EXCEEDING MAXIMUM (NSTR).
6	PRIOR MACHINE FAILURE TO BRANCH ON = OR TO DETECT KPI GT KQ OR LE 0.
7	TOO FEW MEASURED DIAMETERS FOR PROJECTION SPECIFIED -------- MINIMUM IS 4 FOR CONCAVE-CONVEX, 1 FOR CONIC, 2 FOR ALL OTHERS.

FIGURE 13. LOG AND TREE INFORMATION WRITTEN ON TAPE JX FOR USE BY GRADE-YIELD AND REALIZATION SUBROUTINE PROD WHEN 5TH JOB OPTION IS 2,3,4,5,6 (SEE PAGE 103 FOR EXAMPLE OF PRINTOUT WHEN 5TH JOB OPTION IS 5).

TAPE JX HAS TWO 19-WORD BINARY RECORDS INVOLVING JOB PARAMETERS THAT ARE LAST 2 RECORDS WRITTEN, BUT FIRST 2 RECORDS READ AFTER FULL SORT.

```
0|WRITE (JX)              IZERO,CDID,JPAGE,ADALFA(1),MULL,MULL,   |TREE  37
1|ADALFA(2),ADALFA(3),  JZ,(ALFATH(I),I=1,10)                    |TREE  38
0|WRITE (JX)              B,Q,U,G,MULL,  JY,PRBS,KQ,NSTR,IQ,LSSS, |TREE  39
1|LS5,LS6,(ALFATH(I),I=11,16)                                     |TREE  40
```

TAPE JX ALSO HAS 'IZERO' 19-WORD BINARY RECORDS INVOLVING SAMPLE-TREE DATA.

```
0|WRITE (JX)              KREENO,I,LST, CERT,BETATH,GAMATH(I),DBH, |ST22 297
1|E(N),DR(I),E(I),CC(I),C(I),H(I),FREQ,WV(LST),SUMV,SUMS,SUMH,PKI  |ST22 298
```

THESE 19 DATA WORDS ARE MORE FAMILIAR TO USERS UNDER FOLLOWING ALIASES --

```
 1 =KREENO= TREE NUMBER.
 2 =   I   = DIAMETER SEQUENCE WITHIN TREE.
 3 =  LST  = VALUE STRATUM.
 4 = CERT  = SAMPLING CLASS (1=CERTAIN, 2=SAMPLE).
 5 =BETATH= OTHER TREE CLASSIFICATIONS.
 6 =GAMATH= GRADE AND DEFECT.
 7 =  DBH  = BREAST-HIGH DIAMETER O.B. (INCHES OR CENTIMETERS).
 8 = E(N)  = HEIGHT ABOVE STUMP OF TOPMOST MEASURED DIAM. (FT. OR M.).
 9 =  DR   = UPPER DIAMETER OF LOG (IN. OR CM., I.B. OR O.B.).
10 =   E   = HEIGHT OF UPPER END OF LOG ABOVE STUMP (FT. OR M.).
11 =  CC   = CUBIC VOLUME OF  LOG (FEET OR METERS, I.B. OR O.B.).
12 =   C   = CIRCUMFERENTIAL SURFACE OF  LOG (FT. OR M., I.B. OR O.B.).
13 =   H   = LENGTH OF MATERIAL IN  LOG (FT. OR M.).
14 = FREQ  = POPULATION FREQUENCY REPRESENTED BY SAMPLE LOG.
15 =  WV   = STRATUM VALUE PER UNIT VOLUME.
16 = SUMV  = CUBIC VOLUME OF TREE (FEET OR METERS, I.B. OR O.B.).
17 = SUMS  = CIRCUMFERENTIAL SURFACE OF TREE (FT. OR M., I.B. OR O.B.).
18 = SUMH  = LENGTH OF MATERIAL IN TREE (FT. OR M., INCLUDING FORKS).
19 =  PKI  = PREDICTED VOLUME OR VALUE FOR TREE (FLOATING POINT).
```

================================ APPENDIX B ================================

APPROPRIATE RUNSTREAM FOR ESTABLISHING 4-PROGRAM DENDROMETRY/3P LIBRARY
FOR USE WITH UNIVAC 1106-1108-1110 UNDER EXEC 8 OPERATING SYSTEM,
ALONG WITH EXAMPLES OF PROCEDURES FOR PROGRAM MODIFICATION
AND SEVERAL NUMERICAL EXAMPLES OF INPUT AND OUTPUT
ILLUSTRATING MANY CAPABILITIES AND OPTIONS

UNIVAC 1108 RUN-STREAM NEEDED TO INPUT SOURCE, COMPILE, CATALOG READ-ONLY SOURCE AND RELOCATABLE LIBRARY, MAP, AND EXECUTE UNDER EXEC 8 OP. SYSTEM.

```
@RUN    GROZ11,99B9999,GROSENBAUGH, 5,500/100    03-03-73
@ASG,CPR  GROSENBAUGH*DNDR3P,F2/// .  ASSIGN, CATALOG  PUBLIC READ-ONLY F2 FILE
@USE      AZ,GROSENBAUGH*DNDR3P .      EQUATE AZ TO GROSENBAUGH*DNDR3P.
@ASG,T    SOURCE,T,W41N .       ASSIGN TAPE REEL W41 (NO RING) FOR SOURCE IMAGES
@ASG,T    B,F .                 ASSIGN SIM TAPE FOR SCRATCH .
@ASG,T    C,F .                 ASSIGN SIM TAPE FOR SCRATCH .
@USE      4,B .                 EQUATE B TO FORTRAN I/O UNIT 4 .
@USE      8,C .                 EQUATE C TO FORTRAN I/O UNIT 8 .
@COPY,G   SOURCE.,AZ. .         ROLLIN PROGRAM FILE FROM SOURCE TO AZ.
@REWIND,I SOURCE .              REWIND REEL W41 (NAMED SOURCE) WITH INTERLOCK.
@ERS      TPF$. .               ERASE TPF$.
@FOR,S    AZ.REX,TPF$.REX,TPF$.REX     . PUT SOURCE,RELOCATABLE ELEMENTS IN TPF$
@FOR,S    AZ.BLRM,TPF$.BLRM,TPF$.BLRM
-44,44
      DATA MRE/ 5/,MPR/ 6/,MPU/1/,JW/4/,JX/8/,MEOF/ 0/                BLRM  44
@FOR,S    AZ.TRNX,TPF$.TRNX,TPF$.TRNX
@FOR,S    AZ.PALM,TPF$.PALM,TPF$.PALM
@FOR,S    AZ.MATX,TPF$.MATX,TPF$.MATX
@FOR,S    AZ.SKRN,TPF$.SKRN,TPF$.SKRN
@FOR,S    AZ.CBXR,TPF$.CBXR,TPF$,CBXR
@FOR,S    AZ.RSID,TPF$.RSID,TPF$.RSID
@ELT,LI   TPF$.REXMAP                  . PUT SYMBOLIC STRUCTURE (MAP) IN TPF$.
 LIB      AZ. .
 SEG      LINKO
 IN       REX,BLRM,TRNX
 SEG      LINK1*,(LINKO)
 IN       PALM,MATX
 SEG      LINK2*,(LINKO)
 IN       SKRN
 SEG      LINK3*,(LINKO)
 IN       CBXR
 SEG      LINK4*,(LINKO)
 IN       RSID
@FOR,S    AZ.RN3P,TPF$.RN3P,TPF$.RN3P . PUT SOURCE,RELOCATABLE ELEMENTS IN TPF$
-116,116
     ODATA IMX/34359738367/,MWL/35/,MRE/ 5/,MPR/ 6/,MEOF/0/,          RN3P 116
@ELT,LI   TPF$.RN3MAP                  . PUT SYMBOLIC STRUCTURE (MAP) IN TPF$.
 LIB      AZ. .
 SEG      LINKO
 IN       RN3P
@FOR,S    AZ.STX,TPF$.STX,TPF$.STX     . PUT SOURCE,RELOCATABLE ELEMENTS IN TPF$
@FOR,S    AZ.BLD,TPF$.BLD,TPF$.BLD
-9,9
     ODATA MRE/ 5/,MPR/ 6/,MPU/1/,JW/4/,JX/8/,MEF/0/,JY/2/,N3/0/,NP/0/,BLD    9
-14,14
     5RDE/.90/,UDTRO/.45/,QUAN/ 1.0/,DENO/ 2.0/,MULL/  0/,J/ 3/,K/ 3/, BLD   14
-19,19
      DATA   V/45*0./                                                 BLD   19
```

```
================== CONTINUATION OF APPROPRIATE RUN-STREAM ====================

@FOR,S     AZ.TREE,TPF$.TREE,TPF$.TREE
@FOR,S     AZ.ST11,TPF$.ST11,TPF$.ST11
@FOR,S     AZ.ST22,TPF$.ST22,TPF$.ST22
@FOR,S     AZ.GAPP,TPF$.GAPP,TPF$.GAPP
@FOR,S     AZ.SBRD,TPF$.SBRD,TPF$.SBRD
@FOR,S     AZ.DLIN,TPF$.DLIN,TPF$.DLIN
@FOR,S     AZ.OPCL,TPF$.OPCL,TPF$.OPCL
@FOR,S     AZ.OPFK,TPF$.OPFK,TPF$.OPFK
@FOR,S     AZ.OTHR,TPF$.OTHR,TPF$.OTHR
@FOR,S     AZ.FFB3,TPF$.FFB3,TPF$.FFB3
@FOR,S     AZ.FFH3,TPF$.FFH3,TPF$.FFH3
@FOR,S     AZ.FFS3,TPF$.FFS3,TPF$.FFS3
@FOR,S     AZ.FFV3,TPF$.FFV3,TPF$.FFV3
@FOR,S     AZ.BALF,TPF$.BALF,TPF$.BALF
@FOR,S     AZ.ST33,TPF$.ST33,TPF$.ST33
@FOR,S     AZ.PREP,TPF$.PREP,TPF$.PREP
@FOR,S     AZ.VSRT,TPF$.VSRT,TPF$.VSRT
@FOR,S     AZ.PROD,TPF$.PROD,TPF$.PROD
@FOR,S     AZ.SUBT,TPF$.SUBT,TPF$.SUBT
@FOR,S     AZ.ST44,TPF$.ST44,TPF$.ST44
@ELT,LI    TPF$.STXMAP                     . PUT SYMBOLIC STRUCTURE (MAP) IN TPF$.
 LIB       AZ. .
 SEG       LINKO
 IN        STX,BLD
 SEG       LINK1*,(LINKO)
 IN        TREE,ST11,ST22,GAPP,SBRD,DLIN,OPCL,OPFK,OTHR,FFB3,FFH3,FFS3,;
           FFV3,BALF,ST33
 SEG       LINK2*,(LINKO)
 IN        PREP,VSRT
 SEG       LINK3*,(LINKO)
 IN        PROD,SUBT,ST44
@FOR,S     AZ.USMT,TPF$.USMT,TPF$.USMT . PUT SOURCE,RELOCATABLE ELEMENTS IN TPF$
-57,57
     7IPLS/1H+/,LASK/1H*/,LAST/4H9999/,MRE/ 5/,MPR/ 6/,MPU/ 1/,MEOF/ 0/USMT  57
@ELT,LI    TPF$.USMMAP                     . PUT SYMBOLIC STRUCTURE (MAP) IN TPF$.
 LIB       AZ. .
 SEG       LINKO
 IN        USMT
@PREP      TPF$. .               PREPARE ENTRY-POINT TABLE FOR TPF$.
@COPY      TPF$.,AZ. .           COPY TPF$ INTO AZ.
@PRT,T     AZ. .                 PRINT TABLE OF CONTENTS FOR AZ.
@ERS       TPF$. .               ERASE TPF$.
@MAP       AZ.RN3MAP,TPF$.RN3RN3           . PUT ABSOLUTE LINKEDITED MODULE IN TPF$.
@XQT       .RN3RN3                         . LOAD AND EXECUTE ABSOLUTE MODULE.
    SS3P RANDOM INTEGERS FOR SINGLE-STAGE 3P SAMPLES                       SS3P   1
 995562457      500        60         60                                  SS3P   2
    XMPL RANDOM INTEGERS FOR POINT-3P, POINT, AREA-POINT SAMPLES          XMPL   1
 621489793      500        21         24                                  XMPL   2
9999

====== OUTPUT WILL BE SHOWN CNLY FOR XMPL, THE LATTER OF THE TWO INPUTS. ======
```

XMPL RANDOM INTEGERS FOR POINT-3P, POINT, AREA-POINT SAMPLES PAGE 1
L= 621489793, LIM= 500, K= 21, KZ= 24 XMPL

7	19	-99999	4	3	4	1	12	-99999	3
9	9	8	13	12	18	16	2	6	1
14	7	20	14	16	-99999	1	-99999	-99999	10
1	5	-99999	19	11	15	21	19	19	15
10	7	5	15	-99999	14	17	4	19	10
8	15	16	-99999	20	-99999	8	-99999	3	19
19	17	20	14	18	21	-99999	-99999	19	-99999
20	2	9	2	14	12	-99999	14	10	19
17	12	1	5	21	2	9	2	12	1
4	10	19	10	16	11	-99999	6	19	19
3	7	2	11	11	14	10	16	3	-99999
13	6	7	-99999	-99999	15	-99999	20	15	17
5	-99999	12	20	21	16	3	15	8	-99999
8	7	10	-99999	11	1	4	16	3	-99999
-99999	-99999	-99999	12	7	18	-99999	19	8	10
17	13	12	20	-99999	5	5	15	6	1
11	-99999	20	12	7	4	11	7	-99999	8
6	20	19	1	-99999	8	16	16	11	19
21	11	17	17	8	6	13	1	16	20
7	19	4	19	17	15	17	1	20	10
13	8	20	7	-99999	21	12	5	20	6
11	21	2	3	3	12	15	12	-99999	19
8	9	2	14	1	7	4	2	7	9
6	16	-99999	11	11	21	-99999	5	3	20
8	2	17	2	-99999	10	7	19	3	4
14	16	19	13	4	1	-99999	20	4	9
20	8	14	-99999	12	2	6	18	19	18
13	3	17	14	11	7	4	4	15	14
17	17	1	13	15	1	-99999	15	11	-99999
-99999	20	18	18	8	11	2	-99999	19	14
11	3	2	3	6	8	-99999	1	4	8
-99999	17	14	16	5	6	-99999	20	3	2
7	12	8	-99999	15	12	10	17	17	11
13	1	2	1	4	5	17	9	15	8
8	21	10	1	9	14	9	-99999	1	3
4	17	12	12	12	-99999	4	-99999	10	17
2	18	6	12	18	1	20	4	2	20
19	1	13	4	12	20	16	2	12	-99999
1	16	15	21	-99999	6	18	8	15	13
12	9	18	5	4	15	15	2	7	-99999
7	14	8	8	2	10	17	14	18	4
4	15	20	11	18	-99999	4	20	7	14
19	-99999	11	12	10	4	4	13	21	21
5	20	18	6	17	17	-99999	12	1	3
7	21	7	15	16	3	5	5	8	2
10	4	3	-99999	10	7	2	4	-99999	12
19	14	21	1	8	-99999	15	21	17	12
18	17	9	2	8	6	1	16	4	3
10	19	-99999	1	1	2	12	7	17	-99999
11	1	16	8	8	-99999	-99999	21	-99999	4

XMPL XMPL XMPL XMPL XMPL XMPL XMPL XMPL XMPL XMPL

```
XMPL RANDOM INTEGERS FOR POINT-3P, POINT, AREA-POINT SAMPLES PAGE    2
L=   621489793, LIM=    500, K=     21, KZ=     24                XMPL

XMPL      KSUM          =          4679,   NK       =    437,   NKZ=    500
EXPECTED  NK*(K+1)/2=              4807,   NKZ*K/KZ=     437,   LIM=    500
```

```
    INPUTS LACKING POINT-SAMPLING (IQ=-1), LACKING DENDROMETRY (TREE TERM=*)
=================================================================================

@ERS         TPF$. .                  ERASE TPF$.
@MAP         AZ.STXMAP,TPF$.STXSTX
@XQT          .STXSTX
    PLOT, HORIZONTAL LINE, SINGLE-STAGE-3P SAMPLING                       IQ-1    1
    LRG 03-03-73                                 3   60   60        -1 122000 IQ-1    2
                                                                          IQ-1    3
                                                                          IQ-1    4
                                                                          IQ-1    5
    10.0     60.0     1.0                                                 IQ-1    6
                                                                          IQ-1    7
                                                                          IQ-1    8
   10     1=PLOT   6.0                          6.0                  *     IQ-1
   20     1=PLOT  12.0                          4.0                  *     IQ-1
   30     1=PLOT  18.0                           .5                  *     IQ-1
11130     1=PLOT  18.0                           .5                  *     IQ-1
   10     2=LINE   6.0                          6.0      6.0         *     IQ-1
   20     2=LINE  12.0                          8.0     12.0         *     IQ-1
   30     2=LINE  18.0                          1.5     18.0         *     IQ-1
11130     2=LINE  18.0                          1.5     18.0         *     IQ-1
         13 SS3P   6.0                         59.0                        IQ-1
   10    13*SS3P   6.0                          1.0                  *     IQ-1
         63 SS3P  12.0                         36.0                        IQ-1
   20    63*SS3P  12.0                          4.0                  *     IQ-1
        363 SS3P  18.0                          2.0                        IQ-1
   30   363*SS3P  18.0                          3.0                  *     IQ-1
        363 SS3P  18.0                          2.0                        IQ-1
11130   363*SS3P  18.0                          3.0                  *     IQ-1
9999
```

EXCERPTS FROM OUTPUT GENERATED BY INPUT ON OPPOSITE PAGE

```
===========================================================================
PLOT, HORIZONTAL LINE, SINGLE-STAGE-3P SAMPLING                IQ-1  PAGE   3
LRG 03-03-73   .000  .00000000   .0000   .0000 3    60.   60        -1 122000
                        DETAILED LOG AND/OR TREE REPORT
===========================================================================
TREE/  VOLUME  / SURFACE / LENGTH / D.B.H. /
 NO./  CU.FT.  /  SQ.FT. /   FT.  /  IN.   /
===========================================================================
   1         .0        .0      .0      6.0=D,F=  60.000,    0,   .0 011 PLOT 1
   2         .0        .0      .0     12.0=D,F=  40.000,    0,   .0 011 PLOT 1
   3         .0        .0      .0     18.0=D,F=   5.000,    0,   .0 011 PLOT 1
1113         .0        .0      .0     18.0=D,F=   5.000,    0,   .0 011 PLOT 1
   1         .0        .0      .0      6.0=D,F=  60.000,    0,   .0 011 LINE 2
   2         .0        .0      .0     12.0=D,F=  40.000,    0,   .0 011 LINE 2
   3         .0        .0      .0     18.0=D,F=   5.000,    0,   .0 011 LINE 2
1113         .0        .0      .0     18.0=D,F=   5.000,    0,   .0 011 LINE 2
   1         .0        .0      .0      6.0=D,F=  60.000,    1,   .0 011 SS3P 3
   2         .0        .0      .0     12.0=D,F=  40.000,    6,   .0 011 SS3P 3
   3         .0        .0      .0     18.0=D,F=   5.000,   36,   .0 011 SS3P 3
1113         .0        .0      .0     18.0=D,F=   5.000,   36,   .0 011 SS3P 3



---------------------------------------------------------------------------
TOTALS                         STRATUM 1       STRATUM 2       STRATUM 3
--------------------           ---------       ---------       ---------
    TREES(FREQUENCY)            110.000         110.000         110.000
    PREDICT.(EF KPI)               .000            .000         660.000
    B.A.(SQ.FT.O.B.)            60.9            60.9            60.9
---------------------------------------------------------------------------
```

INPUTS INVOLVING POINT-SAMPLING (IQ=-100), LACKING DENDROMETRY (TREE TERM=*)

```
===========================================================================

    POINT, POINT-3P, AREA-PCINT-3P SAMPLING                                 IQ-C    1
    LRG 03-03-73                                3   24    21     -100 122000 IQ-C    2
                                                                            IQ-C    3
                                                                            IQ-C    4
                                                                            IQ-C    5
 .654498 1.96350 981.750                                                    IQ-C    6
                                                                            IQ-C    7
                                                                            IQ-C    8
        81 PTEQ   6.0                                   12.0                    IQ-C
   10   81*PTEQ   6.0                                    6.0               *    IQ-C
        81 PTEQ  12.0                                   32.0                    IQ-C
   20   81*PTEQ  12.0                                   16.0               *    IQ-C
        81 PTEQ  18.0                                    9.0                    IQ-C
   30   81*PTEQ  18.0                                    4.5               *    IQ-C
        81 PTEQ  18.0                                    9.0                    IQ-C
11130   81*PTEQ  18.0                                    4.5               *    IQ-C
        42 PT3P   6.0                                    5.0                    IQ-C
   10   42*PT3P   6.0                                    1.0               *    IQ-C
        62 PT3P  12.0                                   12.0                    IQ-C
   20   62*PT3P  12.0                                    4.0               *    IQ-C
       162 PT3P  18.0                                    1.5                    IQ-C
   30  162*PT3P  18.0                                    3.0               *    IQ-C
       162 PT3P  18.0                                    1.5                    IQ-C
11130  162*PT3P  18.0                                    3.0               *    IQ-C
        43 APT3   6.0                                    5.0          1000.     IQ-C
   10   43*APT3   6.0                                    1.0          1000.*    IQ-C
        63 APT3  12.0                                   12.0          1000.     IQ-C
   20   63*APT3  12.0                                    4.0          1000.*    IQ-C
       163 APT3  18.0                                    1.5          1000.     IQ-C
   30  163*APT3  18.0                                    3.0          1000.*    IQ-C
       163 APT3  18.0                                    1.5          1000.     IQ-C
11130  163*APT3  18.0                                    3.0          1000.*    IQ-C
        43 APT3   6.0                                   10.0          2000.     IQ-C
   10   43*APT3   6.0                                    2.0          2000.*    IQ-C
        63 APT3  12.0                                   24.0          2000.     IQ-C
   20   63*APT3  12.0                                    8.0          2000.*    IQ-C
       163 APT3  18.0                                    3.0          2000.     IQ-C
   30  163*APT3  18.0                                    6.0          2000.*    IQ-C
       163 APT3  18.0                                    3.0          2000.     IQ-C
11130  163*APT3  18.0                                    6.0          2000.*    IQ-C
9999
```

EXCERPTS FROM OUTPUT GENERATED BY INPUT ON OPPOSITE PAGE

```
POINT, POINT-3P, AREA-PCINT-3P SAMPLING                          IQ-C  PAGE   3
LRG 03-03-73   .000  .00000000   .0000   .0000  3     24.   21       -100 122000
                      DETAILED LOG AND/OR TREE REPORT

TREE/  VOLUME  / SURFACE / LENGTH / D.B.H. /
 NO./  CU.FT.  /  SQ.FT. /   FT.  /  IN.   /

   1         .0        .0       .0     6.0=D,F=  60.000,   8,   .0 011 PTEQ 1
   2         .0        .0       .0    12.0=D,F=  40.000,   8,   .0 011 PTEQ 1
   3         .0        .0       .0    18.0=D,F=   5.000,   8,   .0 011 PTEQ 1
1113         .0        .0       .0    18.0=D,F=   5.000,   8,   .0 011 PTEQ 1
   1         .0        .0       .0     6.0=D,F=  60.000,   4,   .0 011 PT3P 2
   2         .0        .0       .0    12.0=D,F=  40.000,   6,   .0 011 PT3P 2
   3         .0        .0       .0    18.0=D,F=   5.000,  16,   .0 011 PT3P 2
1113         .0        .0       .0    18.0=D,F=   5.000,  16,   .0 011 PT3P 2
   1         .0        .0       .0     6.0=D,F=  30.000,   4,   .0 011 APT3 3
   2         .0        .0       .0    12.0=D,F=  20.000,   6,   .0 011 APT3 3
   3         .0        .0       .0    18.0=D,F=   2,500,  16,   .0 011 APT3 3
1113         .0        .0       .0    18.0=D,F=   2.500,  16,   .0 011 APT3 3
   1         .0        .0       .0     6.0=D,F=  30.000,   4,   .0 011 APT3 3
   2         .0        .0       .0    12.0=D,F=  20.000,   6,   .0 011 APT3 3
   3         .0        .0       .0    18.0=D,F=   2.500,  16,   .0 011 APT3 3
1113         .0        .0       .0    18.0=D,F=   2.500,  16,   .0 011 APT3 3
```

TOTALS	STRATUM 1	STRATUM 2	STRATUM 3
TREES(FREQUENCY)	110.000	110.000	110.000
PREDICT.(EF KPI)	486.946	518.364	518.364
B.A.(SQ.FT.O.B.)	60.9	60.9	60.9

INPUTS USING CC8 FOR ESTIMATE OF EFFECTIVE KPI, WITHOUT FREQUENCY-BALANCING

```
   1ST STAGE EST OR QI*(CC8) USED AS EFFECTIVE KPI (OPT 1,3 OR 2,4)     EK      1
   LRG 03-03-73                                2   24    21     -100 222000 EK      2
      4       4                                                         EK      3
     42      42                                                         EK      4
                                                                        EK      5
 1.96350 1.96350                                                        EK      6
                                                                        EK      7
 500.000 518.363                                                        EK      8
   10   41*DFIR   6.0 21                                2.                  EK
   11              80  0.0RP     60  4.0ZP      50  8.0ZP     40  4.0ZP*     EK
   20   61*DFIR  12.0 21                                3.                  EK
   21             140  0.0RP    120  4.0BC     100 16.0BA     80  4.0BB*     EK
   30  161*DFIR  18.0 21                                4.                  EK
   31             210  0.0RP    180  4.0AA     170  8.0AB    140 36.0CB      EK
   32             120 16.0CC                                          *      EK
11130  161*DFIR  18.0 21                                4.                  EK
11131             210  0.0RP    180  4.0XX     170  8.0AC    140 36.0CA      EK
11132             120 16.0UU                                          *      EK
   10   42*DFIR   6.0 21                                2.                  EK
   11              80  0.0RP     60  4.0ZP      50  8.0ZP     40  4.0ZP*     EK
   20   62*DFIR  12.0 21                                3.                  EK
   21             140  0.0RP    120  4.0BC     100 16.0BA     80  4.0BB*     EK
   30  162*DFIR  18.0 21                                4.                  EK
   31             210  0.0RP    180  4.0AA     170  8.0AB    140 36.0CB      EK
   32             120 16.0CC                                          *      EK
11130  162*DFIR  18.0 21                                4.                  EK
11131             210  0.0RP    180  4.0XX     170  8.0AC    140 36.0CA      EK
11132             120 16.0UU                                          *      EK
9999
```

EXCERPTS FROM OUTPUT GENERATED BY INPUT ON OPPOSITE PAGE

```
==========================================================================
1ST STAGE EST OR QI*(CC8) USED AS EFFECTIVE KPI (OPT 1,3 OR 2,4) EK     PAGE    3
LRG 03-03-73    .000  .00000000   .0000   .0000  2      24.   21      -100 222000
                        DETAILED LOG AND/OR TREE REPORT
==========================================================================
TREE/  VOLUME   / SURFACE / LENGTH / D.B.H. /
 NO./  CU.FT.   /  SQ.FT. /   FT.  /  IN.   /
==========================================================================
   1        2.3      21.2     16.0      6.0=D,F=   97.942,    4,   .0 211 DFIR 1
   2       13.0      62.2     24.0     12.0=D,F=   24.485,    6,   .0 211 DFIR 1
   3       67.9     231.8     64.0     18.0=D,F=    5.441,   16,   .0 211 DFIR 1
1113       67.9     231.8     64.0     18.0=D,F=    5.441,   16,   .0 211 DFIR 1
   1        2.3      21.2     16.0      6.0=D,F=  101.539,    4,   .0 211 DFIR 2
   2       13.0      62.2     24.0     12.0=D,F=   25.385,    6,   .0 211 DFIR 2
   3       67.9     231.8     64.0     18.0=D,F=    5.641,   16,   .0 211 DFIR 2
1113       67.9     231.8     64.0     18.0=D,F=    5.641,   16,   .0 211 DFIR 2
```

TOTALS	STRATUM 1	STRATUM 2
TREES(FREQUENCY)	133.309	138.205
PREDICT.(EF KPI)	500.000	518.363
B.A.(SQ.FT.O.B.)	57.7	59.8
LENGTH(FT.)	2851.2	2955.9
SURFACE(SQ.FT.IB.)	6123.1	6348.0
VOLUME(CU.FT.I.B.)	1282.5	1329.6

INPUTS USING CC8 FOR ESTIMATE OF EFFECTIVE KPI, WITH FREQUENCY BALANCED TO CC7

```
    1ST STAGE EST OR QI*(CC7) USED TO BAL FREQUENCY (OPT   3 OR   4)    EKFR   1
    LRG 03-03-73                                 2   24   21     -100 422000 EKFR   2
       4       4                                                           EKFR   3
      42      42                                                           EKFR   4
                                                                           EKFR   5
 1.96350 1.96350                                                           EKFR   6
 100.000 110.000                                                           EKFR   7
 500.000 518.363                                                           EKFR   8
   10    41*DFIR   6.0 21                           2.                         EKFR
   11             80   0.0RP      60   4.0ZP      50   8.0ZP      40   4.0ZP*    EKFR
   20    61*DFIR  12.0 21                           3.                         EKFR
   21            140   0.0RP     120   4.0BC     100  16.0BA      80   4.0BB*    EKFR
   30   161*DFIR  18.0 21                           4.                         EKFR
   31            210   0.0RP     180   4.0AA     170   8.0AB     140  36.0CB     EKFR
   32            120  16.0CC                                                *    EKFR
11130   161*DFIR  18.0 21                           4.                         EKFR
11131            210   0.0RP     180   4.0XX     170   8.0AC     140  36.0CA     EKFR
11132            120  16.0UU                                                *    EKFR
   10    42*DFIR   6.0 21                           2.                         EKFR
   11             80   0.0RP      60   4.0ZP      50   8.0ZP      40   4.0ZP*    EKFR
   20    62*DFIR  12.0 21                           3.                         EKFR
   21            140   0.0RP     120   4.0BC     100  16.0BA      80   4.0BB*    EKFR
   30   162*DFIR  18.0 21                           4.                         EKFR
   31            210   0.0RP     180   4.0AA     170   8.0AB     140  36.0CB     EKFR
   32            120  16.0CC                                                *    EKFR
11130   162*DFIR  18.0 21                           4.                         EKFR
11131            210   0.0RP     180   4.0XX     170   8.0AC     140  36.0CA     EKFR
11132            120  16.0UU                                                *    EKFR
9999
9999
```

EXCERPTS FROM OUTPUT GENERATED BY INPUT ON OPPOSITE PAGE

```
==========================================================================================
1ST STAGE EST OR QI*(CC7) USED TO BAL FREQUENCY (OPT   3 OR   4) EKFR  PAGE   3
LRG 03-03-73   .000  .00000000   .0000   .0000  2      24.    21        -100 422000
                              DETAILED LOG AND/OR TREE REPORT
==========================================================================================
TREE/  VOLUME  / SURFACE / LENGTH / D.B.H. /
 NO./  CU.FT.  /  SQ.FT. /   FT.  /  IN.   /
==========================================================================================
   1       2.3      21.2    16.0      6.0=D,F=   54.501,    4,    .0 211 DFIR 1
   2      13.0      62.2    24.0     12.0=D,F=   35.195,    6,    .0 211 DFIR 1
   3      67.9     231.8    64.0     18.0=D,F=    5.152,   16,    .0 211 DFIR 1
1113      67.9     231.8    64.0     18.0=D,F=    5.152,   16,    .0 211 DFIR 1
   1       2.3      21.2    16.0      6.0=D,F=   64.755,    4,    .0 211 DFIR 2
   2      13.0      62.2    24.0     12.0=D,F=   34.453,    6,    .0 211 DFIR 2
   3      67.9     231.8    64.0     18.0=D,F=    5.396,   16,    .0 211 DFIR 2
1113      67.9     231.8    64.0     18.0=D,F=    5.396,   16,    .0 211 DFIR 2
```

TOTALS	STRATUM 1	STRATUM 2
TREES(FREQUENCY)	100.000	110.000
PREDICT.(EF KPI)	500.000	518.363
B.A.(SQ.FT.O.B.)	56.6	58.8
LENGTH(FT.)	2376.2	2553.7
SURFACE(SQ.FT.IB.)	5734.0	6018.5
VOLUME(CU.FT.I.B.)	1282.5	1329.6

```
======================= TEST INPUT (TWO  SETS OF DATA) ========================

@ERS         TPF$. .                   ERASE TPF$.
@MAP         AZ.STXMAP,TPF$.STXSTX
@XQT        .STXSTX
    VISIT ALL TREES, GUESS H*D**2, MEASURE SINGLE-STAGE-3P SAMPLE       SS3P   1
    LRG 03-03-73                                     1   60   60       1 122000 SS3P   2
                                                                             SS3P   3
                                                                             SS3P   4
                                                                             SS3P   5
                                                                             SS3P   6
                                                                             SS3P   7
                                                                             SS3P   8
        11 DFIR   6.0                                                            SS3P
 ---ACTUAL INPUT CONTAINS AN AGGREGATE OF 59          CARDS LIKE THAT  ABOVE----
   10    11*DFIR   6.0 21                                                        SS3P
   11              80  0.0RP      60  4.0ZP      50  8.0ZP      40  4.0ZP*     SS3P
 ---ACTUAL INPUT CONTAINS AN AGGREGATE OF  1 PAIR  OF CARDS LIKE THAT  ABOVE----

        61 DFIR  12.0                                                            SS3P
 ---ACTUAL INPUT CONTAINS AN AGGREGATE OF 36          CARDS LIKE THAT  ABOVE----
   20    61*DFIR  12.0 21                                                        SS3P
   21             140  0.0RP     120  4.0BC     100 16.0BA      80  4.0BB*     SS3P
 ---ACTUAL INPUT CONTAINS AN AGGREGATE OF  4 PAIRS OF CARDS LIKE THOSE ABOVE----

       361 DFIR  18.0                                                            SS3P
 ---ACTUAL INPUT CONTAINS AN AGGREGATE OF  2          CARDS LIKE THAT  ABOVE----
   30   361*DFIR  18.0 21                                                        SS3P
   31             210  0.0RP     180  4.0AA     170  8.0AB     140 36.0CB      SS3P
   32             120 16.0CC                                            *      SS3P
 ---ACTUAL INPUT CONTAINS AN AGGREGATE OF  3 TRIOS OF CARDS LIKE THOSE ABOVE----

       361 DFIR  18.0                                                            SS3P
 ---ACTUAL INPUT CONTAINS AN AGGREGATE OF  2          CARDS LIKE THAT  ABOVE----
11130   361*DFIR  18.0 21                                                        SS3P
11131             210  0.0RP     180  4.0XX     170  8.0AC     140 36.0CA      SS3P
11132             120 16.0UU                                            *      SS3P
 ---ACTUAL INPUT CONTAINS AN AGGREGATE OF  3 TRIOS OF CARDS LIKE THOSE ABOVE----

9999
```

```
========================= CONTINUATION OF TEST INPUT ==========================
   VISIT 3 PTS (2 PARTIALS), GUESS H, XMPLIFY 3 KINDS SUBSAMPLE          XMPL    1
   LRG 03-03-73 08000 01964673-11905 15658 3   24    21       -589 223021 XMPL    2
     13        9       4                                                XMPL    3
     96      168      48                                                XMPL    4
      1.       2.                                                       XMPL    5
 -.333362                                                               XMPL    6
  18.6758 6.22526 5.09340                                               XMPL    7
  88.0076 168.014 48.0042                                               XMPL    8
   10    41*DFIR    6.0 21     .3                   1.                      XMPL
   11              80  0.0RP     60   4.0ZP      50  8.0ZP     40  4.0ZP*   XMPL
   20    61*DFIR   12.0 21     .7  .5               4.                      XMPL
   21             140  0.0RP    120   4.0BC     100 16.0BA     80  4.0BB*   XMPL
   30   161*DFIR   18.0 21     .9                   3.                      XMPL
   31             210  0.0RP    180   4.0AA     170  8.0AB    140 36.0CB    XMPL
   32             120 16.0CC                                          *     XMPL
11130   161*DFIR   18.0 212    .9      16.125       3.                      XMPL
11131             210  0.0RP    180   4.0XX     170  8.0AC    140 36.0CA    XMPL
11132            -999      UU                                         *     XMPL
 2030   212*DNDR   18.0 2     -.9                   3.                      XMPL
 2031             189  0.0RP    162   4.0IB     153  8.0IB    126 36.0IB    XMPL
 2032             108 16.0IB                                          *     XMPL
 2230   212*DNDR   18.0 22     .9                   3.                      XMPL
 2231             210  0.0RP    180   4.0B2     170  8.0B2    140 36.0B2    XMPL
 2232             120 16.0B2                                          *     XMPL
 2330   212*DNDR   18.0 23     .9                   3.                      XMPL
 2331             210  0.0RP    180   4.0B3     170  8.0B3    140 36.0B3    XMPL
 2332             120 16.0B3                                          *     XMPL
 2430   212*DNDR   18.0 1      .9                   3.                      XMPL
 2431         -999 210  4.0RP    180   8.0MV 509 779 8809MV               +     XMPL
 2432          557 73610000RP 559 70512324MV 561 68413283MV-999-99915483UU*  XMPL
 2530   212*DNDR   18.0 3      .9                   3.                      XMPL
 2531         -999 210  4.0RP    180   8.0ZT1007 170 93.2ZT               +     XMPL
 2532         1500 170100.0RP1542 140113.5ZT1581 120119.2ZT-999-999133.3UU*  XMPL
 2640   212*DNDR   18.0 211   -.9      10.500       3.                      XMPL
 2641             210  0.0RP    180   4.0FK     170  8.0FK                +     XMPL
 2642             160  0.0RP    150  10.0CX     130 10.0CX    100 10.0CX    XMPL
 2643            -999      UU                                         +     XMPL
 2644             160  0.0RP    140  10.0CN     120 10.0CN    100 10.0CN    XMPL
 2645            -999      UU                                         +     XMPL
 2646             160  0.0RP    150  10.0CV     120 10.0CV    100 10.0CV    XMPL
 2647            -999      UU                                         *     XMPL
 2740   212*DNDR   18.0 112   -.9       5.200       3.                      XMPL
 2741          331101410000RP 332 93210797FK 342 90012340FK               +     XMPL
 2742          342 87312340RP 366 83514020LT 394 77115385LT 422 69216420LT  XMPL
 2743            -999      UU                                         +     XMPL
 2744          342 87312340RP 366 80914020LT 394 74715385LT 422 69216420LT  XMPL
 2745            -999      UU                                         +     XMPL
 2746          342 87312340RP 366 83514020LT 394 74715385LT 422 69216420LT  XMPL
 2747            -999      UU                                         *     XMPL
 2850     2=DNDR   12.0 011   -.6      32.750       4.                      XMPL
 2851          508 197-0397RP 508 197 0000FR 508 707+0397BK 508 707+0797BK  XMPL
 2852          509 793+1191AN 509 509+1191UU                          *     XMPL
  302   123*CULL   12.0                             4.      1.0       *     XMPL
 3002   123*CULL   12.0                             4.      2.0       *     XMPL
 9999
 9999
```

```
====================== TEST OUTPUT (TWO SETS OF DATA) ======================

VISIT ALL TREES, GUESS H*D**2, MEASURE SINGLE-STAGE-3P SAMPLE    SS3P  PAGE   1
LRG 03-03-73    .000  .00000000    .0000    .0000  1     60.   60        1 122000
            PRELIMINARY REPORT--COUNTS AND AGGREGATE PREDICTIONS
==============================================================================

        STRATUM 1                                TREE COUNTS    PREDICTIONS
------------------------------------------------------------------------------
            SURE-TO-BE MEASURED  TREES(=1)          0               0
            THREE-PEE  MEASURED  TREES(*2)         11             241
            THREE-PEE  PREDICTED TREES( 3)         99             419
------------------------------------------------------------------------------
                            ALL TREES(1,2,3)     110             660
------------------------------------------------------------------------------
                   ALL MEASURED  TREES(1,2)        11             241
                   ALL THREE-PEE TREES(2,3)       110             660
                 EXPECTED VALUES  FOR (*2)        11.000          241.000
                 EXP. VAL. ST. ERRORS (*2)         2.643           56.930

     TOTALS FOR ALL 1 STRATA                     TREE COUNTS    PREDICTIONS
------------------------------------------------------------------------------
            SURE-TO-BE MEASURED  TREES(=1)          0               0
            THREE-PEE  MEASURED  TREES(*2)         11             241
            THREE-PEE  PREDICTED TREES( 3)         99             419
------------------------------------------------------------------------------
                            ALL TREES(1,2,3)     110             660
------------------------------------------------------------------------------
                   ALL MEASURED  TREES(1,2)        11             241
                   ALL THREE-PEE TREES(2,3)       110             660
                 EXPECTED VALUES  FOR (*2)        11.000          241.000
                 EXP. VAL. ST. ERRORS (*2)         2.643           56.930
```

```
VISIT ALL TREES, GUESS H*D**2, MEASURE SINGLE-STAGE-3P SAMPLE'   SS3P  PAGE   2
LRG 03-03-73   .000  .00000000   .0000   .0000  1     60.   60        1 122000
             PRELIMINARY REPORT--COUNTS AND AGGREGATE PREOICTIONS
==============================================================================

PUNCH CONTROL CARDS 3 AND 4 AS FOLLOWS TO PROCESS THIS JOB UNOER
SUMMARY INPUT OPTIONS (WITH '2' OR '4' PUNCHED IN COLUMN 66 OF CONTROL CARD 2) --
     110                                                              SS3P   3
     660                                                              SS3P   4

CONTROL CARDS 5, 6, 7, 8 ALSO REQUIRED BY STX 03-03-73 MUST CONTAIN FOLLOWING FLOATING-POINT INFORMATION FOR OPTIONS
'2' OR '4', REDUCED TO NINE 8-COLUMN FIELDS (BLANKS CAN REPLACE ZEROS, IMPLICIT INPUT FORMAT IS 9F8.0) --

  1.000000   .0000000   .0000000   .0000000   .0000000   .0000000   .0000000   .0000000   .0000000   SS3P   5
  .0000000   .0000000   .0000000   .0000000   .0000000   .0000000   .0000000   .0000000   .0000000   SS3P   6
  110.0000   .0000000   .0000000   .0000000   .0000000   .0000000   .0000000   .0000000   .0000000   SS3P   7
  660.0000   .0000000   .0000000   .0000000   .0000000   .0000000   .0000000   .0000000   .0000000   SS3P   8

ALL SUBSEQUENT FREQUENCIES RESULT FROM ADJUSTMENT SUCH THAT F'=FREQ+(VI+V2*KPI+V3*POUT)*FREQ**2.        KPI SHOULO
INCLUOE BA  IN CASE POINT-SAMPLING IS INVOLVED.  IF V1   AND OTHER V'S ARE 0,  THEN FREQUENCIES ARE UNAOJUSTED, ELSE
V'S HAVE BEEN OERIVEO TO LEAVE ESTIMATES OF TOTAL VOLUME AND EFFECTIVE KPI UNCHANGED, BUT TO ADJUST FREQUENCY ESTIMATES
SO THEY WILL TOTAL POPULATION COUNT OR BEST SAMPLE-BASED ESTIMATE OF COUNT.  INPUT OPTION '1' OR '2' IS APPROPRIATE
WHEN USER MANUALLY INSERTS ADJUSTED V'S BY BLOCK DATA STATEMENT AFTER INITIAL DERIVATION.  V'S EFFECTIVE FOR THIS RUN =

  .0000000   .0000000   .0000000
```

======================= CONTINUATION OF TEST OUTPUT ========================

VISIT ALL TREES, GUESS H*D**2, MEASURE SINGLE-STAGE-3P SAMPLE SS3P PAGE 3
LRG 03-03-73 .000 .00000000 .0000 .0000 1 60. 60 1 122000

DETAILED LOG AND/OR TREE REPORT

TREE/ NO./	VOLUME / CU.FT. /	SURFACE / SQ.FT. /	LENGTH / FT. /	D.B.H. / IN. /					
1	2.3	21.2	16.0	6.0=D,F=	60.000,	1,	.0	211	DFIR 1
2	13.0	62.2	24.0	12.0=D,F=	10.000,	6,	.0	211	DFIR 1
2	13.0	62.2	24.0	12.0=D,F=	10.000,	6,	.0	211	DFIR 1
2	13.0	62.2	24.0	12.0=D,F=	10.000,	6,	.0	211	DFIR 1
2	13.0	62.2	24.0	12.0=D,F=	10.000,	6,	.0	211	DFIR 1
3	67.9	231.8	64.0	18.0=D,F=	1.667,	36,	.0	211	DFIR 1
3	67.9	231.8	64.0	18.0=D,F=	1.667,	36,	.0	211	DFIR 1
3	67.9	231.8	64.0	18.0=D,F=	1.667,	36,	.0	211	DFIR 1
1113	67.9	231.8	64.0	18.0=D,F=	1.667,	36,	.0	211	DFIR 1
1113	67.9	231.8	64.0	18.0=D,F=	1.667,	36,	.0	211	DFIR 1
1113	67.9	231.8	64.0	18.0=D,F=	1.667,	36,	.0	211	DFIR 1

==================== CONTINUATION OF TEST OUTPUT ====================

VISIT ALL TREES, GUESS H*D**2, MEASURE SINGLE-STAGE-3P SAMPLE SS3P PAGE 4
LRG 03-03-73 .000 .00000000 .0000 .0000 1 60. 60 1 122000
SUMMARY REPORT--SURE-TO-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES

STRATUM 1 SAMPLE VARIABLES	SURE-TO-BE MEASURED AGGREGATIONS	3P-EXPANDED SAMPLE ESTIMATES	TOTAL SAMPLE ESTIMATES PLUS SURE
TREES(FREQUENCY)	.000	110.000	110.000
PREDICT.(EF KPI)	.000	660.000	660.000
B.A.(SQ.FT.O.B.)	.0	60.9	60.9
LENGTH(FT.)	.0	2560.0	2560.0
SURFACE(SQ.FT.IB.)	.0	6079.0	6079.0
VOLUME(CU.FT.I.B.)	.0	1337.0	1337.0
REL.VAL.PER MF.UNIT	1.00	1.00	1.00
GROSS MF.UNITS	.0	1337.0	1337.0
ST.ERROR(PCT.)	-----	2.5	2.5

COMPONENT ITEMS	(1=) NUMBER	(2*) NUMBER	(1,2) NUMBER
MEASURED TREES	0	11	11
MEASURED LOGS	0	39	39

```
======================= CONTINUATION OF TEST OUTPUT ==========================

VISIT ALL TREES, GUESS H*D**2, MEASURE SINGLE-STAGE-3P SAMPLE    SS3P  PAGE   5
LRG 03-03-73    .000  .00000000    .0000    .0000  1      60.   60          1 122000
      SUMMARY REPORT--SURE-TO-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES
================================================================================


TOTALS ALL   1 STRATA*******************************************************************
                     /   SURE-TO-BE    /   3P-EXPANDED   /  TOTAL SAMPLE   /
                     /    MEASURED     /     SAMPLE      /   ESTIMATES     /
   SAMPLE VARIABLES/  AGGREGATIONS   /   ESTIMATES     /   PLUS SURE     /
--------------------------------------------------------------------------------
     TREES(FREQUENCY)          .000          110.000          110.000
     PREDICT.(EF KPI)          .000          660.000          660.000
     B.A.(SQ.FT.O.B.)          .0             60.9             60.9
     LENGTH(FT.)               .0           2560.0           2560.0
     SURFACE(SQ.FT.IB.)        .0           6079.0           6079.0
     VOLUME(CU.FT.I.B.)        .0           1337.0           1337.0
     REL.VAL.PER MF.UNIT       .00             1.00             1.00
     GROSS MF.UNITS            .0           1337.0           1337.0
       ST.ERROR(PCT.)        -----             2.5              2.5
     GROSS WTD.MF.UNITS        .00          1337.02          1337.02
       ST.ERROR(PCT.)        -----             2.5              2.5

--------------------------------------------------------------------------------
                              (1=)            (2*)             (1,2)
     COMPONENT ITEMS         NUMBER          NUMBER           NUMBER
--------------------------------------------------------------------------------
       MEASURED TREES          0               11               11
       MEASURED LOGS           0               39               39


--------------------------------------------------------------------------------
MF.UNITS=  CU. FT. INSIDE BARK
 =(   .10000000+01)*(CU.FT.)+(    .00000000    )*(SQ.FT.)+(    .00000000    )*(FT.)
================================================================================
```

```
======================== CONTINUATION OF TEST OUTPUT ==========================

VISIT ALL TREES, GUESS H*D**2, MEASURE SINGLE-STAGE-3P SAMPLE    SS3P  PAGE   0
LRG 03-03-73    .000  .00000000    .0000    .0000 1      60.   60          1 122000
       SUMMARY REPORT--SURE-TO-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES
================================================================================


DATA PROCESSING BLOCKED BY    0 INPUT FLAWS.
SAMPLE ESTIMATES INVOLVE    0 SUSPICIOUS ITEMS NUMBERED
              0
INPUT READ BEFORE FLAW,IF ANY---
    CARDS WITH TREE PREDICTIONS ONLY          (FIRST)                          99
    CARDS WITH MEASURED TREE INFO             (FIRST)                          11
    ---------------------------------------------------------------------------
    CARDS WITH MEASURED TREE INFO             (SECOND)                         11
    CARDS WITH ADDITIONAL DENDROMETER INFO    (SECOND)                         17

PROCESSING DONE BEFORE FLAW,IF ANY---
    NUMBER OF MEASURED TREES PROCESSED                                         11
    NUMBER OF MEASURED LOGS PROCESSED                                          39
    TREE CARDS PUNCHED OR WRITTEN                                               0
    LOG CARDS PUNCHED OR WRITTEN                                                0
    LABEL ON CARD OUTPUT                                                     SS3P

CHECK OF INPUT AGGREGATES WITH EXPANDED 3P SAMPLE
    AGGREGATE NUMBER OF TREES INPUT(1+2+3)                             110
    SAMPLE ESTIMATE(2 EXPANDED)+NO.SURE(1 EXPANDED IF SB SAMPLE)       110.000
    STANDARD ERROR OF ESTIMATED NUMBER                                  56.642
    ---------------------------------------------------------------------------
    AGGREGATE PREDICTIONS(KPI) INPUT(1+2+3) NOT EXPANDED               660
    SAMPLE ESTIMATE(2 EXPANDED)+SURE KPI(EXPANDED IF SB SAMPLE)        660.000
================================================================================
```

======================= CONTINUATION OF TEST OUTPUT ==========================

VISIT 3 PTS (2 PARTIALS), GUESS H, XMPLIFY 3 KINDS SUBSAMPLE XMPL PAGE 1
LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 3 24. 21 -589 223021
PRELIMINARY REPORT--COUNTS AND AGGREGATE PREDICTIONS

STRATUM 1	TREE COUNTS	PREDICTIONS
SURE-TO-BE MEASURED TREES(=1)	0	0
THREE-PEE MEASURED TREES(*2)	4	42
THREE-PEE PREDICTED TREES(3)	9	54
ALL TREES(1,2,3)	13	96
ALL MEASURED TREES(1,2)	4	42
ALL THREE-PEE TREES(2,3)	13	96
EXPECTED VALUES FOR (*2)	4.000	42.000
EXP. VAL. ST. ERRORS (*2)	1.500	14.526

STRATUM 2	TREE COUNTS	PREDICTIONS
SURE-TO-BE MEASURED TREES(=1)	1	0
THREE-PEE MEASURED TREES(*2)	7	147
THREE-PEE PREDICTED TREES(3)	1	21
ALL TREES(1,2,3)	9	168
ALL MEASURED TREES(1,2)	8	147
ALL THREE-PEE TREES(2,3)	8	168
EXPECTED VALUES FOR (*2)	7.000	147.000
EXP. VAL. ST. ERRORS (*2)	.935	19.644

STRATUM 3	TREE COUNTS	PREDICTIONS
SURE-TO-BE MEASURED TREES(=1)	0	0
THREE-PEE MEASURED TREES(*2)	2	24
THREE-PEE PREDICTED TREES(3)	2	24
ALL TREES(1,2,3)	4	48
ALL MEASURED TREES(1,2)	2	24
ALL THREE-PEE TREES(2,3)	4	48
EXPECTED VALUES FOR (*2)	2.000	24.000
EXP. VAL. ST. ERRORS (*2)	1.000	12.000

TOTALS FOR ALL 3 STRATA	TREE COUNTS	PREDICTIONS
SURE-TO-BE MEASURED TREES(=1)	1	0
THREE-PEE MEASURED TREES(*2)	13	213
THREE-PEE PREDICTED TREES(3)	12	99
ALL TREES(1,2,3)	26	312
ALL MEASURED TREES(1,2)	14	213
ALL THREE-PEE TREES(2,3)	25	312
EXPECTED VALUES FOR (*2)	13.000	213.000
EXP. VAL. ST. ERRORS (*2)	2.031	27.219

```
VISIT 3 PTS (2 PARTIALS), GUESS H, XMPLIFY 3 KINOS SUBSAMPLE      XMPL  PAGE   2
LRG 03-03-73  8.000  .01964673 -1.1905  1.5658  3     24.    21        -589 223021
               PRELIMINARY REPORT--COUNTS ANO AGGREGATE PREOICTIONS
==================================================================================

PUNCH CONTROL CAROS 3 ANO 4 AS FOLLOWS TO PROCESS THIS JOB UNOER
SUMMARY INPUT OPTIONS (WITH '2' OR '4' PUNCHEO IN COLUMN 66 OF CONTROL CARD 2) --
      13        9       4                                            XMPL   3
      96      168      48                                            XMPL   4

CONTROL CAROS 5, 6, 7, 8 ALSO REQUIREO BY STX 03-03-73 MUST CONTAIN FOLLOWING FLOATING-POINT INFORMATION FOR OPTIONS
'2' OR '4', REOUCEO TO NINE 8-COLUMN FIELOS (BLANKS CAN REPLACE ZEROS, IMPLICIT INPUT FORMAT IS 9F8.0) --

  1.000000    2.000000    1.000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    XMPL   5
 -.3333620    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    XMPL   6
  18.67580    6.225260    5.093400    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    XMPL   7
  88.00760    168.0140    48.00420    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    XMPL   8

ALL SUBSEQUENT FREQUENCIES RESULT FROM AOJUSTMENT SUCH THAT F'=FREQ+(V1+V2*KPI+V3*POUT)*FREQ**2.          KPI SHOULO
INCLUDE BA  IN CASE POINT-SAMPLING IS INVOLVEO.  IF V1   ANO OTHER V'S ARE 0,  THEN FREQUENCIES ARE UNADJUSTEO, ELSE
V'S HAVE BEEN OERIVED TO LEAVE ESTIMATES OF TOTAL VOLUME ANO EFFECTIVE KPI UNCHANGED, BUT TO AOJUST FREQUENCY ESTIMATES
SO THEY WILL TOTAL POPULATION COUNT OR BEST SAMPLE-BASED ESTIMATE OF COUNT.  INPUT OPTION '1' OR '2' IS APPROPRIATE
WHEN USER MANUALLY INSERTS AOJUSTEO V'S BY BLOCK DATA STATEMENT AFTER INITIAL OERIVATION.  V'S EFFECTIVE FOR THIS RUN =

  .0000000    .0000000    .0000000
  .0000000    .0000000    .0000000
  .0000000    .0000000    .0000000
```

======================== CONTINUATION OF TEST OUTPUT ==========================

VISIT 3 PTS (2 PARTIALS), GUESS H, XMPLIFY 3 KINDS SUBSAMPLE XMPL PAGE 3
LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 3 24. 21 -589 223021

DETAILED LOG AND/OR TREE REPORT

TREE/ NO./	VOLUME / CU.FT. /	SURFACE / SQ.FT. /	LENGTH / FT. /	D.I.B. / IN.	LOG/ /CODE/	RANGE/ FT./	TGRADS	FGRADS	SINELV
	.4	4.2	4.0	3.6	ZP	.0	.0	4.0	4.0000
	1.1	10.4	8.0	4.5	ZP	.0	.0	5.0	8.0000
	.9	6.6	4.0	5.4	ZP	.0	.0	6.0	4.0000
	.0	.0	.0	7.2	RP	.0	.0	8.0	.0000
1	2.3	21.2	16.0	6.0=D,F=		60.000,	4,	.6	211 DFIR 1
	1.4	8.5	4.0	7.2	BB	.0	.0	8.0	4.0000
	8.6	41.5	16.0	9.0	BA	.0	.0	10.0	16.0000
	3.0	12.3	4.0	10.8	BC	.0	.0	12.0	4.0000
	.0	.0	.0	12.6	RP	.0	.0	14.0	.0000
2	13.0	62.2	24.0	12.0=D,F=		40.000,	6,	1.2	211 DFIR 1
	12.0	49.0	16.0	10.8	CC	.0	.0	12.0	16.0000
	38.3	131.5	36.0	12.6	CB	.0	.0	14.0	36.0000
	10.8	33.0	8.0	15.3	AB	.0	.0	17.0	8.0000
	6.7	18.4	4.0	16.2	AA	.0	.0	18.0	4.0000
	.0	.0	.0	18.9	RP	.0	.0	21.0	.0000
3	67.9	231.8	64.0	18.0=D,F=		5.000,	16,	1.8	211 DFIR 1
	12.0	49.0	16.0	10.8	UU	.0	.0	-99.9	.0000
	38.3	131.5	36.0	12.6	CA	.0	.0	14.0	36.0000
	10.8	33.0	8.0	15.3	AC	.0	.0	17.0	8.0000
	6.7	18.4	4.0	16.2	XX	.0	.0	18.0	4.0000
	.0	.0	.0	18.9	RP	.0	.0	21.0	.0000
1113	67.9	231.9	64.0	18.0=D,F=		5.000,	16,	1.8	212*DFIR 1

```
======================== CONTINUATION OF TEST OUTPUT ===========================

VISIT 3 PTS (2 PARTIALS), GUESS H, XMPLIFY 3 KINDS SUBSAMPLE      XMPL  PAGE   4
LRG 03-03-73  8.000  .01964673 -1.1905  1.5658  3      24.   21       -589 223021
                     DETAILED LOG AND/OR TREE REPORT
================================================================================
TREE/  VOLUME  / SURFACE / LENGTH / D.I.B. / LOG/RANGE/
NO./  CU.FT.  /  SQ.FT. /   FT.  /   IN.   /CODE/  FT./ TGRADS  FGRADS   SINELV
================================================================================
          12.0      49.0     16.0      10.8   IB       .0       .0   10.8  16.0000
          38.3     131.5     36.0      12.6   IB       .0       .0   12.6  36.0000
          10.8      33.0      8.0      15.3   IB       .0       .0   15.3   8.0000
           6.7      18.4      4.0      16.2   IB       .0       .0   16.2   4.0000
            .0        .0       .0      18.9   RP       .0       .0   18.9    .0000
--------------------------------------------------------------------------------
203       67.9     231.8     64.0      18.0=D,F=    3.810,     21, -1.8 211 DNDR 2
--------------------------------------------------------------------------------
          12.5      50.2     16.0      11.1   B2       .0       .0   12.0  16.0000
          39.3     133.1     36.0      12.9   B2       .0       .0   14.0  36.0000
          10.9      33.1      8.0      15.4   B2       .0       .0   17.0   8.0000
           6.6      18.2      4.0      16.2   B2       .0       .0   18.0   4.0000
            .0        .0       .0      18.5   RP       .0       .0   21.0    .0000
--------------------------------------------------------------------------------
223       69.3     234.5     64.0      18.0=D,F=    3.810,     21,  1.8 221 DNDR 2
--------------------------------------------------------------------------------
          11.3      47.6     16.0      10.4   B3       .0       .0   12.0  16.0000
          37.3     129.6     36.0      12.3   B3       .0       .0   14.0  36.0000
          10.8      32.9      8.0      15.2   B3       .0       .0   17.0   8.0000
           6.9      18.6      4.0      16.2   B3       .0       .0   18.0   4.0000
            .0        .0       .0      19.3   RP       .0       .0   21.0    .0000
--------------------------------------------------------------------------------
233       66.2     228.6     64.0      18.0=D,F=    3.810,     21,  1.8 231 DNDR 2
--------------------------------------------------------------------------------
           9.8      65.5     46.1        .1   UU       .0    -99.9  -99.9    .5483
          11.9      49.0     16.0      10.8   MV   158.4     56.1   68.4    .3283
          38.4     131.6     36.0      12.6   MV   154.9     55.9   70.5    .2324
            .0        .0       .0      15.3   RP   151.6     55.7   73.6    .0000
          10.8      33.0      8.0      15.3   MV   101.0     50.9   77.9   -.1191
           6.7      18.4      4.0      16.2   MV       .0       .0   18.0   8.0000
            .0        .0       .0      18.9   RP       .0    -99.9   21.0   4.0000
--------------------------------------------------------------------------------
243       77.7     297.4    110.1      18.0=D,F=    3.810,     21,  1.8 111 DNDR 2
--------------------------------------------------------------------------------
           9.9      65.7     46.1        .1   UU       .0    -99.9  -99.9  33.3000
          12.0      49.0     16.0      10.8   ZT   158.1    158.1   12.0  19.2000
          38.3     131.5     36.0      12.6   ZT   154.2    154.2   14.0  13.5000
            .0        .0       .0      15.3   RP   150.0    150.0   17.0    .0000
          10.8      33.0      8.0      15.3   ZT   100.7    100.7   17.0  -6.8000
           6.7      18.4      4.0      16.2   ZT       .0       .0   18.0   8.0000
            .0        .0       .0      18.9   RP       .0    -99.9   21.0   4.0000
--------------------------------------------------------------------------------
253       77.7     297.5    110.1      18.0=D,F=    3.810,     21,  1.8 311 DNDR 2
--------------------------------------------------------------------------------
```

VISIT 3 PTS (2 PARTIALS), GUESS F, XMPLIFY 3 KINDS SUBSAMPLE XMPL PAGE 5
LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 3 24. 21 -589 223021

DETAILED LOG AND/OR TREE REPORT

TREE/ NO./	VOLUME / CU.FT. /	SURFACE / SQ.FT. /	LENGTH / FT. /	D.I.B. / IN. /	LOG/ CODE/	RANGE/ FT./	TGRADS	FGRADS	SINELV
	3.0	14.9	6.0	9.0	UU	.0	.0	-99.9	.0000
	6.6	28.8	10.0	10.0	CV	.0	.0	10.0	10.0000
	10.0	35.3	10.0	12.0	CV	.0	.0	12.0	10.0000
	13.1	40.6	10.0	15.0	CV	.0	.0	15.0	10.0000
	.0	.0	.0	16.0	RP	.0	.0	16.0	.0000
	2.5	12.4	5.0	9.0	UU	.0	.0	-99.9	.0000
	6.6	28.8	10.0	10.0	CN	.0	.0	10.0	10.0000
	9.2	34.0	10.0	12.0	CN	.0	.0	12.0	10.0000
	12.3	39.3	10.0	14.0	CN	.0	.0	14.0	10.0000
	.0	.0	.0	16.0	RP	.0	.0	16.0	.0000
	1.2	6.3	2.5	9.0	UU	.0	.0	-99.9	.0000
	7.3	30.1	10.0	10.0	CX	.0	.0	10.0	10.0000
	10.7	36.7	10.0	13.0	CX	.0	.0	13.0	10.0000
	13.1	40.6	10.0	15.0	CX	.0	.0	15.0	10.0000
	.0	.0	.0	16.0	RP	.0	.0	16.0	.0000
	13.4	36.7	8.0	17.0	FK	.0	.0	17.0	8.0000
	8.3	20.4	4.0	18.0	FK	.0	.0	18.0	4.0000
	.0	.0	.0	21.0	RP	.0	.0	21.0	.0000
264	117.2	404.9	115.5	18.0=D.F=		3.810,	21,	-1.8*211*DNDR 2	
	2.5	12.4	5.0	9.0	UU	.0	.0	-99.9	.0000
	6.6	28.8	10.0	10.0	LT	65.5	42.2	69.2	.6420
	10.0	35.4	10.0	12.0	LT	59.4	39.4	74.7	.5385
	13.1	40.5	10.0	15.0	LT	54.7	36.6	83.5	.4020
	.0	.0	.0	16.0	RP	51.4	34.2	87.3	.2340
	2.5	12.4	5.0	9.0	UU	.0	.0	-99.9	.0000
	6.6	28.8	10.0	10.0	LT	65.5	42.2	69.2	.6420
	9.3	34.1	10.0	12.0	LT	59.4	39.4	74.7	.5385
	12.3	39.2	10.0	14.0	LT	54.7	36.6	80.9	.4020
	.0	.0	.0	16.0	RP	51.4	34.2	87.3	.2340
	2.5	12.4	5.0	9.0	UU	.0	.0	-99.9	.0000
	7.2	30.1	10.0	10.0	LT	65.5	42.2	69.2	.6420
	10.7	36.7	10.0	13.0	LT	59.4	39.4	77.1	.5385
	13.1	40.5	10.0	15.0	LT	54.7	36.6	83.5	.4020
	.0	.0	.0	16.0	RP	51.4	34.2	87.3	.2340
	13.4	36.8	8.0	17.0	FK	51.4	34.2	90.0	.2340
	8.3	20.4	4.0	18.0	FK	50.2	33.2	93.2	.0797
	.0	.0	.0	21.0	RP	50.1	33.1	101.4	.0000
274	118.0	408.5	117.0	18.0=D.F=		3.810,	21,	-1.8*112*DNDR 2	

====================== CONTINUATION OF TEST OUTPUT ========================

VISIT 3 PTS (2 PARTIALS), GUESS F, XMPLIFY 3 KINDS SUBSAMPLE XMPL PAGE 6
LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 3 24. 21 -589 223021
DETAILED LOG ANC/OR TREE REPORT

TREE/ NO./	VOLUME / CU.FT. /	SURFACE / SQ.FT. /	LENGTH / FT. /	D.I.B. / IN.	LOG/ /CODE/	RANGE/ FT./	TGRADS	FGRADS	SINELV
	20.6	70.5	20.0	9.0	UU	.0	50.9	50.9	.1191
	5.0	15.8	4.0	18.0	AN	101.0	50.9	79.3	.1191
	3.2	12.6	4.0	12.0	BK	100.4	50.8	70.7	.0797
	3.1	12.6	4.0	12.0	BK	100.4	50.8	70.7	.0397
	3.2	12.6	4.0	12.0	FR	100.4	50.8	19.7	.0000
	.0	.0	.0	12.0	RP	100.4	50.8	19.7	-.0397
285	35.0	124.1	36.0	12.0=D,F=		10.000,	0,	-1.2	011*DNDR 2
	.0	.0	.0	.0	@@	.0	.0	.0	.0000
302	.0	.0	.0	12.0=D,F=		20.000,	12,	.0	011 CULL 3
	.0	.0	.0	.0	@@	.0	.0	.0	.0000
3002	.0	.0	.0	12.0=D,F=		10.000,	12,	.0	011 CULL 3

======================== CONTINUATION OF TEST OUTPUT ============================

VISIT 3 PTS (2 PARTIALS), GUESS H, XMPLIFY 3 KINDS SUBSAMPLE XMPL PAGE 7
LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 3 24. 21 -589 223021
SUMMARY REPORT--SURE-TO-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES

STRATUM 1 SAMPLE VARIABLES	SURE-TO-BE MEASURED AGGREGATIONS	3P-EXPANDED SAMPLE ESTIMATES	TOTAL SAMPLE ESTIMATES PLUS SURE
TREES(FREQUENCY)	.000	110.000	110.000
PREDICT.(EF KPI)	.000	518.365	518.365
B.A.(SQ.FT.O.B.)	.0	60.9	60.9
LENGTH(FT.)	.0	2560.0	2560.0
SURFACE(SQ.FT.IB.)	.0	6079.0	6079.0
VOLUME(CU.FT.I.B.)	.0	1337.0	1337.0
REL.VAL.PER MF.UNIT	1.00	1.00	1.00
GROSS MF.UNITS	.0	1337.0	1337.0
ST.ERROR(PCT.)	-----	4.5	4.5

COMPONENT ITEMS	(1=) NUMBER	(2*) NUMBER	(1,2) NUMBER
MEASURED TREES	0	4	4
MEASURED LOGS	0	14	14

====================== CONTINUATION OF TEST OUTPUT ==========================

VISIT 3 PTS (2 PARTIALS), GUESS H, XMPLIFY 3 KINDS SUBSAMPLE XMPL PAGE 8
LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 3 24. 21 -589 223021
SUMMARY REPORT--SURE-TC-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES

STRATUM 2 / SAMPLE VARIABLES	2 SURE-TO-BE MEASURED AGGREGATIONS	2 3P-EXPANDED SAMPLE ESTIMATES	2 TOTAL SAMPLE ESTIMATES PLUS SURE
TREES(FREQUENCY)	10.000	26.667	36.667
PREDICT.(EF KPI)	.000	989.602	989.602
B.A.(SQ.FT.O.B.)	7.9	47.1	55.0
LENGTH(FT.)	359.9	2456.1	2816.0
SURFACE(SQ.FT.IB.)	1241.5	8012.5	9253.9
VOLUME(CU.FT.I.B.)	350.4	2262.5	2612.9
REL.VAL.PER MF.UNIT	2.00	2.00	2.00
GROSS MF.UNITS	350.4	2262.5	2612.9
ST.ERROR(PCT.)	-----	10.2	8.8

COMPONENT ITEMS	(1=) NUMBER	(2*) NUMBER	(1,2) NUMBER
MEASURED TREES	1	7	8
MEASURED LOGS	5	50	55

======================== CONTINUATION OF TEST OUTPUT ========================

VISIT 3 PTS (2 PARTIALS), GUESS H, XMPLIFY 3 KINDS SUBSAMPLE XMPL PAGE 9
LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 3 24. 21 -589 223021
SUMMARY REPORT--SURE-TO-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES

STRATUM 3---------------3---------------3---------------3

SAMPLE VARIABLES	SURE-TO-BE MEASURED AGGREGATIONS	3P-EXPANDED SAMPLE ESTIMATES	TOTAL SAMPLE ESTIMATES PLUS SURE
TREES(FREQUENCY)	.000	30.000	30.000
PREDICT.(EF KPI)	.000	282.745	282.745
B.A.(SQ.FT.O.B.)	.0	23.6	23.6
LENGTH(FT.)	.0	.0	.0
SURFACE(SQ.FT.IB.)	.0	.0	.0
VOLUME(CU.FT.I.B.)	.0	.0	.0
REL.VAL.PER MF.UNIT	1.00	1.00	1.00
GROSS MF.UNITS	.0	.0	.0
ST.ERROR(PCT.)	-----	.0	.0

COMPONENT ITEMS	(1=) NUMBER	(2*) NUMBER	(1,2) NUMBER
MEASURED TREES	0	2	2
MEASURED LOGS	0	0	0

STRATUM 3 HAS LESS THAN TWO SAMPLES.

VISIT 3 PTS (2 PARTIALS), GUESS F, XMPLIFY 3 KINDS SUBSAMPLE XMPL PAGE 10
LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 3 24. 21 -589 223021

SUMMARY REPORT--SURE-TO-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES

TOTALS ALL 3 STRATA

SAMPLE VARIABLES	SURE-TO-BE MEASURED AGGREGATIONS	3P-EXPANDED SAMPLE ESTIMATES	TOTAL SAMPLE ESTIMATES PLUS SURE
TREES(FREQUENCY)	10.000	166.667	176.667
PREDICT.(EF KPI)	.000	1790.712	1790.712
B.A.(SQ.FT.O.B.)	7.9	131.6	139.4
LENGTH(FT.)	359.9	5016.1	5376.0
SURFACE(SQ.FT.IB.)	1241.5	14091.5	15332.9
VOLUME(CU.FT.I.B.)	350.4	3599.5	3950.0
REL.VAL.PER MF.UNIT	2.00	1.63	1.66
GROSS MF.UNITS	350.4	3599.5	3950.0
ST.ERROR(PCT.)	-----	6.6	6.0
GROSS WTD.MF.UNITS	700.88	5862.03	6562.91
ST.ERROR(PCT.)	-----	7.9	7.1

COMPONENT ITEMS	(1=) NUMBER	(2*) NUMBER	(1,2) NUMBER
MEASURED TREES	1	13	14
MEASURED LOGS	5	64	69

MF.UNITS= CU. FT. INSIDE BARK
=(.10000000+01)*(CU.FT.)+(.00000000)*(SQ.FT.)+(.00000000)*(FT.)

```
======================== CONTINUATION OF TEST OUTPUT ==========================

VISIT 3 PTS (2 PARTIALS), GUESS H, XMPLIFY 3 KINDS SUBSAMPLE      XMPL  PAGE   0
LRG 03-03-73  8.000  .01964673 -1.1905  1.5658  3      24.   21       -589 223021
       SUMMARY REPORT--SURE-TO-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES
===============================================================================


DATA PROCESSING BLOCKED BY    0 INPUT FLAWS.
SAMPLE ESTIMATES INVOLVE   1 SUSPICIOUS ITEMS NUMBERED
            285
INPUT READ BEFORE FLAW,IF ANY---
    CARDS WITH TREE PREDICTICNS CNLY         (FIRST)                          12
    CARDS WITH MEASURED TREE INFO            (FIRST)                          14
    ---------------------------------------------------------------------------
    CARDS WITH MEASURED TREE INFO            (SECOND)                         14
    CARDS WITH ADDITIONAL DENCROMETER INFO   (SECOND)                         32

PROCESSING DCNE BEFORE FLAW,IF ANY---
    NUMBER OF MEASURED TREES PROCESSED                                        14
    NUMBER OF MEASURED LOGS PROCESSED                                         69
    TREE CARDS PUNCHED CR WRITTEN                                              0
    LOG CARDS PUNCHED CR WRITTEN                                               0
    LABEL ON CARD OUTPUT                                                    XMPL

CHECK OF INPUT AGGREGATES WITH EXPANDED 3P SAMPLE
    AGGREGATE NUMBER OF TREES INPUT(1+2+3)                               26
    SAMPLE ESTIMATE(2 EXPANDED)+NO.SURE(1 EXPANDED IF SB SAMPLE)         176.667
    STANDARD ERROR OF ESTIMATED NUMBER                                    70.711
    ---------------------------------------------------------------------------
    AGGREGATE PREDICTIONS(KPI) INPUT(1+2+3) NOT EXPANDED                 312
    SAMPLE ESTIMATE(2 EXPANDED)+SURE KPI(EXPANDED IF SB SAMPLE)         1790.712
===============================================================================
```

VISIT 3 PTS (2 PARTIALS), GUESS H, XMPLIFY 3 KINDS SUBSAMPLE XMPL PAGE 11
LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 3 24. 21 -589 223021

GRADE-YIELD AND REALIZATION REPORT

CLAS	GR	CU.FT.IB.VOL.	SQ.FT.IB.SURF.	LIN.FT.LENGTH	LOG FREQ.	COUNT
DFIR	AA	33.66	91.89	20.00	5.00	1
DFIR	AB	54.13	164.93	40.00	5.00	1
DFIR	AC	54.13	164.93	40.00	5.00	1
DFIR	BA	343.06	1658.77	640.00	40.00	1
DFIR	BB	57.49	339.29	160.00	40.00	1
DFIR	BC	119.70	490.09	160.00	40.00	1
DFIR	CA	191.65	657.38	180.00	5.00	1
DFIR	CB	191.65	657.38	180.00	5.00	1
DFIR	CC	59.85	245.05	80.00	5.00	1
DFIR	UU	59.85	245.05	80.00	5.00	1
DFIR	XX	33.66	91.89	20.00	5.00	1
DFIR	ZP	138.19	1272.35	960.00	180.00	3
DNDR	AN	50.18	158.46	40.34	10.00	1
DNDR	BK	63.11	251.87	79.99	20.00	2
DNDR	B2	263.85	893.36	243.81	15.24	4
DNDR	B3	252.12	870.94	243.81	15.24	4
DNDR	CN	107.21	388.96	114.29	11.43	3
DNDR	CV	113.17	398.93	114.29	11.43	3
DNDR	CX	118.36	408.91	114.29	11.43	3
DNDR	FK	165.36	435.32	91.52	15.24	4
DNDR	FR	31.55	125.68	39.84	10.00	1
DNDR	IB	258.51	883.24	243.81	15.24	4
DNDR	LT	338.65	1196.43	342.88	34.29	9
DNDR	MV	258.63	883.50	243.88	15.24	4
DNDR	UU	333.73	1475.17	659.45	40.48	9
DNDR	ZT	258.49	883.16	243.79	15.24	4
TOTALS		3949.97	15332.93	5375.99	580.48	69

VISIT 3 PTS (2 PARTIALS), GUESS F, XMPLIFY 3 KINDS SUBSAMPLE XMPL PAGE 12
LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 3 24. 21 -589 223021
GRADE-YIELD AND REALIZATION REPORT

CLAS GR	SAWKERF CU.FT.IB.	SHORTS(TRIM) CU.FT.IB.	SLABS-EDGES CU.FT.IB.	UNUSABLE LBR. CU.FT.IB.	USABLE LBR. BD.FT.	LBR.VALUE DOLLARS
DFIR AA	6.46	.40	5.69	.00	238.59	39.55
DFIR AB	10.38	.56	10.20	3.16	334.93	50.74
DFIR AC	10.38	.50	10.20	6.01	295.95	39.92
DFIR BA	65.79	3.24	101.66	.00	1947.24	266.64
DFIR BB	11.02	.43	20.69	2.43	257.47	27.19
DFIR BC	22.95	.99	30.14	11.92	586.14	60.33
DFIR CA	36.75	2.11	40.56	.00	1267.66	123.64
DFIR CB	36.75	1.90	40.56	10.77	1141.24	103.52
DFIR CC	11.48	.50	15.07	5.96	293.07	24.24
DFIR UU	11.48	.56	15.07	2.78	338.28	35.42
DFIR XX	.00	.00	.00	33.66	.00	.00
DFIR ZP	.00	.00	.00	.00	.00	.00
SUBTOT	223.43	11.19	289.85	76.70	6700.58	771.18
DNDR AN	.00	.00	.00	.00	.00	.00
DNDR BK	.00	.00	.00	.00	.00	.00
DNDR B2	.00	.00	.00	.00	.00	.00
DNDR B3	.00	.00	.00	.00	.00	.00
DNDR CN	.00	.00	.00	.00	.00	.00
DNDR CV	.00	.00	.00	.00	.00	.00
DNDR CX	.00	.00	.00	.00	.00	.00
DNDR FK	.00	.00	.00	.00	.00	.00
DNDR FR	.00	.00	.00	.00	.00	.00
DNDR IB	.00	.00	.00	.00	.00	.00
DNDR LT	.00	.00	.00	.00	.00	.00
DNDR MV	.00	.00	.00	.00	.00	.00
DNDR UU	.00	.00	.00	.00	.00	.00
DNDR ZT	.00	.00	.00	.00	.00	.00
SUBTOT	.00	.00	.00	.00	.00	.00
TOTALS	223.43	11.19	289.85	76.70	6700.58	771.18

VOLUME (CU.FT.IB.) PAIRED WITH YIELD COEFFICIENTS= 1198.84

```
@ERS          TPF$. .                ERASE TPF$.
@FOR,W        AZ.BLD,TPF$.BLD
-9,9
     0DATA MRE/ 5/,MPR/ 6/,MPU/1/,JW/4/,JX/8/,MEF/ 0/,JY/2/,N3/1/,NP/1/,BLD      9
@FOR,W        AZ.ST33,TPF$.ST33
-33,35
      58HB.A.(SQ.,A3,5H0.B.),F16.2,2F17.2/6X,7HLENGTH(,A3,1H),4X,3F17.2/ ST33  33
      66X,11HSURFACE(SQ.,A3,4HIB.),F14.2,2F17.2/6X,10HVOLUME(CU.,A3,     ST33  34
      75HI.B.),F14.2,2F17.2/6X,19HREL.VAL.PER MF.UNIT,                   ST33  35
@FOR,W        AZ.PROD,TPF$.PRCD
-27,28
    4 FORMAT (1X,A4,1X,A2,3F16.3,F16.3,2X,I6)                            PROD  27
    5 FORMAT (1X,79(1H=)/1X,A4,A3,3F16.3,F16.3,2X,I6)                    PROD  28
-35,38
    8 FORMAT (1X,A4,1X,A2,1X,4F14.3,2F14.2)                              PROD  35
    9 FORMAT (1X, 92(1H-)/1X,A4,A3,1X,4F14.3,2F14.2)                     PROD  36
  100FORMAT (1X, 92(1H=)/1X,A4,A3,1X,4F14.3,2F14.2/1X,11HVOLUME (CU.,    PROD  37
     1A3,36HIB.) PAIRED WITH YIELC COEFFICIENTS=,F14.3)                  PROD  38
```

======================== CONTINUATION OF TEST INPUT ========================

```
@FOR,W      AZ.ST44,TPF$.ST44
-26,67
      DATA LC(  1, 1)/4HDFIR/                                             ST44  26
     ODATA LC(  2, 1)/2HAA/,P1AA/                                         ST44  27
     1      .19176,.0,.0,.01488,-.0003505,.0000065,                       ST44  28
     2      .0,.01912,-.000347,.0,.0,.0,                                  ST44  29
     3      316.42,-7.481,.135,52.97,-1.292,.013/                         ST44  30
     ODATA LC( 21, 1)/2HAB/,P1AB/                                         ST44  31
     1      .19176,.0,.0,.01339,-.0003139,.0000056,                       ST44  32
     2      .0,.01912,-.000347,.07616,-.00180,.0000325,                   ST44  33
     3      284.78,-6.727,.121,45.91,-1.292,.013/                         ST44  34
     ODATA LC( 40, 1)/2HAC/,P1AC/                                         ST44  35
     1      .19176,.0,.0,.01205,-.0002835,.0000046,                       ST44  36
     2      .0,.01912,-.000347,.14470,-.003423,.0000622,                  ST44  37
     3      252.78,-6.060,.108,38.85,-1.292,.013/                         ST44  38
     ODATA LC( 59, 1)/2HBA/,P1BA/                                         ST44  39
     1      .19176,.0,.0,.01488,-.0003505,.0000065,                       ST44  40
     2      .0,.01912,-.000347,.0,.0,.0,                                  ST44  41
     3      316.42,-7.481,.135,47.67,-1.292,.013/                         ST44  42
     ODATA LC( 78, 1)/2HBB/,P1BB/                                         ST44  43
     1      .19176,.0,.0,.01339,-.0003139,.0000056,                       ST44  44
     2      .0,.01912,-.000347,.07616,-.00180,.0000325,                   ST44  45
     3      284.78,-6.727,.121,41.32,-1.292,.013/                         ST44  46
     ODATA LC( 97, 1)/2HBC/,P1BC/                                         ST44  47
     1      .19176,.0,.0,.01205,-.0002835,.0000046,                       ST44  48
     2      .0,.01912,-.000347,.14470,-.003423,.0000622,                  ST44  49
     3      252.78,-6.060,.108,34.96,-1.292,.013/                         ST44  50
     ODATA LC(116, 1)/2HCA/,P1CA/                                         ST44  51
     1      .19176,.0,.0,.01488,-.0003505,.0000065,                       ST44  52
     2      .0,.01912,-.000347,.0,.0,.0,                                  ST44  53
     3      316.42,-7.481,.135,37.19,-1.292,.013/                         ST44  54
     ODATA LC(135, 1)/2HCB/,P1CB/                                         ST44  55
     1      .19176,.0,.0,.01339,-.0003139,.0000056,                       ST44  56
     2      .0,.01912,-.000347,.07616,-.00180,.0000325,                   ST44  57
     3      284.78,-6.727,.121,33.48,-1.292,.013/                         ST44  58
     ODATA LC(154, 1)/2HCC/,P1CC/                                         ST44  59
     1      .19176,.0,.0,.01205,-.0002835,.0000046,                       ST44  60
     2      .0,.01912,-.000347,.14470,-.003423,.0000622,                  ST44  61
     3      252.78,-6.060,.108,31.47,-1.292,.013/                         ST44  62
     ODATA LC(173, 1)/2HUU/,P1UU/                                         ST44  63
     1      .19176,.0,.0,.01203,.0001341,-.000308,                        ST44  64
     2      .0,.01912,-.000347,.15438,-.02636,.01711,                     ST44  65
     3      256.00,2.831,-6.562,35.315,-1.076,.0033/                      ST44  66
      DATA LC(192, 1)/2HXX/,P1XX/9*0.0,1.0,8*0.0/                         ST44  67
```

========================= CONTINUATION OF TEST INPUT =========================

```
@MAP         AZ.STXMAP,TPF$.STXSTX
@XQT        .STXSTX
    US UNITS TESTING US PROCESSING OR US-METRIC CONVERSION                    USMT    1
    LRG 03-03-73 08000 01964673-11905 15658 1   24   21     -196 223051 USMT    2
      13                                                                USMT    3
      96                                                                USMT    4
                                                                        USMT    5
 1.00178                                                                USMT    6
 56.1224                                                                USMT    7
 264.471                                                                USMT    8
   10    4 *DFIR   6.0 311   .3      8.800          1.                      USMT
   11         500  80100.0RP 502  60104.6ZP 515  50113.5ZP 526  40117.7ZP    USMT
   12            -999     UU                                          *    USMT
   20    6 *DFIR  12.0 11    .6                        .250000              USMT
   21         331 82310000RP 332 76610797BC 361 70213714BA 371 64514327BB    USMT
   22        -999-99914327UU                                          *    USMT
   30   16 *DFIR  18.0 2    -.9                         3.                  USMT
   31             189  0.0RP     162  4.0AA      153  8.0AB     126 36.0CB   USMT
   32             108 16.0CC                                          *    USMT
11130   16 *DFIR  18.0 012   .9      16.125             3.                  USMT
11131        -999 210  4.0RP     180  8.0XX 509 779-1191AC            +    USMT
11132         557 736 0000RP 559 705+2324CA    -999      UU           *    USMT
9999
9999
```

=== TEST OUTPUT (U.S. INPUT DATA, METRIC SUMMARIES AND PRODUCT-CONVERSIONS) ===

```
US UNITS TESTING US PROCESSING OR US-METRIC CONVERSION           USMT  PAGE   1
LRG 03-03-73  8.000  .01964673 -1.1905  1.5658  1     24.   21      -196 223051
              PRELIMINARY REPORT--COUNTS AND AGGREGATE PREDICTIONS
===============================================================================
```

STRATUM 1	TREE COUNTS	PREDICTIONS
SURE-TO-BE MEASURED TREES(=1)	0	0
THREE-PEE MEASURED TREES(*2)	4	42
THREE-PEE PREDICTED TREES(3)	9	54
ALL TREES(1,2,3)	13	96
ALL MEASURED TREES(1,2)	4	42
ALL THREE-PEE TREES(2,3)	13	96
EXPECTED VALUES FOR (*2)	4.000	42.000
EXP. VAL. ST. ERRORS (*2)	1.500	14.526

TOTALS FOR ALL 1 STRATA	TREE COUNTS	PREDICTIONS
SURE-TO-BE MEASURED TREES(=1)	0	0
THREE-PEE MEASURED TREES(*2)	4	42
THREE-PEE PREDICTED TREES(3)	9	54
ALL TREES(1,2,3)	13	96
ALL MEASURED TREES(1,2)	4	42
ALL THREE-PEE TREES(2,3)	13	96
EXPECTED VALUES FOR (*2)	4.000	42.000
EXP. VAL. ST. ERRORS (*2)	1.500	14.526

```
US UNITS TESTING US PROCESSING OR US-METRIC CONVERSION           USMT  PAGE   2
LRG 03-03-73  8.000  .01964673 -1.1905  1.5658  1     24.   21       -196 223051
              PRELIMINARY REPORT--COUNTS AND AGGREGATE PREOICTIONS
================================================================================

PUNCH CONTROL CAROS 3 AND 4 AS FOLLOWS TO PROCESS THIS JOB UNOER
SUMMARY INPUT OPTIONS (WITH '2' OR '4' PUNCHEO IN COLUMN 66 OF CONTROL CARO 2) --
      13                                                                USMT   3
      96                                                                USMT   4

CONTROL CARDS 5, 6, 7, 8 ALSO REQUIRED BY STX 03-03-73 MUST CONTAIN FOLLOWING FLOATING-POINT INFORMATION FOR OPTIONS
'2' OR '4', REDUCEO TO NINE 8-COLUMN FIELDS (BLANKS CAN REPLACE ZEROS, IMPLICIT INPUT FORMAT IS 9F8.0) --

  1.000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    USMT   5
  1.001780    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    USMT   6
  56.12240    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    USMT   7
  264.4710    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    USMT   8

ALL SUBSEQUENT FREQUENCIES RESULT FROM AOJUSTMENT SUCH THAT F'=FREQ+(V1+V2*KPI+V3*POUT)*FREQ**2.          KP1 SHOULD
INCLUDE BA  IN CASE POINT-SAMPLING IS INVOLVEO.  IF V1   AND OTHER V'S ARE O,  THEN FREQUENCIES ARE UNAOJUSTEO, ELSE
V'S HAVE BEEN DERIVED TO LEAVE ESTIMATES OF TOTAL VOLUME AND EFFECTIVE KPI UNCHANGED, BUT TO ADJUST FREQUENCY ESTIMATES
SO THEY WILL TOTAL POPULATION COUNT OR BEST SAMPLE-BASED ESTIMATE OF COUNT.  INPUT OPTION '1' OR '2' IS APPROPRIATE
WHEN USER MANUALLY INSERTS ADJUSTED V'S BY BLOCK DATA STATEMENT AFTER INITIAL DERIVATION.  V'S EFFECTIVE FOR THIS RUN =

  .0000000    .0000000    .0000000
```

```
====================== CONTINUATION OF TEST OUTPUT ========================

US UNITS TESTING US PROCESSING OR US-METRIC CONVERSION          USMT  PAGE  3
LRG 03-03-73  8.000  .01964673 -1.1905  1.5658  1     24.   21      -196 223051
                     DETAILED LOG AND/OR TREE REPORT
==============================================================================
TREE/  VOLUME   / SURFACE / LENGTH / D.I.B. / LOG/RANGE/
 NO./  CU.FT.  /  SQ.FT. /   FT.  /   IN.   /CODE/  FT./ TGRADS   FGRADS    SINELV
==============================================================================
            .0        .0       .0       3.6   UU      .0      .0  -99.9     .0000
            .4       4.2      4.0       3.6   ZP    52.6    52.6    4.0   17.7000
           1.1      10.4      8.0       4.5   ZP    51.5    51.5    5.0   13.5000
            .9       6.6      4.0       5.4   ZP    50.2    50.2    6.0    4.6000
            .0        .0       .0       7.2   RP    50.0    50.0    8.0     .0000
------------------------------------------------------------------------------
   1       2.3      21.2     16.0       6.0=D,F=   60.000,     4,    .6 311*DFIR 1
------------------------------------------------------------------------------
            .0        .0       .0        .1   UU      .0   -99.9  -99.9     .4327
           1.4       8.4      4.0       7.2   BB    55.5    37.1   64.5     .4327
           8.6      41.6     16.0       9.0   BA    53.9    36.1   70.2     .3714
           3.0      12.3      4.0      10.8   BC    50.2    33.2   76.6     .0797
            .0        .0       .0      12.6   RP    50.1    33.1   82.3     .0000
------------------------------------------------------------------------------
   2      13.0      62.2     24.0      12.0=D,F=   40.000,     6,   1.2 111 DFIR 1
------------------------------------------------------------------------------
          12.0      49.0     16.0      10.8   CC      .0      .0   10.8   16.0000
          38.3     131.5     36.0      12.6   CB      .0      .0   12.6   36.0000
          10.8      33.0      8.0      15.3   AB      .0      .0   15.3    8.0000
           6.7      18.4      4.0      16.2   AA      .0      .0   16.2    4.0000
            .0        .0       .0      18.9   RP      .0      .0   18.9     .0000
------------------------------------------------------------------------------
   3      67.9     231.8     64.0      18.0=D,F=    5.000,    16,  -1.8 211 DFIR 1
------------------------------------------------------------------------------
          12.0      49.0     16.0      10.8   UU      .0      .0  -99.9     .0000
          38.4     131.6     36.0      12.6   CA   154.9    55.9   70.5     .2324
            .0        .0       .0      15.3   RP   151.6    55.7   73.6     .0000
          10.8      33.0      8.0      15.3   AC   101.0    50.9   77.9    -.1191
           6.7      18.4      4.0      16.2   XX      .0      .0   18.0    8.0000
            .0        .0       .0      18.9   RP      .0   -99.9   21.0    4.0000
------------------------------------------------------------------------------
1113      67.9     232.0     64.0      18.0=D,F=    5.000,    16,   1.8 012*DFIR 1
------------------------------------------------------------------------------
```

US UNITS TESTING US PROCESSING OR US-METRIC CONVERSION USMT PAGE 4
LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 1 24. 21 -196 223051
SUMMARY REPORT--SURE-TO-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES

STRATUM 1 SAMPLE VARIABLES	SURE-TO-BE MEASURED AGGREGATIONS	3P-EXPANDED SAMPLE ESTIMATES	TOTAL SAMPLE ESTIMATES PLUS SURE
TREES(FREQUENCY)	.000	110.000	110.000
PREDICT.(EF KPI)	.000	518.363	518.363
B.A.(SQ.M. O.B.)	.00	5.65	5.65
LENGTH(M.)	.00	780.10	780.10
SURFACE(SQ.M. IB.)	.00	564.88	564.88
VOLUME(CU.M. I.B.)	.00	37.88	37.88
REL.VAL.PER MF.UNIT	1.00	1.00	1.00
GROSS MF.UNITS	.0	1337.8	1337.8
ST.ERROR(PCT.)	-----	4.5	4.5

COMPONENT ITEMS	(1=) NUMBER	(2*) NUMBER	(1,2) NUMBER
MEASURED TREES	0	4	4
MEASURED LOGS	0	16	16

```
====================== CONTINUATION OF TEST OUTPUT ========================

US UNITS TESTING US PROCESSING OR US-METRIC CONVERSION          USMT  PAGE   5
LRG 03-03-73  8.000  .01964673 -1.1905  1.5658  1     24.    21       -196 223051
      SUMMARY REPORT--SURE-TO-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES
=============================================================================

TOTALS ALL  1 STRATA*********************************************************
                          /   SURE-TO-BE   /   3P-EXPANDED  /  TOTAL SAMPLE  /
                          /    MEASURED    /     SAMPLE     /   ESTIMATES    /
      SAMPLE VARIABLES/  AGGREGATIONS  /   ESTIMATES    /   PLUS SURE    /
-----------------------------------------------------------------------------
     TREES(FREQUENCY)            .000          110.000          110.000
     PREDICT.(EF KPI)            .000          518.363          518.363
     B.A.(SQ.M. O.B.)            .00             5.65             5.65
     LENGTH(M. )                 .00           780.10           780.10
     SURFACE(SQ.M. IB.)          .00           564.88           564.88
     VOLUME(CU.M. I.B.)          .00            37.88            37.88
     REL.VAL.PER MF.UNIT         .00             1.00             1.00
     GROSS MF.UNITS              .0            1337.8           1337.8
       ST.ERROR(PCT.)           -----             4.5              4.5
     GROSS WTD.MF.UNITS          .00           1337.80          1337.80
       ST.ERROR(PCT.)           -----             4.5              4.5

-----------------------------------------------------------------------------
                                (1=)            (2*)             (1,2)
     COMPONENT ITEMS           NUMBER          NUMBER           NUMBER
-----------------------------------------------------------------------------
       MEASURED TREES             0               4                4
       MEASURED LOGS              0              16               16

-----------------------------------------------------------------------------
MF.UNITS=  CU. FT. INSIDE BARK
 =(    .10000000+01)*(CU.FT.)+(    .00000000    )*(SQ.FT.)+(    .00000000    )*(FT.)
=============================================================================
```

```
======================== CONTINUATION OF TEST OUTPUT ===========================

US UNITS TESTING US PROCESSING OR US-METRIC CONVERSION          USMT  PAGE   0
LRG 03-03-73  8.000  .01964673 -1.1905  1.5658  1     24.    21      -196 223051
      SUMMARY REPORT--SURE-TO-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES
================================================================================


DATA PROCESSING BLOCKED BY   0 INPUT FLAWS.
SAMPLE ESTIMATES INVOLVE   0 SUSPICIOUS ITEMS NUMBERED
INPUT READ BEFORE FLAW,IF ANY---
    CARDS WITH TREE PREDICTICNS ONLY         (FIRST)                           9
    CARDS WITH MEASURED TREE INFO            (FIRST)                           4
    ----------------------------------------------------------------------------
    CARDS WITH MEASURED TREE INFC            (SECCND)                          4
    CARDS WITH ADDITIONAL DENDROMETER INFO   (SECOND)                          8

PROCESSING DONE BEFORE FLAW,IF ANY---
    NUMBER OF MEASUREC TREES PROCESSED                                         4
    NUMBER OF MEASURED LCGS PROCESSED                                         16
    TREE CARDS PUNCHED OR WRITTEN                                              0
    LOG CARDS PUNCHED OR WRITTEN                                               0
    LABEL ON CARD OUTPUT                                                    USMT

CHECK OF INPUT AGGREGATES WITH EXPANDED 3P SAMPLE
    AGGREGATE NUMBER OF TREES INPUT(1+2+3)                                13
    SAMPLE ESTIMATE(2 EXPANDED)+NO.SURE(1 EXPANDED IF SB SAMPLE)      110.000
    STANDARD ERROR OF ESTIMATED NUMBER                                 70.711
    ----------------------------------------------------------------------------
    AGGREGATE PREDICTIONS(KPI) INPUT(1+2+3) NOT EXPANDED              96
    SAMPLE ESTIMATE(2 EXPANDED)+SURE KPI(EXPANDED IF SB SAMPLE)       518.363
================================================================================
```

======================= CONTINUATION OF TEST OUTPUT ========================

US UNITS TESTING US PROCESSING OR US-METRIC CONVERSION USMT PAGE 6
LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 1 24. 21 -196 223051

REPORT BY GRADE WITHIN TREE

TREE	CL.	DIB.	CU.FT.IB.VOL.	SQ.FT.IB.SURF.	LIN.FT.LENGTH	TREE FREQ.	COUNT
	ZP	3.6	2.31	21.21	15.99		3
1	DFIR		2.31	21.21	56.99	60.00	3
	BA	9.0	8.60	41.56	16.04		1
	BB	7.2	1.42	8.39	3.96		1
	BC	10.8	3.00	12.26	4.00		1
2	DFIR		13.01	62.21	24.00	40.00	3
	AA	16.2	6.73	18.38	4.00		1
	AB	15.3	10.83	32.99	8.00		1
	CB	12.6	38.33	131.48	36.00		1
	CC	10.8	11.97	49.01	16.00		1
3	DFIR		67.86	231.85	64.00	5.00	4
	AC	15.3	10.82	32.98	8.00		1
	CA	12.6	38.40	131.61	36.01		1
	UU	10.8	11.97	49.02	16.00		1
	XX	16.2	6.73	18.38	4.00		1
1113	DFIR		67.93	231.98	64.01	5.00	4
WTD TOTALS			1337.80	6080.32	2559.39	110.00	14

US UNITS TESTING US PROCESSING OR US-METRIC CONVERSION USMT PAGE 7
LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 1 24. 21 -196 223051
GRAOE-YIELO ANO REALIZATION REPORT

NO.	IS*CLAS	GR	TR OBH	TR HT.	LG DR.	LG HT.	LG VOL.	LG SUR.	LG LTH.	FREQ.	VAL.	TR VOL.	TR SUR.	TR LTH.	PKI
3	212DFIR	AA	18.0	64.00	16.20	4.00	6.73	18.38	4.00	5.000	1.00	67.86	231.85	64.00	16.
3	3120FIR	A8	18.0	64.00	15.30	12.00	10.83	32.99	8.00	5.000	1.00	67.86	231.85	64.00	16.
1113	3120F1R	AC	18.0	64.01	15.30	12.00	10.82	32.98	8.00	5.000	1.00	67.93	231.98	64.01	16.
2	3120F1R	8A	12.0	24.00	8.98	20.04	8.60	41.56	16.04	40.000	1.00	13.01	62.21	24.00	6.
2	412DF1R	B8	12.0	24.00	7.20	24.00	1.42	8.39	3.96	40.000	1.00	13.01	62.21	24.00	6.
2	2120FIR	8C	12.0	24.00	10.81	4.00	3.00	12.26	4.00	40.000	1.00	13.01	62.21	24.00	6.
1113	512DFIR	CA	18.0	64.01	12.60	48.01	38.40	131.61	36.01	5.000	1.00	67.93	231.98	64.01	16.
3	4120F1R	C8	18.0	64.00	12.60	48.00	38.33	131.48	36.00	5.000	1.00	67.86	231.85	64.00	16.
3	5120FIR	CC	18.0	64.00	10.80	64.00	11.97	49.01	16.00	5.000	1.00	67.86	231.85	64.00	16.
1113	6120FIR	UU	18.0	64.01	10.80	64.01	11.97	49.02	16.00	5.000	1.00	67.93	231.98	64.01	16.
1113	2120FIR	XX	18.0	64.01	16.20	4.00	6.73	18.38	4.00	5.000	1.00	67.93	231.98	64.01	16.
1	412DFIR	ZP	6.0	15.99	3.60	15.99	.36	4.21	3.97	60.000	1.00	2.31	21.21	15.99	4.
1	3120FIR	ZP	6.0	15.99	4.50	12.02	1.07	10.36	8.00	60.000	1.00	2.31	21.21	15.99	4.
1	2120FIR	ZP	6.0	15.99	5.40	4.03	.88	6.64	4.03	60.000	1.00	2.31	21.21	15.99	4.

======================== CONTINUATION OF TEST OUTPUT ========================

US UNITS TESTING US PROCESSING OR US-METRIC CONVERSION USMT PAGE 8

LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 1 24. 21 -196 223051

GRADE-YIELD AND REALIZATION REPORT

CLAS GR	CU.M. IB.VOL.	SQ.M. IB.SURF.	LIN.M. LENGTH	LOG FREQ.	COUNT
DFIR AA	.953	8.537	6.096	5.000	1
DFIR AB	1.533	15.323	12.192	5.000	1
DFIR AC	1.533	15.322	12.192	5.000	1
DFIR BA	9.736	154.449	195.520	40.000	1
DFIR BB	1.608	31.168	48.271	40.000	1
DFIR BC	3.395	45.568	48.760	40.000	1
DFIR CA	5.436	61.133	54.878	5.000	1
DFIR CB	5.427	61.073	54.864	5.000	1
DFIR CC	1.695	22.765	24.384	5.000	1
DFIR UU	1.695	22.769	24.384	5.000	1
DFIR XX	.953	8.537	6.096	5.000	1
DFIR ZP	3.917	118.239	292.465	180.000	3
TOTALS	37.882	564.883	780.102	340.000	14

US UNITS TESTING US PROCESSING OR US-METRIC CONVERSION USMT PAGE 9
LRG 03-03-73 8.000 .01964673 -1.1905 1.5658 1 24. 21 -196 223051

GRADE-YIELD AND REALIZATION REPORT

CLAS GR	SAWKERF CU.M. IB.	SHORTS(TRIM) CU.M. IB.	SLABS-EDGES CU.M. IB.	UNUSABLE LBR. CU.M. IB.	USABLE LBR. BD.FT.	LBR.VALUE DOLLARS
DFIR AA	.183	.011	.161	.000	238.59	39.54
DFIR AB	.294	.016	.289	.090	334.94	50.74
DFIR AC	.294	.014	.289	.170	295.89	39.91
DFIR BA	1.867	.092	2.885	.000	1951.78	267.13
DFIR BB	.308	.012	.579	.068	254.10	26.80
DFIR BC	.651	.028	.854	.338	587.41	60.46
DFIR CA	1.042	.060	1.150	.000	1270.28	123.91
DFIR CB	1.041	.054	1.149	.305	1141.27	103.50
DFIR CC	.325	.014	.427	.169	293.06	24.24
DFIR UU	.325	.016	.427	.079	338.40	35.44
DFIR XX	.000	.000	.000	.953	.00	.00
DFIR ZP	.000	.000	.000	.000	.00	.00
SUBTOT	6.330	.317	8.209	2.172	6705.72	771.67
TOTALS	6.330	.317	8.209	2.172	6705.72	771.67

VOLUME (CU.M. IB.) PAIRED WITH YIELD COEFFICIENTS= 33.965

```
==================== ILLUSTRATION OF INPUT TO USMT 3-03-73 ====================

@MAP        AZ.USMMAP,TPF$.USMUSM
@XQT          .USMUSM
    US UNITS TESTING US PROCESSING OR US-METRIC CONVERSION              USMT    1
    LRG 03-03-73 08000 01964673-11905 15658 1   24   21      -196 223021 USMT    2
      13                                                                USMT    3
      96                                                                USMT    4
                                                                        USMT    5
 1.00178                                                                USMT    6
 56.1224                                                                USMT    7
 264.471                                                                USMT    8
   10   4 *DFIR   6.0 311   .3       8.800               1.                 USMT
   11        500  80100.0RP 502  60104.6ZP 515  50113.5ZP 526  40117.7ZP    USMT
   12           -999     UU                                            *    USMT
   20   6 *DFIR  12.0 11    .6                           .250000            USMT
   21        331 82310000RP 332 76610797BC 361 70213714BA 371 64514327BB    USMT
   22       -999-99914327UU                                            *    USMT
   30  16 *DFIR  18.0 2    -.9                           3.                 USMT
   31            189  0.0RP     162  4.0AA      153  8.0AB     126 36.0CB   USMT
   32            108 16.0CC                                            *    USMT
11130  16 *DFIR  18.0 012   .9      16.125               3.                 USMT
11131       -999 210  4.0RP     180  8.0XX 509 779-1191AC              +    USMT
11132        557 736 0000RP 559 705+2324CA    -999      UU             *    USMT
9999
    METRIC UNITS TESTING METRIC PROCESSING OR METRIC-US CONVERSION      MUST    1
    LRG 03-03-73 20320 01964673-11905 15658 1   24   21      -182+223021 MUST    2
      13                                                                MUST    3
      96                                                                MUST    4
                                                                        MUST    5
 1.00178                                                                MUST    6
 604.096 .000000 .000000 .000000 .000000 .000000 .000000 .000000 .000000MUST    7
 264.471                                                                MUST    8
   10   4 *DFIR  15.2+311     8   0  24800               1.                 MUST
   11++     1524 203100.0RP1530 152104.6ZP1570 127113.5ZP1603 102117.7ZP    MUST
   12++         0-999   .0UU                                           *    MUST
   20   6 *DFIR  30.5+110    15   0    0  0              .250000            MUST
   21++      331 82310000RP 332 76610797BC 361 70213714BA 371 64514327BB    MUST
   22++     -999-99914327UU                                            *    MUST
   30  16 *DFIR  45.7+200   -23   0    0  0              3.                 MUST
   31++          0 480  .00RP   0 411 1.22AA   0 389 2.44AB   0 32010.97CB  MUST
   32++          0 274 4.88CC                                          *    MUST
11130  16 *DFIR  45.7+012    23   0   49 10              3.                 MUST
11131++     -999 533 1.22RP   0 457 2.44XX 509 779-1191AC              +    MUST
11132++      557 736    0RP 559 705 2324CA   0-999     0UU             *    MUST
9999
9999
== US-METRIC AND METRIC-US CONVERSIONS WILL BE EFFECTED AND DECKS PUNCHED OUT. =
======= USMT OUTPUT DECK SHOULD BE COMPARABLE WITH MUST INPUT DECK, AND =======
========= MUST OUTPUT DECK SHOULD BE COMPARABLE WITH USMT INPUT DECK, =========
=============== EXCEPT FOR MINOR DIFFERENCES CAUSED BY ROUNDING. ==============
```

```
=== TEST INPUT (METRIC INPUT DATA, METRIC SUMMARIES AND PRODUCT-CONVERSIONS) ===

@ERS         TPF$. .                   ERASE TPF$.
@FOR,W       AZ.BLD,TPF$.BLD
 9,12
    ODATA MRE/ 5/,MPR/ 6/,MPU/1/,JW/4/,JX/8/,MEF/ 0/,JY/1/,N3/0/,NP/0/,BLD    9
    1 BCDEF/4HCU. ,4HM.  ,4HINSI,4HDE B,4HARK ,4H    ,4H    ,4H    ,  BLD   10
    24H    ,4H    ,4H    ,4H    ,4H    ,4H    ,4H    ,4H    ,4H    /, BLD   11
    3BORD/      1.0/,SLAB/         .0/,CLFT/          .0/,            BLD   12
FOR,W        AZ.ST22,TPF$.ST22
27,28
  16 FORMAT (5X,F11.3,F10.2,F8.2,F9.1,3X,A2,1X,F6.2,F8.1,F7.1,F10.4)    ST22  27
  170FORMAT (1X,79(1H-)/1X,I4,F11.3,F10.2,F8.2,F9.1,5H=D,F=,F9.3,1H,,   ST22  28
35,35
  190FORMAT           (1X,I4,F11.3,F10.2,F8.2,F9.2,5H=D,F=,F9.3,1H,,   ST22  35
37,39
  210FORMAT (2A1,I4,2I1,A4,A1,3I1,F5.1,F4.1,I4,F8.3,F8.2,F5.2,2F8.3,I6,ST22  37
    1A4,I4)                                                            ST22  38
  22 FORMAT(I4,I2,2I1,A4,A1,A2,2(F5.1,F5.2),2F8.3,F5.2,F8.3,F8.1,A4,I4)ST22  39
FOR,W        AZ.ST33,TPF$.ST33
33,35
    58HB.A.(SQ.,A3,5HO.B.),F16.2,2F17.2/6X,7HLENGTH(,A3,1H),4X,3F17.2/ ST33  33
    66X,11HSURFACE(SQ.,A3,4HIB.),F14.2,2F17.2/6X,10HVOLUME(CU.,A3,     ST33  34
    75HI.B.),F14.2,2F17.2/6X,19HREL.VAL.PER MF.UNIT,                   ST33  35
@FOR,W       AZ.PREP,TPF$.PREP
26,28
   5 FORMAT             (6X,A2,1X,F5.1, 3F15.3,16X,I5)                 PREP  26
   6 FORMAT (1X,79(1H-)/1X,I4,1X,A4,4X,3F15.3,F15.3,1X,I5/1X,79(1H-))  PREP  27
   7 FORMAT (1X,79(1H=)/12H  WTD TOTALS,2X,3F15.3,F15.3,1X,I5)         PREP  28
@FOR,W       AZ.PROD,TPF$.PROD
16,17
   10FORMAT (1X,I4,I2,2I1,A4,1X,A2,F6.1,3F8.2,F10.3,2F10.2,F9.3,F7.2,  PROD  16
    1F11.3,2F11.2,F7.0)                                                PROD  17
27,28
   4 FORMAT (1X,A4,1X,A2,3F16.3,F16.3,2X,I6)                           PROD  27
   5 FORMAT (1X,79(1H=)/1X,A4,A3,3F16.3,F16.3,2X,I6)                   PROD  28
35,38
   8 FORMAT (1X,A4,1X,A2,1X,4F14.3,2F14.2)                             PROD  35
   9 FORMAT (1X, 92(1H-)/1X,A4,A3,1X,4F14.3,2F14.2)                    PROD  36
  100FORMAT (1X, 92(1H=)/1X,A4,A3,1X,4F14.3,2F14.2/1X,11HVOLUME (CU.,  PROD  37
    1A3,36HIB.) PAIRED WITH YIELD COEFFICIENTS=,F14.3)                 PROD  38
@FOR,W       AZ.ST44,TPF$.ST44
66,67

============== USE SAME MODS FOR ST44 AS IN PRECEDING PROBLEM ================

@MAP         AZ.STXMAP,TPF$.STXSTX
@ACT        .STXSTX
```

========================= CONTINUATION OF TEST INPUT =========================

```
    METRIC UNITS TESTING METRIC PROCESSING OR METRIC-US CONVERSION      MUST   1
    LRG 03-03-73 20320 01964673-11905 15658 1   24   21      -182+223021 MUST   2
       13                                                               MUST   3
       96                                                               MUST   4
                                                                        MUST   5
 1.00178                                                                MUST   6
604.096 .000000 .000000 .000000 .000000 .000000 .000000 .000000 .000000MUST   7
 264.471                                                                MUST   8
   10   4 *DFIR  15.2+311    8   0  24800              1.                   MUST
   11++     1524 203100.0RP1530 152104.6ZP1570 127113.5ZP1603 102117.7ZP     MUST
   12++       0-999   .0UU                                           *      MUST
   20   6 *DFIR  30.5+110   15   0   0  0                  .250000           MUST
   21++      331 82310000RP 332 76610797BC 361 70213714BA 371 64514327BB     MUST
   22++     -999-99914327UU                                          *      MUST
   30  16 *DFIR  45.7+200  -23   0   0  0                 3.                 MUST
   31++        0 480  .00RP   0 411 1.22AA   0 389 2.44AB   0 32010.97CB     MUST
   32++        0 274 4.88CC                                          *      MUST
11130  16 *DFIR  45.7+012   23   0  49 10                 3.                 MUST
11131++     -999 533 1.22RP   0 457 2.44XX 509 779-1191AC                +      MUST
11132++      557 736    0RP 559 705 2324CA   0-999    0UU                *      MUST
9999
9999
@FIN
```

```
======= EXCERPTS FROM TEST OUTPUT (METRIC INPUT, PROCESSING, AND OUTPUT) ======

METRIC UNITS TESTING METRIC PROCESSING OR METRIC-US CONVERSION   MUST  PAGE   3
LRG 03-03-73 20.320  .01964673 -1.1905  1.5658  1      24.   21      -182+223021
                          DETAILED LOG AND/OR TREE REPORT
=================================================================================
TREE/  VOLUME  / SURFACE / LENGTH / D.I.B. / LOG/RANGE/
 NO./  CU.M.   /  SQ.M.  /    M.  /   CM.   /CODE/  M. / TGRADS  FGRADS    SINELV
=================================================================================
          .000       .00      .00       9.1   UU     .00      .0  -99.9     .0000
          .010       .39     1.21       9.1   ZP  16.03    160.3   10.2   17.7000
          .030       .96     2.44      11.4   ZP  15.70    157.0   12.7   13.5000
          .024       .61     1.23      13.6   ZP  15.30    153.0   15.2    4.6000
          .000       .00      .00      18.2   RP  15.24    152.4   20.3     .0000
---------------------------------------------------------------------------------
  1       .064      1.96     4.87      15.2=D,F=   60.286,      4,  1.6 311*DFIR 1
---------------------------------------------------------------------------------
          .000       .00      .00        .1   UU     .00    -99.9  -99.9     .4327
          .040       .78     1.21      18.3   BB  16.90     37.1   64.5     .4327
          .244      3.87     4.89      22.9   BA  16.44     36.1   70.2     .3714
          .085      1.14     1.22      27.5   BC  15.29     33.2   76.6     .0797
          .000       .00      .00      32.1   RP  15.26     33.1   82.3     .0000
---------------------------------------------------------------------------------
  2       .370      5.79     7.31      30.5=D,F=   39.928,      6,  3.0 111 DFIR 1
---------------------------------------------------------------------------------
          .339      4.55     4.88      27.4   CC     .00      .0   27.4    4.8800
         1.086     12.22    10.97      32.0   CB     .00      .0   32.0   10.9700
          .307      3.07     2.44      38.9   AB     .00      .0   38.9    2.4400
          .191      1.71     1.22      41.1   AA     .00      .0   41.1    1.2200
          .000       .00      .00      48.0   RP     .00      .0   48.0     .0000
---------------------------------------------------------------------------------
  3   .  1.922     21.54    19.51      45.7=D,F=    5.002,     16, -4.6 211 DFIR 1
---------------------------------------------------------------------------------
          .342      4.58     4.90      27.6   UU     .00      .0  -99.9     .0000
         1.086     12.22    10.98      32.0   CA  47.23     55.9   70.5     .2324
          .000       .00      .00      38.9   RP  46.21     55.7   73.6     .0000
          .306      3.06     2.44      38.8   AC  30.79     50.9   77.9    -.1191
          .190      1.71     1.22      41.1   XX     .00      .0   45.7    2.4400
          .000       .00      .00      47.9   RP     .00    -99.9   53.3    1.2200
---------------------------------------------------------------------------------
1113     1.924     21.57    19.54      45.7=D,F=    5.002,     16,  4.6 012*DFIR 1
---------------------------------------------------------------------------------
```

================== CONTINUATION OF EXCERPTS FROM TEST OUTPUT ==================

```
METRIC UNITS TESTING METRIC PROCESSING CR METRIC-US CONVERSION   MUST  PAGE   5
LRG 03-03-73 20.320  .01964673 -1.1905  1.5658  1      24.    21      -182+223021
      SUMMARY REPORT--SURE-TO-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES
==================================================================================

TOTALS ALL   1 STRATA*************************************************************
```

SAMPLE VARIABLES	SURE-TO-BE MEASURED AGGREGATIONS	3P-EXPANDED SAMPLE ESTIMATES	TOTAL SAMPLE ESTIMATES PLUS SURE
TREES(FREQUENCY)	.000	110.218	110.218
PREDICT.(EF KPI)	.000	48.134	48.134
B.A.(SQ.M. O.B.)	.00	5.65	5.65
LENGTH(M.)	.00	781.14	781.14
SURFACE(SQ.M. IB.)	.00	564.84	564.84
VOLUME(CU.M. I.B.)	.00	37.89	37.89
REL.VAL.PER MF.UNIT	.00	1.00	1.00
GROSS MF.UNITS	.0	37.9	37.9
ST.ERROR(PCT.)	-----	4.5	4.5
GROSS WTD.MF.UNITS	.00	37.89	37.89
ST.ERROR(PCT.)	-----	4.5	4.5

COMPONENT ITEMS	(1=) NUMBER	(2*) NUMBER	(1,2) NUMBER
MEASURED TREES	0	4	4
MEASURED LOGS	0	16	16

```
MF.UNITS=  CU. M.   INSIDE BARK
 =(    .10000000+01)*(CU.M. )+(    .00000000    )*(SQ.M. )+(    .00000000    )*(M. )
==================================================================================
```

================== CONTINUATION OF EXCERPTS FROM TEST OUTPUT ==================

METRIC UNITS TESTING METRIC PROCESSING OR METRIC-US CONVERSION MUST PAGE 6

LRG 03-03-73 20.320 .01964673 -1.1905 1.5658 1 24. 21 -182+223021

GRADE-YIELD AND REALIZATION REPORT

CLAS GR	CU.M. IB.VOL.	SQ.M. IB.SURF.	LIN.M. LENGTH	LOG FREQ.	COUNT
DFIR AA	.953	8.541	6.102	5.002	1
DFIR AB	1.534	15.337	12.205	5.002	1
DFIR AC	1.531	15.323	12.205	5.002	1
DFIR BA	9.754	154.450	195.167	39.928	1
DFIR BB	1.611	31.168	48.184	39.928	1
DFIR BC	3.402	45.568	48.672	39.928	1
DFIR CA	5.431	61.112	54.899	5.002	1
DFIR CB	5.433	61.109	54.871	5.002	1
DFIR CC	1.694	22.775	24.409	5.002	1
DFIR UU	1.710	22.931	24.509	5.002	1
DFIR XX	.952	8.534	6.102	5.002	1
DFIR ZP	3.882	117.992	293.815	180.859	3
TOTALS	37.887	564.841	781.140	340.658	14

METRIC UNITS TESTING METRIC PROCESSING OR METRIC-US CONVERSION MUST PAGE 7
LRG 03-03-73 20.320 .01964673 -1.1905 1.5658 1 24. 21 -182+223021

GRADE-YIELD AND REALIZATION REPORT

CLAS GR	SAWKERF CU.M. IB.	SHORTS(TRIM) CU.M. IB.	SLABS-EDGES CU.M. IB.	UNUSABLE LBR. CU.M. IB.	USABLE LBR. BD.FT.	LBR.VALUE DOLLARS
DFIR AA	.183	.011	.161	.000	238.52	39.53
DFIR AB	.294	.016	.289	.090	335.18	50.77
DFIR AC	.294	.014	.289	.170	295.54	39.85
DFIR BA	1.870	.092	2.885	.000	1957.36	267.97
DFIR BB	.309	.012	.579	.068	254.92	26.92
DFIR BC	.652	.028	.854	.339	588.97	60.68
DFIR CA	1.041	.060	1.149	.000	1268.58	123.72
DFIR CB	1.042	.054	1.149	.306	1142.74	103.65
DFIR CC	.325	.014	.427	.169	292.94	24.22
DFIR UU	.328	.016	.430	.079	341.94	35.81
DFIR XX	.000	.000	.000	.952	.00	.00
DFIR ZP	.000	.000	.000	.000	.00	.00
SUBTOT	6.338	.318	8.214	2.172	6716.69	773.13
TOTALS	6.338	.318	8.214	2.172	6716.69	773.13

VOLUME (CU.M. IB.) PAIRED WITH YIELD COEFFICIENTS= 34.005

U.S. GOVERNMENT PRINTING OFFICE: 1974 - 640-939/424 - Region 4

Grosenbaugh, L. R.
1974. STX 3-3-73: tree content and value estimation using various sample designs, dendrometry methods, and V-S-L conversion coefficients.

Southeast. Forest Exp. Stn., USDA Forest Serv. Res. Paper SE-117, 112 pp.

Describes comprehensive Fortran computer program that handles trees selected individually or in clusters by means of constant or varying probabilities in single-stage or multi-stage sample designs using photos, strips, plots, lines, points, lists, 3P, or combinations of these. Dendrometry may be nominal (D.B.H only) or at several points along the stem. Summary of primary units (U.S. or metric units of volume, surface, length) by quality-defect class can be program-converted to related quantities of interest (product, value, etc.)

CLASSIFICATION (UDC): 524.34 -- U.518.5[+524.63:521.62]
+652.51 -- U.518.5 + U.681.3

RETRIEVAL TERMS: point-sampling, 3P-sampling, point-3P-sampling, dendrometry, volume-surface-length, forest inventory, timber appraisal, digital-computer program.

The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

USDA Forest Service Research Paper SE-118 September 1974

Volume of Saw-Log Residues as Calculated from Log Rule Formulae

by

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Volume of Saw-Log Residues as Calculated from Log Rule Formulae

by

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Total utilization of our harvested timber is increasingly important. Residues which were once wasted and expensive to remove or destroy are now major sources of income. Slabs and edgings in the sawmill industry are an example. Although several studies have dealt with the volume of these residues, most, if not all, involved measurement of the outturn at the sawmill. An estimate of the portion of a log that goes into slabs and edgings, as well as kerf, can also be obtained directly from some of the log rule formulae. This paper illustrates how the International and Scribner Log Rule formulae can be used to estimate the volumes of slabs, edging, and kerf in saw logs, as well as 1-inch boards.

For forest managers primarily interested in the estimated volumes of these components according to the two log rules, tables of component volumes for various log lengths appear on pages 9 through 14. These tables are discussed on page 8. For those interested in the methods of deriving these tables, the equations from which the tables were generated are presented and discussed in the following sections on pages 1 through 8.

THE INTERNATIONAL LOG RULE

The International Rule allows a 2-inch taper in a 16-foot log. Increased lumber output resulting from log taper is accounted for by computing volumes in 4-foot sections and assuming a 1/2-inch increase in small-end diameter for each 4 feet of log length. The rule treats the 4-foot bolt as a cylinder with a volume in cubic feet of

$$V_c = \frac{\pi}{(12)^2} D^2 = 0.021817D^2 \qquad (1)$$

where D is the scaling diameter in inches. At 12 board feet per cubic foot, the total volume of the cylinder in board feet becomes

$$V_b = \frac{\pi}{12} D^2 = 0.261799D^2. \qquad (2)$$

A portion of this total volume is lost in slabs, edgings, and saw kerf. Clark,[1] developer of the International Rule, also made an allowance for shrinkage. For each 1-inch board, he allowed 1/8 inch for kerf and 1/16 inch for shrinkage. Thus, the total thickness needed for each 1-inch green board is 1 + 1/8 + 1/16 inch, or 19/16 inches. Of this total, 16/19 is saved as boards, slabs, and edgings. He therefore adjusted equation (2) for the loss to kerf and shrinkage as follows:

$$\left(\frac{16}{19}\right) \ 0.261799D^2 = 0.220463D^2 .$$

Clark determined that the volume in slabs and edgings was proportional to the surface of the cylinder. This relationship meant that a constant could be developed which, when multiplied by diameter, would account for these residues. He determined this constant in terms of board feet to be 0.71 for white pine logs. On the assumption that this constant is applicable to other species, he derived a formula for lumber volume of a 4-foot bolt on the basis of a 1/8-inch kerf:

$$V_{b'} = 0.220463D^2 - 0.71D. \qquad (3)$$

Because many mills use a 1/4-inch saw, Bruce and Schumacher[2] adjusted equation (3) for the larger kerf. Their allowance for each board was 1 + 1/16 + 4/16 inch, or 21/16 inches, and 16/21 (the amount left after the allowance for kerf and shrinkage) is 90.48 percent of 16/19 (the remainder after the kerf and shrinkage allowance for a 1/8-inch kerf). From this computation, they derived a new equation for lumber volume in board feet on the basis of a 1/4-inch kerf:

$$V_{b''} = 0.9048\ V_{b'} = 0.199467D^2 - 0.642381D. \qquad (4)$$

When only the board foot content is considered, the adjustment applied to equation (4) is logically sound. However, as we sought to develop equations for measuring kerf and slab-edging volumes, we observed that the Bruce-Schumacher technique for converting to the 1/4-inch rule adjusted only the board foot allowance for the additional kerf produced by the 1/4-inch saw. Clark, in developing the 1/8-inch rule, adjusted the entire bolt volume for loss to kerf and shrinkage. Although Bruce and Schumacher make no comment about measuring kerf and slab-edging volumes, it seems evident from their adjustment that they were not concerned with estimating these values, and, further, that their adjustment imposes the proposition that slab-edging volume varies with kerf width. Paradoxically, if the adjustment for the 1/4-inch kerf is applied to the entire bolt volume instead of only to lumber volume as in equation (4), we would have to adopt the premise that loss to slabs and edging is the same regardless of kerf width. Because the actual differences between the two approaches are relatively minor and we have no hard evidence on vari-

---

[1] Clark, Judson F. The measurement of sawlogs. For. Q. 14(2): 79-93. 1906.

[2] Bruce, Donald, and Schumacher, Francis X. Forest Mensuration. Ed. 3, 434 pp. New York: McGraw-Hill Book Co., Inc. 1950.

ation in slab-edging volume in relation to kerf width, our model is designed to accommodate both Clark's 1/8-inch kerf and Bruce and Schumacher's 1/4-inch kerf.

Through the introduction of the parameter β, equations (3) and (4) for lumber volume can be generalized and expressed in cubic feet as

$$V_\ell = \left(\frac{16}{\beta}\right) V_c - \left(\frac{19}{\beta}\right) \gamma D = \frac{0.349066}{\beta} D^2 - \frac{1.124167}{\beta} D \qquad (5)$$

where

β = the number of 1/16-inch units needed to produce a 1-inch board when kerf and shrinkage are considered

and

$\gamma = 0.05916667.$

The γ coefficient is simply Clark's slab-edging coefficient converted to cubic feet,that is,

$\gamma = 0.71/12.$

Equations (3), (4), and (5) were derived by using a cylindrical log model. To establish estimates of kerf and slab-edging volumes, we must consider the difference in volume between a frustum of a cone and a cylinder with the same diameter as that of the small end of the frustum.[3] The cubic foot volume of a 4-foot-long cone frustum is

$$V_f = \frac{4\pi}{(12)^3} (3D^2 + 3D\tau + \tau^2) = 0.021817D^2 + 0.021817(\tau)D$$

$$+ 0.007272(\tau^2) \qquad (6)$$

where τ (taper) represents the difference in inches between the end diameters of the cone frustum. The volume in addition to the cylinder is then the difference between equation (6) and equation (1), or

$$V_d = \frac{4\pi}{(12)^3} (3D^2 + 3D\tau + \tau^2) = 0.021817(\tau)D + 0.007272(\tau^2). \qquad (7)$$

The unadjusted slab-edging volume in cubic feet is given as γD; hence, this residue volume for the cone frustum then becomes

$$V_{se} = \gamma D + \left(\frac{16}{\beta}\right) V_d = 0.059167D + 0.349066\left(\frac{\tau}{\beta}\right) D$$

$$+ 0.116355\left(\frac{\tau^2}{\beta}\right) \qquad (8)$$

[3] There may be debate as to whether a frustum of a cone represents a log, but Clark's specification of a constant increase in diameter per 4-foot increase in the cylinder length implies such a geometric form.

where $\frac{16}{\beta}$ is that portion of V_d not attributable to kerf or shrinkage.

The kerf volume produced when sawing the cone frustum can be calculated in cubic feet according to the generalized equation (5) as

$$V_k = \left(\frac{\beta-16-\sigma}{\beta}\right) V_f - \left(\frac{\beta-19}{\beta}\right) \Upsilon D$$

$$= \left[0.021817 - \frac{0.349066}{\beta} - 0.021817 \left(\frac{\sigma}{\beta}\right)\right] D^2$$

$$+ \left[0.021817(\tau) - 0.349066\left(\frac{\tau}{\beta}\right) - 0.021817 \left(\frac{\tau\sigma}{\beta}\right) - 0.059167\right.$$

$$\left. + \frac{1.124167}{\beta}\right] D$$

$$+ 0.007272(\tau^2) - 0.116355\left(\frac{\tau^2}{\beta}\right) - 0.007272 \left(\frac{\tau^2 \sigma}{\beta}\right) \qquad (9)$$

where σ is a parameter representing the number of 1/16-inch units allowed for shrinkage.

To account for the remaining bolt volume, shrinkage can be calculated in cubic feet as

$$V_{sh} = \left(\frac{\sigma}{\beta}\right) V_f = 0.021817 \left(\frac{\sigma}{\beta}\right) D^2 + 0.021817\left(\frac{\tau\sigma}{\beta}\right) D$$

$$+ 0.007272\left(\frac{\tau^2\sigma}{\beta}\right). \qquad (10)$$

Equations (5), (8), (9), and (10) account for the entire cubic volume of a 4-foot-long frustum of a cone. To produce volume estimates of the four quantities for logs of varying lengths, an appropriate number of 4-foot units (plus, in some cases, a fraction of a unit) must be summed, with the summation allowing for a uniform increase in the scaling diameter for each additional section. The following equations result:

$${}_LV_\ell = 0.087266\left(\frac{L}{\beta}\right) D^2 - \left[0.281042\left(\frac{L}{\beta}\right) - 0.087266\left(\frac{\eta\tau}{\beta}\right) [2L\right.$$

$$\left. - 4(\eta+1)]\right] D - \left[0.140521\left(\frac{\eta\tau}{\beta}\right) [2L - 4(\eta+1)]\right.$$

$$\left. - 0.029089\left(\frac{\tau^2}{\beta}\right) [-8\eta^3+3\eta^2(L-2)+2\eta]\right], \qquad (11)$$

$${}_LV_k = \left[0.005454\left(\frac{\beta-16-\sigma}{\beta}\right) L\right] D^2 - \left[0.014792\left(\frac{\beta-19}{\beta}\right) L\right.$$

$$- 0.001364\left(\frac{\beta-16-\sigma}{\beta}\right)\tau L^2\Bigg] D - \Bigg[0.007396\left(\frac{\eta\tau}{\beta}\right)(\beta-19)[2L$$

$$- 4(\eta+1)] - 0.000114\left(\frac{\beta-16-\sigma}{\beta}\right)\tau^2 L^3\Bigg], \qquad (12)$$

$$_LV_{se} = \left[0.014792(L) + 0.087266\left(\frac{\tau}{\beta}\right)\left(\frac{L^2}{4} - \eta[2L - 4(\eta+1)]\right)\right] D$$

$$+ \Bigg[0.007396(\eta\tau)[2L - 4(\eta+1)] + 0.029089\left(\frac{\tau^2}{\beta}\right)\Bigg(\frac{L^3}{16}$$

$$- [-8\eta^3 + 3\eta^2(L-2) + 2\eta]\Bigg)\Bigg], \qquad (13)$$

and

$$_LV_{sh} = \left[0.005454\left(\frac{\sigma L}{\beta}\right)\right] D^2 + \left[0.001364\left(\frac{\sigma\tau L^2}{\beta}\right)\right] D$$

$$+ \left[0.000114\left(\frac{\sigma\tau^2 L^3}{\beta}\right)\right] \qquad (14)$$

where $_LV_\ell$ = board foot volume expressed in cubic feet,

$_LV_k$ = saw kerf volume in cubic feet,

$_LV_{se}$ = slab-edging volume (chip volume) in cubic feet,

$_LV_{sh}$ = shrinkage volume in cubic feet,

L = log length in feet,

η = number of complete 4-foot bolts (i.e., the integer part of $L/4$),

and all other parameters are as previously defined. The method of deriving equations (11), (12), (13), and (14) is presented in the appendix. To produce board foot estimates of lumber volume, equation (11) should be multiplied by 12.

It should be remembered that equations (11), (12), (13), and (14) are based on the following assumptions:

(A) All component volumes are based on 4-foot-long sections and log volumes are obtained by adding an appropriate number of sections plus a fraction of a 4-foot section when log lengths are not multiples of 4,

(B) the geometric shape of the 4-foot sections is a frustum of a cone,

(C) kerf and shrinkage volumes are proportional to bolt volume,

(D) the slab-edging volume is proportional to log circumference, or scaling diameter, and Clark's constant (0.71) developed for sawing white pine logs is applicable to other species.

As an example of how equations (11), (12), (13), and (14) can be used, consider equation (11) and the parameter values

L = 4 feet,

β = twenty-one 1/16-inch units per board,

η = 1 complete 4-foot section, and

τ = 0.5 inch of taper per 4 feet of log length (equivalent to 2-inch taper for 16-foot log).

Substituting these values into equation (11) and multiplying by 12 yields the equation for lumber volume in board feet for a 1/4-inch kerf and a 4-foot bolt as given by Bruce and Schumacher (see equation (4)):

$$_4V_\ell\ (12) = 0.1995D^2 - 0.6424D. \qquad (15)$$

Equations for estimating the volumes of saw kerf, slabs and edging, and shrinkage can be similarly developed from equations (12), (13), and (14). Implicit in all of these equations are the assumptions that the lumber product consists only of 1-inch boards and that σ equals one 1/16-inch unit per board. Additional modification of equations (11) through (14) can be made to allow for variable board thickness and the scant sawing practices of today.

THE SCRIBNER LOG RULE

The Scribner Log Rule is based on diagrams of circles, with a 1/4-inch kerf allowance for each 1-inch board plotted. In the construction of the rule, no taper was recognized, that is, the log was considered to be a 16-foot cylinder with a diameter equal to that of the small end of the log. The board foot contents of logs of the same diameter are, therefore, directly proportional to log length.

Although in the construction of the rule no thought was given to curve form and its relationship to volume, plotted Scribner values define a parabolic curve.[4] Using the method of least squares, Bruce and Schumacher fitted a curve to the Scribner values and produced the following equation for estimating the volume of a 16-foot log in board feet:

[4] Bruce and Schumacher, loc. cit.

$$ {}_{16}V_{\ell} = 0.79D^2 - 1.98D - 4.3 \qquad (16) $$

where D equals the scaling diameter.

Although values calculated from this equation deviate slightly from the original Scribner volumes for a 16-foot log, over a wide range the deviations are no greater than those produced by rounding the original Scribner values to the nearest 10 feet to produce the Decimal C Rule.

Because board foot content is directly proportional to length under the Scribner Rule, it is legitimate to reduce equation (16) to the volume for a 1-foot section in cubic feet:

$$ {}_{1}V_{\ell} = \frac{0.790}{(16)(12)} D^2 - \frac{1.98}{(16)(12)} D - \frac{4.3}{(16)(12)} $$

$$ = 0.004115D^2 - 0.010312D - 0.022396. \qquad (17) $$

Therefore, the equation for the lumber volume of an L-foot-long log in cubic feet is

$$ {}_{L}V_{\ell} = 0.004115(L)D^2 - 0.010312(L)D - 0.022396(L). \qquad (18) $$

The cubic foot volume for an L-foot-long frustum is

$$ {}_{L}V_{f} = 0.005454(L)D^2 + 0.005454(L^2\delta)D + 0.001818(L^3\delta^2) \qquad (19) $$

where δ equals the difference in diameter between the ends of any 1-foot section of a frustum and by definition is constant for any of these sections.

If we consider kerf to be proportional to bolt volume as with the International Rule, we have for the cubic foot volume of kerf resulting from sawing the frustum

$$ {}_{L}V_{k}^{*} = (0.2)\,{}_{L}V_{f} = 0.001091(L)D^2 + 0.001091(L^2\delta)D $$

$$ + 0.000364(L^3\delta^2) \qquad (20) $$

where all parameters are as previously defined. Added to the above quantity is an allowance for kerf produced when the boards are edged. This additional kerf is obviously a function of the number of boards sawn. The approximate number of boards produced (b) is equal to the ratio of wood going to lumber (0.8) times the width between the slabs on opposite sides of the log, where both slabs are such that the last pass of the saw produces a board of the acceptable minimum width ($w_m = 4$):

$$ b = (0.8)\sqrt{D^2 - w_m^2}\,. \qquad (21) $$

Multiplying the estimated number of boards (b) by the kerf volume from each board and adding this quantity to equation (20) produces the estimate for the total volume of kerf in cubic feet:

$$ {}_{L}V_{k} = {}_{L}V_{k}^{*} + \frac{2L}{(12)^2(4)} b = 0.001091(L)D^2 + 0.001091(L^2\delta)D $$

$$ + 0.000364(L^3\delta^2) + 0.002778(L\sqrt{D^2 - 16}) \ . \qquad (22) $$

Subtracting the lumber and kerf volumes from the frustum volume produces the slab-edging volume in cubic feet:

$$ {}_{L}V_{se} = 0.000248(L)D^2 + \left[0.004363(L^2\delta) + 0.010312(L)\right] D $$

$$ + 0.001454(L^3\delta^2) + 0.022396(L) $$

$$ - 0.002778(L\sqrt{D^2 - w_m^2}) \ . \qquad (23) $$

As with the International Rule, the Scribner Rule can be adapted to varying degrees of taper.

VOLUMES OF SAW-LOG RESIDUES

The volumes of saw-log residues as determined by the equations derived from the International and Scribner Rules can be directly compared by referring to tables 1 and 2. A taper increase of 0.5 inch per 4 feet of log length was used with each log rule. The relative volumes vary according to the length of log produced. This variation results because the International Rule for calculating board foot volume allows for an increase in diameter with each 4-foot increase in log length whereas the Scribner Rule makes no allowance for such an increase. Thus, the proportion of the log volume converted to lumber increases with log length by the International Rule but decreases by the Scribner Rule. Consequently, the percentage of the log volume going into slabs and edgings decreases slightly with log length by the International Rule but increases by the Scribner Rule. The same relationships of course apply to slab-edging volumes per thousand board feet. With both the International and Scribner Rules, however, the percentage of the log volume going to kerf varies only slightly with log length.

Table 1. -Volumes of lumber, kerf, shrinkage, and slabs and edging for various log lengths as determined by the International 1/4-Inch Log Rule[1]

Diameter (inches)	Lumber			Kerf		Shrinkage		Slab-edging		Slab-edging/1,000 board feet
	Board feet	Cubic feet	Percent of total	Cubic feet	Percent of total	Cubic feet	Percent of total	Cubic feet[2]	Percent of total	Cubic feet
8-FOOT LOG										
6	8	0.63	33.0	0.29	15.2	0.09	4.8	0.87	45.6	115.11
7	12	.97	38.2	.40	15.7	.12	4.8	1.01	39.7	86.57
8	17	1.38	42.3	.53	16.1	.16	4.8	1.15	35.2	69.35
9	22	1.86	45.5	.67	16.4	.19	4.8	1.29	31.6	57.84
10	29	2.40	48.1	.83	16.6	.24	4.8	1.43	28.7	49.61
11	36	3.01	50.3	1.01	16.9	.28	4.8	1.57	26.2	43.42
12	44	3.68	52.2	1.20	17.0	.34	4.8	1.70	24.2	38.61
13	53	4.42	53.7	1.41	17.2	.39	4.8	1.84	22.4	34.75
14	63	5.23	55.1	1.64	17.3	.45	4.8	1.98	20.9	31.60
15	73	6.10	56.3	1.89	17.4	.52	4.8	2.12	19.6	28.97
16	84	7.04	57.3	2.15	17.5	.58	4.8	2.26	18.4	26.74
17	97	8.05	58.3	2.43	17.6	.66	4.8	2.40	17.4	24.83
18	109	9.12	59.1	2.73	17.7	.73	4.8	2.54	16.4	23.18
19	123	10.26	59.9	3.04	17.7	.82	4.8	2.68	15.6	21.73
20	138	11.47	60.5	3.37	17.8	.90	4.8	2.81	14.9	20.45
21	153	12.74	61.1	3.72	17.9	.99	4.8	2.95	14.2	19.32
22	169	14.08	61.7	4.09	17.9	1.09	4.8	3.09	13.5	18.30
23	186	15.48	62.2	4.47	18.0	1.19	4.8	3.23	13.0	17.38
24	203	16.96	62.7	4.87	18.0	1.29	4.8	3.37	12.5	16.56
25	222	18.49	63.1	5.29	18.0	1.40	4.8	3.51	12.0	15.80
26	241	20.10	63.5	5.72	18.1	1.51	4.8	3.65	11.5	15.12
27	261	21.77	63.9	6.17	18.1	1.62	4.8	3.78	11.1	14.49
28	282	23.51	64.2	6.64	18.1	1.74	4.8	3.92	10.7	13.91
29	304	25.31	64.6	7.13	18.2	1.87	4.8	4.06	10.4	13.37
30	326	27.18	64.9	7.63	18.2	2.00	4.8	4.20	10.0	12.88
10-FOOT LOG										
6	10	0.85	34.4	0.38	15.3	0.12	4.8	1.10	44.4	107.45
7	15	1.29	39.5	.52	15.8	.16	4.8	1.27	38.8	81.89
8	22	1.81	43.4	.67	16.1	.20	4.8	1.44	34.4	66.14
9	29	2.42	46.5	.86	16.4	.25	4.8	1.61	30.9	55.46
10	37	3.11	49.1	1.06	16.7	.30	4.8	1.78	28.1	47.75
11	47	3.88	51.2	1.28	16.9	.36	4.8	1.95	25.7	41.92
12	57	4.74	53.0	1.52	17.0	.43	4.8	2.12	23.7	37.36
13	68	5.67	54.5	1.79	17.2	.50	4.8	2.29	22.0	33.69
14	80	6.70	55.8	2.08	17.3	.57	4.8	2.46	20.6	30.68
15	94	7.80	57.0	2.38	17.4	.65	4.8	2.64	19.3	28.16
16	108	8.99	58.0	2.71	17.5	.74	4.8	2.81	18.1	26.02
17	123	10.26	58.9	3.06	17.6	.83	4.8	2.98	17.1	24.19
18	139	11.61	59.8	3.44	17.7	.93	4.8	3.15	16.2	22.59
19	157	13.05	60.5	3.83	17.7	1.03	4.8	3.32	15.4	21.20
20	175	14.57	61.2	4.24	17.8	1.13	4.8	3.49	14.6	19.96
21	194	16.17	61.8	4.68	17.9	1.25	4.8	3.66	14.0	18.86
22	214	17.86	62.3	5.14	17.9	1.36	4.8	3.83	13.4	17.88
23	236	19.63	62.8	5.61	18.0	1.49	4.8	4.00	12.8	16.99
24	258	21.48	63.3	6.11	18.0	1.62	4.8	4.17	12.3	16.19
25	281	23.42	63.7	6.64	18.0	1.75	4.8	4.34	11.8	15.46
26	305	25.44	64.1	7.18	18.1	1.89	4.8	4.52	11.4	14.79
27	330	27.54	64.5	7.74	18.1	2.03	4.8	4.69	11.0	14.18
28	357	29.72	64.8	8.33	18.2	2.18	4.8	4.86	10.6	13.62
29	384	31.99	65.1	8.93	18.2	2.34	4.8	5.03	10.2	13.10
30	412	34.34	65.4	9.56	18.2	2.50	4.8	5.20	9.9	12.62

continued

See footnotes at end of table.

Table 1.--Volumes of lumber, kerf, shrinkage, and slabs and edging for various log lengths as determined by the International 1/4-Inch Log Rule[1] (continued)

12-FOOT LOG

Diameter (inches)	Lumber			Kerf		Shrinkage		Slab-edging		Slab-edging/1,000 board feet
	Board feet	Cubic feet	Percent of total	Cubic feet	Percent of total	Cubic feet	Percent of total	Cubic feet[2]	Percent of total	Cubic feet
6	13	1.07	34.9	0.47	15.4	0.15	4.8	1.35	43.9	104.85
7	19	1.61	39.8	.64	15.8	.19	4.8	1.55	38.4	80.50
8	27	2.25	43.6	.83	16.2	.25	4.8	1.76	34.2	65.31
9	36	2.98	46.7	1.05	16.5	.30	4.8	1.97	30.8	54.93
10	46	3.82	49.2	1.30	16.7	.37	4.8	2.17	28.0	47.40
11	57	4.76	51.4	1.57	16.9	.44	4.8	2.38	25.7	41.68
12	70	5.79	53.1	1.86	17.1	.52	4.8	2.58	23.7	37.19
13	83	6.93	54.7	2.18	17.2	.60	4.8	2.79	22.0	33.57
14	98	8.16	56.0	2.53	17.3	.69	4.8	3.00	20.6	30.59
15	114	9.50	57.2	2.90	17.4	.79	4.8	3.20	19.3	28.10
16	131	10.93	58.2	3.29	17.5	.89	4.8	3.41	18.1	25.98
17	150	12.47	59.1	3.72	17.6	1.00	4.8	3.62	17.1	24.16
18	169	14.10	59.9	4.16	17.7	1.12	4.8	3.82	16.2	22.58
19	190	15.84	60.6	4.64	17.8	1.24	4.8	4.03	15.4	21.19
20	212	17.67	61.3	5.14	17.8	1.37	4.8	4.23	14.7	19.97
21	235	19.61	61.9	5.66	17.9	1.51	4.8	4.44	14.0	18.87
22	260	21.64	62.5	6.21	17.9	1.65	4.8	4.65	13.4	17.89
23	285	23.77	63.0	6.78	18.0	1.80	4.8	4.85	12.9	17.01
24	312	26.01	63.4	7.38	18.0	1.95	4.8	5.06	12.3	16.21
25	340	28.34	63.9	8.01	18.1	2.11	4.8	5.27	11.9	15.48
26	369	30.77	64.3	8.66	18.1	2.28	4.8	5.47	11.4	14.82
27	400	33.30	64.6	9.34	18.1	2.45	4.8	5.68	11.0	14.21
28	431	35.94	65.0	10.04	18.2	2.63	4.8	5.88	10.6	13.64
29	464	38.67	65.3	10.77	18.2	2.82	4.8	6.09	10.3	13.12
30	498	41.50	65.6	11.52	18.2	3.01	4.8	6.30	10.0	12.64

14-FOOT LOG

Diameter (inches)	Board feet	Cubic feet	Percent of total	Cubic feet	Percent of total	Cubic feet	Percent of total	Cubic feet	Percent of total	Cubic feet
6	16	1.34	36.1	0.57	15.4	0.18	4.8	1.59	42.8	99.00
7	24	1.98	40.8	.77	15.9	.23	4.8	1.83	37.6	76.86
8	33	2.74	44.5	1.00	16.2	.29	4.8	2.07	33.5	62.80
9	43	3.62	47.5	1.26	16.5	.36	4.8	2.30	30.2	53.08
10	55	4.61	49.9	1.55	16.7	.44	4.8	2.54	27.5	45.96
11	69	5.72	52.0	1.86	16.9	.52	4.8	2.78	25.3	40.52
12	83	6.95	53.7	2.21	17.1	.62	4.8	3.02	23.3	36.23
13	99	8.29	55.2	2.59	17.2	.72	4.8	3.26	21.7	32.76
14	117	9.75	56.5	2.99	17.3	.82	4.8	3.50	20.3	29.90
15	136	11.32	57.6	3.43	17.4	.94	4.8	3.73	19.0	27.49
16	156	13.01	58.6	3.89	17.5	1.06	4.8	3.97	17.9	25.45
17	178	14.82	59.5	4.39	17.6	1.19	4.8	4.21	16.9	23.68
18	201	16.74	60.3	4.91	17.7	1.32	4.8	4.45	16.0	22.15
19	225	18.78	61.0	5.47	17.8	1.47	4.8	4.69	15.2	20.80
20	251	20.94	61.7	6.05	17.8	1.62	4.8	4.93	14.5	19.61
21	279	23.21	62.3	6.66	17.9	1.77	4.8	5.16	13.9	18.54
22	307	25.60	62.8	7.31	17.9	1.94	4.8	5.40	13.3	17.59
23	337	28.11	63.3	7.98	18.0	2.11	4.8	5.64	12.7	16.73
24	369	30.73	63.8	8.68	18.0	2.29	4.8	5.88	12.2	15.95
25	402	33.47	64.2	9.41	18.1	2.48	4.8	6.12	11.7	15.23
26	436	36.32	64.6	10.17	18.1	2.68	4.8	6.36	11.3	14.58
27	471	39.29	65.0	10.96	18.1	2.88	4.8	6.59	10.9	13.99
28	509	42.38	65.3	11.78	18.2	3.09	4.8	6.83	10.5	13.44
29	547	45.58	65.6	12.64	18.2	3.31	4.8	7.07	10.2	12.93
30	587	48.90	65.9	13.51	18.2	3.53	4.8	7.31	9.9	12.46

continued

See footnotes at end of table.

Table 1.--Volumes of lumber, kerf, shrinkage, and slabs and edging for various log lengths as determined by the International 1/4-Inch Log Rule[1] (continued)

16-FOOT LOG

Diameter (inches)	Lumber			Kerf		Shrinkage		Slab-edging		Slab-edging/1,000 board feet
	Board feet	Cubic feet	Percent of total	Cubic feet	Percent of total	Cubic feet	Percent of total	Cubic feet[2]	Percent of total	Cubic feet
6	19	1.60	36.5	0.68	15.5	0.21	4.8	1.86	42.3	96.44
7	28	2.35	41.1	.91	15.9	.27	4.8	2.13	37.2	75.41
8	39	3.24	44.8	1.18	16.3	.34	4.8	2.40	33.2	61.89
9	51	4.25	47.7	1.48	16.5	.42	4.8	2.68	30.0	52.47
10	65	5.40	50.1	1.81	16.8	.51	4.8	2.95	27.4	45.53
11	80	6.68	52.1	2.17	16.9	.61	4.8	3.23	25.1	40.21
12	97	8.10	53.8	2.57	17.1	.72	4.8	3.50	23.3	36.00
13	116	9.65	55.3	3.01	17.2	.83	4.8	3.77	21.6	32.59
14	136	11.33	56.6	3.47	17.4	.95	4.8	4.05	20.2	29.77
15	158	13.14	57.7	3.97	17.5	1.08	4.8	4.32	19.0	27.39
16	181	15.09	58.7	4.51	17.6	1.22	4.8	4.59	17.9	25.37
17	206	17.17	59.6	5.08	17.6	1.37	4.8	4.87	16.9	23.63
18	233	19.38	60.4	5.68	17.7	1.53	4.8	5.14	16.0	22.11
19	261	21.73	61.1	6.32	17.8	1.69	4.8	5.41	15.2	20.77
20	290	24.21	61.8	6.99	17.8	1.87	4.8	5.69	14.5	19.58
21	322	26.82	62.4	7.69	17.9	2.05	4.8	5.96	13.9	18.53
22	355	29.56	62.9	8.43	17.9	2.24	4.8	6.24	13.3	17.58
23	389	32.44	63.4	9.20	18.0	2.44	4.8	6.51	12.7	16.72
24	425	35.45	63.9	10.00	18.0	2.64	4.8	6.78	12.2	15.94
25	463	38.59	64.3	10.84	18.1	2.86	4.8	7.06	11.8	15.24
26	502	41.87	64.7	11.71	18.1	3.08	4.8	7.33	11.3	14.59
27	543	45.28	65.1	12.62	18.1	3.31	4.8	7.60	10.9	13.99
28	586	48.82	65.4	13.56	18.2	3.55	4.8	7.88	10.6	13.45
29	630	52.50	65.7	14.53	18.2	3.80	4.8	8.15	10.2	12.94
30	676	56.31	66.0	15.54	18.2	4.06	4.8	8.42	9.9	12.47

Note: The percentages of total volume for the various components at each diameter do not total 100 because a 3-inch trim allowance was included on all log lengths when calculating slab-edging and kerf volumes but omitted when calculating board foot volumes. The latter also deviate slightly, in some instances, from published values because some coefficients were not rounded at the same points as in the original rule.

[1] The component values can be calculated for any desired diameter and log length.

[2] When the slab volume is converted to chips by chipping head-rigs, these estimates should be increased by 19 percent and the kerf estimates reduced by the calculated amount.

Table 2.--Volumes of lumber, kerf, and slabs and edging for various log lengths as determined by the Scribner 1/4-Inch Log Rule[1]

8-FOOT LOG

Diameter (inches)	Lumber			Kerf		Slab-edging		Slab-edging/1,000 board feet
	Board feet	Cubic feet	Percent of total	Cubic feet	Percent of total	Cubic feet[2]	Percent of total	Cubic feet
6	6	0.51	26.7	0.49	25.4	0.90	47.1	147.16
7	10	.86	33.6	.64	25.2	1.02	40.1	99.45
8	15	1.27	38.8	.81	24.9	1.15	35.1	75.46
9	21	1.74	42.8	1.00	24.5	1.28	31.4	61.08
10	27	2.29	45.9	1.21	24.2	1.41	28.4	51.54
11	35	2.90	48.5	1.43	23.9	1.56	26.0	44.75
12	43	3.57	50.6	1.67	23.7	1.70	24.1	39.68
13	52	4.31	52.4	1.93	23.4	1.85	22.5	35.75
14	61	5.12	54.0	2.20	23.2	2.00	21.1	32.62
15	72	5.99	55.3	2.50	23.1	2.16	19.9	30.07
16	83	6.93	56.4	2.81	22.9	2.32	18.9	27.94
17	95	7.93	57.4	3.14	22.7	2.49	18.0	26.16
18	108	9.00	58.3	3.49	22.6	2.66	17.2	24.63
19	122	10.14	59.1	3.85	22.5	2.83	16.5	23.30
20	136	11.34	59.9	4.24	22.4	3.01	15.9	22.15
21	151	12.60	60.5	4.64	22.3	3.20	15.3	21.13
22	167	13.94	61.1	5.06	22.2	3.38	14.8	20.23
23	184	15.34	61.6	5.50	22.1	3.57	14.4	19.42
24	202	16.80	62.1	5.95	22.0	3.77	13.9	18.70
25	220	18.33	62.6	6.43	21.9	3.97	13.5	18.05
26	239	19.93	63.0	6.92	21.9	4.17	13.2	17.45
27	259	21.59	63.4	7.43	21.8	4.38	12.9	16.91
28	280	23.32	63.7	7.95	21.7	4.59	12.6	16.41
29	301	25.11	64.1	8.50	21.7	4.81	12.3	15.96
30	324	26.97	64.4	9.06	21.6	5.03	12.0	15.54
				10-FOOT LOG				
6	8	0.64	25.8	0.62	25.1	1.20	48.4	156.15
7	13	1.07	32.7	.82	25.0	1.36	41.5	105.61
8	19	1.58	37.9	1.03	24.7	1.52	36.4	80.16
9	26	2.18	41.9	1.27	24.4	1.70	32.6	64.89
10	34	2.86	45.1	1.53	24.1	1.88	29.6	54.74
11	43	3.62	47.7	1.81	23.8	2.06	27.2	47.51
12	54	4.46	49.9	2.11	23.6	2.26	25.2	42.10
13	65	5.39	51.8	2.43	23.4	2.45	23.6	37.91
14	77	6.40	53.3	2.78	23.2	2.65	22.1	34.57
15	90	7.49	54.7	3.15	23.0	2.86	20.9	31.85
16	104	8.66	55.9	3.54	22.8	3.07	19.8	29.58
17	119	9.91	57.0	3.95	22.7	3.29	18.9	27.67
18	135	11.25	57.9	4.39	22.6	3.51	18.1	26.03
19	152	12.67	58.7	4.84	22.5	3.74	17.3	24.62
20	170	14.17	59.5	5.32	22.3	3.98	16.7	23.38
21	189	15.76	60.2	5.82	22.2	4.21	16.1	22.29
22	209	17.42	60.8	6.35	22.1	4.46	15.6	21.32
23	230	19.17	61.3	6.90	22.1	4.71	15.1	20.46
24	252	21.00	61.9	7.46	22.0	4.96	14.6	19.69
25	275	22.91	62.3	8.06	21.9	5.22	14.2	18.98
26	299	24.91	62.8	8.67	21.8	5.48	13.8	18.35
27	324	26.99	63.2	9.30	21.8	5.75	13.5	17.77
28	350	29.15	63.5	9.96	21.7	6.03	13.1	17.23
29	377	31.39	63.9	10.64	21.7	6.31	12.8	16.75
30	405	33.71	64.2	11.35	21.6	6.59	12.6	16.29

continued

See footnotes at end of table.

Table 2.--Volumes of lumber, kerf, and slabs and edging for various log lenghts as determined by the Scribner 1/4-Inch Log Rule[1] (continued)

Diameter (inches)	Lumber			Kerf		Slab-edging		Slab-edging/1,000 board feet
	Board feet	Cubic feet	Percent of total	Cubic feet	Percent of total	Cubic feet[2]	Percent of total	Cubic feet
12-FOOT LOG								
6	9	0.77	24.9	0.77	25.0	1.52	49.6	165.60
7	15	1.28	31.8	1.00	24.8	1.73	42.7	112.06
8	23	1.90	36.9	1.27	24.6	1.94	37.7	85.07
9	31	2.62	41.0	1.55	24.3	2.16	33.9	68.85
10	41	3.43	44.2	1.86	24.0	2.39	30.8	58.06
11	52	4.34	46.9	2.20	23.8	2.63	28.4	50.37
12	64	5.36	49.1	2.57	23.5	2.87	26.3	44.62
13	78	6.47	51.0	2.96	23.3	3.12	24.6	40.16
14	92	7.68	52.6	3.37	23.1	3.37	23.1	36.60
15	108	8.98	54.1	3.82	23.0	3.63	21.9	33.69
16	125	10.39	55.3	4.29	22.8	3.90	20.8	31.27
17	143	11.90	56.4	4.78	22.7	4.17	19.8	29.23
18	162	13.50	57.4	5.31	22.5	4.45	18.9	27.49
19	182	15.20	58.2	5.86	22.4	4.74	18.1	25.98
20	204	17.01	59.0	6.43	22.3	5.03	17.5	24.66
21	227	18.91	59.7	7.03	22.2	5.33	16.8	23.49
22	251	20.91	60.4	7.66	22.1	5.63	16.3	22.46
23	276	23.00	60.9	8.32	22.0	5.95	15.7	21.54
24	302	25.20	61.5	9.00	22.0	6.26	15.3	20.71
25	330	27.50	62.0	9.71	21.9	6.59	14.8	19.96
26	359	29.89	62.4	10.45	21.8	6.91	14.4	19.28
27	389	32.38	62.9	11.21	21.8	7.25	14.1	18.65
28	420	34.98	63.2	12.00	21.7	7.59	13.7	18.09
29	452	37.67	63.6	12.82	21.7	7.94	13.4	17.56
30	485	40.46	64.0	13.66	21.6	8.29	13.1	17.08
14-FOOT LOG								
6	11	0.89	24.1	0.92	24.8	1.88	50.7	175.41
7	18	1.50	30.8	1.20	24.7	2.14	43.9	118.74
8	27	2.22	36.0	1.51	24.4	2.40	38.9	90.13
9	37	3.05	40.0	1.84	24.2	2.67	35.1	72.94
10	48	4.00	43.3	2.21	23.9	2.95	32.0	61.49
11	61	5.07	46.0	2.61	23.7	3.24	29.5	53.32
12	75	6.25	48.3	3.03	23.5	3.54	27.4	47.21
13	91	7.54	50.2	3.49	23.3	3.84	25.6	42.46
14	107	8.96	51.9	3.98	23.1	4.16	24.1	38.68
15	126	10.48	53.4	4.50	22.9	4.48	22.8	35.58
16	145	12.12	54.6	5.05	22.8	4.80	21.6	33.01
17	167	13.88	55.7	5.63	22.6	5.14	20.6	30.84
18	189	15.75	56.7	6.25	22.5	5.48	19.7	28.98
19	213	17.74	57.6	6.89	22.4	5.83	18.9	27.37
20	238	19.84	58.5	7.56	22.3	6.18	18.2	25.96
21	265	22.06	59.2	8.27	22.2	6.54	17.6	24.72
22	293	24.39	59.9	9.01	22.1	6.91	17.0	23.62
23	322	26.84	60.5	9.77	22.0	7.29	16.4	22.64
24	353	29.40	61.0	10.57	21.9	7.67	15.9	21.75
25	385	32.08	61.6	11.40	21.9	8.07	15.5	20.95
26	418	34.87	62.0	12.26	21.8	8.46	15.1	20.23
27	453	37.78	62.5	13.15	21.7	8.87	14.7	19.56
28	490	40.81	62.9	14.08	21.7	9.28	14.3	18.96
29	527	43.94	63.3	15.03	21.6	9.70	14.0	18.40
30	566	47.20	63.6	16.01	21.6	10.13	13.7	17.88

continued

See footnotes at end of table.

Table 2.--Volumes of lumber, kerf, and slabs and edging for various log lengths as determined by the Scribner 1/4-Inch Log Rule[1] (continued)

16-FOOT LOG

Diameter (inches)	Lumber			Kerf		Slab-edging		Slab-edging/1,000 board feet
	Board feet	Cubic feet	Percent of total	Cubic feet	Percent of total	Cubic feet[2]	Percent of total	Cubic feet
6	12	1.02	23.3	1.08	24.6	2.27	51.8	185.54
7	21	1.71	29.9	1.40	24.5	2.58	45.1	125.62
8	30	2.53	35.0	1.76	24.3	2.90	40.1	95.34
9	42	3.49	39.1	2.15	24.1	3.23	36.2	77.13
10	55	4.57	42.4	2.57	23.8	3.57	33.1	64.99
11	70	5.79	45.2	3.03	23.6	3.92	30.5	56.33
12	86	7.14	47.5	3.52	23.4	4.27	28.4	49.85
13	103	8.62	49.4	4.05	23.2	4.64	26.6	44.82
14	123	10.23	51.1	4.61	23.0	5.01	25.0	40.80
15	144	11.98	52.6	5.21	22.9	5.39	23.7	37.51
16	166	13.85	53.9	5.84	22.7	5.78	22.5	34.78
17	190	15.86	55.1	6.51	22.6	6.18	21.5	32.47
18	216	18.00	56.1	7.21	22.5	6.59	20.5	30.50
19	243	20.27	57.0	7.95	22.4	7.00	19.7	28.79
20	272	22.67	57.9	8.72	22.3	7.43	19.0	27.29
21	303	25.21	58.6	9.53	22.2	7.86	18.3	25.97
22	334	27.87	59.3	10.37	22.1	8.30	17.7	24.80
23	368	30.67	60.0	11.25	22.0	8.74	17.1	23.76
24	403	33.60	60.6	12.17	21.9	9.20	16.6	22.82
25	440	36.66	61.1	13.12	21.9	9.66	16.1	21.97
26	478	39.85	61.6	14.10	21.8	10.14	15.7	21.19
27	518	43.18	62.0	15.12	21.7	10.62	15.3	20.49
28	560	46.63	62.5	16.18	21.7	11.10	14.9	19.84
29	603	50.22	62.9	17.27	21.6	11.60	14.5	19.25
30	647	53.94	63.2	18.40	21.6	12.11	14.2	18.70

Note: The percentages of total volume for the various components at each diameter do not total 100 because a 3-inch trim allowance was included on all log lengths when calculating slab-edging and kerf volumes but omitted when calculating board foot volumes. The latter also deviate slightly, in some instances, from published values because some coefficients were not rounded at the same points as in the original rule.

[1] The component values can be calculated for any desired diameter and log length. However, as log length increases, the percentage of log volume going to slabs increases.

[2] When the slab volume is converted to chips by chipping head-rigs, these estimates should be increased by 20 percent and the kerf estimates reduced by the calculated amounts.

DISCUSSION

Estimates of slabs, edging, and kerf from these procedures may be questioned because the log is treated as a frustum of a cone. Admittedly, log form is not so constant, but this fact has not prevented use of the board foot predictions from log rules based on this concept. It may also be suggested that estimates of slabs, edging, and kerf from the methods presented here will be inaccurate when a combination of 1-inch boards and dimension material is sawn; but, again, the same can be said for the accepted log rules, which estimate board feet only in terms of 1-inch boards. The acceptableness of lumber estimates based on log rules should carry over to the estimates of the volumes of residues.

An obvious advantage of these extensions of the International and Scribner Log Rules is that the equations for predicting volume are flexible with regard to log taper. This flexibility can be particularly advantageous with species that have excessive taper or with older stands of many species where taper is minimal in the bottom portion of the merchantable stem. If so desired, rules can be constructed by log position in the tree. The primary benefit from such a scheme with the International Rule would be increased precision in estimating board foot volume; with the Scribner Rule, more accurate estimates of slab and kerf volumes would be obtained. As an added feature, if taper curves are available for a species,[5] then the estimated taper from these curves can be used in the equations for predicting the volume of components. Volume tables could be constructed on this basis.

Several points about these extensions of the two log rules should be emphasized: (A) The volumes of slabs, edging, and kerf as estimated by the International Log Rule should apply if the logs are bucked into lengths that eliminate most of the sweep and crook and are carefully and properly sawn. (B) The volumes of slabs and edging as estimated by the International Rule will be the minimum to expect; less careful sawing practices will produce more residue volume. (C) These techniques can be adapted to any degree of taper with both rules and also to varying kerf width with the International Rule. (D) If taper curves are available for a species, both International and Scribner Rules for estimating volumes of board feet, slabs and edgings, and kerf can be constructed by individual log position in the tree. (E) Establishment of taper curves by diameter-height classes will permit construction of tables expressing 100 percent of the tree volume in veneer or board feet, chip volume, kerf, and topwood (the merchantable portion of a tree remaining after removal of a primary product).

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[5] Bennett, Frank A., and Swindel, Benee F. Taper curves for planted slash pine. Southeast. For. Exp. Stn., USDA For. Serv. Res. Note SE-179, 4 pp. 1972.

APPENDIX

Equations (11), (12), (13), and (14) for estimating the component volumes for the International Log Rule are obtained by adding volumes from an appropriate number (η) of 4-foot bolts, plus a fraction of a bolt, with equations (5), (8), (9), and (10) used as the bolt volumes for the respective components. For each added bolt, the scaling diameter is increased by one unit of the taper (τ). A general statement of the above summation procedure is as follows. Let a general expression for any component volume from a 4-foot-long bolt be

$$V = aD^2 + bD + cD\tau + d\tau^2 . \qquad (A1)$$

Then the component volume for a L-foot-long log is

$$
\begin{aligned}
{}_LV = \sum_{i=1}^{\eta} & (a[D + (i-1)\tau]^2 + b[D + (i-1)\tau] + c[D + (i-1)\tau]\tau \\
& + d\tau^2) + (\frac{L-4\eta}{4}) (a[D + \eta\tau]^2 + b[D + \eta\tau] + c[D + \eta\tau](\frac{L-4\eta}{4})\tau \\
& + d(\frac{L-4\eta}{4})^2 \tau^2) \\
= a(\eta D^2 & + 2 \sum_{i=1}^{\eta} (i-1)D\tau + \sum_{i=1}^{\eta} (i-1)^2 \tau^2) + b(\eta D + \sum_{i=1}^{\eta} (i-1)\tau) \\
& + c(\eta D\tau + \sum_{i=1}^{\eta} (i-1)\tau^2) + d\,\eta\tau^2 + a[D + \eta\tau]^2 (\frac{L-4\eta}{4}) \\
& + b[D + \eta\tau](\frac{L-4\eta}{4}) + c[D + \eta\tau](\frac{L-4\eta}{4})^2 \tau + d(\frac{L-4\eta}{4})^3 \tau^2 , \qquad (A2)
\end{aligned}
$$

where

$\frac{L - 4\eta}{4}$ = the fraction of a 4-foot bolt needed to complete the log length L,

$$\sum_{i=1}^{\eta} (i-1) = \frac{\eta(\eta-1)}{2}$$

and

$$\sum_{i=1}^{\eta} (i-1)^2 = \frac{2\eta^3 - 3\eta^2 + \eta}{6} .$$

☆U.S. G.P.O.: 1974— 640-938/416

Bennett, Frank A., and Lloyd, F. Thomas
1974. Volume of saw-log residues as calculated from log rule formulae. Southeast. For. Exp. Stn., USDA For. Serv. Res. Pap. SE-118, 16 p.

The formulae used in constructing the International and Scribner Log Rules were extended to include the estimation of the volumes of slabs, edging, and saw kerf. These techniques were adapted to allow varying log taper for both rules and varying kerf thicknesses for the International Rule. Volume tables of lumber and residues according to the two rules are presented for various log lengths. As reliable taper curves become available for various species, the described techniques can also be adapted to provide volume tables for board feet, slabs, edging, kerf, and topwood, thereby accounting for total tree volume.

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PREDICTED GREEN LUMBER AND RESIDUE YIELDS FROM THE MERCHANTABLE STEM OF YELLOW-POPLAR

BY
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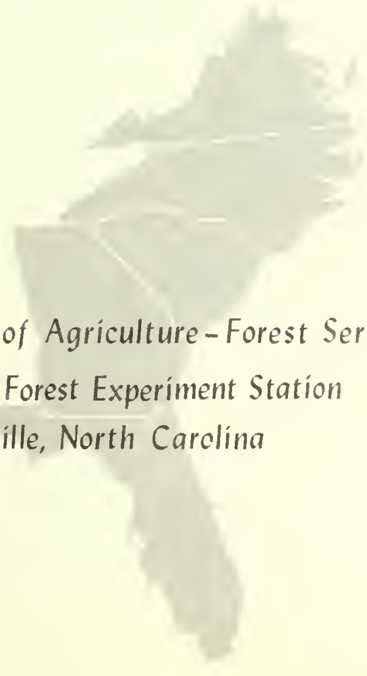

U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

PREDICTED GREEN LUMBER AND RESIDUE YIELDS FROM THE MERCHANTABLE STEM OF YELLOW-POPLAR

by

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Because of increasing demands for timber and changing utilization practices, chippable residues are now marketable products. Timber appraisals, therefore, should consider not only volumes of lumber anticipated but also amounts (weights) of chippable residue produced when processing sale trees. Some information is available on saw-log weight and amount of chippable residue produced from trees and logs of certain hardwood species (King 1952; Callahan and Nacker 1970; Timson 1972; Phillips 1974; Phillips et al. 1974), but no information is available on amount of chippable residue produced from the merchantable stem of yellow-poplar (Liriodendron tulipifera L.).

This paper reports prediction equations and yield tables for estimating chippable residue, bark residue, lumber, and sawdust weight produced from yellow-poplar sawtimber trees. It also reports cubic-foot volumes, board-foot volumes, and weights of the main stems.

PROCEDURE

A stratified random sample of 47 yellow-poplar sawtimber trees was selected from a mountain cove stand of mature, uneven-aged, natural yellow-poplar on the Pisgah National Forest in western North Carolina. Site index (age 50) ranged from 100 to 110. Five or six trees from each even-inch class from 12 to 26 inches and two trees from the 28-inch class were selected. Sample trees averaged 19.3 inches d.b.h. and 69 feet to an 8-inch or merchantable top. Means and ranges in tree characteristics were:

Item and unit of measure	Mean	Range
D.b.h. (inches)	19.3	11.7 - 28.4
Total height (feet)	116	85 - 147
Height to 8-inch or merchantable top (feet)	69	34 - 102
Form class	83	78 - 91
Age (years)	70	56 - 99

This study was conducted by the Southeastern Forest Experiment Station in cooperation with and through the financial assistance of the Range, Timber, and Wildlife Program Area of Region 8 of the National Forest System. Field personnel were provided by the Pisgah District of the Pisgah National Forest. Cooperation and assistance were also received from the Canton Hardwood Lumber Company and the Timberlands Division of Champion International Corporation.

After felling and limbing, the main stem of each sample tree was bucked into merchantable saw logs 8 to 16 feet long. Saw-log merchantability was limited by an 8-inch d.i.b. top or degrading quality indicators such as large knots. Saw-log stem top d.i.b. averaged 9.5 inches. Stem material above saw-log merchantability to a 4-inch d.i.b. top was classed as pulpwood and all stem material from a 4 to 2 inch d.i.b. top was considered topwood. Maximum and minimum diameters were measured on both ends of each log, and log length was recorded. Pulpwood and topwood were weighed in the field, and saw logs were weighed individually before and after debarking at the sawmill.

The debarked logs were sawn into 4/4 lumber on a bandsaw. During sawing, chippable residue (slabs, edgings, and end trim) from each log was collected and weighed. Lumber was weighed and tallied by size, grade,[1] and surface measure. Sawdust weight was determined by subtracting the weight of chippable residue and lumber from debarked log weight.

Moisture content and specific gravity of stemwood and bark were determined from disks taken at each saw-log bucking point and at 4 and 2 inches d.i.b. Cross sections removed at 8, 4, and 2 inches d.i.b. were used to determine bark percent for pulpwood and topwood. Moisture content samples were dried to a constant weight at 103° C, and the results expressed as a percent of ovendry weight. Specific gravity is based on green volume and ovendry weight. Weighted values for moisture content and specific gravity of bark and wood were calculated by weighting cross-section values in proportion to the volume of the component they represent.

Cubic volumes of the saw-log and pulpwood sections were computed by Smalian's formula:

$$\text{stem cubic foot volume } (V) = \left(\frac{B + b}{2}\right) L$$

where: V = volume in cubic feet

B = area of disk from base of log in square feet

b = area of disk from top of log in square feet

L = length of log in feet

To adjust for taper in the butt log, its volume was computed by applying Smalian's formula to two sections within the log--the butt 4 feet and the remainder. The volumes of the saw-log and pulpwood sections were summarized to determine tree cubic volume.

Regression equations were developed to predict green weight of chippable residue, bark residue, lumber, and sawdust, and the green board-foot volume of lumber produced from the saw-log portion of the stem. Equations were also developed to predict weight and cubic-foot volume of the main stem to 8-, 4-, and 2-inch d.i.b. merchantable tops. Independent variables examined in various combinations were d.b.h., merchantable height, total height, and form class. The variable D^2Mh (d.b.h.^{2} x merchantable height) accounted for most of the variation associated with regression. Component weights were estimated with the equation

---

[1]Lumber graded by National Hardwood Lumber Association certified grader.

$$Y = b_0 + b_1 D^2Mh + e \quad (1)$$

where: Y = green weight or volume of component

b_0, b_1 = regression coefficients

D = diameter at breast height in inches

Mh = merchantable height in feet

e = experimental error

Since plottings of the data indicated a heterogeneous variance, a weighted model was developed to make the variance more nearly homogeneous and meet the basic assumptions of regression analysis. A weighting factor inversely proportional to the variance of the residuals was developed for each component by Schreuder and Swank's (1971) procedure. An average of the weighting factors was computed and applied to all prediction equations so that component equations would be additive. Green weight or volume of each component was computed with equation (2):

$$\frac{Y}{(D^2Mh)^{0.4}} = \frac{b_0}{(D^2Mh)^{0.4}} + b_1 (D^2Mh)^{0.6} \quad (2)$$

Appropriate coefficients for each true component were estimated by least squares regression analysis, and each equation was algebraically transformed back to its original form.

RESULTS AND DISCUSSION

Lumber and Residue Yields

The 47 yellow-poplar stems weighed 269,354 pounds. Of this amount, 89 percent was saw-log material, 10 percent pulpwood, and 1 percent topwood which was left with the crown as logging residue. The saw-log portion of the trees yielded 54 percent lumber, 18 percent chippable residue (slabs, edgings, end trim), 15 percent bark residue, and 13 percent sawdust (table 1). The trees produced 28,135 board feet of 4/4 lumber.

Table 1.--Lumber tally, saw-log-merchantable stem weight, and proportions of lumber, chippable residue, bark residue, and sawdust recovered for yellow-poplar sawtimber trees, by d.b.h. class

D.b.h. class (inches)	Average merchantable height[1]	Sample trees	Average lumber tally	Average stem weight[2]	Average component recovery			
					Lumber	Chippable residue	Bark residue	Saw-dust
	Feet	Number	Board feet	Pounds	Percent			
12	43	6	117	1,241	42	29	17	12
14	60	6	224	2,202	48	23	16	13
16	68	6	353	3,063	52	20	15	13
18	66	5	409	3,661	51	19	17	13
20	70	5	595	5,044	55	18	15	12
22	76	6	736	6,103	55	18	14	13
24	88	5	1,008	8,232	55	17	15	13
26	77	6	1,130	9,342	56	18	14	12
28	82	2	1,352	11,623	59	16	12	13
Study average			599	5,099	54	18	15	13

[1]Merchantable height to an 8-inch or merchantable top (includes a 1-foot stump allowance).
[2]Saw-log stem weight with bark.

The proportion of the tree in lumber and mill residue varies with tree size (table 1). Lumber yield increased as tree size increased, ranging from 42 percent in 12-inch trees to 59 percent in 28-inch trees. Chippable residue decreased as tree size increased and ranged from 29 percent in small trees to 16 percent in large trees. The portion of the saw-log-merchantable stem removed as bark residue during processing ranged from 17 percent in small trees to 12 percent in large trees. Bark residue includes an estimated 2 to 3 percent wood removed during debarking on the rosser-head debarker. Sawdust produced averaged 12 to 13 percent regardless of tree size.

Prediction Equations

Regression equations developed to predict weight of green lumber, chippable residue, bark residue, sawdust, and green lumber volume produced when processing the saw-log portion of the stem are presented in table 2. Also shown in table 2 are equations to predict stem weight with and without bark, and bark weight alone as well as stemwood cubic volume to an 8-inch, 4-inch, and 2-inch top. The coefficient of determination and the standard error of the estimate are shown for each equation. Diameter at breast height and saw-log-merchantable height are tree measurements normally made during timber cruises, and the weighted combination of these variables accounted for 97 to 99 percent of the variation associated with regression, as indicated by the coefficients of determination.

Table 2.--Regression equations for predicting green weight of lumber, chippable residue, sawdust, and bark residue; merchantable stem weight with and without bark; and volume of stem and lumber of yellow-poplar trees in western North Carolina

Component	Equation	Coefficient of determination (R^2)	Standard error of estimate ($S_{y.x}$)
Primary product weight (pounds)			
Chippable residue	$Y = 185.56929 + 0.02570\ D^2Mh$	0.99	1.89
Bark residue	$Y = 85.79319 + 0.02255\ D^2Mh$	0.98	1.60
Lumber	$Y = -81.67664 + 0.09688\ D^2Mh$	0.98	6.48
Sawdust	$Y = 32.15269 + 0.02071\ D^2Mh$	0.98	1.35
Lumber volume (board feet)	$Y = -14.61814 + 0.02085\ D^2Mh$	0.99	0.98
Stem weight with bark (pounds) to			
8-inch top d.i.b.	$Y = 221.83854 + 0.16583\ D^2Mh$	0.99	9.50
4-inch top d.i.b.	$Y = 529.21459 + 0.17735\ D^2Mh$	0.97	16.76
2-inch top d.i.b.	$Y = 567.34904 + 0.17721\ D^2Mh$	0.97	16.77
Stem weight without bark (pounds) to			
8-inch top d.i.b.	$Y = 136.04534 + 0.14328\ D^2Mh$	0.98	8.96
4-inch top d.i.b.	$Y = 380.65921 + 0.15315\ D^2Mh$	0.97	14.93
2-inch top d.i.b.	$Y = 412.20504 + 0.15303\ D^2Mh$	0.97	14.95
Stem bark weight (pounds) to			
4-inch top d.i.b.	$Y = 148.55538 + 0.02419\ D^2Mh$	0.97	2.59
2-inch top d.i.b.	$Y = 155.14400 + 0.02418\ D^2Mh$	0.97	2.59
Stem volume without bark (cubic feet) to			
8-inch top d.i.b.	$Y = 3.51846 + 0.00293\ D^2Mh$	0.99	0.12
4-inch top d.i.b.	$Y = 8.22224 + 0.00309\ D^2Mh$	0.98	0.22
2-inch top d.i.b.	$Y = 8.78961 + 0.00309\ D^2Mh$	0.98	0.22

Equations were developed for predicting weights of pulpwood and topwood above the merchantable saw-log top, but these equations are not included in this paper. Pulpwood equations were poor predictors because amount of pulpwood above the saw-log top varies considerably due to defects which stop saw-log merchantability short of 8 inches. On the average, there were 672 pounds of pulpwood from an 8- to 4-inch top, of which 17 percent was bark. Since weight and cubic volume of topwood remain nearly constant as tree size increases, as indicated by the slopes and intercepts in the 4- and 2-inch stem equations (table 2), topwood regression equations were also poor predictors. Topwood had an average volume of about 0.6 cubic foot and weighed approximately 34 pounds, of which 23 percent was bark.

Wood Properties

Wood specific gravity averaged 0.412 in the saw-log portion of the stem, 0.428 in the pulpwood portion, and 0.436 in the topwood. Weighted stemwood specific gravity did not vary significantly with tree size except in 28-inch trees, in which specific gravity was 10 percent higher than the study average.

Moisture content of the saw-log portion of the main stem averaged 98 percent, pulpwood moisture content 94 percent, and topwood 112 percent. Moisture content, like specific gravity, did not vary significantly with tree size except for the 28-inch trees, in which moisture content of the main stem was 5 percent lower than the study average.

Bark specific gravity averaged 0.308, 0.347, and 0.343, respectively, for the saw-log, pulpwood, and topwood portions of the stem. Bark moisture content averaged 114 percent in the saw-log portion of the stem, 102 percent in the pulpwood, and 139 percent in the topwood. Bark specific gravity and moisture content varied considerably, but showed no trends with increasing tree size.

Weight Factors

Weight conversion factors based on original data were developed for each d.b.h. class sampled to show how they vary with tree size (table 3). Green weight of chips per board foot of lumber produced and green weight of chips per cubic foot of log input both decreased as tree size increased. Weight of chips per board foot of lumber ranged from 3.0 pounds in the 12-inch trees to 1.4 pounds in the 28-inch trees and averaged 1.6 pounds (table 3). Green weight of chips per cubic foot of wood input decreased from 15.9 pounds in small trees to 10.0 pounds in large trees and averaged 10.5 pounds.

Bark weight per board foot of lumber decreased from 1.8 pounds per board foot in 12-inch trees to 1.0 pound per board foot in 28-inch trees and averaged 1.2 pounds per board foot (table 3). Weight of sawdust produced per board foot of lumber sawn did not differ with tree size except for 12- and 14-inch trees which produced 1.3 pounds of sawdust per board foot compared to the study average of 1.1 pounds of sawdust per board foot. Since residue weight factors vary with tree size, estimates of sawmill residue yields based on weight factors must consider the size and distribution of the trees being processed.

Table 3.--Average yellow-poplar green weight conversion factors by tree d.b.h. classes

D.b.h. class (inches)	Merchantable height	Lumber weight	Chippable residue weight	Bark residue weight	Sawdust weight	Saw-log stemwood weight	Chippable residue weight	Lumber recovery factor
	Feet	- - - - Pounds/board foot			- - -	Pounds/cubic foot		Board feet/ cubic foot
12	43	4.4	3.0	1.8	1.3	46.0	15.9	5.2
14	60	4.7	2.2	1.6	1.3	49.9	13.6	6.1
16	68	4.5	1.8	1.3	1.1	47.4	11.4	6.4
18	66	4.6	1.7	1.5	1.1	47.1	11.0	6.3
20	70	4.7	1.5	1.3	1.0	49.1	10.0	6.8
22	76	4.6	1.5	1.2	1.1	48.5	10.0	6.8
24	88	4.5	1.4	1.2	1.0	47.7	9.9	6.9
26	77	4.6	1.4	1.2	1.0	48.0	9.8	6.9
28	82	5.0	1.4	1.0	1.1	53.0	10.0	7.0
Study average		4.6	1.6	1.2	1.1	48.5	10.5	6.7

Lumber weight per board foot averaged 4.6 pounds and did not differ significantly with tree size except in 28-inch trees, which yielded 9 percent heavier lumber due to higher wood specific gravity. Wood green weight averaged 48.5 pounds per cubic foot and did not increase consistently with increasing tree size. However, average wood green weight per cubic foot was slightly lower in 12-inch trees and slightly higher than the study average in 28-inch trees (table 3).

Lumber recovery factor (L.R.F.)[2] increased with tree size up to 20 inches d.b.h. and then remained relatively constant. The L.R.F. ranged from 5.2 board feet per cubic foot in 12-inch trees to 7.0 board feet per cubic foot in 28-inch trees. Average L.R.F. for the study was 6.7 board feet per cubic foot (table 3).

Yield Tables

Predicted green weights of chippable residue, bark residue, sawdust, and lumber for trees 12 to 30 inches are presented in tables 4-7 of the Appendix. Predicted green lumber volume yields in board feet are presented in Appendix table 8. Green weight of the merchantable stem with and without bark, weight of bark alone, as well as cubic-foot volume of wood in the stem to an 8- and 4-inch top are presented in Appendix tables 9-15. Estimates of pulpwood can be computed by subtracting predicted merchantable stem weight to an 8-inch top from predicted weight to a 4-inch top for comparable sized trees.

Weight factors and yield tables presented in this paper should not be used indiscriminately over the range of yellow-poplar. Differences in green weight per cubic foot and tree form could affect the precision of these data. For optimum predicting performance, these equations and weight factors should be applied to timber of the same form and wood properties which will be cut at a band sawmill.

[2]Lumber recovery factor is the ratio of actual lumber volume recovered to the cubic volume of the piece processed; expressed as board feet/cubic foot.

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APPENDIX

Table 4.--Weight of chippable residue from yellow-poplar saw-log-merchantable stem to 8-inch d.i.b. top[1/] [2/]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3/]										
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6	6-1/2
	Pounds										
12	278	308	337	367	397	426	456				
13	294	329	364	398	433	468	503	537			
14	311	352	392	432	473	513	553	594	634		
15	330	376	423	469	515	561	608	654	700	746	
16		403	455	508	561	613	666	718	771	824	876
17		431	490	550	609	668	728	787	847	906	965
18		460	527	594	660	727	793	860	927	993	1,060
19			566	640	714	789	863	937	1,011	1,086	1,160
20			607	689	772	854	936	1,018	1,100	1,183	1,265
21			650	741	832	922	1,013	1,104	1,194	1,285	1,376
22			696	795	895	994	1,094	1,193	1,293	1,392	1,492
23				852	961	1,069	1,178	1,287	1,396	1,504	1,613
24				911	1,029	1,148	1,266	1,385	1,503	1,621	1,740
25				973	1,101	1,230	1,358	1,487	1,615	1,744	1,872
26					1,176	1,315	1,454	1,593	1,732	1,871	2,010
27					1,253	1,403	1,553	1,703	1,853	2,003	2,153
28					1,334	1,495	1,656	1,818	1,979	2,140	2,301
29						1,590	1,763	1,936	2,109	2,282	2,455
30						1,689	1,874	2,059	2,244	2,429	2,614

[1/] $Y = 185.56929 + 0.02570 D^2Mh$.

[2/] Blocked-in area indicates the range of our data.

[3/] Includes a 1-foot stump allowance.

Table 5.--Weight of bark residue from yellow-poplar saw-log-merchantable stem to 8-inch d.i.b. top[1/] [2/]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3/]										
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6	6-1/2
	Pounds										
12	167	193	219	245	271	297	323				
13	181	212	242	273	303	334	364	394			
14	196	232	267	302	338	373	408	444	479		
15	213	253	294	334	375	416	456	497	537	578	
16		276	322	369	415	461	507	553	600	646	692
17		301	353	405	457	509	562	614	666	718	770
18		327	385	444	502	561	619	678	736	794	853
19			420	485	550	615	680	745	810	875	941
20			456	528	600	672	744	816	889	961	1,033
21			494	573	653	732	812	891	971	1,050	1,130
22			533	621	708	795	883	970	1,057	1,144	1,232
23				670	766	861	957	1,052	1,147	1,243	1,338
24				722	826	930	1,034	1,138	1,242	1,346	1,450
25				776	889	1,002	1,115	1,227	1,340	1,453	1,566
26					955	1,077	1,199	1,321	1,442	1,564	1,686
27					1,023	1,154	1,286	1,417	1,549	1,680	1,812
28					1,094	1,235	1,376	1,518	1,659	1,801	1,942
29						1,318	1,470	1,622	1,774	1,925	2,077
30						1,405	1,567	1,730	1,892	2,054	2,217

[1/] $Y = 85.79319 + 0.02255\ D^2Mh$.

[2/] Blocked-in area indicates the range of our data.

[3/] Includes a 1-foot stump allowance.

Table 6.--Weight of sawdust from yellow-poplar saw-log-merchantable stem to 8-inch d.i.b. top[1/] [2/]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3/]										
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6	6-1/2
	Pounds										
12	107	131	154	178	202	226	250				
13	120	148	176	204	232	260	288	316			
14	134	166	199	231	264	296	328	361	393		
15	149	186	223	260	298	335	372	410	447	484	
16		207	250	292	334	377	419	462	504	546	589
17		230	278	325	373	421	469	517	565	613	661
18		254	307	361	415	468	522	576	629	683	737
19			339	398	458	518	578	638	698	757	817
20			372	438	504	571	637	703	769	836	902
21			407	480	553	626	699	772	845	918	991
22			443	523	604	684	764	844	924	1,004	1,085
23				569	657	744	832	920	1,007	1,095	1,182
24				617	712	808	903	998	1,094	1,189	1,285
25				666	770	873	977	1,081	1,184	1,288	1,391
26					830	942	1,054	1,166	1,278	1,390	1,502
27					893	1,013	1,134	1,255	1,376	1,497	1,617
28					958	1,088	1,217	1,347	1,477	1,607	1,737
29						1,164	1,304	1,443	1,582	1,722	1,861
30						1,244	1,393	1,542	1,691	1,840	1,989

[1/] $Y = 32.15269 + 0.02071\ D^2Mh$.

[2/] Blocked-in area indicates the range of our data.

[3/] Includes a 1-foot stump allowance.

Table 7.--Weight of 4/4 lumber produced from yellow-poplar saw-log-merchantable stem to 8-inch d.i.b. top[1/] [2/]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3/]										
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6	6-1/2
	Pounds										
12	267	379	490	602	714	825	937				
13	328	459	590	721	852	983	1,114	1,245			
14	393	545	697	849	1,001	1,153	1,304	1,456	1,608		
15	463	638	812	986	1,161	1,335	1,510	1,684	1,858	2,033	
16		737	935	1,134	1,332	1,530	1,729	1,927	2,126	2,324	2,522
17		842	1,066	1,290	1,514	1,738	1,962	2,186	2,410	2,634	2,858
18		954	1,205	1,456	1,708	1,959	2,210	2,461	2,712	2,963	3,214
19			1,352	1,632	1,912	2,192	2,471	2,751	3,031	3,311	3,591
20			1,507	1,817	2,127	2,437	2,747	3,057	3,367	3,677	3,987
21			1,670	2,012	2,354	2,695	3,037	3,379	3,721	4,063	4,404
22			1,841	2,216	2,591	2,966	3,341	3,716	4,092	4,467	4,842
23				2,430	2,840	3,250	3,660	4,070	4,480	4,890	5,300
24				2,653	3,099	3,546	3,992	4,438	4,885	5,331	5,778
25				2,885	3,370	3,854	4,338	4,823	5,307	5,792	6,276
26					3,651	4,175	4,699	5,223	5,747	6,271	6,795
27					3,944	4,509	5,074	5,639	6,204	6,769	7,334
28					4,248	4,855	5,463	6,071	6,678	7,286	7,893
29						5,214	5,866	6,518	7,170	7,821	8,473
30						5,586	6,283	6,981	7,678	8,376	9,073

1/ $Y = -81.67664 + 0.09688\ D^2Mh$.

2/ Blocked-in area indicates the range of our data.

3/ Includes a 1-foot stump allowance.

Table 8.--Volume of 4/4 lumber produced from yellow-poplar saw-log-merchantable stem to 8-inch d.i.b. top[1/] [2/]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3/]										
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6	6-1/2
	Board feet										
12	60	84	108	132	157	181	205				
13	73	102	130	158	186	214	243	271			
14	88	120	153	186	218	251	284	316	349		
15	103	140	178	215	253	290	328	365	403	440	
16		162	204	247	290	332	375	418	460	503	546
17		184	232	281	329	377	425	473	522	570	618
18		208	262	316	370	424	479	533	587	641	695
19			294	354	414	475	535	595	655	715	776
20			327	394	461	527	594	661	728	794	861
21			362	436	509	583	657	730	804	877	951
22			399	480	561	641	722	803	884	964	1,045
23				526	614	702	791	879	967	1,055	1,143
24				574	670	766	862	958	1,054	1,150	1,246
25				624	728	832	937	1,041	1,145	1,249	1,354
26					789	902	1,014	1,127	1,240	1,353	1,465
27					852	973	1,095	1,217	1,338	1,460	1,581
28					917	1,048	1,179	1,309	1,440	1,571	1,702
29						1,125	1,265	1,406	1,546	1,686	1,827
30						1,205	1,355	1,505	1,655	1,806	1,956

1/ $Y = -14.61814 + 0.02085\ D^2Mh$.

2/ Blocked-in area indicates the range of our data.

3/ Includes a 1-foot stump allowance.

Table 9.--Yellow-poplar saw-log stem weight with bark to 8-inch d.i.b. top[1/] [2/]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3/]										
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6	6-1/2
	Pounds										
12	819	1,010	1,201	1,392	1,583	1,774	1,965				
13	922	1,147	1,371	1,595	1,819	2,043	2,268	2,492			
14	1,034	1,294	1,554	1,814	2,074	2,335	2,595	2,855	3,115		
15	1,155	1,453	1,752	2,050	2,349	2,647	2,946	3,244	3,543	3,841	
16		1,623	1,962	2,302	2,642	2,981	3,321	3,660	4,000	4,340	4,679
17		1,803	2,187	2,570	2,954	3,337	3,720	4,104	4,487	4,871	5,254
18		1,995	2,425	2,855	3,284	3,714	4,144	4,574	5,004	5,434	5,863
19			2,676	3,155	3,634	4,113	4,592	5,071	5,550	6,029	6,508
20			2,941	3,472	4,003	4,533	5,064	5,595	6,125	6,656	7,187
21			3,220	3,805	4,390	4,975	5,560	6,145	6,730	7,316	7,901
22			3,513	4,155	4,797	5,439	6,081	6,723	7,365	8,007	8,649
23				4,520	5,222	5,924	6,626	7,327	8,029	8,731	9,433
24				4,902	5,666	6,431	7,195	7,959	8,723	9,487	10,251
25				5,300	6,130	6,959	7,788	8,617	9,446	10,275	11,104
26					6,612	7,508	8,405	9,302	10,199	11,096	11,992
27					7,113	8,080	9,047	10,014	10,981	11,948	12,915
28					7,632	8,673	9,713	10,753	11,793	12,833	13,873
29						9,287	10,403	11,518	12,634	13,750	14,865
30						9,923	11,117	12,311	13,505	14,699	15,893

[1/] $Y = 221.83854 + 0.16583\ D^2Mh$.

[2/] Blocked-in area indicates the range of our data.

[3/] Includes a 1-foot stump allowance.

Table 10.--Yellow-poplar saw-log stem weight without bark to 8-inch d.i.b. top[1/] [2/]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3/]										
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6	6-1/2
	Pounds										
12	652	817	982	1,147	1,312	1,477	1,642				
13	741	935	1,129	1,323	1,516	1,710	1,904	2,097			
14	838	1,063	1,287	1,512	1,737	1,961	2,186	2,411	2,635		
15	942	1,200	1,458	1,716	1,974	2,232	2,489	2,747	3,005	3,263	
16		1,346	1,640	1,933	2,227	2,520	2,814	3,107	3,401	3,694	3,987
17		1,503	1,834	2,165	2,496	2,828	3,159	3,490	3,821	4,153	4,484
18		1,668	2,039	2,411	2,782	3,154	3,525	3,896	4,268	4,639	5,010
19			2,257	2,671	3,084	3,498	3,912	4,326	4,739	5,153	5,567
20			2,486	2,944	3,403	3,861	4,320	4,778	5,237	5,695	6,154
21			2,727	3,232	3,738	4,243	4,749	5,254	5,760	6,265	6,771
22			2,979	3,534	4,089	4,644	5,198	5,753	6,308	6,863	7,418
23				3,850	4,456	5,063	5,669	6,275	6,882	7,488	8,095
24				4,180	4,840	5,500	6,161	6,821	7,481	8,141	8,802
25				4,524	5,240	5,957	6,673	7,390	8,106	8,822	9,539
26					5,657	6,432	7,207	7,981	8,756	9,531	10,306
27					6,090	6,925	7,761	8,597	9,432	10,268	11,103
28					6,539	7,438	8,336	9,235	10,134	11,032	11,931
29						7,968	8,932	9,896	10,860	11,824	12,788
30						8,518	9,550	10,581	11,613	12,644	13,676

[1/] $Y = 136.04534 + 0.14328\ D^2Mh$.

[2/] Blocked-in area indicates the range of our data.

[3/] Includes a 1-foot stump allowance.

Table 11.--Yellow-poplar stem weight with bark to 4-inch d.i.b. top[1/] [2/]

D.b.h. (inches)	Merchantable tree height to 8-inch d.i.b. top (number of 16-foot logs)[3/]										
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6	6-1/2
	Pounds										
12	1,168	1,372	1,576	1,781	1,985	2,189	2,394				
13	1,279	1,518	1,758	1,998	2,238	2,477	2,717	2,957			
14	1,398	1,676	1,954	2,232	2,511	2,789	3,067	3,345	3,623		
15	1,527	1,846	2,165	2,484	2,804	3,123	3,442	3,761	4,081	4,400	
16		2,027	2,391	2,754	3,117	3,480	3,844	4,207	4,570	4,933	5,296
17		2,221	2,631	3,041	3,451	3,861	4,271	4,681	5,091	5,501	5,911
18		2,425	2,885	3,345	3,805	4,264	4,724	5,184	5,643	6,103	6,563
19			3,154	3,666	4,179	4,691	5,203	5,715	6,227	6,739	7,252
20			3,438	4,005	4,573	5,140	5,708	6,275	6,843	7,410	7,978
21			3,736	4,362	4,987	5,613	6,239	6,864	7,490	8,116	8,741
22			4,049	4,735	5,422	6,109	6,795	7,482	8,169	8,855	9,542
23				5,126	5,877	6,627	7,378	8,182	8,879	9,630	10,380
24				5,535	6,352	7,169	7,986	8,804	9,621	10,438	11,255
25				5,961	6,847	7,734	8,621	9,508	10,394	11,281	12,168
26					7,363	8,322	9,281	10,240	11,199	12,158	13,118
27					7,899	8,933	9,967	11,002	12,036	13,070	14,104
28					8,455	9,567	10,679	11,792	12,904	14,016	15,129
29						10,224	11,417	12,610	13,804	14,997	16,190
30						10,904	12,181	13,458	14,735	16,012	17,289

[1/] $Y = 529.21459 + 0.17735\ D^2Mh$.

[2/] Blocked-in area indicates the range of our data.

[3/] Includes a 1-foot stump allowance.

Table 12.--Weight of bark residue from yellow-poplar stem to 4-inch d.i.b. top[1/] [2/]

D.b.h. (inches)	Merchantable tree height to 8-inch d.i.b. top (number of 16-foot logs)[3/]										
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6	6-1/2
	Pounds										
12	236	264	291	319	347	375	403				
13	251	283	316	349	382	414	447	480			
14	267	305	343	381	419	457	495	533	571		
15	285	328	372	415	459	502	546	589	633	677	
16		353	402	452	502	551	601	650	700	749	799
17		379	435	491	547	603	659	715	771	827	883
18		407	470	533	595	658	721	783	846	909	971
19			507	576	646	716	786	856	926	996	1,065
20			545	623	700	777	855	932	1,010	1,087	1,165
21			586	671	757	842	927	1,013	1,098	1,183	1,269
22			629	722	816	910	1,003	1,097	1,191	1,284	1,378
23				776	878	980	1,083	1,185	1,287	1,390	1,492
24				831	943	1,054	1,166	1,277	1,389	1,500	1,612
25				889	1,010	1,131	1,252	1,373	1,494	1,615	1,736
26					1,081	1,211	1,342	1,473	1,604	1,735	1,866
27					1,154	1,295	1,436	1,577	1,718	1,859	2,000
28					1,230	1,381	1,533	1,685	1,836	1,988	2,140
29						1,471	1,634	1,796	1,959	2,122	2,285
30						1,564	1,738	1,912	2,086	2,160	2,435

[1/] $Y = 148.55538 + 0.02419\ D^2Mh$.

[2/] Blocked-in area indicates the range of our data.

[3/] Includes a 1-foot stump allowance.

Table 13.--Yellow-poplar stem weight without bark to 4-inch d.i.b. top[1/] [2/]

D.b.h. (inches)	Merchantable tree height to 8-inch d.i.b. top (number of 16-foot logs)[3/]										
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6	6-1/2
	Pounds										
12	932	1,108	1,285	1,461	1,638	1,814	1,991				
13	1,028	1,235	1,442	1,649	1,856	2,063	2,270	2,477			
14	1,131	1,371	1,611	1,852	2,092	2,332	2,572	2,812	3,052		
15	1,242	1,518	1,793	2,069	2,344	2,620	2,896	3,172	3,447	3,723	
16		1,674	1,988	2,302	2,615	2,929	3,243	3,556	3,870	4,184	4,497
17		1,841	2,195	2,549	2,903	3,258	3,612	3,966	4,320	4,674	5,028
18		2,018	2,415	2,812	3,209	3,606	4,003	4,400	4,797	5,194	5,591
19			2,647	3,090	3,532	3,974	4,417	4,859	5,301	5,744	6,186
20			2,892	3,382	3,872	4,363	4,853	5,343	5,833	6,323	6,813
21			3,150	3,690	4,230	4,771	5,311	5,851	6,392	6,932	7,472
22			3,420	4,013	4,606	5,199	5,792	6,385	6,978	7,571	8,164
23				4,350	4,999	5,647	6,295	6,943	7,591	8,239	8,887
24				4,703	5,409	6,115	6,820	7,526	8,232	8,937	9,643
25				5,071	5,837	6,602	7,368	8,134	8,900	9,665	10,431
26					6,282	7,110	7,938	8,767	9,595	10,423	11,251
27					6,744	7,638	8,531	9,424	10,317	11,210	12,104
28					7,225	8,185	9,146	10,106	11,067	12,027	12,988
29						8,753	9,783	10,813	11,844	12,874	13,905
30						9,340	10,443	11,545	12,648	13,751	14,853

1/ $Y = 380.65921 + 0.15315 D^2Mh$.

2/ Blocked-in area indicates the range of our data.

3/ Includes a 1-foot stump allowance.

Table 14.--Yellow-poplar stem cubic volume without bark to 8-inch d.i.b. top[1/] [2/]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3/]										
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6	6-1/2
	Cubic feet										
12	14	17	21	24	28	31	34				
13	16	20	24	28	32	36	40	44			
14	18	22	27	32	36	41	45	50	55		
15	20	25	31	36	41	46	52	57	62	67	
16		28	34	40	46	52	58	64	70	76	82
17		31	38	45	52	59	65	72	79	86	92
18		35	42	50	58	65	73	80	88	96	103
19			47	55	64	72	81	89	98	106	115
20			52	61	70	80	89	98	108	117	127
21			56	67	77	88	98	108	119	129	139
22			62	73	84	96	107	118	130	141	152
23				79	92	104	117	129	141	154	166
24				86	100	113	127	140	154	167	181
25				93	108	123	137	152	166	181	196
26					116	132	148	164	180	196	211
27					125	142	159	177	194	211	228
28					134	153	171	190	208	226	245
29						164	183	203	223	243	262
30						175	196	217	238	259	280

1/ $Y = 3.51846 + 0.00293 D^2Mh$.

2/ Blocked-in area indicates the range of our data.

3/ Includes a 1-foot stump allowance.

Table 15.--Yellow-poplar stem cubic volume without bark to 4-inch d.i.b. top[1/] [2/]

D.b.h. (inches)	Merchantable tree height to 8-inch d.i.b. top (number of 16-foot logs)[3/]										
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6	6-1/2
	Cubic feet										
12	19	23	26	30	34	37	41				
13	21	25	30	34	38	42	46	51			
14	23	28	33	38	43	48	52	57	62		
15	26	31	37	42	48	53	59	65	70	76	
16		34	41	47	53	60	66	72	79	85	91
17		38	45	52	59	66	73	81	88	95	102
18		41	49	57	65	73	81	89	97	105	113
19			54	63	72	81	90	99	108	116	125
20			59	69	79	89	98	108	118	128	138
21			64	75	86	97	108	119	130	140	151
22			70	82	93	105	117	129	141	153	165
23				88	101	114	128	141	154	167	180
24				95	110	124	138	152	167	181	195
25				103	118	134	149	165	180	196	211
26					127	144	161	177	194	211	228
27					137	155	173	191	209	227	245
28					146	166	185	204	224	243	263
29						177	198	219	240	260	281
30						189	211	233	256	278	300

1/ $Y = 8.22224 + 0.00309 D^2Mh$.

2/ Blocked-in area indicates the range of our data.

3/ Includes a 1-foot stump allowance.

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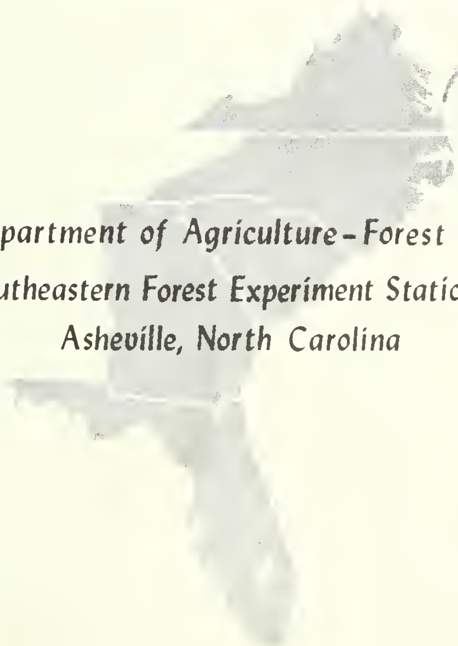
USDA Forest Service Research Paper SE-120 December 1974

Predicted Green Lumber and Residue Yields from the Merchantable Stem of Black Oak Trees

by

Douglas R. Phillips
James G. Schroeder
and
Michael A. Taras



U.S. Department of Agriculture-Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Phillips, Douglas R., Schroeder, James G., and Taras, Michael A. 1974. Predicted green lumber and residue yields from the merchantable stem of black oak trees. USDA For. Serv. Res. Pap. SE-120, 10 p. Southeast. For. Exp. Stn., Asheville, N.C.

Forty black oak sawtimber trees, 11.9 to 25.6 inches d.b.h., were felled, bucked, and processed in a sawmill in western North Carolina. Regression equations to predict the weight of lumber, chippable residue (slabs, edgings, and end trim), bark residue, and sawdust from tree d.b.h. and merchantable height had coefficients of determination ($\underline{R}^2$) of from 0.89 to 0.96. Merchantable stems contained an average of 55 percent lumber, 20 percent chippable residue, 15 percent bark residue, and 10 percent sawdust. Tables constructed from the equations provide weight and volume yields by tree size.

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by

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Solid wood residues from lumber manufacturing are currently providing valuable income to sawmills through the sale of chips. Other residues such as bark and sawdust are used in many areas as fuel or sold as mulch.

The added value residues have assumed dictates that they no longer be ignored when evaluating standing timber. Timber should be appraised on the basis of its residue-producing potential, as well as its lumber-producing potential, if a fair and equitable exchange is to take place between buyer and seller.

In this paper we have developed equations based on d.b.h. and merchantable height to predict the weight of lumber, chippable residue, bark residue, and sawdust from the merchantable stem of black oak (Quercus velutina Lam.) sawtimber trees. Total merchantable stem weight and lumber volume are also predicted. Although our equations are based on sample trees from one location processed at one mill, we believe they will have practical value for many people who are buying, selling, or processing black oak sawtimber trees.

PROCEDURES

Sample trees were selected from a mature, uneven-aged stand of mixed oaks on an upland slope of the Pisgah National Forest near Brevard, North Carolina. Means and ranges in characteristics of the 40 selected trees were:

Item and unit of measure	Mean	Range
D.b.h. (inches)	18.7	11.9 - 25.6
Total height (feet)	93	67 - 112
Merchantable height (feet)	45	26 - 69
Form class	81	73 - 91

Estimates of rot, sweep, and crook were recorded for each standing tree.

This study was conducted by the Southeastern Forest Experiment Station in cooperation with and through the financial assistance of the Range, Timber, and Wildlife Program Area of Region 8 of the National Forest System. Field personnel were provided by the Pisgah District of the Pisgah National Forest. Assistance was also received from the Canton Hardwood Lumber Company, the Timberlands Division of Champion International Corporation, and the Quality and Grade of Hardwood Timber Project of the Northeastern Forest Experiment Station.

The trees were felled and bucked into logs 8 to 16 feet in length to a minimum merchantable top diameter of 8 inches. The 8-inch top was seldom reached because of roughness in the upper portion of the stem. Average top diameter of the trees was approximately 12.0 inches. Log length was measured to the nearest 0.1 foot, and inside- and outside-bark diameters of both ends of the logs were measured to the nearest 0.1 inch. At each bucking point, a sample disk approximately 2 inches thick was cut. From each disk a wedge (approximately one-fourth of the disk) free of rot was split out and used for determining moisture content and specific gravity. Wood and bark from the wedge were weighed separately in the field on a top-loading balance.

At the millyard, individual logs were weighed to the nearest pound with electronic load cells and a digital reader. The logs were debarked with a rosser-head debarker and immediately reweighed. The difference between the first and second weights provided us with estimates of bark residue, which we defined after Wartluft (1971) as all the material removed during debarking including wood fiber.

The logs were sawn in a mill with a thin-kerf band headsaw, an in-line edger, and end-trim saws. Mill capacity was approximately 20,000 board feet in an 8-hour shift. The mill was in good repair and produced high quality boards. All lumber and chippable residues (slabs, edgings, and end trim) from each log were weighed to the nearest $\frac{1}{4}$ pound on platform scales. Rough board dimensions were recorded and used to compute lumber volume. Saw-log yields were combined to estimate tree yields.

Wood samples collected in the field were dried in the laboratory at 103° C. until a constant weight was attained. This ovendry weight was used as the base for wood moisture content determinations. Specific gravity of wood and bark was determined on a green volume-ovendry weight basis. Average merchantable stem specific gravity and moisture content were determined by weighting individual sample values by the proportion of stem volume each sample represented.

ANALYSIS

The first step in the analysis was to determine which variables were best for predicting the yield of primary products (lumber, chippable residue, bark residue, and sawdust) from the merchantable stem of black oak sawtimber trees. We knew d.b.h. and merchantable height would be strong independent variables because they are good predictors of stem volume which is highly correlated with stem weight. We also expected rot, sweep, and crook deductions, and possibly form class or diameter at the top of the merchantable stem to be important.

Standard regression analyses were used to test these independent variables individually and in various combinations. We found d.b.h., merchantable height, and diameter at the top of the merchantable stem to be significant at the 0.05 level. A closer check showed that diameter at the top of the merchantable stem, although significant, improved the equation very little. Since this measurement is difficult to obtain on standing trees, we decided, from a practical standpoint, to drop the variable from our equations.

The rot, sweep, and crook variables did not come into our equations, probably because of one or more of the following factors:

(1) the amount of rot, sweep, and crook in our trees was minimal,

(2) rot is often impossible to detect in some standing trees, and

(3) sweep and crook deviations in the standing tree are often reduced or even eliminated by the way the tree is bucked into logs.

After selecting the independent variables, our next step was to determine the most appropriate form of the equations. The linear form using d.b.h. and merchantable height in combination (D^2Mh) was examined and found to produce high coefficients of determination (R^2). However, in some instances the variance of the dependent variable increases with increasing tree size. In such cases, a weighted or transformed equation is appropriate (Steel and Torrie 1960). We examined the variance across the D^2Mh scale for all weight predictions and found little or no increase. Since the variance was essentially homogeneous and a plot of residuals showed no abnormalities, we chose the linear form. Thus, the general model for all predictions is:

$$Y = b_0 + b_1 (D^2Mh) + e$$

where:

Y = weight of primary product in pounds

b_0, b_1 = regression coefficients

D = diameter at breast height in inches

Mh = merchantable height in feet

e = experimental error

The same form of the equation was used for all predictions, so that primary product weights would be additive.

RESULTS AND DISCUSSION

On a green-weight basis, the study trees yielded 49 to 61 percent rough lumber, 16 to 25 percent chippable residue, 13 to 16 percent bark residue, and 10 to 12 percent sawdust (table 1). Lumber yield as a percent of total merchantable stem weight increased as tree d.b.h. increased, while chippable residue decreased with increasing d.b.h. The percentage of bark residue and sawdust remained relatively constant over the range of tree diameters (table 1).

Examination of disk samples indicated that bark residue contained about 20 percent wood. This value seems reasonable since Fisher (1972) reported that bark residue removed with rosser-head debarkers contains a minimum of 10 percent wood fiber.

The percentage of sawdust is strongly influenced by the type of headsaw. Our band headsaw produced sawdust percentages of 10 to 12 percent, while Massengale (1971) reported values of 17 to 22 percent from a circular saw in Missouri. This difference is as expected since a bandsaw has a thinner kerf. Also, since less of our wood went to sawdust, it is not surprising that more of it went to lumber and chippable residue. Our lumber yields are 5 to 6 percent higher and our chippable residue yields are 4 to 5 percent higher than Massengale's (1971).

Table 1.--Average lumber, chippable residue, bark residue, and sawdust recovery percentages for black oak sawtimber trees

D.b.h. class (inches)	Trees	Average merchantable height	Average merchantable stem weight with bark	Primary product recovery				Average lumber tally
				Lumber	Chippable residue[1]	Bark residue[2]	Sawdust	
	Number	Feet	Pounds	- - - - - -	Percent	- - - - - -		Board feet
12	2	29	1,194	50	25	15	10	96
13	2	30	1,444	53	20	15	12	126
14	1	41	2,047	50	24	14	12	168
15	3	32	1,978	51	22	16	11	166
16	5	40	2,670	49	24	16	11	210
17	5	48	3,330	54	19	16	11	293
18	4	42	3,188	50	23	16	11	258
19	0	--	--	--	--	--	--	--
20	3	48	4,612	57	19	14	10	430
21	4	55	5,622	55	19	15	11	503
22	5	52	5,872	56	19	15	10	547
23	1	40	5,798	61	16	13	10	595
24	1	56	8,413	57	18	14	10	823
25	2	60	8,569	57	17	16	10	832
26	2	49	7,866	59	17	14	10	760
Weighted study average			4,219	55	20	15	10	382

[1] Includes slabs, edgings, and end trim.
[2] Includes wood fiber removed during debarking.

Table 2 gives regression equations to predict the weight of primary products as well as merchantable stem weight with and without bark and merchantable stem lumber volume. These equations fit the data well; coefficients of determination (R^2) range from 0.89 for chippable residue to 0.96 for merchantable stem weight. Table 2 also shows standard errors of estimate ($S_{y.x}$) and coefficients of variation (CV). $S_{y.x}$ is a measure of the variation about regression and is given for those who may wish to place confidence intervals about the regression lines. CV is a relative measure of variation which indicates that the stem-weight equation is the most efficient (CV = 10.3), and the chippable residue equation is least efficient (CV = 15.5).

Table 2.--Black oak regression equations and associated statistics

Item	Equation	Coefficient of determination (R^2)	Standard error of estimate ($S_{y.x}$)	Coefficient of variation (CV)
				Percent
Primary product weight (pounds)				
Lumber	$Y = 13.43933 + 0.13074\ D^2Mh$	0.94	316.2	13.7
Chippable residue	$Y = 200.51412 + 0.03545\ D^2Mh$	0.89	127.7	15.5
Bark residue	$Y = 77.43299 + 0.03224\ D^2Mh$	0.95	74.5	11.6
Sawdust	$Y = 63.40778 + 0.02119\ D^2Mh$	0.95	49.1	11.2
Merchantable stem weight with bark (pounds)	$Y = 354.79422 + 0.21963\ D^2Mh$	0.96	433.5	10.3
Merchantable stem weight without bark (pounds)	$Y = 277.36124 + 0.18739\ D^2Mh$	0.96	381.6	10.7
Merchantable stem lumber volume (board feet)	$Y = -6.00562 + 0.02203\ D^2Mh$	0.94	56.1	14.7

The regression equations in table 2 were used to construct tables of primary product weights (Appendix tables 3-6), merchantable stem weights (Appendix tables 7-8), and merchantable stem lumber volume (Appendix table 9). Predictions are tabulated by 1-inch d.b.h. classes from 10 to 30 inches and by the number of 16-foot logs from 1 to 4½. Values between d.b.h. and/or merchantable height classes can be interpolated with the equations. The blocked-in areas indicate the range of our data.

Merchantable stem weight prediction equations have been reported for black oak trees by the Tennessee Valley Authority (1972). Our results cannot be compared directly to theirs because they used only d.b.h. as an independent variable where we used d.b.h. and merchantable height. Also, they computed log weights instead of actually weighing logs as we did.

Average merchantable stemwood specific gravity for the study was 0.54 and ranged from 0.47 to 0.60. The Wood Handbook (USDA Forest Products Laboratory 1974) gives 0.56 as the overall average for the species. Moisture content of the wood in the merchantable stem of the trees averaged 94.9 percent and ranged from 80.4 to 111.8 percent. Bark specific gravity averaged 0.55. Bark moisture content was not sampled.

Wood and bark specific gravity and moisture content are important because they directly affect tree weight. Where possible, these properties should be examined and compared to our data before a decision is made to use our equations. Taras (1956) points out that a difference in wood specific gravity of 0.02 at the 100-percent moisture content level represents a difference in wood weight of approximately 2.5 pounds per cubic foot. For a tree with a volume of 32 cubic feet (15-inch 3-log tree), the difference in merchantable stem weight would be 80 pounds or about 3 percent of total merchantable stem weight.

Our tables are based on a single set of conditions for one oak species. They are directly applicable only to timber of the same form and wood properties sawn on a bandsaw. Ultimately, a general equation may be developed for all commercial red oak species, or equations for individual species may prove necessary. In the meantime, our black oak equations should serve as a general guide.

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APPENDIX

Table 3.--Lumber weights of black oak sawtimber trees[1/] [2/]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3/]							
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2
	- - - - - - - - - - - - - - - -Pounds- - - - - - - - - - - - - - - - -							
10	236	340	445	549				
11	282	409	535	662	789			
12	333	484	635	785	936			
13	389	566	743	919	1,096	1,273		
14	449	654	859	1,064	1,269	1,474		
15	514	749	984	1,220	1,455	1,690	1,926	
16	582	850	1,118	1,386	1,653	1,921	2,189	
17	656	958	1,260	1,563	1,865	2,167	2,469	
18	734	1,072	1,411	1,750	2,089	2,428	2,767	3,106
19	816	1,193	1,571	1,949	2,326	2,704	3,081	3,459
20	902	1,321	1,739	2,158	2,576	2,994	3,413	3,831
21	994	1,455	1,916	2,377	2,839	3,300	3,761	4,222
22	1,089	1,595	2,102	2,608	3,114	3,620	4,127	4,633
23	1,189	1,742	2,296	2,849	3,402	3,956	4,509	5,062
24	1,294	1,896	2,499	3,101	3,703	4,306	4,908	5,511
25		2,056	2,710	3,364	4,017	4,671	5,325	5,978
26		2,223	2,930	3,637	4,344	5,051	5,758	6,465
27			3,159	3,921	4,684	5,446	6,209	6,971
28			3,396	4,216	5,036	5,856	6,676	7,496
29				4,521	5,401	6,281	7,160	8,040
30				4,838	5,779	6,720	7,662	8,603

1/ $Y = 13.43933 + 0.13074\ D^2Mh$.

2/ Blocked-in areas indicate the range of our data.

3/ Includes a 1-foot stump allowance.

Table 4.--Chippable residue weights of black oak sawtimber trees[1/] [2/]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3/]							
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2
	- - - - - - - - - - - - - - - -Pounds- - - - - - - - - - - - - - - - -							
10	261	289	317	346				
11	273	308	342	376	411			
12	287	328	369	410	451			
13	302	350	398	446	494	542		
14	319	374	430	485	541	597		
15	336	400	464	528	591	655	719	
16	355	427	500	573	645	718	790	
17	375	457	539	621	703	784	866	
18	396	488	580	671	763	855	947	1,039
19	418	520	623	725	828	930	1,032	1,135
20	442	555	668	782	895	1,009	1,122	1,236
21	466	591	716	841	967	1,092	1,217	1,342
22	492	629	767	904	1,041	1,179	1,316	1,453
23	519	669	819	969	1,119	1,269	1,419	1,569
24	548	711	874	1,038	1,201	1,364	1,528	1,691
25		754	932	1,109	1,286	1,463	1,641	1,818
26		800	991	1,183	1,375	1,566	1,759	1,950
27			1,053	1,260	1,467	1,674	1,880	2,087
28			1,118	1,340	1,562	1,785	2,007	2,229
29				1,423	1,661	1,900	2,138	2,377
30				1,509	1,764	2,019	2,274	2,530

1/ $Y = 200.51412 + 0.03545\ D^2Mh$.

2/ Blocked-in areas indicate the range of our data.

3/ Includes a 1-foot stump allowance.

Table 5.--Bark residue weights of black oak sawtimber trees[1/] [2/]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3/]							
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2
	- - - - - -	- - - - - -	- - - - - -	- - -Pounds-	- - - - - -	- - - - - -	- - - - - -	- - - - - -
10	132	158	184	210				
11	144	175	206	237	269			
12	156	193	231	268	305			
13	170	214	257	301	344	388		
14	185	235	286	337	387	438		
15	201	259	317	375	433	491	549	
16	218	284	350	416	482	548	614	
17	236	310	385	459	534	609	683	
18	255	339	422	506	589	673	756	840
19	275	368	462	555	648	741	834	927
20	297	400	503	606	709	813	916	1,019
21	319	433	547	660	774	888	1,002	1,115
22	343	468	592	717	842	967	1,092	1,217
23	367	504	640	777	913	1,050	1,186	1,322
24	393	542	690	839	987	1,136	1,284	1,433
25		581	742	904	1,065	1,226	1,387	1,548
26		622	797	971	1,145	1,320	1,494	1,668
27			853	1,041	1,229	1,417	1,605	1,793
28			912	1,114	1,316	1,518	1,720	1,923
29				1,189	1,406	1,623	1,840	2,057
30				1,267	1,499	1,731	1,963	2,196

1/ $Y = 77.43299 + 0.03224\ D^2Mh$.

2/ Blocked-in areas indicate the range of our data.

3/ Includes a 1-foot stump allowance.

Table 6.--Sawdust weights of black oak sawtimber trees[1/] [2/]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3/]							
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2
	- - - - - -	- - - - - -	- - - - - -	- - -Pounds-	- - - - - -	- - - - - -	- - - - - -	- - - - - -
10	99	116	133	150				
11	107	128	148	169	189			
12	115	140	164	189	213			
13	124	153	182	210	239	268		
14	134	167	200	234	267	300		
15	144	183	221	259	297	335	373	
16	156	199	242	286	329	373	416	
17	168	217	265	314	363	412	461	
18	180	235	290	345	400	455	510	565
19	193	255	316	377	438	499	561	622
20	207	275	343	411	479	547	614	682
21	222	297	372	447	521	596	671	746
22	238	320	402	484	566	648	730	812
23	254	344	433	523	613	702	792	882
24	271	369	466	564	661	759	857	954
25		395	500	606	712	818	924	1,030
26		422	536	651	765	880	994	1,109
27			573	697	820	944	1,067	1,191
28			612	745	877	1,010	1,143	1,276
29				794	937	1,079	1,222	1,364
30				845	998	1,150	1,303	1,456

1/ $Y = 63.40778 + 0.02119\ D^2Mh$.

2/ Blocked-in areas indicate the range of our data.

3/ Includes a 1-foot stump allowance.

Table 7.--Merchantable stem weights with bark of black oak sawtimber trees[1/] [2/]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3/]							
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2
	- - - - - - - - - - - - - - - - -Pounds- - - - - - - - - - - - - - - - -							
10	728	904	1,080	1,255				
11	807	1,019	1,232	1,444	1,657			
12	892	1,145	1,398	1,651	1,905			
13	986	1,283	1,580	1,877	2,174	2,470		
14	1,087	1,431	1,775	2,120	2,464	2,808		
15	1,195	1,590	1,986	2,381	2,776	3,172	3,567	
16	1,311	1,760	2,210	2,660	3,110	3,560	4,009	
17	1,434	1,942	2,449	2,957	3,465	3,973	4,481	
18	1,565	2,134	2,703	3,272	3,842	4,411	4,980	5,549
19	1,703	2,337	2,971	3,606	4,240	4,874	5,508	6,143
20	1,848	2,551	3,254	3,957	4,660	5,362	6,065	6,768
21	2,001	2,776	3,551	4,326	5,101	5,876	6,650	7,425
22	2,162	3,012	3,863	4,713	5,564	6,414	7,264	8,115
23	2,330	3,259	4,189	5,118	6,048	6,977	7,907	8,836
24	2,505	3,517	4,530	5,542	6,554	7,566	8,578	9,590
25		3,787	4,885	5,983	7,081	8,179	9,277	10,375
26		4,067	5,254	6,442	7,630	8,818	10,005	11,193
27			5,638	6,919	8,200	9,481	10,762	12,043
28			6,037	7,415	8,792	10,170	11,547	12,925
29				7,928	9,406	10,883	12,361	13,839
30				8,459	10,040	11,622	13,203	14,784

1/ $Y = 354.79422 + 0.21963\ D^2Mh$.

2/ Blocked-in areas indicate the range of our data.

3/ Includes a 1-foot stump allowance.

Table 8.--Merchantable stem weights without bark of black oak sawtimber trees[1/] [2/]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3/]							
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2
	- - - - - - - - - - - - - - - - -Pounds- - - - - - - - - - - - - - - - -							
10	596	746	896	1,046				
11	663	844	1,026	1,207	1,388			
12	736	952	1,168	1,384	1,600			
13	816	1,069	1,322	1,576	1,829	2,082		
14	902	1,196	1,489	1,783	2,077	2,371		
15	994	1,331	1,669	2,006	2,343	2,681	3,018	
16	1,093	1,477	1,860	2,244	2,628	3,012	3,396	
17	1,198	1,631	2,064	2,498	2,931	3,364	3,797	
18	1,310	1,795	2,281	2,767	3,252	3,738	4,224	4,710
19	1,427	1,969	2,510	3,051	3,592	4,133	4,674	5,216
20	1,552	2,151	2,751	3,351	3,950	4,550	5,149	5,749
21	1,682	2,343	3,004	3,666	4,327	4,988	5,649	6,310
22	1,819	2,545	3,270	3,996	4,721	5,447	6,173	6,898
23	1,963	2,756	3,549	4,342	5,135	5,928	6,721	7,514
24	2,112	2,976	3,839	4,703	5,566	6,430	7,293	8,157
25		3,205	4,142	5,079	6,016	6,953	7,890	8,827
26		3,444	4,458	5,471	6,484	7,498	8,511	9,525
27			4,785	5,878	6,971	8,064	9,157	10,250
28			5,126	6,301	7,476	8,651	9,827	11,002
29				6,739	8,000	9,260	10,521	11,782
30				7,192	8,541	9,890	11,240	12,589

1/ $Y = 277.36124 + 0.18739\ D^2Mh$.

2/ Blocked-in areas indicate the range of our data.

3/ Includes a 1-foot stump allowance.

Table 9.--Merchantable stem lumber volume of black oak sawtimber trees [1/] [2/]

D.h.b. (inches)	Merchantable height (number of 16-foot logs) [3/]							
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2
	Board feet							
10	31	49	67	84				
11	39	61	82	103	125			
12	48	73	99	124	149			
13	57	87	117	147	176	206		
14	67	102	136	171	206	240		
15	78	118	158	197	237	277	316	
16	90	135	180	225	270	315	361	
17	102	153	204	255	306	357	408	
18	115	172	230	287	344	401	458	515
19	129	193	256	320	384	447	511	575
20	144	214	285	355	426	496	567	637
21	159	237	315	392	470	548	625	703
22	175	261	346	431	516	602	687	772
23	192	285	379	472	565	658	751	845
24	210	311	413	514	616	717	819	920
25		338	448	559	669	779	889	999
26		366	485	605	724	843	962	1,081
27			524	652	781	909	1,038	1,166
28			564	702	840	978	1,117	1,255
29				754	902	1,050	1,198	1,346
30				807	966	1,124	1,283	1,441

[1/] $Y = -6.00562 + 0.02203\ D^2Mh$.

[2/] Blocked-in areas indicate the range of our data.

[3/] Includes a 1-foot stump allowance.

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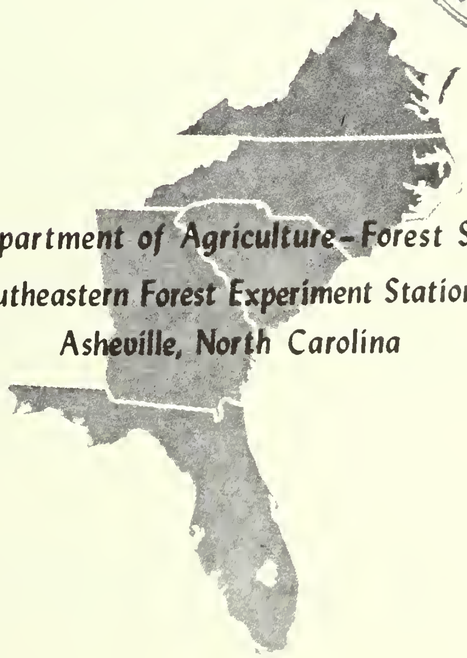

U.S. Department of Agriculture-Forest Service
Southeastern Forest Experiment Station
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Predicted Green Lumber and Residue Yields from the Merchantable Stem of Loblolly Pine

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Solid wood residues (slabs, edgings, and end trim) of the sawmill industry were at one time considered waste, but today most sawmills in the South receive significant income by chipping their residues and selling the chips to nearby pulpmills. An equitable appraisal of standing timber should consider the values of all profitable products, including these chips.

Today stumpage prices are based primarily on the income derived from a single end product of the tree, such as poles, lumber, or veneer, with little to no consideration given to chippable residues or other by-products. Chip yield factors for southern yellow pine were developed by King (1952a, 1952b), Kramer (1957), Applefield (1958, 1960), and Page and Saucier (1958), but their studies were confined to saw logs and did not apply to trees. They showed that chip yields varied with log diameter, type of wood (hardwood and softwood), and type of sawmill.

In the study reported here, a series of prediction equations was developed for estimating the amount of chippable residue as well as lumber, bark, and fine residues in loblolly pine (*Pinus taeda* L.) sawtimber trees.

PROCEDURES

A stratified sample of 48 loblolly pine trees was obtained from the Enoree District of the Sumter National Forest near Newberry, South Carolina. Eight trees were selected for each even-inch d.b.h. class from 10 to 20 inches. Only trees within ½ inch of the center point of each diameter class were sampled; i.e., 10-inch d.b.h. = 9.6-10.5 inches, 12-inch d.b.h. = 11.6-12.5 inches, etc. An attempt was made to get a wide range of tree heights within each diameter class.

This study was conducted by the Southeastern Forest Experiment Station with the cooperation and financial assistance of the Range, Timber, and Wildlife Program Area of Region 8 and the field personnel of the Enoree District of the Sumter National Forest in South Carolina. Cooperation of the Southwest Forest Industries, Inc., Newberry Division, for the use of their mill facilities, and the Timberlands Division of Champion International Corporation for use of their logging equipment is greatly appreciated.

The following tabulation shows the means and ranges in characteristics of the test trees:

Item and unit of measure	Mean	Range
D.b.h. (inches)	15.1	9.8 - 20.4
Total height (feet)	88	65 - 117
Merchantable height (feet)	63	38 - 99
Age (years)	48	32 - 66
Form class	79	69 - 87

The trees were felled and bucked into logs 8 to 16 feet long. Log length was controlled by merchantable length of the tree and the relative straightness of the stem. Merchantable top was 6 inches d.i.b., unless some defect made the stem unmerchantable below this level. Maximum and minimum d.i.b. and d.o.b. were measured on both ends of each log to the nearest 0.1 inch. Log length was recorded to the nearest 0.1 foot. The pulpwood portion of the tree between the saw-log-merchantable top and the 2-inch top was measured and weighed to the nearest 0.25 pound. The saw logs were weighed individually in the millyard before and after debarking. All weights reported in this study are green weights. No data were collected on moisture content or specific gravity.

The logs were debarked on a ring-type debarker and sawn on a circular sawmill into dimension and board lumber. During sawing, the lumber and chippable residues (slabs, edgings, and end trim) from each log were collected separately and weighed on a platform-type balance to the nearest 0.25 pound. The amount of sawdust was determined by subtraction. The lumber was also tallied by size and the actual board-foot volume computed.

The data were summarized by tree to give the following information:

(1) stem weight with bark to 6-inch top,

(2) stem weight without bark to 6-inch top,

(3) stem weight with bark to 4-inch top,

(4) stem weight with bark to 2-inch top,

(5) lumber weight in the saw-log portion of tree,

(6) chippable residue weight in saw-log portion of tree (slabs, edgings, end trim),

(7) sawdust weight, in saw-log portion of tree, and

(8) bark weight of the saw-log portion of the tree.

These data were then examined by standard regression analysis. Independent variables were: d.b.h., merchantable height, total height, form class, and various combinations or functions of these. The variable D^2Mh (d.b.h.^{2} x merchantable height) accounted for most of the variation associated with regression. The other variables were therefore dropped from consideration. The general model for all our predictions is:

$$Y = b_o + b_1 (D^2 Mh) + e$$

where:

Y = weight of the product in pounds

b_o, b_1 = regression coefficients

D = diameter at breast height in inches

Mh = merchantable height in feet

e = experimental error

RESULTS AND DISCUSSION

The total green weight of the saw-log portions of the 48 sample trees was 138,975 pounds. Of this amount, 50.3 percent was lumber, 28.5 percent was chippable residue, 7.6 percent was bark, and 13.6 percent was sawdust. The trees yielded 12,667 board feet of lumber cut to the old lumber standards, of which 88 percent was 8/4 dimension and 12 percent was 4/4 boards. Tree size strongly affected the yields of lumber and the respective residue components (table 1). Lumber yield increased as tree size increased, ranging from about 37 percent in 10-inch trees to about 55 percent in 20-inch trees. Chippable residue, on the other hand, decreased as tree size increased, ranging from a high of about 39 percent in 10-inch trees to a low of 25 percent in 20-inch trees. Bark yield, as expected, decreased as tree size increased, ranging from a high of about 9 percent to a low of 7 percent. Sawdust weight decreased slightly with increasing tree size, ranging from 14.4 percent in small trees to 12.9 percent in the large ones.

Table 1.--Average proportions of lumber, chippable residue, bark, and sawdust recovered from loblolly pine sawtimber trees, by diameter classes

D.b.h. class (inches)	Merchantable height[1]	Sample trees	Lumber tally	Merchantable stem weight with bark	Component recovery			
					Lumber	Chippable residue	Bark	Sawdust
	Feet	Number	Board feet	Pounds	Percent			
10	44	8	59	824	37.1	39.3	9.2	14.4
12	55	8	116	1,455	44.6	33.8	7.9	13.7
14	64	8	203	2,308	46.0	31.7	8.0	14.3
16	70	8	297	3,267	50.2	27.9	7.3	14.6
18	71	8	372	4,018	51.7	27.6	7.5	13.2
20	75	8	536	5,500	54.6	25.3	7.2	12.9
Study average	63		264	2,895	50.3	28.5	7.6	13.6

[1]Merchantable height to a 6-inch top (includes a 1-foot stump allowance).

Regression equations were developed for predicting the weight of each of the tree components just discussed, as well as the weight of the stem to three different top diameters, and the board-foot lumber volume. These equations together with their coefficients of determination and standard errors associated with regression are shown in table 2. The coefficients of determination, which ranged from 0.92 to 0.97, indicate our model fits the data well.

Table 2.--Regression equations for predicting green merchantable stem weight, lumber, chippable residue, sawdust, and bark weight, and lumber volume of loblolly pine trees in the Piedmont of South Carolina

Component	Regression equation	Standard error of estimate ($S_{y \cdot x}$)	Coefficient of determination (R^2)
Stem weight (pounds) to			
6-inch top with bark	$Y = 58.79856 + 0.17533\ (D^2Mh)$[1]	298.6	0.97
4-inch top with bark	$Y = 201.87332 + 0.17417\ (D^2Mh)$	332.5	0.96
2-inch top with bark	$Y = 231.15616 + 0.17377\ (D^2Mh)$	334.3	0.96
6-inch top without bark	$Y = 35.32403 + 0.16327\ (D^2Mh)$	288.8	0.97
Lumber weight (pounds)	$Y = -151.81303 + 0.09940\ (D^2Mh)$	251.7	0.93
Chippable residue weight (pounds)	$Y = 160.04149 + 0.04119\ (D^2Mh)$	98.3	0.94
Sawdust weight (pounds)	$Y = 27.09557 + 0.02269\ (D^2Mh)$	53.3	0.93
Bark weight (pounds)	$Y = 23.47453 + 0.01205\ (D^2Mh)$	34.5	0.92
Lumber volume (board feet)	$Y = -23.26196 + 0.01775\ (D^2Mh)$	38.2	0.95

[1]D = d.b.h. in inches; Mh = merchantable height in feet to a 6-inch top (includes a 1-foot allowance for stump height).

We tried to develop equations for predicting the amount of pulpwood above the merchantable saw-log top. This effort failed because of the extreme variation in the amount of pulpwood between the merchantable saw-log top and the 4- and 2-inch tops. Equations were therefore developed to predict tree stem weight to a 4- and a 2-inch top (table 2). Pulpwood yields can be computed with these equations by first applying the equation to a 6-inch top and getting a tree weight, and then applying the equation for the 4- or 2-inch top. The difference in total weight computed from the two equations is an estimate of the weight of pulpwood above the merchantable saw-log top. On the average, there were 124 pounds of pulpwood including bark from the 6- to 4-inch top and 147 pounds from the 6- to 2-inch top.

Predicted yields for the stem to a 6-, 4-, and 2-inch top, as well as the yields of lumber, bark, chippable residue, and sawdust, are shown in Appendix tables 3-11. Appendix tables 3, 5, and 6 can also be used to estimate the amount of pulpwood available above a 6-inch top by merely subtracting the values in table 3 from those in table 5 or 6 for trees of comparable size. The blocked-in areas in these tables indicate the range of our data.

In addition to the equations and tables, we developed the following conversion factors: green wood weight per cubic foot, pounds of chips per board foot of lumber produced, pounds of chips per cubic foot of log input, pounds of sawdust per board foot of lumber produced, pounds of bark per board foot of lumber produced, board feet of output per cubic foot of log input (lumber recovery factor). These factors are shown for each tree diameter class in Appendix table 12.

Green wood weight per cubic foot increased markedly with increasing tree size, ranging from 50.4 pounds per cubic foot in small trees (10 inches) to 57.8 pounds per cubic foot in large trees (20 inches). Thus, green weight per cubic foot changed 13 percent with increasing tree size. The average green wood weight per cubic foot for the study was 55.0 pounds. Green weight of a board foot of lumber was somewhat variable, but also increased about 0.4 pound per board foot as tree size increased. Although this change appears minor, it represents about a 7 percent change in weight. Average weight per board foot of lumber was 5.5 pounds.

Chip yields per board foot of lumber produced and chip yields per cubic foot of log input both decreased as tree size increased. Chip yield per board foot decreased from 5.6 pounds in small trees to 2.6 pounds in the larger trees, and averaged 3.7 pounds. Chip yields per cubic foot of wood input decreased from 21.7 pounds to 15.7 pounds and averaged 17.4 pounds.

Sawdust per board foot decreased as tree size increased, decreasing from 2.0 pounds per board foot for small trees to 1.3 pounds per board foot in the larger trees. Bark per board foot of lumber produced decreased with tree size from 1.3 pounds per board foot to 0.7 pound per board foot.

Lumber recovery factors for the study increased with tree size from 4.0 board feet per cubic foot in the small trees to about 6.1 board feet per cubic foot in the large trees (Appendix table 12). Average for the study was 5.2, which is 0.5 unit lower than that reported for sawmills in the Southeast, and 1.3 units lower than the average reported for sawmills in the United States.

The weight factors presented here are not necessarily applicable over the entire range of the species. Timber from other geographic areas may have a different form as well as a different green weight per cubic foot, which could affect the precision of these data considerably. The type of sawmill and its relative efficiency also can affect tree yields. For optimum predicting performance, these equations should be applied to timber of the same general character from a similar geographic area.

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APPENDIX

Table 3.--Loblolly pine stem weight with bark to 6-inch d.i.b. top[1] [2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]									
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6
	Pounds									
10	497	637	778	918	1,058					
11	589	759	929	1,098	1,268	1,438				
12	690	892	1,094	1,296	1,498	1,700	1,902			
13	800	1,037	1,274	1,511	1,748	1,985	2,222	2,459		
14	918	1,193	1,468	1,743	2,018	2,293	2,567	2,842	3,117	
15	1,045	1,361	1,676	1,992	2,307	2,623	2,939	3,254	3,570	3,885
16	1,181	1,540	1,899	2,258	2,617	2,976	3,335	3,694	4,054	4,413
17	1,326	1,731	2,136	2,542	2,947	3,352	3,758	4,163	4,568	4,974
18		1,933	2,388	2,842	3,297	3,751	4,206	4,660	5,115	5,569
19		2,148	2,654	3,160	3,667	4,173	4,679	5,186	5,692	6,198
20			2,934	3,495	4,056	4,617	5,178	5,739	6,301	6,852
21				3,848	4,466	5,085	5,703	6,322	6,940	7,559

[1] $Y = 58.79856 + 0.17533\ D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 4.--Loblolly pine stem weight without bark to 6-inch d.i.b. top[1] [2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]									
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6
	Pounds									
10	443	574	705	835	966					
11	529	687	845	1,003	1,161	1,319				
12	623	811	999	1,187	1,375	1,564	1,752			
13	725	946	1,167	1,387	1,608	1,829	2,050	2,270		
14	835	1,091	1,347	1,603	1,859	2,115	2,371	2,627	2,883	
15	954	1,248	1,541	1,835	2,129	2,423	2,717	3,011	3,305	3,599
16	1,080	1,415	1,749	2,083	2,418	2,752	3,087	3,421	3,755	4,090
17	1,215	1,592	1,970	2,347	2,725	3,102	3,480	3,857	4,235	3,612
18		1,781	2,204	2,627	3,051	3,474	3,897	4,320	4,743	5,167
19		1,980	2,452	2,923	3,395	3,866	4,338	4,809	5,281	5,753
20			2,713	3,235	3,758	4,280	4,803	5,325	5,848	6,370
21				3,563	4,139	4,715	5,291	5,867	6,444	7,020

[1] $Y = 35.32403 + 0.16327\ D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 5.--Loblolly pine stem weight with bark to 4-inch d.i.b. top[1] [2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]									
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6
	Pounds									
10	637	777	916	1,055	1,195					
11	729	897	1,066	1,235	1,403	1,572				
12	829	1,030	1,230	1,431	1,631	1,832	2,033			
13	938	1,173	1,409	1,644	1,880	2,115	2,351	2,586		
14	1,055	1,328	1,602	1,875	2,148	2,421	2,694	2,967	3,240	
15	1,182	1,495	1,809	2,122	2,436	2,749	3,063	3,376	3,690	4,003
16	1,317	1,673	2,030	2,387	2,743	3,100	3,457	3,813	4,170	4,527
17	1,460	1,863	2,266	2,668	3,071	3,474	3,876	4,279	4,682	5,084
18		2,064	2,516	2,967	3,418	3,870	4,321	4,773	5,224	5,676
19		2,277	2,780	3,283	3,786	4,289	4,792	5,295	5,798	6,301
20			3,058	3,616	4,173	4,730	5,288	5,845	6,402	6,960
21				3,966	4,580	5,194	5,809	6,423	7,038	7,652

[1] $Y = 201.87332 + 0.17417\ D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 6.--Loblolly pine stem weight with bark to 2-inch d.i.b. top[1] [2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]									
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6
	Pounds									
10	666	805	944	1,083	1,222					
11	757	925	1,093	1,261	1,430	1,598				
12	857	1,057	1,257	1,457	1,657	1,858	2,058			
13	965	1,200	1,435	1,670	1,905	2,140	2,375	2,610		
14	1,083	1,355	1,628	1,900	2,173	2,445	2,717	2,990	3,262	
15	1,209	1,521	1,834	2,147	2,460	2,773	3,085	3,398	3,711	4,024
16	1,343	1,699	2,055	2,411	2,767	3,123	3,479	3,834	4,190	4,546
17	1,487	1,888	2,290	2,692	3,094	3,495	3,897	4,299	4,701	5,102
18		2,089	2,540	2,990	3,440	3,891	4,341	4,792	5,242	5,692
19		2,301	2,803	3,305	3,807	4,309	4,811	5,312	5,814	6,316
20			3,081	3,637	4,193	4,749	5,305	5,861	6,417	6,973
21				3,986	4,599	5,212	5,825	6,438	7,051	7,665

[1] $Y = 231.15616 + 0.17377 D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 7.--Loblolly pine lumber weight[1] [2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]									
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6
	Pounds									
10	97	176	256	335	415					
11	149	245	341	438	534	630				
12	206	321	435	550	664	779	893			
13	268	403	537	671	806	940	1,074	1,209		
14	335	491	647	803	959	1,115	1,270	1,426	1,582	
15	407	586	765	944	1,123	1,302	1,481	1,660	1,839	2,018
16	484	688	891	1,095	1,299	1,502	1,706	1,909	2,113	2,316
17	566	796	1,026	1,256	1,486	1,715	1,945	2,175	2,405	2,635
18		911	1,169	1,426	1,684	1,942	2,199	2,457	2,714	2,972
19		1,032	1,319	1,606	1,894	2,181	2,468	2,755	3,042	3,329
20			1,478	1,796	2,115	2,433	2,751	3,069	3,387	3,705
21				1,996	2,347	2,697	3,048	3,399	3,750	4,100

[1] $Y = -151.81303 + 0.09940 D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 8.--Loblolly pine chippable residue weight[1] [2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]									
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6
	Pounds									
10	263	296	329	362	395					
11	285	325	364	404	444	484				
12	308	356	403	451	498	546	593			
13	334	390	445	501	557	613	668	724		
14	362	426	491	556	620	685	749	814	879	
15	392	466	540	614	688	762	837	911	985	1,059
16	424	508	592	677	761	845	930	1,014	1,099	1,183
17	458	553	648	743	839	934	1,029	1,124	1,219	1,315
18		600	707	814	921	1,028	1,134	1,241	1,348	1,455
19		651	770	889	1,008	1,127	1,246	1,364	1,483	1,602
20			836	967	1,099	1,231	1,363	1,495	1,626	1,758
21				1,050	1,195	1,341	1,486	1,631	1,777	1,922

[1] $Y = 160.04149 + 0.04119\ D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 9.--Loblolly pine sawdust weight[1] [2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]									
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6
	Pounds									
10	84	102	120	138	156					
11	96	118	140	162	184	206				
12	109	135	161	187	213	240	266			
13	123	154	184	215	246	276	307	338		
14	138	174	209	245	281	316	352	387	423	
15	155	196	236	277	318	359	400	441	482	522
16	172	219	265	312	358	405	451	498	544	591
17	191	244	296	348	401	453	506	558	611	663
18		270	329	387	446	505	564	623	681	740
19		297	363	429	494	560	625	691	756	822
20			399	472	544	617	690	762	835	908
21				517	597	678	758	838	918	998

[1] $Y = 27.09557 + 0.02269\ D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 10.--Loblolly pine bark weight[1 2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]									
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6
	Pounds									
10	54	63	73	83	92					
11	60	72	83	95	107	118				
12	67	81	95	108	122	136	150			
13	74	91	107	123	140	156	172	188		
14	83	101	120	139	158	177	196	215	234	
15	91	113	135	156	178	200	221	243	265	286
16	101	125	150	175	199	224	249	273	298	323
17	111	138	166	194	222	250	278	306	333	361
18		152	184	215	246	277	308	340	371	402
19		167	202	237	271	306	341	376	411	445
20			221	260	298	337	375	414	452	491
21				284	326	369	411	454	496	539

[1] $Y = 23.47453 + 0.01205 D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 11.--Loblolly pine lumber volume[1 2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]									
	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6
	Board feet									
10	21	35	50	64	78					
11	30	48	65	82	99	116				
12	41	61	82	102	122	143	163			
13	52	76	100	124	148	172	196	220		
14	64	92	119	147	175	203	231	259	286	
15	77	109	140	172	204	236	268	300	332	364
16	90	127	163	199	236	272	308	345	381	418
17	105	146	187	228	269	310	351	392	433	474
18		167	213	259	305	351	397	443	489	535
19		188	239	291	342	393	445	496	547	598
20			268	325	381	438	495	552	609	665
21				360	423	486	548	611	673	736

[1] $Y = -23.26196 + 0.01775 D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 12.--Average loblolly pine green-weight factors by tree-diameter classes

D.b.h. class (inches)	Merchantable height	Component weight						Lumber recovery factor
		Lumber	Chippable residue	Bark residue	Sawdust	Stemwood	Chippable residue	
	Feet	- - - - Pounds/board foot - - - -				Pounds/cubic foot		Board feet/cubic foot
10	44	5.2	5.6	1.3	2.0	50.4	21.7	4.0
12	55	5.6	4.4	1.0	1.7	53.8	19.7	4.6
14	64	5.2	3.6	0.9	1.6	54.3	18.7	5.2
16	70	5.5	3.1	0.8	1.6	57.2	17.2	5.6
18	71	5.6	3.0	0.8	1.4	56.6	17.2	5.7
20	75	5.6	2.6	0.7	1.3	57.8	15.7	6.1
Study average		5.5	3.7	0.9	1.6	55.0	17.4	5.2

Taras, Michael A., Schroeder, James G., and Phillips, Douglas R.
1974. Predicted green lumber and residue yields from the merchantable stem of loblolly pine. USDA For. Serv. Res. Pap. SE-121, 11 p. Southeast. For. Exp. Stn., Asheville, N.C.

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The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

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Slash Pine Sawtimber Stem Weights and Sawmill Residue Yields

by
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In the South, short-log logging and stick scaling have been replaced by tree length logging and weight scaling. Slabs and edgings are no longer found in the South because mill residues are now chipped and sold for processing into fiber and particle wood products. Logs are now debarked before sawing and bark residue is marketed as a soil amender, mulch, or ground cover. Because of these advances in harvesting, scaling, and utilization, prediction equations and yield tables are needed for estimating individual stem weights and sawmill residue yields.

Such equations and weight tables have been developed for natural stands of loblolly pine, shortleaf pine, and longleaf pine by Taras et al. 1974, Phillips and Schroeder 1975, and Schroeder et al. 1975. McGee (1959) developed stem weight tables for plantation-grown slash pine in the sandhills of the Carolinas. Little information, however, is available on the stem weight of slash pine sawtimber grown in natural stands.

Several studies have been conducted on sawmill residue yields from southern pine saw logs (King 1952; Todd and Anderson 1955; Applefield 1958, 1960; Page and Saucier 1958; Row et al. 1965), but these data cannot be applied to trees. Equations are available for predicting chip residue yields from loblolly, shortleaf, and longleaf trees (Taras et al. 1974; Phillips and Schroeder 1975; Schroeder et al. 1975), but no equations are available for predicting sawmill residue yields from slash pine (*Pinus elliottii* Engelm. var. *elliottii*) trees. The published reports indicate that proportions of stem weight that become lumber, chippable residue, and bark residue vary with tree size and that the weights of these primary products from the same size tree vary by species due to differences in specific gravity and moisture content.

This paper reports prediction equations and yield tables for estimating chippable residue, bark residue, lumber, and sawdust produced from slash sawtimber trees. It also reports cubic-foot volumes, board-foot volumes, and weights of the main stem with and without bark.

This study was conducted by the Southeastern Forest Experiment Station in cooperation with and through the financial assistance of the Range, Timber, and Wildlife Program Area of Region 8 of the National Forest System. Field personnel were provided by the Conecuh District of the Conecuh National Forest. Cooperation and assistance were also received from the Windam Lumber Company.

PROCEDURE

A stratified random sample of 43 slash pine sawtimber trees was selected from a natural, uneven-aged slash pine stand with a site index of 70 on the Conecuh National Forest in southern Alabama. Eight trees from each even-inch d.b.h. class from 10 to 18 inches, one tree from the 20-inch d.b.h. class, and two trees from the 21-inch d.b.h. class were selected. Sample trees had an average d.b.h. of 14.6 inches and an average height of 50 feet to a 6-inch merchantable top. Means and ranges of the tree characteristics are shown in the following tabulation:

Item and unit of measure	Mean	Range
D.b.h. (inches)	14.6	9.6 - 21.0
Total height (feet)	78	52 - 99
Height to 6-inch or merchantable top (feet)	50	30 - 68
Form class	82	69 - 94
Age (years)	56	32 - 69

Each sample tree was felled, limbed, and bucked into merchantable saw logs and pulpwood. Saw logs 8 to 16 feet long were cut from the main stem to a 6-inch d.i.b. or merchantable top. Since large knots and branches stopped saw-log merchantability below a 6-inch top in large trees, stem top diameter averaged 8 inches in this study. All stem material from the saw-log-merchantable top to 2 inches d.i.b. was classed as pulpwood. Maximum and minimum diameters were measured on both ends of each log, and log length was recorded. Pulpwood was weighed in the field using portable scales. Each saw log was weighed individually at the mill before and after debarking with a rosser head debarker.

The debarked logs were sawn into 4/4 and 8/4 lumber on a conventional 5/16-inch circular saw headrig with an in-line circular edger and trim saws. During sawing, chippable residue (slabs, edgings, and end trim) from each log was collected and weighed. Lumber cut from each log was weighed and tallied by size and grade.[1] Sawdust weight was determined by subtracting weight of chippable residue and lumber from debarked log weight.

Wood and bark moisture content and specific gravity were determined from disks taken at each saw-log bucking point and at the 4- and 2-inch d.i.b. tops. Cross sections removed at 6, 4, and 2 inches d.i.b. were used to determine bark percent for pulpwood. Moisture content samples were dried to a constant weight at 103° C., and the results expressed as a percent of ovendry weight. Specific gravity is based on green volume and ovendry weight. Weighted values for moisture content and specific gravity of wood and bark were calculated by weighting cross-section values in proportion to the volume of the component they represented.

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[1] Lumber graded by Southern Pine Inspection Bureau certified grader.

Cubic volumes of the saw-log and pulpwood sections were computed by Smalian's formula:

$$\text{Stem cubic foot volume, } V = \left(\frac{B + b}{2}\right) L$$

where:

V = volume in cubic feet

B = area of disk from base of log in square feet

b = area of disk from top of log in square feet

L = length of log in feet

To adjust for taper in the butt log, its volume was computed by applying Smalian's formula to two sections within the log--one section consisting of the butt 4 feet and the second, the remainder. The volumes of the saw-log and pulpwood sections were summarized to determine tree cubic volume.

Regression equations were developed to predict green weight of chippable residue, bark residue, lumber, and sawdust, and the green board-foot volume of lumber produced from the saw-log portion of the stem. Equations were also developed to predict cubic-foot volume and weight of the main stem to the 6- and 2-inch d.i.b. tops. Independent variables examined in various combinations were d.b.h., merchantable height, total height, and form class. The variable D^2Mh (dbh^2 x merchantable height) accounted for most of the variation associated with regression. Component weights were estimated with the equation:

$$Y = b_o + b_1 D^2Mh + e \qquad (1)$$

where:

Y = green weight or volume of component

b_o, b_1 = regression coefficients

D = diameter outside bark at breast height in inches

Mh = merchantable height in feet

e = experimental error.

Since grouping of the data into D^2Mh classes indicated that the variance of Y increased with increasing D^2Mh, a weighted model was developed to make the variance more nearly homogeneous and meet the basic assumptions of regression analysis. A weighting factor inversely proportional to the variance of the residuals was developed for each component by Schreuder and Swank's procedure (1971). An average of the weighting factors was computed and applied to all prediction equations so that component equations would be additive. Green weight or volume of each component was computed with the equation:

$$\frac{Y}{(D^2Mh)^{0.4}} = \frac{b_o}{(D^2Mh)^{0.4}} + b_1(D^2Mh)^{0.6}$$

Appropriate coefficients for each tree component were estimated by least squares regression analysis, and each equation was algebraically transformed back to its original form.

RESULTS AND DISCUSSION

Stem Weight and Residue Yields

Stem weight ranged from 1,013 pounds in 10-inch trees to 5,478 pounds in the 21-inch trees. The average 10-inch tree contained 857 pounds of saw logs and 156 pounds of pulpwood, compared to the average 21-inch tree which contained 5,104 pounds of saw logs and 374 pounds of pulpwood (table 1). Proportion of the stem in saw logs generally increased and proportion in pulpwood generally decreased with increasing tree size. On the average, 90 percent of the stem was saw logs and 10 percent pulpwood. Pulpwood contained an average 12 percent bark and 88 percent wood.

The saw-log portion of the trees yielded 51 percent lumber, 22 percent chippable residue, 10 percent bark residue, and 17 percent sawdust.

Table 1.--Average weight of main stem and stem components by d.b.h. classes for slash pine sawtimber trees

D.b.h. class (inches)	Average Merchantable height[1]	Sample trees	Stem weight with bark (butt to 2-inch top)	Weight of stem components with bark	
				Saw logs (butt to 6-inch top)	Pulpwood (6 to 2-inch top)
	Feet	Number	- - - - - - - - - - Pounds	- - - - - - - - - -	
10	40	8	1,013	857	156
12	45	8	1,572	1,367	205
14	51	8	2,257	2,059	198
16	57	8	3,346	2,959	387
18	57	8	4,224	3,860	364
20	40	1	4,372	3,623	749
21	46	2	5,478	5,104	374

[1]Includes a 1-foot stump allowance.

The proportion of the tree in lumber and mill residue varied with tree size (table 2). Lumber yield increased as tree size increased, ranging from 44 to 46 percent in 10- and 12-inch trees to between 52 and 54 percent in 18- and 21-inch trees. Chippable residue decreased as tree size increased and ranged from 25 to 28 percent in small trees to 20 to 22 percent in large trees. The proportion of the saw-log bark residue ranged from 12 percent in small trees to 9 percent in large trees. Bark residue includes an estimated 2 to 3 percent wood removed during debarking on the rosser-head debarker. Sawdust produced averaged 16 to 17 percent regardless of tree size. The trends found in this study in the yields of lumber, chippable residue, bark residue, and sawdust with increasing tree size were identical to those found by Taras et al. (1974), Phillips and Schroeder (1975), and Schroeder et al. (1975) in loblolly, shortleaf, and longleaf pines. In trees of the same size, however, the product mix varies because of differences in species form, sawmill equipment, and sawing practices.

Table 2.--Average saw-log stem weight, volume, lumber tally, and proportions of lumber, chippable residue, bark residue, and sawdust recovered for slash pine sawtimber trees, by d.b.h. class

D.b.h. class (inches)	Merchantable height[1]	Sample trees	Stem weight	Primary product recovery				Lumber tally	Stem wood volume	Lumber recovery factor
				Lumber	Chippable residue	Bark residue	Sawdust			
	Feet	Number	Pounds	Percent				Board feet	Cubic feet	Board feet/ cubic foot
10	40	8	857	46	25	12	17	70	12.8	5.5
12	45	8	1,367	44	28	11	17	111	20.9	5.3
14	51	8	2,059	50	23	11	16	180	31.0	5.8
16	57	8	2,959	51	22	10	17	300	47.5	6.3
18	57	8	3,860	54	20	9	17	398	61.2	6.5
20	40	1	3,623	51	22	11	16	359	57.7	6.2
21	46	2	5,104	52	22	9	17	505	80.2	6.3
Study average			2,387	51	22	10	17	229	37.3	6.1

[1] Includes a 1-foot stump allowance.

In this study, saw-log stem wood volume ranged from 12.8 cubic feet in the 10-inch trees which yielded 70 board feet of lumber to 80.2 cubic feet in the 21-inch trees which produced 505 board feet of lumber. The lumber recovery factor (L.R.F.)[2] increased with tree size up to 18 inches and then decreased slightly. The average L.R.F. ranged from 5.3 board feet per cubic foot in 12-inch trees to 6.5 board feet per cubic foot in 18-inch trees and averaged 6.1 board feet per cubic foot for the study.

PREDICTION EQUATIONS

Regression equations developed to predict weight of green lumber, chippable residue, bark residue, sawdust, and green lumber volume are presented in table 3. Also shown in table 3 are equations to predict stem weight with and without bark, bark weight alone, and stemwood cubic volume to 6- and 2-inch tops. The coefficient of determination and the standard error of the estimate are shown for each equation. The weighted form of d.b.h. and merchantable height accounted for 97 to 99 percent of the variation associated with regression, as indicated by the coefficients of determination.

Equations were developed for predicting weights of pulpwood above the merchantable saw-log top, but these equations are not included in this paper. Pulpwood equations were poor predictors because amount of pulpwood above the saw-log top varies considerably due to defects which stop saw-log merchantability short of 6 inches. On the average, there were 278 pounds of pulpwood from a 6 to a 2 inch top, of which 33 pounds were bark and 245 pounds were wood.

[2] Lumber recovery factor is the ratio of actual lumber volume recovered to the cubic volume of the piece processed; expressed as board feet/cubic foot.

Table 3.--Regression equations for predicting green weight of lumber, chippable residue, sawdust, bark residue, merchantable stem with and without bark, and the cubic-foot and board-foot volume of the stem of slash pine trees

Component	Equation	Coefficient of determination (R^2)	Standard error of estimate ($S_{y \cdot x}$)
Primary product weight (pounds)			
Chippable residue	$Y = 90.31049 + 0.03801\ D^2Mh$	0.98	1.96
Bark residue	$Y = 37.91741 + 0.01760\ D^2Mh$	0.98	0.82
Lumber	$Y = -85.39280 + 0.11137\ D^2Mh$	0.99	3.11
Sawdust	$Y = 7.92778 + 0.03389\ D^2Mh$	0.99	0.81
Lumber volume (board feet)	$Y = -23.68030 + 0.02172\ D^2Mh$	0.99	0.61
Stem weight with bark (pounds) to			
6-inch top d.i.b.	$Y = 50.76288 + 0.20087\ D^2Mh$	0.99	4.48
2-inch top d.i.b.	$Y = 168.20601 + 0.21466\ D^2Mh$	0.99	6.82
Stem weight without bark (pounds) to			
6-inch top d.i.b.	$Y = 12.84547 + 0.18327\ D^2Mh$	0.99	4.04
2-inch top d.i.b.	$Y = 114.85346 + 0.19552\ D^2Mh$	0.99	5.94
Stem bark weight (pounds) to			
2-inch top d.i.b.	$Y = 53.35255 + 0.01914\ D^2Mh$	0.97	1.15
Stem volume without bark (cubic feet) to			
6-inch top d.i.b.	$Y = -0.32985 + 0.00323\ D^2Mh$	0.99	0.07
2-inch top d.i.b.	$Y = 1.20418 + 0.00344\ D^2Mh$	0.99	0.11

Wood Properties

Weight per cubic foot of green wood based on weighted specific gravity and moisture content values from sample disks averaged 58.1 pounds in the saw-log portion of the stem, 60.1 pounds in the pulpwood portion, and 58.4 pounds for the total stem (table 4). Although the average green weight per cubic foot of pulpwood was 2 pounds higher than saw-log green weight per cubic foot, the pulpwood contained 11 percent less dry wood per cubic foot because it had a significantly lower specific gravity (0.461 compared to 0.519). Moisture content of the saw-log portion of the stem was 80 percent compared to 110 percent in the pulpwood portion. Specific gravity, moisture content, and green weight per cubic foot of saw logs, pulpwood, and total stemwood varied randomly with increasing tree size.

Bark green weight per cubic foot averaged 33.4 pounds, 41.4 pounds, and 34.2 pounds, respectively, for saw log, pulpwood, and total stem (table 4). Since the bark in the upper bole was denser and had a higher proportion of moisture, the specific gravity, moisture content, and green weight per cubic foot of pulpwood bark was significantly higher than saw-log or total stem bark. Specific gravity of bark on saw logs and total stems and green weight per cubic foot decreased as tree size increased. For example, saw-log bark specific gravity decreased from 0.380 in the 10-inch trees to 0.338 in the 21-inch trees. This decrease in bark specific gravity and resulting decrease in green weight per cubic foot was because the larger, older trees contain a large proportion of dry, low specific gravity outer bark. The specific gravity, moisture content, and green weight per cubic foot of pulpwood bark did not vary with tree size.

Table 4.--Average specific gravity, moisture content, and green weight per cubic foot of saw logs, pulpwood, and total stem for slash pine sawtimber trees sampled

Stem component	Average and standard deviation		
	Specific gravity	Moisture content	Green weight per cubic foot
		Percent	Pounds
	WOOD		
Saw log	.519 ± .028	80 ± 10	58.1 ± 3.2
Pulpwood	.461 ± .032	110 ± 19	60.1 ± 4.2
Total stem	.514 ± .026	82 ± 11	58.4 ± 3.2
	BARK		
Saw log	.364 ± .031	47 ± 8	33.4 ± 3.1
Pulpwood	.394 ± .035	68 ± 20	41.4 ± 4.8
Total stem	.367 ± .030	49 ± 8	34.2 ± 3.1

Yield Tables

The equations presented in table 3 were used to develop yield tables for predicting primary product weight, stem weight with and without bark, and stem and lumber cubic volumes given d.b.h. and merchantable height. Predicted green weight of chippable residue, bark residue, sawdust, and lumber for trees 10 to 22 inches are presented in tables 5-8 of the Appendix. Predicted green lumber volume yields in board feet are presented in Appendix table 9. Green weight of the merchantable stem with and without bark, weight of bark alone, as well as cubic-foot volume of wood in the stem to a 6- and 2-inch top are presented in Appendix tables 10-16. Estimates of pulpwood can be computed by subtracting predicted merchantable stem weight to a 6-inch top from predicted weight to a 2-inch top for comparable sized trees.

Tree stems with the same d.b.h. and merchantable height measurements can vary considerably in weight because of differences in moisture content and specific gravity and in cubic volume because of varying taper rates. Thus, yield tables presented in this paper should not be used indiscriminately over the range of slash pine. These tables should be applied to trees in natural stands which will be cut at a circular mill and have taper rates and wood properties similar to the trees sampled to develop the tables.

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APPENDIX

Table 5.--Weight of chippable residue from slash pine saw-log-merchantable stem to 6-inch d.i.b. top[1] [2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	155	185	216	246	277	307			
11	168	205	242	279	316	352			
12	183	227	271	315	359	402	446		
13	200	251	302	354	405	456	508	559	
14	217	277	336	396	455	515	575	634	694
15	236	304	373	441	509	578	646	715	783
16		334	411	489	567	645	723	801	878
17		365	453	541	629	716	804	892	980
18		398	497	595	694	792	891	989	1,088
19			543	653	763	872	982	1,092	1,202
20			592	714	835	957	1,079	1,200	1,322
21			643	778	912	1,046	1,180	1,314	1,448
22			697	845	992	1,139	1,286	1,433	1,580

[1] $Y = 90.31049 + 0.03801\ D^2Mh$.
[2] Blocked-in areas indicate the range of our data.
[3] Includes a 1-foot stump allowance.

Table 6.--Weight of bark residue from slash pine saw-log-merchantable stem to 6-inch d.i.b. top[1] [2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	68	82	96	110	124	138			
11	74	91	108	125	142	159			
12	81	101	122	142	162	182	203		
13	88	112	136	160	184	207	231	255	
14	97	124	152	179	207	235	262	290	317
15	105	137	169	200	232	264	295	327	359
16		151	187	223	259	295	331	367	403
17		165	206	246	287	328	369	409	450
18		180	226	272	317	363	409	454	500
19			248	298	349	400	451	502	553
20			270	327	383	439	496	552	608
21			294	356	418	480	542	605	667
22			319	387	455	523	592	660	728

[1] $Y = 37.91741 + 0.01760\ D^2Mh$.
[2] Blocked-in areas indicate the range of our data.
[3] Includes a 1-foot stump allowance.

Table 7.--Weight of sawdust from slash pine saw-log-merchantable stem to 6-inch d.i.b. top[1 2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	66	93	120	147	174	201			
11	78	110	143	176	209	242			
12	91	130	169	208	247	286	325		
13	105	151	197	243	289	334	380	426	
14	121	174	227	280	333	387	440	493	546
15	138	199	260	321	382	443	504	565	626
16		225	294	364	433	502	572	641	711
17		253	331	409	488	566	645	723	801
18		282	370	458	546	634	722	809	897
19			412	510	607	705	803	901	999
20			455	564	672	781	889	998	1,106
21			501	621	740	860	979	1,099	1,219
22			549	680	812	943	1,074	1,205	1,337

[1] $Y = 7.92778 + 0.03389\ D^2Mh$.

[2] Blocked-in areas indicate the range of our data.

[3] Includes a 1-foot stump allowance.

Table 8.--Weight of lumber produced from slash pine saw-log-merchantable stem to 6-inch d.i.b. top[1 2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	104	193	282	371	460	549			
11	144	252	359	467	575	683			
12	187	316	444	572	700	829	957		
13	235	385	536	686	837	987	1,138	1,289	
14	286	460	635	810	984	1,159	1,333	1,508	1,683
15	341	541	742	942	1,142	1,343	1,543	1,744	1,944
16		627	855	1,084	1,312	1,540	1,768	1,996	2,224
17		719	977	1,234	1,492	1,749	2,007	2,264	2,522
18		817	1,105	1,394	1,683	1,971	2,260	2,549	2,837
19			1,241	1,563	1,885	2,206	2,528	2,850	3,171
20			1,385	1,741	2,097	2,454	2,810	3,167	3,523
21			1,535	1,928	2,321	2,714	3,107	3,500	3,893
22			1,693	2,125	2,556	2,987	3,418	3,850	4,281

[1] $Y = -85.39280 + 0.11137\ D^2Mh$.

[2] Blocked-in areas indicate the range of our data.

[3] Includes a 1-foot stump allowance.

Table 9.--Volume of lumber produced from slash pine saw-log-merchantable stem to 6-inch d.i.b. top[1] [2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Board feet								
10	13	31	48	65	83	100			
11	21	42	63	84	105	126			
12	29	55	80	105	130	155	180		
13	39	68	97	127	156	186	215	244	
14	49	83	117	151	185	219	253	287	321
15	59	98	138	177	216	255	294	333	372
16		115	160	204	249	293	338	382	427
17		133	183	234	284	334	384	435	485
18		152	209	265	321	377	434	490	546
19			235	298	361	423	486	549	611
20			263	333	402	472	541	611	680
21			292	369	446	522	599	676	752
22			323	407	491	576	660	744	828

[1] $Y = -23.68030 + 0.02172\ D^2Mh$.
[2] Blocked-in areas indicate the range of our data.
[3] Includes a 1-foot stump allowance.

Table 10.--Slash pine saw-log stem weight with bark to 6-inch d.i.b. top[1] [2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	392	553	714	874	1,035	1,196			
11	464	658	853	1,047	1,242	1,436			
12	542	774	1,005	1,237	1,468	1,700	1,931		
13	628	899	1,171	1,443	1,714	1,986	2,257	2,529	
14	720	1,035	1,350	1,665	1,980	2,296	2,610	2,925	3,240
15	819	1,181	1,542	1,904	2,265	2,627	2,988	3,350	3,712
16		1,336	1,748	2,159	2,570	2,982	3,393	3,805	4,216
17		1,502	1,966	2,431	2,895	3,360	3,824	4,289	4,753
18		1,678	2,198	2,719	3,240	3,760	4,281	4,802	5,322
19			2,444	3,024	3,604	4,184	4,764	5,344	5,924
20			2,702	3,345	3,988	4,631	5,273	5,916	6,559
21			2,974	3,683	4,391	5,100	5,809	6,517	7,226
22			3,259	4,037	4,815	5,592	6,370	7,148	7,926

[1] $Y = 50.76288 + 0.20087\ D^2Mh$.
[2] Blocked-in areas indicate the range of our data.
[3] Includes a 1-foot stump allowance.

Table 11.--Slash pine saw-log stem weight without bark to 6-inch d.i.b. top[1 2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	324	471	618	764	911	1,057			
11	390	567	745	922	1,099	1,277			
12	461	673	884	1,095	1,306	1,517	1,728		
13	539	787	1,035	1,283	1,531	1,778	2,026	2,274	
14	624	911	1,198	1,486	1,773	2,060	2,348	2,635	2,922
15	714	1,044	1,374	1,704	2,033	2,363	2,693	3,023	3,353
16		1,186	1,561	1,936	2,312	2,687	3,062	3,438	3,813
17		1,337	1,761	2,184	2,608	3,032	3,456	3,879	4,303
18		1,497	1,972	2,447	2,922	3,397	3,873	4,348	4,823
19			2,196	2,725	3,255	3,784	4,313	4,843	5,372
20			2,432	3,018	3,605	4,191	4,778	5,364	5,951
21			2,680	3,327	3,973	4,620	5,266	5,913	6,559
22			2,940	3,650	4,359	5,069	5,779	6,488	7,198

[1] $Y = 12.84547 + 0.18327\ D^2Mh$.
[2] Blocked-in areas indicate the range of our data.
[3] Includes a 1-foot stump allowance.

Table 12.--Slash pine stem weight with bark to 2-inch d.i.b. top[1 2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	533	705	877	1,048	1,220	1,392			
11	610	818	1,025	1,233	1,441	1,649			
12	694	941	1,188	1,436	1,683	1,930	2,177		
13	785	1,075	1,365	1,656	1,946	2,236	2,526	2,816	
14	883	1,220	1,557	1,893	2,230	2,566	2,903	3,240	3,576
15	989	1,376	1,762	2,148	2,535	2,921	3,308	3,694	4,080
16		1,542	1,982	2,421	2,861	3,301	3,740	4,180	4,619
17		1,719	2,215	2,712	3,208	3,704	4,201	4,697	5,193
18		1,907	2,463	3,020	3,576	4,133	4,689	5,245	5,802
19			2,725	3,345	3,965	4,585	5,205	5,825	6,445
20			3,002	3,689	4,376	5,062	5,749	6,436	7,123
21			3,292	4,049	4,807	5,564	6,321	7,079	7,836
22			3,597	4,428	5,259	6,090	6,921	7,753	8,584

[1] $Y = 168.20601 + 0.21466\ D^3Mh$.
[2] Blocked-in areas indicate the range of our data.
[3] Includes a 1-foot stump allowance.

Table 13.--Weight of bark residue from slash pine stem to 2-inch d.i.b. top[1] [2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	86	101	117	132	147	162			
11	93	111	130	148	167	185			
12	100	122	144	166	188	210	233		
13	108	134	160	186	212	238	264	289	
14	117	147	177	207	237	267	297	327	357
15	127	161	195	230	264	299	333	368	402
16		176	215	254	293	333	372	411	450
17		192	236	280	324	369	413	457	501
18		208	258	308	357	407	456	506	556
19			281	337	392	447	502	558	613
20			306	367	428	490	551	612	673
21			332	399	467	534	602	670	737
22			359	433	507	581	655	730	804

[1] $Y = 53.35255 + 0.01914\ D^2Mh$.
[2] Blocked-in areas indicate the range of our data.
[3] Includes a 1-foot stump allowance.

Table 14.--Slash pine stem weight without bark to 2-inch d.i.b. top[1] [2]

D.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	447	604	760	916	1,073	1,229			
11	517	706	896	1,085	1,274	1,463			
12	593	819	1,044	1,269	1,494	1,720	1,945		
13	677	941	1,205	1,470	1,734	1,998	2,263	2,527	
14	766	1,073	1,379	1,686	1,993	2,299	2,606	2,912	3,219
15	863	1,215	1,567	1,919	2,270	2,622	2,974	3,326	3,678
16		1,366	1,767	2,167	2,567	2,968	3,368	3,769	4,169
17		1,527	1,980	2,432	2,884	3,336	3,788	4,240	4,692
18		1,699	2,205	2,712	3,219	3,726	4,233	4,739	5,246
19			2,444	3,009	3,573	4,138	4,703	5,267	5,832
20			2,696	3,321	3,947	4,573	5,198	5,824	6,450
21			2,960	3,650	4,340	5,030	5,719	6,409	7,099
22			3,238	3,995	4,752	5,509	6,266	7,023	7,780

[1] $Y = 114.85346 + 0.19552\ D^2Mh$.
[2] Blocked-in areas indicate the range of our data.
[3] Includes a 1-foot stump allowance.

Table 15.--Slash pine stem cubic volume without bark to 6-inch d.i.b. top[1] [2]

O.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Cubic feet								
10	5.2	7.7	10.3	12.9	15.5	18.1			
11	6.3	9.4	12.6	15.7	18.8	21.9			
12	7.6	11.3	15.0	18.7	22.5	26.2	29.9		
13	8.9	13.3	17.7	22.1	26.4	30.8	35.2	39.5	
14	10.4	15.5	20.6	25.6	30.7	35.8	40.8	45.9	50.9
15	12.0	17.8	23.7	29.5	35.3	41.1	46.9	52.7	58.5
16		20.3	27.0	33.6	40.2	46.8	53.4	60.0	66.6
17		23.0	30.5	37.9	45.4	52.9	60.3	67.8	75.3
18		25.8	34.2	42.6	50.9	59.3	67.7	76.1	84.4
19			38.1	47.5	56.8	66.1	75.5	84.8	94.1
20			42.3	52.6	63.0	73.3	83.7	94.0	104.3
21			46.7	58.1	69.5	80.9	92.3	103.7	115.0
22			51.3	63.8	76.3	88.8	101.3	113.8	126.3

[1] $Y = -0.32985 + 0.00323\ D^2Mh$.
[2] Blocked-in areas indicate the range of our data.
[3] Includes a 1-foot stump allowance.

Table 16.--Slash pine stem cubic volume without bark to 2-inch d.i.b. top[1] [2]

O.b.h. (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Cubic feet								
10	7.1	9.8	12.6	15.3	18.1	20.8			
11	8.3	11.6	14.9	18.3	21.6	24.9			
12	9.6	13.6	17.6	21.5	25.5	29.4	33.4		
13	11.1	15.7	20.4	25.0	29.7	34.3	39.0	43.6	
14	12.7	18.1	23.5	28.8	34.2	39.6	45.0	50.4	55.8
15	14.4	20.6	26.7	32.9	39.1	45.3	51.5	57.7	63.9
16		23.2	30.3	37.3	44.4	51.4	58.4	65.5	72.5
17		26.1	34.0	42.0	49.9	57.9	65.8	73.8	81.7
18		29.1	38.0	46.9	55.8	64.7	73.7	82.6	91.5
19			42.2	52.1	62.1	72.0	81.9	91.9	101.8
20			46.6	57.6	68.6	79.6	90.6	101.7	112.7
21			51.3	63.4	75.5	87.7	99.8	111.9	124.1
22			56.1	69.5	82.8	96.1	109.4	122.7	136.1

[1] $Y = 1.20418 + 0.00344\ D^2Mh$.
[2] Blocked-in areas indicate the range of our data.
[3] Includes a 1-foot stump allowance.

Clark, Alexander III, and Taras, Michael A.
1975. Slash pine sawtimber stem weights and sawmill residue yields. USDA For. Serv. Res. Pap. SE-122, 14 p. Southeast. For. Exp. Stn., Asheville, N.C.

Slash pine sawtimber trees 10 to 21 inches d.b.h. were selected in southern Alabama to determine weight and volume of the main stem to a 6- and 2-inch top. Weights of lumber and sawmill residues were determined after the saw-log portion of the main stem was sawn into 8/4 and 4/4 lumber. Approximately 10 percent of main stem was in pulpwood and 90 percent in saw logs. On the average, saw logs produced 51 percent lumber, 22 percent chippable residue, 10 percent bark residue, and 17 percent sawdust. Tables developed with regression equations predict weights of main stem, lumber, and sawmill residues by d.b.h. and merchantable height class.

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USDA Forest Service Research Paper SE-123 January 1975

Board-Foot and Diameter Growth of Yellow-Poplar After Thinning

by
Donald E. Beck
and
Lino Della-Bianca

Forest Service - U.S. Department of Agriculture
Southeastern Forest Experiment Station
Asheville, North Carolina

Cover Photo: A thinned second-growth stand of even-aged yellow-poplar on the Bent Creek Experimental Forest in the Southern Appalachian Mountains. This 60-year-old stand growing on site index 110 land, with a density of 150 square feet of basal area per acre, contains about 32,000 board feet per acre.

Board-Foot and Diameter Growth of Yellow-Poplar After Thinning

by

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and

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Asheville, North Carolina

Because the primary commercial value of yellow-poplar (Liriodendron tulipifera L.) is for lumber and veneer, tree size and quality are important considerations in its management (figs. 1 and 2). Most stands of yellow-poplar can produce substantial numbers of lumber- and veneer-size trees without thinning (Beck and Della-Bianca 1970), but in unthinned stands as old as 70 years more than half the trees may be less than 11 inches d.b.h., the minimum size for sawtimber. Thinnings designed to concentrate growth on the best and largest stems would therefore seem logical for management of yellow-poplar.

This paper provides data needed to determine optimum thinning regimes for yellow-poplar stands. It contains equations and tables for estimating board-foot growth and yield, and residual quadratic mean stand diameter growth for a wide range in site index, age, residual basal area, and residual quadratic mean stand diameter after thinning. Response of individual trees to thinning is also discussed.

The equations and tables presented here were developed from measurements taken on 141 permanent plots 5 years after the first thinning. At the beginning of the 5-year measurement period plots varied widely in site index, age, and residual stand basal area (table 1). Data and methods for calculating various stand parameters are described in detail elsewhere (McGee and Della-Bianca 1967; Beck and Della-Bianca 1970, 1972).

BOARD-FOOT GROWTH AND YIELD

In analyzing the plot data, an equation was derived for estimating board-foot stand volume from mean stand diameter, height, and basal area. Changes in the independent variable were estimated with auxiliary equations. This technique permits projection of stand volume to a future age. Volume growth was computed as the difference between successive stand volume estimates.

Figure 1. --An old-growth yellow-poplar in Spivy Basin, Union County, Georgia, in 1931. The tree was 69 inches d.b.h. and contained 10,930 board feet log scale, as much board-foot volume as is found in a second-growth managed yellow-poplar stand on site index 110 land at age 40, and at a density of 80 square feet per acre of basal area.

Figure 2.--Curly yellow-poplar veneer logs cut from a tree in Spivy Basin, Union County, Georgia, in 1932. Although yellow-poplar stands will not be kept to the great age necessary to produce logs of the size shown here, their potential under management for more efficient production of lumber and veneer is great.

Table 1.--Distribution of yellow-poplar plots by site index, age, and basal area after thinning

Site index (feet at 50 years)	Age class	Residual basal area (square feet per acre)							Total
		40	60	80	100	120	140	160	
	Years	- - - - - - - - - - - Number of plots - - - - - - - - - - -							
	50	--	2	--	--	--	--	--	
80	60	--	--	--	--	--	--	--	3
	70+	--	--	1	--	--	--	--	
	20	--	--	--	--	--	--	--	
	30	3	1	--	--	--	--	--	
90	40	1	1	1	--	--	--	--	16
	50	--	--	1	--	--	--	--	
	60	--	1	3	--	--	--	--	
	70+	--	--	--	1	3	--	--	
	20	2	--	--	1	--	--	--	
	30	2	--	1	--	--	--	--	
100	40	1	--	1	1	--	--	--	32
	50	--	3	3	1	1	--	--	
	60	1	2	1	1	3	--	1	
	70+	--	1	2	3	--	--	--	
	20	--	--	--	1	--	--	--	
	30	1	2	1	1	--	--	--	
	40	2	2	3	2	2	--	--	
110	50	1	1	3	1	3	2	1	52
	60	--	3	5	2	3	3	--	
	70+	--	1	2	2	1	1	--	
	20	--	1	--	--	--	--	--	
	30	3	1	3	2	2	--	1	
	40	1	2	1	2	--	--	--	
120	50	--	--	--	1	2	--	--	26
	60	--	--	--	--	1	1	1	
	70+	--	--	--	1	--	--	--	
	20	1	--	--	--	--	--	--	
	30	--	1	--	1	3	--	--	
	40	1	--	--	1	2	--	--	
130	50	--	--	--	--	--	--	--	10
	60	--	--	--	--	--	--	--	
	70+	--	--	--	--	--	--	--	
	20	--	--	--	--	--	--	--	
	30	--	--	--	1	--	--	--	
	40	--	--	--	--	--	--	--	
140	50	--	--	--	--	--	--	--	2
	60	--	--	--	--	--	--	--	
	70+	--	--	1	--	--	--	--	
Total		20	25	33	26	26	7	4	141

Present Stand Volume

A preliminary analysis indicated that the model for cubic-foot yield, which contained only the independent variables, age, site index, and residual stand basal area, would be inadequate for board-foot yield estimates (Beck and Della-Bianca 1972). Some measure of stand structure was needed. The model eventually derived expresses board-foot stand volume as a function of dominant stand height, residual quadratic mean stand diameter, and residual stand basal area. Coefficients for the equation were computed using the ratio of International $\frac{1}{4}$-inch board-foot stand volume to residual stand basal area as the dependent variable. The equation is:

$$BFV/B_1 = -545.33701 + 222.63551(D^{\frac{1}{2}}) - 18.18270(D) + 0.35306(H*D^{\frac{1}{2}}) \quad (1)$$

where

BFV = International $\frac{1}{4}$-inch board-foot stand volume per acre of all trees 11.0 inches d.b.h. and over.

B_1 = Residual stand basal area in square feet per acre of all trees 4.6 inches d.b.h. and over.

H = Height of the dominant stand in feet; measured on a sample of 15 to 20 dominant and codominant trees per acre. This is equivalent to the height used in determining site index.

D = Residual quadratic mean stand diameter in inches computed as

$$\sqrt{\frac{B_1}{\text{Residual number trees per acre}} \Big/ 0.005454}$$

The equation accounts for 96 percent of the variation in the board-foot/residual basal area ratio, and has a coefficient of variation of 10.8 percent. Appendix table II shows the board-foot/residual basal area ratio for selected values of residual quadratic mean stand diameter and dominant stand height.

Future Stand Volume and Growth

To estimate board-foot growth and future volume with Equation 1, stand height, basal area, and residual quadratic mean stand diameter must first be projected. Suitable equations for projecting height and basal area were derived earlier (Beck 1962; Beck and Della-Bianca 1972). These are shown as Equations 2 and 3, respectively, in Appendix table I. Dominant stand heights in relation to age and site index, obtained from Equation 2, are shown in Appendix figure I. Appendix table III shows expected basal area 5 years after thinning to a specified residual basal area for various age and site classes.

An equation expressing 5-year change in quadratic mean stand diameter as a function of site index, age, and residual stand basal area was developed by regression (Equation 4 in Appendix table I; table IV). Quadratic mean stand diameter 5 years after the first thinning is computed by adding the expected 5-year change in quadratic mean stand diameter (Equation 4 or Appendix table IV) to residual quadratic mean stand diameter as computed from individual stand data taken immediately after thinning.

Present and future board-foot volume and board-foot growth can be computed with Equations 1 through 4 (Appendix table I) for all combinations of site index, age, and residual stand basal area for a range of residual quadratic mean stand diameters.

For simpler but less precise board-foot estimates we developed tables 2, 3, and 4, which show current and future board-foot stand volume per acre and 5-year board-foot growth per acre. These estimates were made using an average residual quadratic mean stand diameter for each age, site, and residual stand basal area class as computed with Equation 5 in Appendix table I. Residual quadratic mean stand diameters by age, site, and residual stand basal area class are shown in Appendix table V; for more precise estimates of residual quadratic mean stand diameter for individual yellow-poplar stands use Equation 5.

DIAMETER GROWTH RESPONSE TO THINNING

The foregoing equations and graphs relate board-foot growth of stands to residual stand basal area for given sites and ages. They do not, however, tell us specifically about the response to thinning. How much does thinning increase growth of individual trees? And, how do trees of different sizes and ages respond?

Because we had no growth data prior to thinning, we extracted increment cores from 133 trees in nine stands. These stands were all in the site 110 class; three stands were in each of the 30-, 50-, and 70-year age classes. For each tree we computed the ratio of radial growth for the 5 years after thinning to the 5-year radial growth before thinning. A ratio less than one indicates a slower rate of growth after thinning. A ratio greater than one indicates an acceleration of growth after thinning.

Table 2.--Board-foot volume per acre of trees over 11.0 inches d.b.h. immediately after thinning to specified residual basal area, by site index and age[1]

Age (years)	Residual basal area (square feet per acre)						
	40	60	80	100	120	140	160
	Board feet per acre						
SITE INDEX 90							
30	860	700	330				
40	3,440	4,550	5,210	5,450	5,370		
50	5,140	6,960	8,350	9,230	9,550		
60	6,300	8,530	10,220	11,420	11,740		
70	6,950	9,430	11,150	12,210	12,410		
SITE INDEX 100							
30	1,830	2,190	2,350	2,200	2,030		
40	4,780	6,610	8,040	9,020	9,810	10,520	
50	6,870	9,620	11,860	13,750	15,140	16,280	17,290
60	8,330	11,640	14,520	16,810	18,700	19,990	20,970
70	9,220	12,900	16,120	18,550	20,610	21,740	22,670
SITE INDEX 110							
30	2,700	3,510	4,120	4,440	4,750		
40	6,020	8,500	10,600	12,500	14,050	15,260	
50	8,380	11,950	15,060	17,840	20,390	22,540	24,290
60	10,050	14,360	18,260	21,790	24,660	27,410	29,690
70	11,210	16,090	20,410	24,270	27,540	30,390	32,630
SITE INDEX 120							
30	3,470	4,810	5,700	6,670	7,160	7,680	
40	7,230	10,350	13,110	15,490	17,690	19,840	21,740
50	9,860	14,210	18,140	21,770	24,990	28,020	30,940
60	11,740	16,960	21,810	26,200	30,270	33,890	37,270
70	13,090	19,000	24,420	29,430	33,940	38,080	41,700
SITE INDEX 130							
30	4,230	5,840	7,270	8,410	9,550	10,480	
40	8,290	11,960	15,290	18,420	21,260	23,790	26,300
50	11,200	16,240	21,010	25,420	29,450	33,300	37,060
60	13,280	19,400	25,130	30,450	35,470	40,090	44,500
70	14,850	21,690	28,110	34,170	39,630	45,060	49,890

[1]Residual quadratic mean stand diameter for each age, site, residual basal area class was computed using Equation 5 in Appendix table I.

Table 3.--Board-foot volume per acre of trees over 11.0 inches d.b.h. 5 years after thinning to specified residual basal area, by site index and age[1]

Initial age (years)	Residual basal area (square feet per acre)						
	40	60	80	100	120	140	160
	Board feet per acre						
SITE INDEX 90							
30	2,540	2,650	2,430				
40	5,270	6,680	7,470	7,720	7,620		
50	6,930	9,020	10,540	11,450	11,720		
60	7,990	10,500	12,290	13,520	13,790		
70	8,540	11,290	13,120	14,210	14,360		
SITE INDEX 100							
30	4,110	4,850	5,210	5,130	4,960		
40	7,180	9,430	11,060	12,100	12,850	13,500	
50	9,190	12,340	14,790	16,740	18,060	19,130	20,000
60	10,400	14,200	17,270	19,620	21,450	22,650	23,480
70	11,250	15,300	18,710	21,190	23,210	24,260	25,050
SITE INDEX 110							
30	5,610	6,930	7,840	8,260	8,580		
40	9,030	12,080	14,480	16,500	18,050	19,180	
50	11,260	15,380	18,780	21,700	24,220	26,310	27,920
60	12,730	17,570	21,750	25,410	28,270	30,940	33,060
70	13,700	19,070	23,670	27,650	30,920	33,690	25,770
SITE INDEX 120							
20	190						
30	7,050	9,080	10,320	11,470	11,980	12,450	
40	10,890	14,740	17,920	20,490	22,760	24,880	26,690
50	13,330	18,400	22,740	26,600	29,890	32,880	35,690
60	14,970	20,870	26,130	30,740	34,890	38,470	41,740
70	16,070	22,610	28,410	33,630	38,210	42,320	45,820
SITE INDEX 130							
20	1,050	100					
30	8,540	10,980	12,900	14,260	15,500	16,440	
40	12,620	17,210	21,100	24,560	27,550	30,080	32,520
50	15,280	21,240	26,580	31,330	35,520	39,410	43,120
60	17,070	24,040	30,320	35,960	41,160	45,810	50,170
70	18,340	25,980	32,920	39,300	44,910	50,380	55,160

[1] Residual quadratic mean stand diameter for each age, site, residual basal area class was computed using Equation 5 in Appendix table I.

Table 4.--Five-year board-foot volume growth per acre of trees over 11.0 inches d.b.h. after thinning to specified residual basal area, by site index and age[1]

Initial age (years)	Residual basal area (square feet per acre)						
	40	60	80	100	120	140	160
	Board feet per acre						
SITE INDEX 90							
30	1,680	1,950	2,100				
40	1,830	2,130	2,260	2,270	2,250		
50	1,790	2,060	2,190	2,220	2,170		
60	1,690	1,970	2,070	2,100	2,050		
70	1,590	1,860	1,970	2,000	1,950		
SITE INDEX 100							
30	2,280	2,660	2,860	2,930	2,930		
40	2,400	2,820	3,020	3,080	3,040	2,980	
50	2,320	2,720	2,930	2,990	2,920	2,850	2,710
60	2,070	2,560	2,750	2,810	2,750	2,660	2,510
70	2,030	2,400	2,590	2,640	2,600	2,520	2,380
SITE INDEX 110							
30	2,910	3,420	3,720	3,820	3,830		
40	3,010	3,580	3,880	4,000	4,000	3,920	
50	2,880	3,430	3,720	3,860	3,830	3,770	3,630
60	2,680	3,210	3,490	3,620	3,610	3,530	3,370
70	2,490	2,980	3,260	3,380	3,380	3,300	3,140
SITE INDEX 120							
20	190						
30	3,580	4,270	4,620	4,800	4,840	4,770	
40	3,660	4,390	4,810	5,000	5,090	5,040	4,950
50	3,470	4,190	4,600	4,830	4,900	4,860	4,750
60	3,230	3,910	4,320	4,540	4,620	4,580	4,470
70	2,980	3,610	3,990	4,200	4,270	4,240	4,120
SITE INDEX 130							
20	1,050	100					
30	4,310	5,140	5,630	5,850	5,950	5,960	
40	4,330	5,250	5,810	6,140	6,290	6,290	6,220
50	4,080	5,000	5,570	5,910	6,070	6,110	6,060
60	3,790	4,640	5,190	5,510	5,690	5,720	5,670
70	3,490	4,290	4,810	5,130	5,280	5,320	5,270

[1]Residual quadratic mean stand diameter for each age, site, residual basal area class was computed using Equation 5 in Appendix table I.

Figure 3 shows the radial growth response ratio by age class, d.b.h. at time of thinning, and severity of thinning expressed as percent of basal area cut. The lines showing the trend of the ratio with d.b.h. were derived by regression analysis. In all but two stands, there was a highly significant inverse relationship between the response ratio and tree d.b.h. In general, the heavier the thinning the greater the radial growth response of individual trees, smaller trees responding more than larger trees in a given stand. It should be remembered in this context that the thinnings from below removed practically all suppressed trees. Therefore, even the smallest trees in a given stand were in the intermediate crown class and had sufficient vigor to respond to thinning. In the two oldest age classes, the lightest thinnings failed to check a declining growth rate for all tree sizes. However, heavier thinnings did increase diameter growth in even the oldest stands.

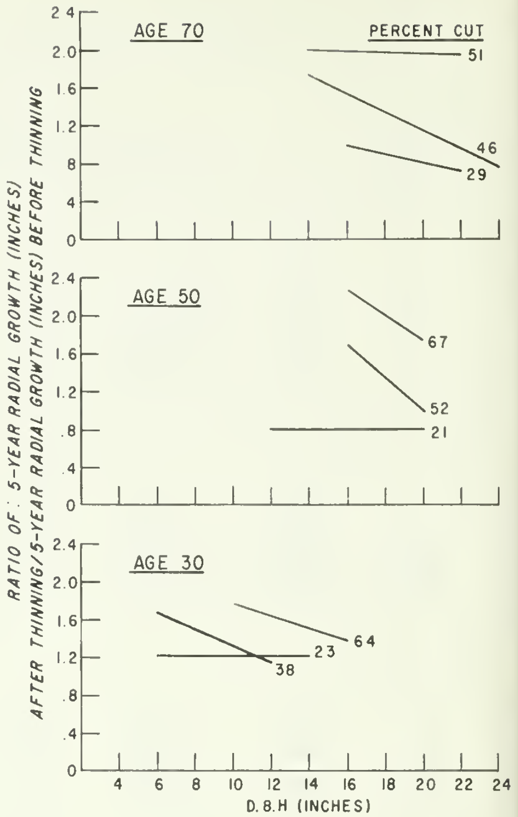

Figure 3.--Ratio of 5-year radial growth after thinning to 5-year radial growth before thinning in relation to d.b.h. at time of thinning for different cutting intensities.

It is sometimes argued that some portion of the largest trees in a stand either is not, or is only slightly, affected by stand density. To determine the effect of density, we derived regression equations for estimating average diameter growth from residual stand basal area for the 12 largest, the 20 largest, and all trees 4.6 inches d.b.h. and over per acre. Equations for the 12 and 20 largest trees per acre were almost identical. Figure 4 shows the relationships of 5-year diameter growth to residual stand basal area for the 20 largest trees per acre and for all trees 4.6 inches d.b.h. and over. At lower densities, where the 20 largest trees comprise a large share of the residual stand, the rates of growth are no different for the two groupings. At higher densities, the 20 largest trees grow faster in d.b.h. than the stand average. However, the overall effect of increasing stand density on diameter growth of the 20 largest trees per acre compares closely with the effect of increasing density on the average stand diameter growth of the total stand. Thus, even the largest trees in the stands responded to thinning.

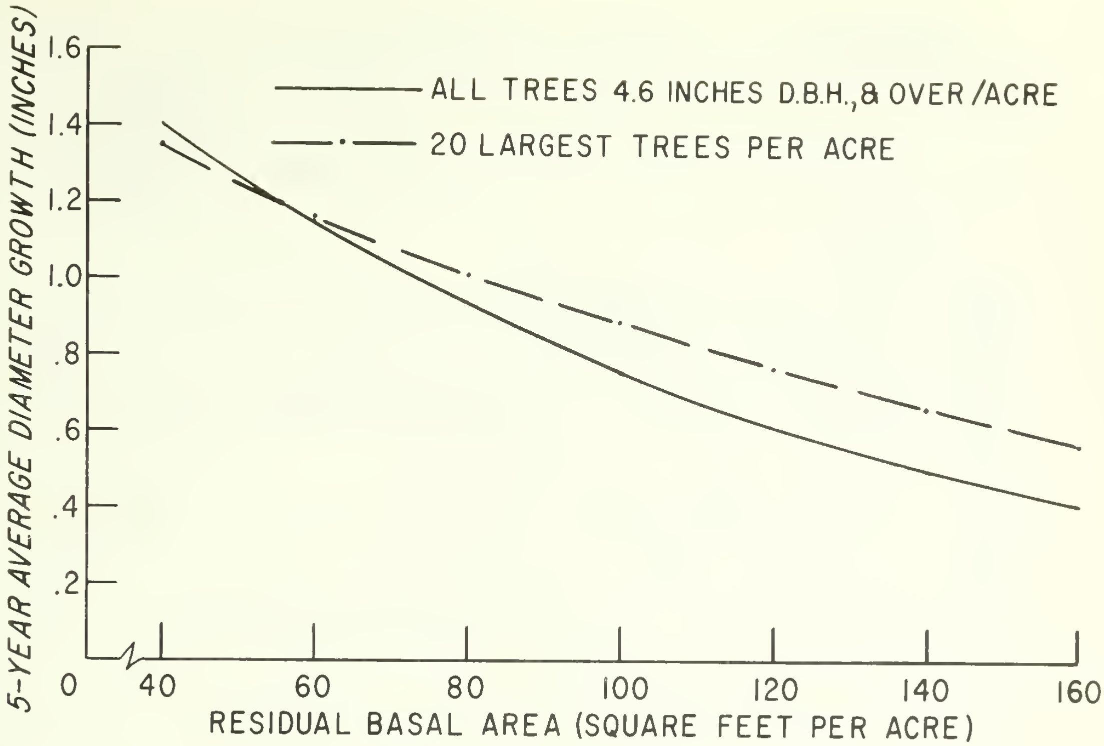

Figure 4.--Five-year average diameter growth in relation to residual basal area for all trees 4.6 inches d.b. h. and over per acre, and for the 20 largest trees per acre. Site index is 110; age is 40 years.

Our general conclusions based on the core analysis are:

1. Diameter growth is increased by thinning; the heavier the thinning, the more diameter growth increases.

2. Even older yellow-poplar stands respond with increased diameter growth after thinning, provided the thinning is heavy.

3. Within a stand, all trees increase diameter growth after heavy thinning, but the smallest trees show the greatest response relative to growth before thinning.

These conclusions agree with observations on other tree species (Spurr 1952; Lundgren and Wambach 1963; and Assmann 1970).

DISCUSSION

Thinning practices can be evaluated and growth and yield for specific situations can be predicted with the equations and tables presented here. Figure 5 illustrates 5-year board-foot growth in relation to residual stand basal area by site class in 40-year-old yellow-poplar stands. On all sites, board-foot growth increases with increasing basal

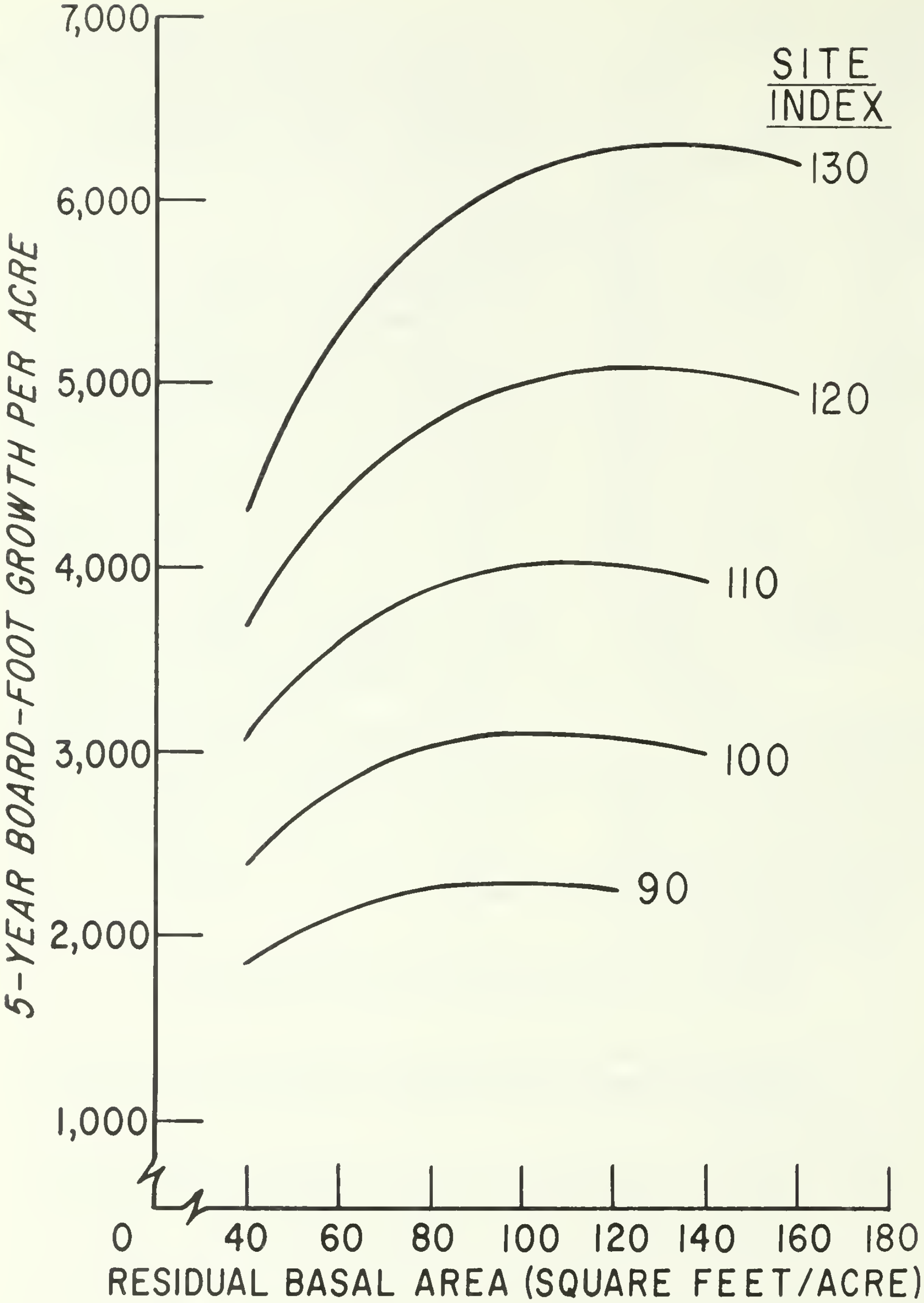

Figure 5. --Five-year board-foot growth in relation to residual stand basal area by site-index classes for stands 40 years of age.

area up to a maximum and thereafter declines. The level of residual basal area at which board-foot growth is maximized increases with site quality. As a rule of thumb, between the ages of 30 and 70 years maximum rates of board-foot growth are reached at basal areas approximately equal to site index, i.e., maximum board-foot growth is reached at 90 square feet of basal area per acre on site 90, 100 square feet on site 100, etc.

The curve of board-foot growth on residual stand basal area is relatively flat. For example, on site index 110 land, 95 percent of maximum board-foot growth can be obtained with a residual stand basal area as low as 75 square feet per acre. Therefore, it is possible to encourage faster growth of individual trees by heavy thinning without markedly decreasing board-foot growth.

In figure 4, the curve for all trees 4.6 inches and larger shows the relationship of expected 5-year average diameter growth by residual basal area for site 110, and stand age 40. If we maintain an average stand at 110 square feet of basal area in order to maximize board-foot growth, we can expect the average 5-year stand diameter growth to be 0.7 inch. On the other hand, if we thin the stand to 75 square feet of basal area, we will get 95 percent of maximum board-foot growth but increase the 5-year average stand diameter growth by 0.3 inch.

From our observations, the majority of unthinned natural yellow-poplar stands are overstocked for maximum board-foot growth as well as for maximum diameter growth. By using the equations or tables presented here, thinning regimes for specific management objectives can be planned for individual natural yellow-poplar stands.

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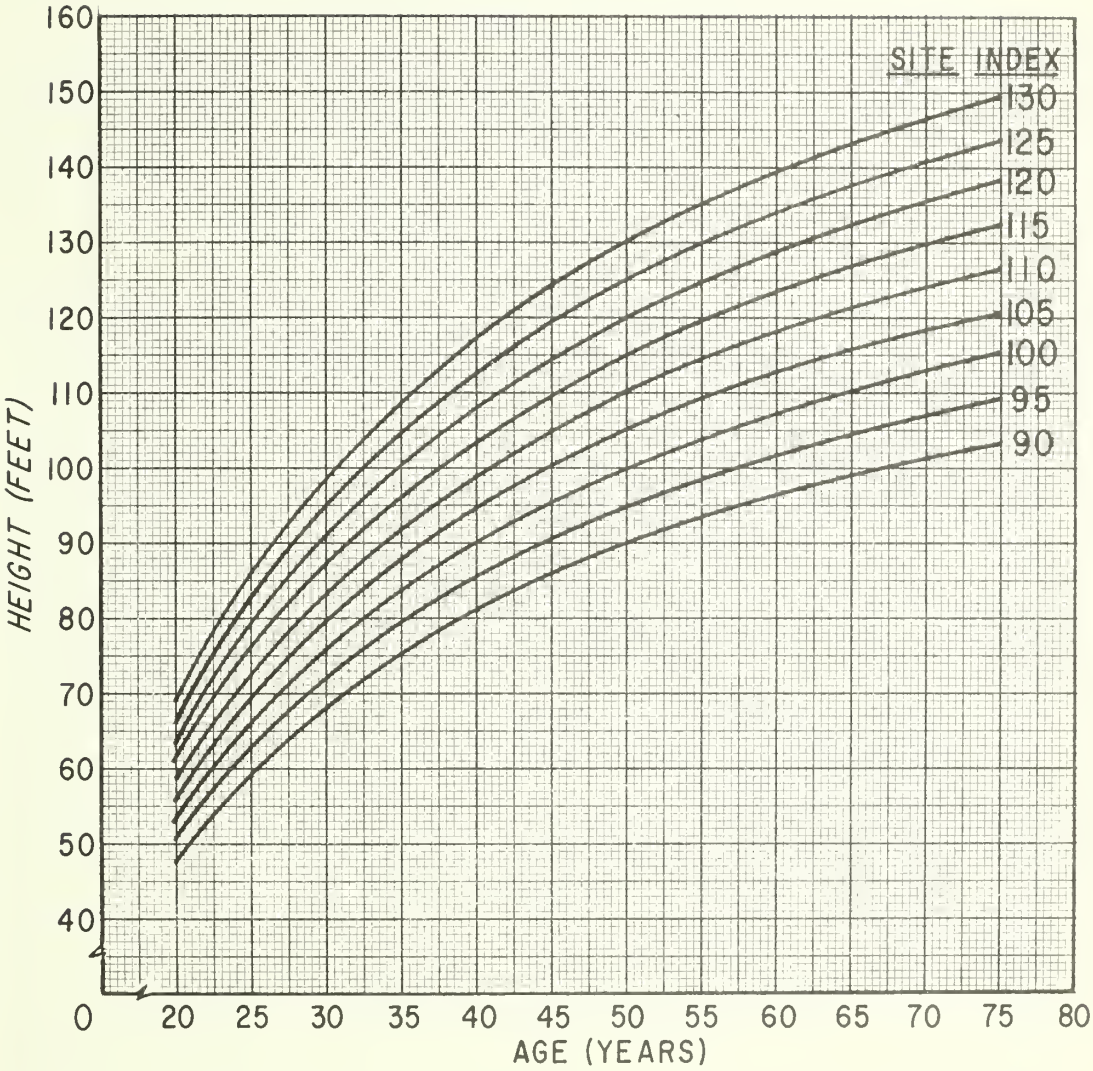
APPENDIX



Appendix figure I. --Dominant stand height, by site index and age.

Table I.--Regression equations used for growth and yield estimates

Equation number	Equation[1]	
1	BFV/B_1	$= -545.33701 + 222.63551(D^{\frac{1}{2}}) - 18.18270(D) + 0.35306(H*D^{\frac{1}{2}})$
2	$\ln H$	$= \ln S + 21.08707(1/50 - 1/A)$
3	$\ln B_2$	$= (\ln B_1)A_1/A_2 + 3.82837(1 - A_1/A_2) + 0.01667(S)(1 - A_1/A_2)$
4	$\ln \Delta D$	$= 2.50044 - 0.00852(B_1) - 195.13700(S^{-1}) - 0.05810(B_1A_1^{-1})$
5	D	$= 1.69866 + 5.11396(A_1S/1000) - 0.28209(A_1^2/100)$
		$= - 0.43439(S^2/1000) - 0.80745(A_1 B_1/1000) + 0.05724(B_1^2/1000)$

BFV = Board-foot stand volume per acre of trees 11.0 inches d.b.h. and over; International ¼-inch rule.
B_1 = Residual stand basal area in square feet per acre; all trees 4.6 inches d.b.h. and over are included.
B_2 = Future stand basal area in square feet per acre; all trees 4.6 inches d.b.h. and over are included.
ΔD = Five-year residual quadratic mean stand diameter growth (inches); all trees 4.6 inches d.b.h. and over are included.
H = Dominant stand height (feet).
D = Residual quadratic mean stand diameter (inches); all trees 4.6 inches d.b.h. and over are included.
S = Site index in feet at age 50 years.
A_1 = Initial age (years).
A_2 = Future age (years).
ln = Natural logarithm.

Table II. --Ratio of board-foot stand volume per acre to residual stand basal area per acre for selected values of dominant stand height and residual quadratic mean stand diameter[1] [2]

Residual quadratic mean stand diameter (inches)	Dominant stand height (feet)										
	50	60	70	80	90	100	110	120	130	140	150
7					0.49	9.83	19.17	28.52	37.86	47.20	56.54
8				18.80	28.78	38.77	48.76	58.74	68.73	78.71	88.70
9		22.48	33.07	43.66	54.25	64.84	75.44	86.03	96.62	107.21	117.80
10	32.69	43.86	55.02	66.19	77.35	88.52	99.68	110.85	122.01	133.18	144.34
11	51.60	63.31	75.02	86.73	98.44	110.15	121.86	133.57	145.28	156.99	168.70
12	68.85	81.08	93.31	105.55	117.78	130.01	142.24	154.47	166.70	178.93	191.16
13	84.66	97.39	110.12	122.85	135.58	148.31	161.04	173.77	186.50	199.23	211.96
14	99.18	112.39	125.60	138.81	152.02	165.23	178.44	191.65	204.86	218.08	231.29
15	112.56	126.23	139.90	153.58	167.25	180.93	194.60	208.27	221.95	235.62	249.30
16	124.89	139.02	153.14	167.26	181.38	195.51	209.63	223.75	237.87	252.00	266.12
17	136.29	150.85	165.41	179.96	194.52	209.08	223.63	238.19	252.75	267.31	281.86
18	146.83	161.81	176.79	191.77	206.75	221.73	236.71	251.69	266.66	281.64	296.62
19	156.59	171.97	187.36	202.75	218.14	233.53	248.92	264.31	279.70	295.09	310.48
20	165.61	181.40	197.19	212.98	228.77	244.56	260.35	276.14	291.93	307.72	323.51
21	173.97	190.15	206.33	222.50	238.68	254.86	271.04	287.22	303.40	319.58	335.76
22	181.70	198.26	214.82	231.38	247.94	264.50	281.06	297.62	314.18	330.74	347.30
23	188.84	205.78	222.71	239.64	256.57	273.50	290.44	307.37	324.30	341.23	358.17
24	195.45	212.74	230.04	247.34	264.63	281.93	299.22	316.52	333.82	351.11	368.41
25	201.54	219.19	236.84	254.50	272.15	289.80	307.46	325.11	342.76	360.42	378.07

[1] Board-foot stand volume per acre of trees 11.0 inches d.b.h. and over using International $\frac{1}{4}$-inch rule.
[2] Residual stand basal area (square feet per acre) includes all trees 4.6 inches d.b.h. and over per acre.

Table III. --Expected basal area by site index and age 5 years after thinning to a specified residual basal area

Initial age (years)	Residual basal area (square feet per acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	----------------- Square feet per acre -----------------												
SITE INDEX 90													
20	56	66	77	87									
30	51	61	72	82	92	101	111						
40	48	59	69	79	89	99	108	118	127				
50	46	57	67	77	87	97	107	116	126	136			
60	45	56	66	76	86	96	106	115	125	135	144		
70	45	55	65	75	85	95	105	115	124	134	144	153	
SITE INDEX 100													
20	57	69	79	90	100								
30	52	63	73	84	94	104	114	124					
40	49	60	70	80	91	101	110	120	130	139	149		
50	47	58	68	78	89	99	108	118	128	138	147	157	166
60	46	56	67	77	87	97	107	117	127	136	146	156	165
70	45	56	66	76	86	96	106	116	126	135	145	155	165
SITE INDEX 110													
20	59	71	82	93	103								
30	53	64	75	86	96	106	116	126	136	146			
40	50	61	71	82	92	102	112	122	132	142	152	161	171
50	48	59	69	80	90	100	110	120	130	140	150	159	169
60	47	57	68	78	88	99	109	119	128	138	148	158	168
70	46	56	67	77	87	97	107	117	127	137	147	157	166
SITE INDEX 120													
20	61	73	85	96	107	117							
30	54	66	77	88	98	109	119	129	139	149	159		
40	51	62	73	83	94	104	115	125	135	145	155	164	174
50	49	60	70	81	91	102	112	122	132	142	152	162	171
60	47	58	69	79	89	100	110	120	130	140	150	160	170
70	46	57	67	78	88	98	108	119	129	139	149	158	168
SITE INDEX 130													
20	63	76	88	99	110	121	132						
30	56	67	79	90	101	111	122	132	143	153	163	172	182
40	52	63	74	85	96	106	117	127	137	147	157	167	177
50	49	60	71	82	93	103	113	124	134	144	154	164	174
60	48	59	69	80	91	101	111	122	132	142	152	162	172
70	47	57	68	79	89	99	110	120	130	140	150	160	170

Table IV.--Five-year residual quadratic mean stand diameter growth by site index, initial age, and residual basal area

Initial age (years)	Residual basal area (square feet per acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
							Inches						
SITE INDEX 90													
20	.88	.79	.70	.63									
30	.92	.83	.74	.67	.60	.54	.49						
40	.94	.85	.77	.69	.63	.57	.51	.47	.42				
50	.95	.86	.78	.71	.64	.58	.53	.48	.44	.40			
60	.95	.87	.79	.72	.65	.59	.54	.49	.45	.41	.37		
70	.96	.87	.80	.72	.66	.60	.55	.50	.45	.41	.38	.34	
SITE INDEX 100													
20	1.10	.98	.87	.78	.69								
30	1.14	1.03	.92	.83	.75	.68	.61	.55					
40	1.16	1.05	.95	.86	.78	.71	.64	.58	.52	.47	.43		
50	1.18	1.07	.97	.88	.80	.72	.66	.60	.54	.49	.45	.41	.37
60	1.18	1.08	.98	.89	.81	.74	.67	.61	.55	.50	.46	.42	.38
70	1.19	1.08	.99	.90	.82	.75	.68	.62	.56	.51	.47	.43	.39
SITE INDEX 110													
20	1.31	1.17	1.04	.93	.83								
30	1.36	1.23	1.10	.99	.90	.81	.73	.65	.59	.53			
40	1.39	1.26	1.14	1.03	.93	.84	.76	.69	.62	.57	.51	.46	.42
50	1.40	1.27	1.16	1.05	.95	.87	.79	.71	.65	.59	.53	.48	.44
60	1.41	1.29	1.17	1.06	.97	.88	.80	.73	.66	.60	.55	.50	.45
70	1.42	1.30	1.18	1.07	.98	.89	.81	.74	.67	.61	.55	.51	.46
SITE INDEX 120													
20	1.52	1.35	1.21	1.08	.96	.86							
30	1.58	1.42	1.28	1.15	1.04	.94	.84	.76	.68	.62	.55		
40	1.61	1.46	1.32	1.19	1.08	.98	.88	.80	.72	.66	.59	.54	.49
50	1.63	1.48	1.34	1.22	1.10	1.00	.91	.83	.75	.68	.62	.56	.51
60	1.64	1.49	1.36	1.23	1.12	1.02	.93	.84	.77	.70	.64	.58	.53
70	1.65	1.50	1.37	1.25	1.13	1.03	.94	.86	.78	.71	.65	.59	.54
SITE INDEX 130													
20	1.72	1.53	1.37	1.22	1.09	.97	.87						
30	1.79	1.61	1.45	1.31	1.18	1.06	.95	.86	.77	.70	.63	.57	.51
40	1.82	1.65	1.49	1.35	1.22	1.11	1.00	.91	.82	.74	.67	.61	.55
50	1.84	1.67	1.52	1.38	1.25	1.14	1.03	.94	.85	.77	.70	.64	.58
60	1.86	1.69	1.54	1.40	1.27	1.16	1.05	.96	.87	.79	.72	.65	.60
70	1.87	1.70	1.55	1.41	1.29	1.17	1.07	.97	.88	.81	.73	.67	.61

Table V.--Residual quadratic mean stand diameter, immediately after thinning, by site index, age, and residual basal area

Age (years)	Residual basal area (square feet per acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	- - - - - - - - - - - - - - Inches - - - - - - - - - - - - - -												
						SITE INDEX 90							
20	5.7	5.6	5.5	5.4									
30	8.6	8.4	8.2	8.0	7.9	7.7	7.6						
40	10.9	10.6	10.4	10.1	9.9	9.6	9.4	9.2	9.0				
50	12.6	12.3	11.9	11.6	11.3	11.0	10.7	10.4	10.1	9.9			
60	13.8	13.4	12.9	12.5	12.1	11.7	11.4	11.0	10.6	10.3	10.0		
70	14.4	13.9	13.4	12.9	12.4	12.0	11.5	11.0	10.6	10.2	9.8	9.4	
						SITE INDEX 100							
20	5.9	5.8	5.7	5.6	5.5								
30	9.3	9.1	8.9	8.7	8.6	8.4	8.3	8.2					
40	12.1	11.8	11.6	11.3	11.1	10.8	10.6	10.4	10.2	10.1	9.9		
50	14.4	14.0	13.7	13.3	13.0	12.7	12.4	12.1	11.8	11.6	11.3	11.1	10.9
60	16.0	15.6	15.2	14.8	14.4	14.0	13.6	13.2	12.9	12.6	12.2	11.9	11.6
70	17.2	16.6	16.1	15.6	15.2	14.7	14.2	13.8	13.4	13.0	12.5	12.1	11.8
						SITE INDEX 110							
20	6.0	5.9	5.8	5.7	5.6								
30	9.9	9.7	9.5	9.4	9.2	9.1	8.9	8.8	8.7	8.6			
40	13.2	13.0	12.7	12.4	12.2	12.0	11.8	11.6	11.4	11.2	11.0	10.9	10.7
50	16.0	15.6	15.3	15.0	14.6	14.4	14.0	13.8	13.5	13.2	13.0	12.8	12.5
60	18.2	17.8	17.3	16.9	16.5	16.1	15.8	15.4	15.0	14.7	14.4	14.1	13.8
70	19.8	19.3	18.8	18.3	17.8	17.4	16.9	16.5	16.0	15.6	15.2	14.8	14.4
						SITE INDEX 120							
20	6.0	5.9	5.8	5.7	5.7	5.6							
30	10.4	10.2	10.1	9.9	9.7	9.6	9.5	9.3	9.2	9.1	9.0		
40	14.3	14.0	13.8	13.5	13.3	13.0	12.8	12.6	12.4	12.2	12.1	11.9	11.8
50	17.6	17.2	16.9	16.5	16.2	15.9	15.6	15.3	15.0	14.8	14.5	14.3	14.1
60	20.3	19.8	19.4	19.0	18.6	18.2	17.8	17.5	17.1	16.8	16.4	16.1	15.8
70	22.4	21.9	21.4	20.9	20.4	20.0	19.5	19.0	18.6	18.2	17.8	17.4	17.0
						SITE INDEX 130							
20	6.0	5.9	5.8	5.7	5.6	5.5	5.5						
30	10.9	10.7	10.5	10.4	10.2	10.0	9.9	9.8	9.7	9.6	9.5	9.4	9.4
40	15.2	15.0	14.7	14.5	14.2	14.0	13.8	13.6	13.4	13.2	13.0	12.9	12.7
50	19.0	18.7	18.3	18.0	17.7	17.4	17.1	16.8	16.5	16.3	16.0	15.8	15.6
60	22.2	21.8	21.4	21.0	20.6	20.2	19.8	19.4	19.1	18.8	18.4	18.1	17.8
70	24.9	24.4	23.9	23.4	22.9	22.4	22.0	21.6	21.1	20.7	20.3	19.9	19.5

*U.S. GOVERNMENT PRINTING OFFICE: 1978-740-271/4964. Region 4.

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1975. Board-foot and diameter growth of yellow-poplar after thinning. USDA For. Serv. Res. Pap. SE-123, 20 p. Southeast. For. Exp. Stn., Asheville, N.C.

Board-foot growth and yield of thinned yellow-poplar stands (Liriodendron tulipifera L.) is related to age, site index, residual basal area, and residual quadratic mean stand diameter after thinning. Diameter growth of individual trees is increased considerably by thinning. Equations describing growth and yield are based on data from 141 natural yellow-poplar stands in the Appalachian Mountains of Virginia, North Carolina, and Georgia.

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by

W. H. Blackmarr

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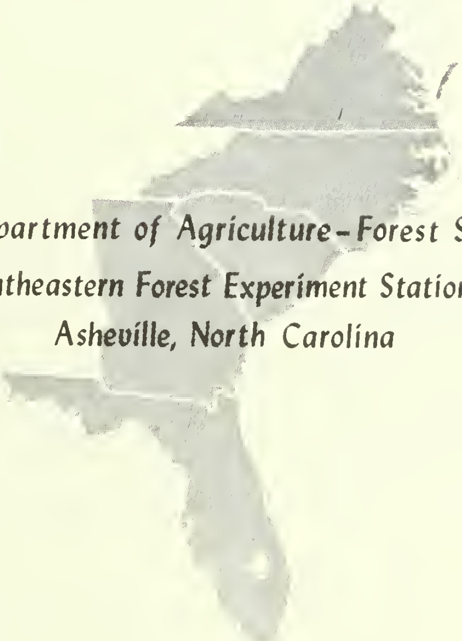

U.S. Department of Agriculture-Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

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by

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INTRODUCTION

In an earlier report (Blackmarr and Flanner 1968) we discussed the seasonal variation in moisture content of six shrub species found in pocosins[1] of the eastern North Carolina organic soils area. The report compared moisture content of foliage and stem tissue with the average moisture content of the whole plant. The data covered only one annual growth cycle.

This report contains further documentation of seasonal moisture trends over a 2-year period. It also compares observations made in widely separated locations along the North Carolina coastline. The species included are the same as in the earlier report: gallberry (Ilex glabra (L.) Gray), swamp cyrilla (Cyrilla racemiflora L.), redbay (Persea borbonia (L.) Spreng.), switch cane (Arundinaria tecta (Walt.) Muhl.), fetterbush (Lyonia lucida (Lam.) K. Koch), and honeycup (Zenobia pulverulenta (Bartr.) Pollard). These plants are an important part of the total fuel complex of forest lands in the organic soils area because they become a severe fire hazard during low points in their annual moisture cycle. Their peculiar branching habit enhances their flammability by forming a dense, relatively homogeneous mixture of finely divided fuel particles suspended just above the litter surface.

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[1] Pocosins are poorly drained organic soil deposits which are often slightly higher in elevation near their center than they are around their perimeter. Hence, the term "pocosin," an Indian name meaning swamp on a hill, is used.

METHODS

Seasonal variation in moisture content of six species of shrubs native to the eastern North Carolina organic soils area was observed throughout two successive annual growth cycles (March 1964 through December 1965). Samples of each species were collected from three areas along the North Carolina coastline (fig. 1). We separated the sampling areas to observe any possible effects of geographic location on the timing of the annual growth cycles. In all three sampling areas, each species was sampled on two to four different plots located within 25 miles of each other. We chose the plot locations to represent a cross section of typical habitat conditions. We did not make detailed analyses of soils to determine the drainage class, but simply observed local habitat conditions, such as soil profile, relief, floristic structure, etc., prior to establishing each plot. Most plots were on organic soils, but a few were on mineral soils.

Old foliage, new foliage, and stem tissue were sampled separately at weekly intervals between noon and 4 p.m. throughout the 22-month period. Sampling was less frequent during the winter, when moisture content fluctuated very little. The method of sampling on each plot has been described by Blackmarr and Flanner (1968). Moisture content was determined by ovendrying for 24 hours at 100° to 105° C.

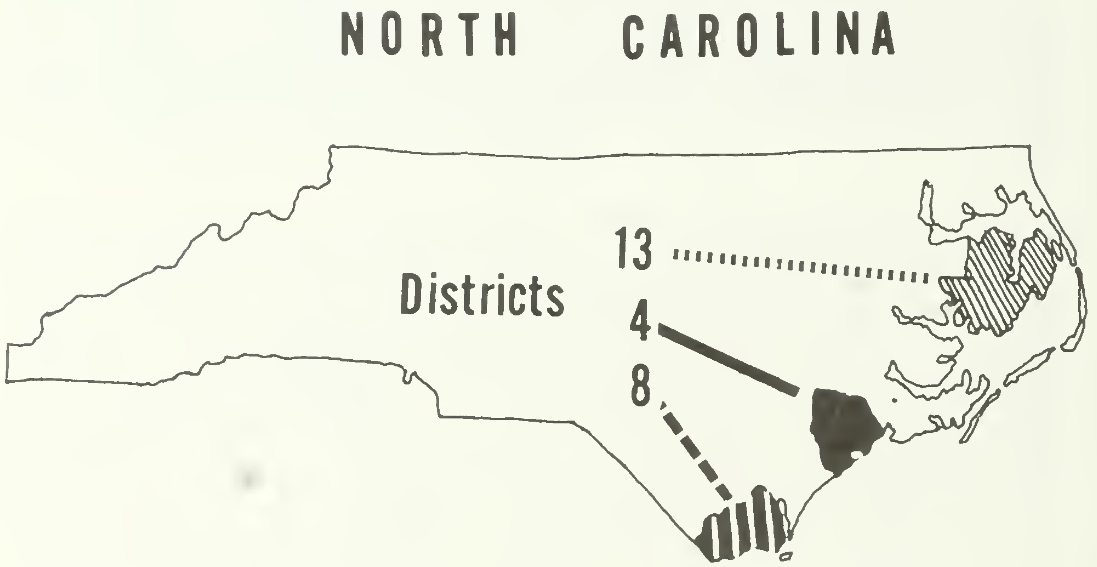

Figure 1.--Three areas where moisture content samples of gallberry, fetterbush, redbay, swamp cyrilla, honeycup, and switch cane were collected.

RESULTS AND DISCUSSION

The annual cycle of moisture variation exhibited a characteristic pattern in each species (appendix A and B). The pattern was relatively consistent over both annual growth cycles of this study and agrees closely with Wendel and Storey's (1962) earlier study of four of the same species. Figure 2 illustrates the consistency between 1964 and 1965 moisture cycles in the evergreen species and the deciduous species. Year-to-year consistency in moisture cycles has been observed in other wildland shrubs. For example, Van Wagner (1967) found that seasonal trends in foliar moisture of some Canadian conifers and hardwoods had a characteristic pattern that was closely duplicated over three successive years, and Reifsnyder (1961) found a consistent pattern of moisture variation in mountain-laurel over two annual growth cycles. Differences in precipitation between the 2 years had little effect on the pattern of seasonal moisture variation. Although we made no attempt to relate moisture variation to weather conditions, it appears that the pattern of seasonal moisture content variation may be little affected by year-to-year differences in precipitation.

There are characteristics which are typical of the evergreen species and others which are typical of the deciduous species. The evergreens (gallberry, fetterbush, and redbay) usually had a lower moisture content than the deciduous species (swamp cyrilla, honeycup, and switch cane) at any given time of the year. This should make the evergreen species more flammable than the deciduous species if other properties affecting flammability were the same.

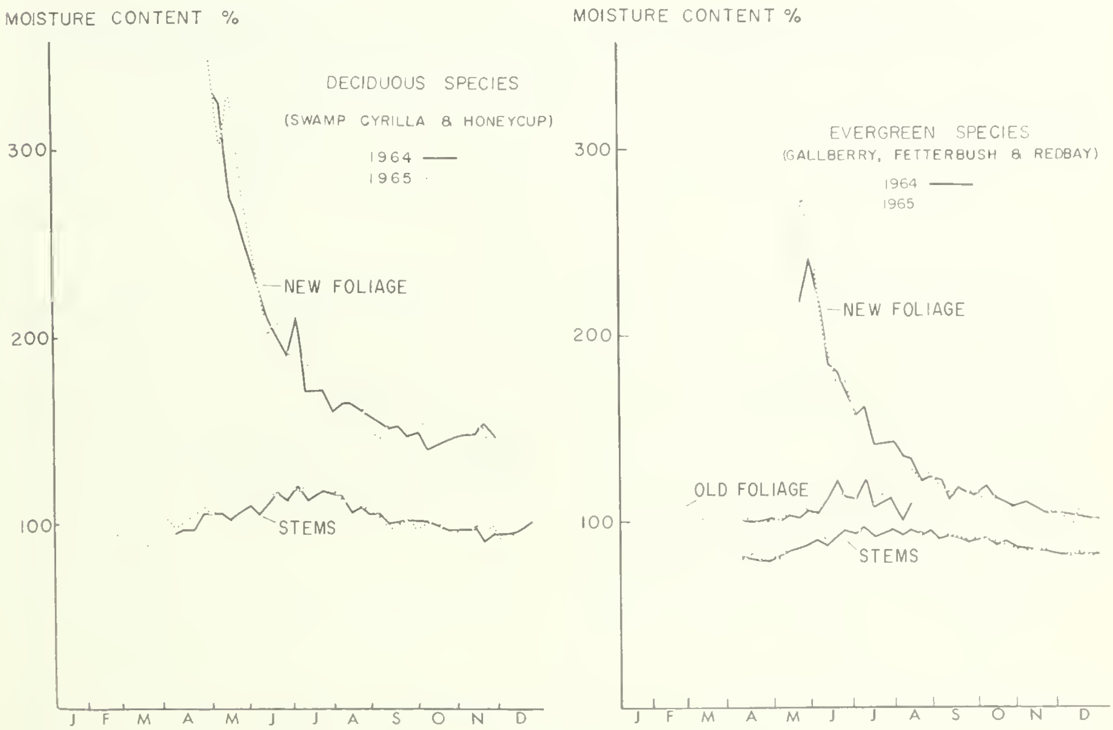

Figure 2.--Annual moisture content cycles in selected evergreen and deciduous pocosin shrubs during 1964 and 1965.

The initiation and development of new foliage in the spring occurred first on the sample area located farthest south (figs. 3 and 4). The development of new tissue on the shrubs in the northernmost district, District 13, lagged about 2 to 3 weeks behind that in the southernmost district, District 8. These differences in seasonal growth patterns reflect the influence of climatic variation due to differences in latitude. Factors other than latitude may modify seasonal moisture content cycles since resumption of new spring growth is influenced by air temperature as well as solar radiation (Meyer, Anderson, and Bohning 1960). For example, factors which affect seasonal cycles of air temperature, such as proximity to the seacoast, also may influence the initiation of new growth of pocosin shrubs as did north-south location.

We observed that new spring growth in District 13 does not always lag behind new spring growth of plants in District 4. This could be because the sample plots in District 4 were located about 35 to 40 miles inland from the coast, whereas those in District 8 and 13 were only about 10 to 15 miles inland. Our observations are supported by climatic maps for the east coast of North Carolina (U.S. Department of Commerce, Environmental Science Services Administration 1964) which show District 4 in a zone with lower minimum daily temperatures in the spring. The average date of the last killing frost is also later in the spring in District 4 than it is in the other districts.

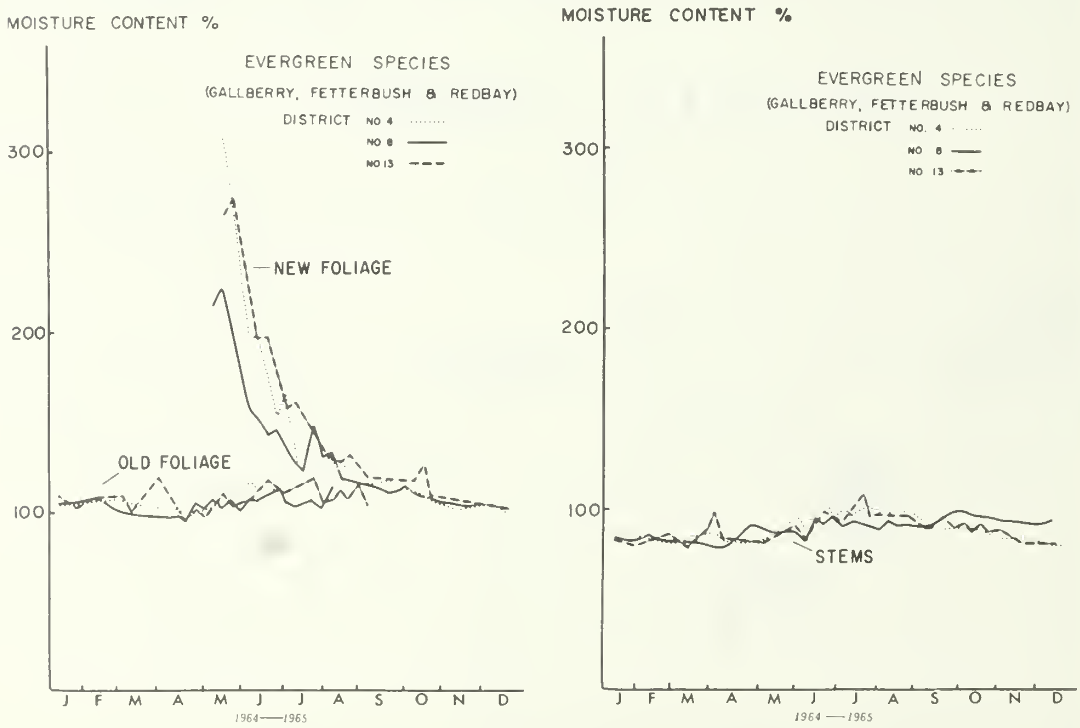

Figure 3.--Annual moisture content cycles in selected evergreen pocosin shrubs at three different locations in eastern North Carolina.

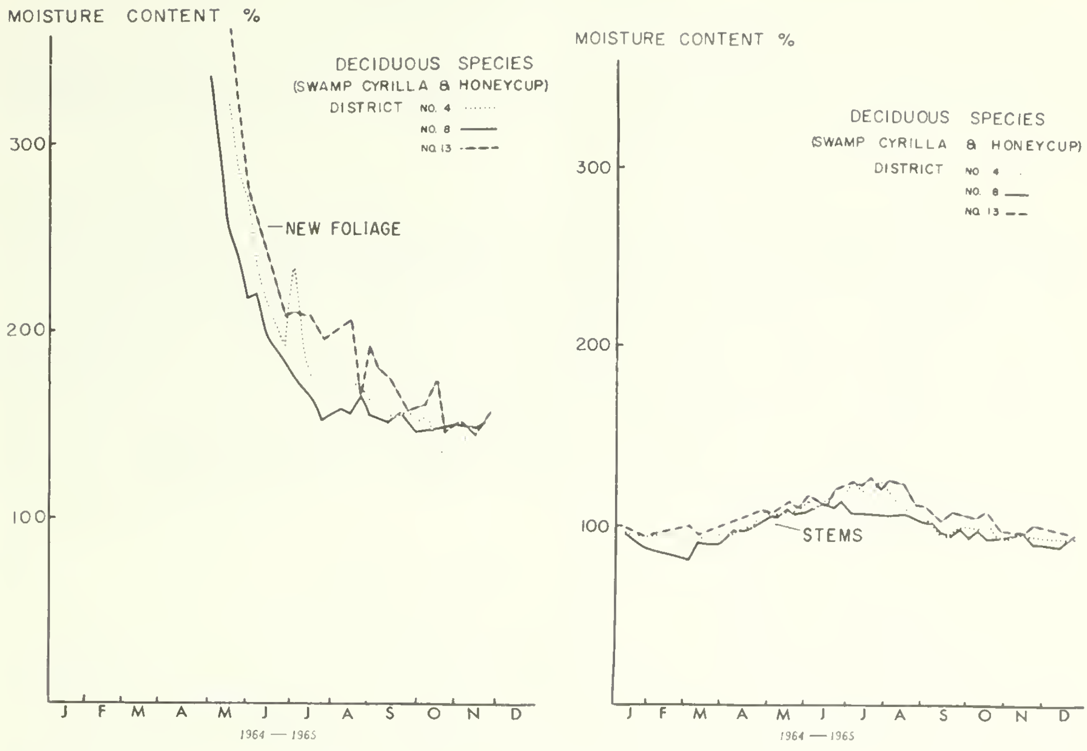

Figure 4.--Annual moisture content cycles in selected deciduous pocosin shrubs at three different locations in eastern North Carolina.

Rapid development of new foliage of all species began, both years, during the fourth week in April through the month of May. This agrees with Wendel and Storey's (1962) findings, and suggests this period as the most likely time when moisture content of pocosin shrubs in eastern North Carolina begins its rapid increase. These data support our earlier conclusion (Blackmarr and Flanner 1968) that bud break and the rapid buildup of moisture in the whole plant begin at about the same time.

March through April, and October through November are two periods when high intensity fires are most frequent. Fires are usually more intense and more difficult to control during the spring fire season than they are during the fall fire season. One reason is that weather conditions favoring high intensity fires are more frequent in the spring. There are characteristics of the moisture regime of pocosin shrubs, however, which also would encourage higher intensity fires in the spring. For example, moisture content of the evergreen foliage and of both evergreen and deciduous stems reaches a minimum just prior to the resumption of new growth in the spring. The moisture content of stems is also higher in the fall than during the spring. Furthermore, green foliage has a higher moisture content than stems, and it makes up a higher proportion of the whole plant in the fall. All of this produces a higher average plant moisture content in the fall than in the spring. The differences between spring and fall in both the amount and the distribution of water in these shrubs should make them more flammable in the spring if the influence of moisture only is considered.

The occurrence of a spring minimum moisture content has been observed in other evergreen plants and may be a characteristic of many of these species. Van Wagner (1967), Johnson (1966), and Jameson (1966) observed this in the foliage of some coniferous species. Reifsnyder (1961) also found it in mountain-laurel foliage.

This report documents seasonal cycles of moisture content variation in pocosin shrubs. However, additional research that relates specific plant moisture contents to actual fire behavior is still needed. We could gain further insight by studying fuel moisture variation during the two most critical periods, March-April and October-November. Specific plant moisture contents could possibly be related to visible phenological characteristics of the plants. A visible indicator of current moisture levels could then be used in conjunction with flammability ratings, based on fuel moisture content, to monitor fuel flammability and predict fire behavior and difficulty of control in the pocosins of North Carolina.

SUMMARY AND CONCLUSIONS

Seasonal variation in the moisture content of six species of pocosin shrubs was observed over two growing seasons at three locations along the coast of eastern North Carolina. The species were gallberry, fetterbush, redbay, swamp cyrilla, honeycup, and switch cane. Moisture content cycles in new foliage, old foliage (evergreen species only), and stems were observed.

Most species exhibited a rapid buildup of moisture content as new growth resumed in the spring. Moisture content declined rapidly during the first few weeks of growth, then tapered off gradually toward the end of the growing season. Each species had a characteristic pattern of moisture content variation that was relatively consistent over two growing seasons.

The moisture content of most species reached a minimum level in the spring, just prior to the initiation of new growth. This was most obvious in the foliage of the evergreen shrubs.

Evergreen shrubs usually had lower moisture contents than deciduous shrubs at any given time of the year.

Growth initiation in the spring was apparently influenced by the north-south location and nearness to the seacoast. Plants located at the northern extreme or further inland began new spring growth as much as 3 weeks later than those in the south or near the coast.

The date of new growth initiation in the spring was not consistent from one year to the next. In most species, however, new growth usually began before the third week in May, and could start as early as the fourth week in April.

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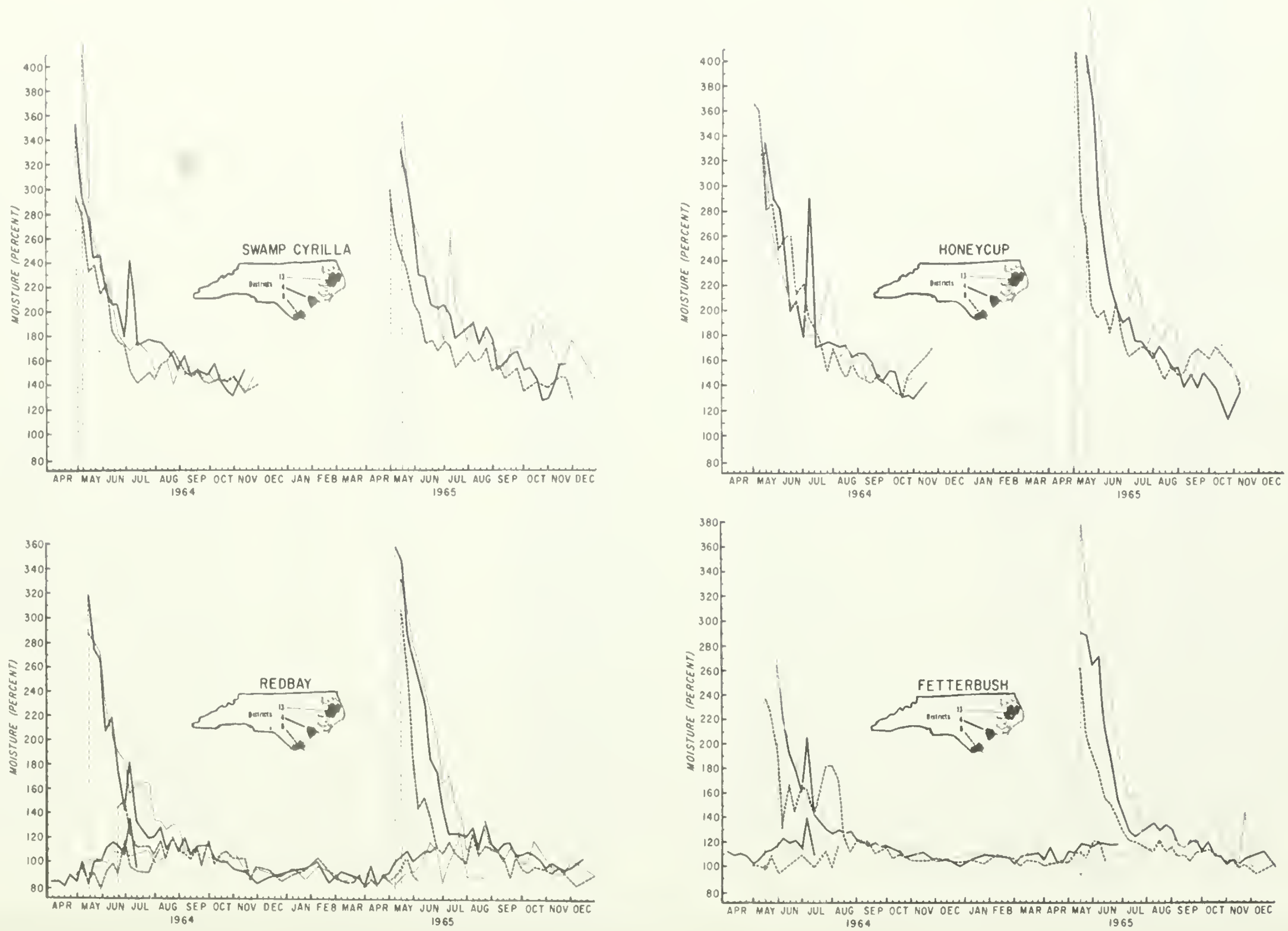
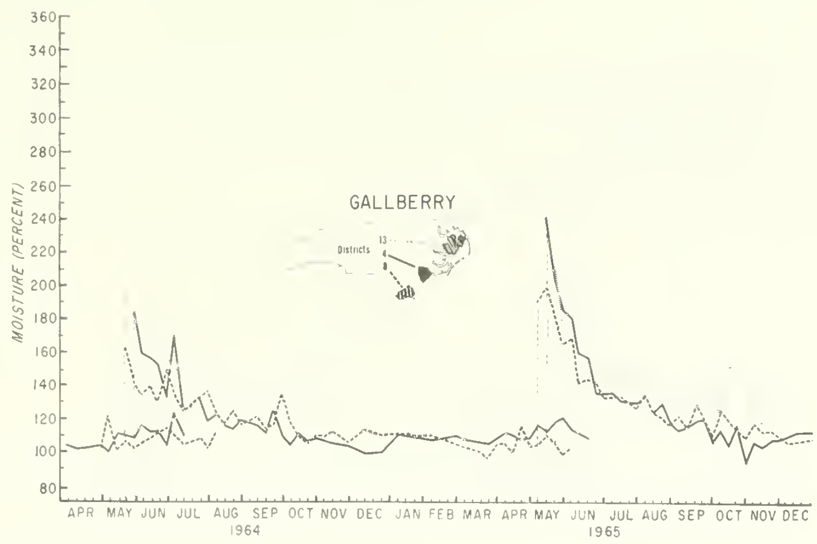
APPENDIX A

Seasonal variation in moisture content of the foliage of swamp cyrilla, honeycup, redbay, fetterbush, gallberry, and switch cane plants of the eastern North Carolina organic soils area.




GALLBERRY
Districts
13
4
8
MOISTURE (PERCENT)
360
340
320
300
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260
240
220
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180
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140
120
100
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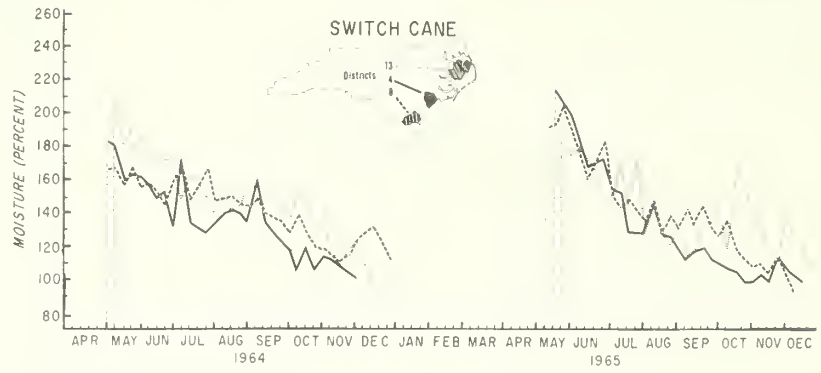
APR MAY JUN JUL AUG SEP OCT NOV DEC
1964
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1965


SWITCH CANE
Districts
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MOISTURE (PERCENT)
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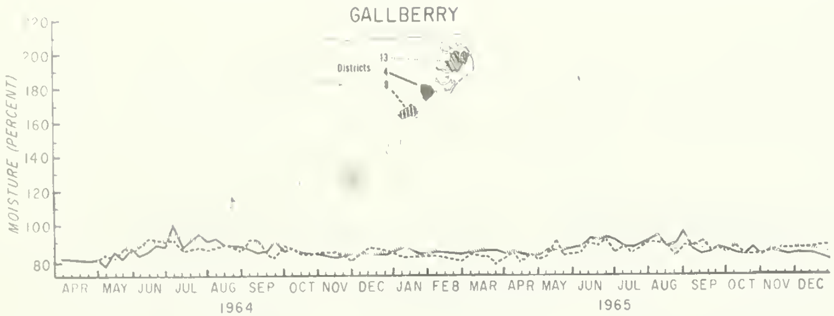
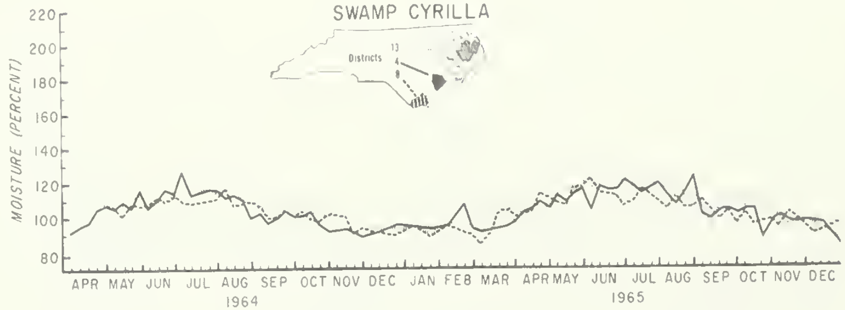
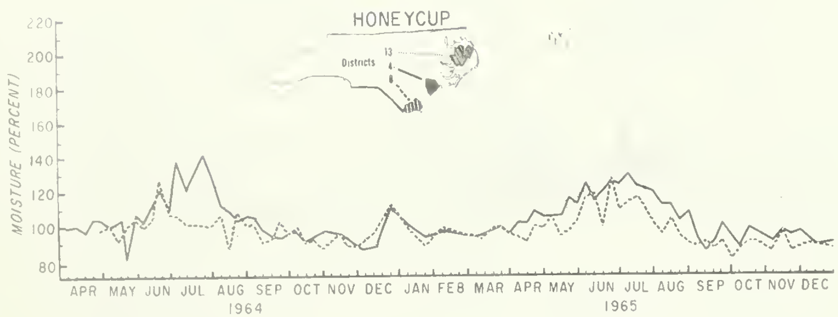
APR MAY JUN JUL AUG SEP OCT NOV DEC
1964
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1965

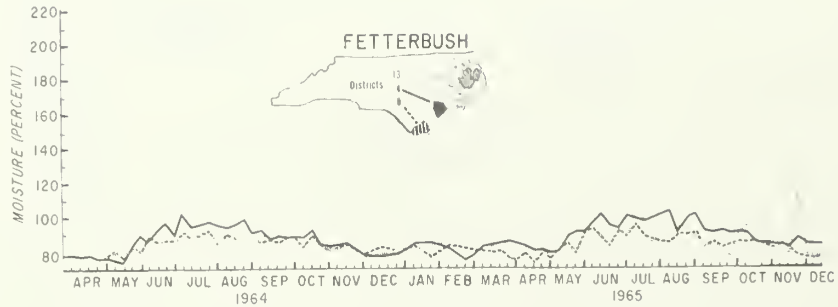
APPENDIX B

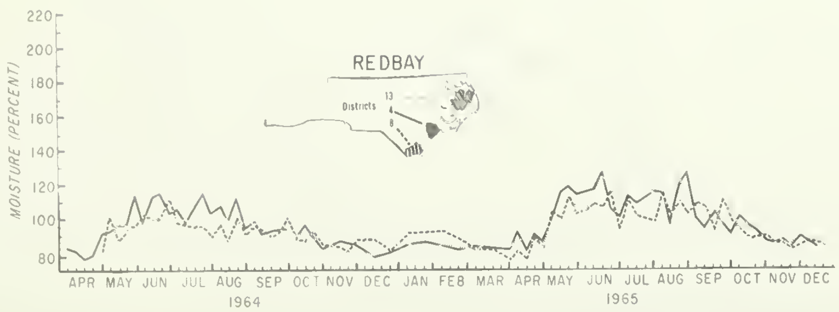
Seasonal variation in moisture content of the stems of gallberry, swamp cyrilla, honeycup, fetterbush, redbay, and switch cane plants of the eastern North Carolina organic soils area.

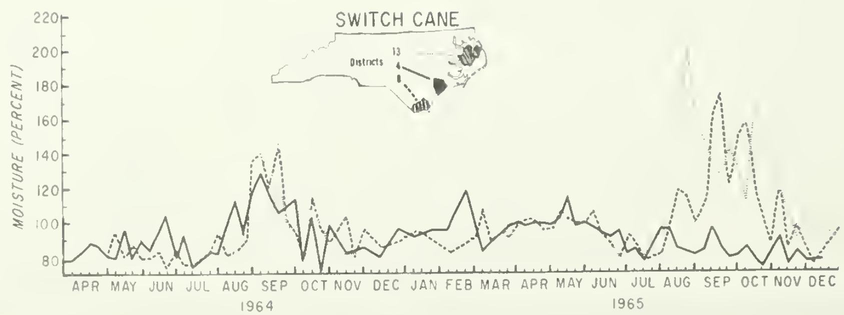












Blackmarr, W. H., and William B. Flanner
1974. Moisture variation in selected pocosin shrubs of eastern North Carolina. USDA For. Serv. Res. Pap. SE-124, 10 p. Southeast. For. Exp. Stn., Asheville, N.C.

Seasonal moisture content cycles in selected understory shrubs of eastern North Carolina pocosins were observed over two successive growing seasons. Each species had a characteristic pattern of moisture variation which was closely duplicated over two annual growth cycles. North-south location of the sample area and proximity to the seacoast were related to the timing of the annual moisture content cycles. Moisture content was lowest in most species during the spring, just before the appearance of new growth.

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The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

JSDA Forest Service Research Paper SE-125 March 1975

Regeneration Alternatives in Mixed Oak Stands

by
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Asheville, North Carolina

Regeneration Alternatives in Mixed Oak Stands

by

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The controversy over systems of management, cutting techniques, and regeneration methods for forest land continues to boil. This paper documents the different types of desirable timber-producing regeneration that can result from different intensities of cutting in moderately good hardwood stands in the Southern Appalachians.

The study that provides the primary data for this paper was first reported 3 years after the cutting treatments.[1] That report emphasized the effectiveness of clearcutting, but also pointed out that regeneration developed regardless of cutting intensity. This paper will emphasize cutting alternatives and will discuss certain advantages and disadvantages related to each cutting intensity.

STAND TREATMENT

In early 1963 eight mixed hardwood stands on Bent Creek Experimental Forest were selected for study. A circular $\frac{2}{3}$-acre plot plus a buffer zone was installed in each stand prior to logging. By spring all of the stands except the two controls had been cut (table 1). Two stands were cut to 66 square feet of basal area per acre, two were cut to 33 square feet, and two were clearcut. The partially cut plots were thinned from below so that the residual trees made up well-distributed oak stands, similar to stands formed by light or heavy shelterwood cuts.

In May 1963, during the latter stages of logging, a tally of advance regeneration was made on 16 milacres systematically established on each plot. Other tallies were made one (1963), three (1965), and nine (1972) growing seasons after cutting treatments. On the final tally all material over 5 feet in height was measured on the central $\frac{1}{2}$ acre of each plot; material over 18 inches but under 5 feet in height was measured on the central 1/40 acre, and material under 18 inches was measured on the sixteen 1-milacre plots.

[1] McGee, Charles E. 1967. Regeneration in Southern Appalachian oak stands. USDA For. Serv. Res. Note SE-72, 6 p. Southeast. For. Exp. Stn., Asheville, N.C.

Table 1.--Site and stand characteristics before and after cutting in 1963

Plot number	Site index[1]	Stand age	Overstory basal area		Basal area by species after cutting					
			1963	1972	Northern red oak	White oak	Black oak	Scarlet oak	Chestnut oak	Other species[2]
	Feet	Years	Square feet		- - - - - - - - - - - Percent - - - - - - - - - - -					
1	60	68	93	107	0	1	10	61	23	5
2	63	63	98	114	4	49	1	4	34	8
3	73	71	66	67	0	74	7	4	0	14
4	74	79	66	73	9	9	56	4	15	7
5	63	82	33	38	0	9	12	67	0	12
6	72	72	33	46	41	0	0	4	54	1
7	58	67	0	--	0	0	0	0	0	0
8	67	65	0	--	0	0	0	0	0	0

[1] Schnur, G. Luther. Yield, stand, and volume tables for even-aged upland oak forests. U.S. Dep. Agric. Tech. Bull. 560, 88 p. 1937.

[2] Other species include yellow-poplar, white and yellow pine, hickory, red maple, black locust, southern red oak, black cherry, and sourwood.

In interpreting the results it should be stressed that the stands included in the study, though contiguous, are highly variable. Species composition varied considerably between stands prior to treatment and to a lesser extent there are differences in site index, elevation, aspect, slope, age, and original basal area. It is also important that browsing pressure from deer has been light on this area for the past 5 years. If the deer had been present in larger numbers, their impact on the partially cut plots and the relatively small clearcuts could have been considerable.

RESULTS

The consistently large number of seedlings and sprouts found in the two uncut control plots on each of the four regeneration measurements indicates that small, undeveloped regeneration is usually present under mature mixed-hardwood stands in the Southern Appalachians (table 2). The few chestnut oak and white oak over 5 feet in height in the control areas are actually quite old. Many of the smaller stems are very young, and unless the stand is cut most will quickly die to be replaced by new stems.

Table 2.--Regeneration present by cutting treatment and date

Plot number and cutting treatment		Advance regeneration (May 1963)		One growing season after logging (August 1963)		Three growing seasons after logging (August 1965)		Nine growing seasons after logging (February 1972)	
		Oaks[1]	Other desirables[2]	Oak	Other desirables	Oak	Other desirables	Oak	Other desirables
		Number of stems per acre							
1	Control	4,250	312	5,312	812	4,500	1,562	2,559	1,484
2	Control	16,812	687	19,312	874	17,812	1,312	10,436	830
3	66 feet basal area left	5,875	500	7,375	6,312	4,250	8,312	4,319	17,304
4	66 feet basal area left	3,125	437	3,437	6,124	3,812	12,750	4,254	23,113
5	33 feet basal area left	3,187	624	5,000	1,187	4,437	1,999	6,995	5,390
6	33 feet basal area left	9,062	125	11,437	6,500	9,437	7,437	17,329	14,397
7	Clearcut	2,437	375	3,062	1,937	2,125	2,374	3,003	2,691
8	Clearcut	2,125	437	4,125	1,124	4,000	1,062	3,967	1,343

[1] Oak species are scarlet, white, black, chestnut, and northern red oak.
[2] Other desirable timber species include yellow-poplar, black cherry, ash, birch, yellow-pine, and a few planted white pine.

Although the four partially cut plots have different major overstory species, their regeneration development follows a somewhat similar pattern. Yellow-poplar is present in large numbers on each plot, and significant numbers of yellow-poplar have made height growth (tables 3, 4, and 5). White oak on plot 3 (66 feet basal area) is the predominant overstory species, and a number of white oak saplings are present. Black oak predominates the overstory on plot 4 (66 feet basal area), but chestnut oak and northern red oak along with the ever-present yellow-poplar numerically dominate the regeneration. On plot 5 (33 feet basal area) scarlet oak is the predominant overstory tree, but black oak and white oak are the most numerous oaks in the regeneration group. On plot 6 (33 feet basal area) chestnut oak is the predominant overstory species and also carries through to dominate the regeneration. In this case, chestnut oak development even overshadows that of yellow-poplar.

It is significant that each partially cut plot has over 800 desirable stems over 5 feet tall. Some of these stems are not free to grow, being overtopped by other regeneration or by the overstory. However, each partially cut plot has over 200 desirable stems per acre that are over 10 feet tall and most of these are relatively free from direct overhead competition. The 26 to 40 stems that are over 20 feet tall are almost all found in the middle of small openings created by the cutting treatments.

The two clearcut plots have numerous yellow-poplar stems per acre that are already over 20 feet tall. However, an unexpected result is the excellent general development of oak sprouts on these two clearcut plots. Northern red oak and chestnut oak have performed particularly well on plot 7, while black and white oak as well as chestnut oak excel on plot 8. It appears now that the oaks have a strong relative position on these two plots and have a good opportunity to be dominant in the new stand. Because of the rapid height development of a large number of trees, the reservoir of small stems is low on these two plots. The partially cut plots generally have much greater numbers of desirable stems under 10 feet in height.

Each plot also contains numerous stems of nontimber-producing or less desirable species. Most of these stems are small, but some are large and will be in the dominant stand. If so desired, these stems can be readily controlled, and their presence will not be emphasized in this paper.

Table 3.--Desirable timber regeneration 5 feet and over in height present 9 years after cutting (February 1972)

Plot number and cutting treatment	Timber species							
	Yellow-poplar	Northern red oak	White oak	Chestnut oak	Scarlet oak	Black oak	Other desirables[1]	Total
	Number per acre							
1 Control	0	0	0	8	0	0	70	78
2 Control	0	0	18	40	2	8	0	68
3 Basal area--66 feet	1,312	0	34	2	4	12	8	1,372
4 Basal area--66 feet	1,136	54	12	86	0	0	10	1,288
5 Basal area--33 feet	414	0	90	10	10	86	234	844
6 Basal area--33 feet	1,106	184	22	1,400	0	6	34	2,752
7 Clearcut	406	84	98	572	32	78	36	1,306
8 Clearcut	100	12	238	480	32	112	56	1,030

[1] Other desirable timber species include black cherry, ash, white pine, other pines, sweet birch, and others.

Table 4.--Desirable timber regeneration 10 feet and over in height present 9 years after cutting (February 1972)

Plot number and cutting treatment		Timber species							
		Yellow-poplar	Northern red oak	White oak	Chestnut oak	Scarlet oak	Black oak	Other desirables[1]	Total
		- - - - - - - -	- - - - - - - -	- - - - - - - -	Number	per acre	- - - - - - - -	- - - - - - - -	- - - - - - - -
1	Control	0	0	0	0	0	0	30	30
2	Control	0	0	4	4	0	0	0	8
3	Basal area--66 feet	210	0	14	0	0	4	2	230
4	Basal area--66 feet	202	18	2	30	0	0	0	252
5	Basal area--33 feet	106	0	28	0	0	18	98	250
6	Basal area--33 feet	42	30	0	252	0	0	6	330
7	Clearcut	314	70	0	158	12	46	0	600
8	Clearcut	86	4	78	180	22	78	42	490

[1]Other desirable timber species include black cherry, ash, white pine, other pines, sweet birch, and others.

Table 5.--Desirable timber regeneration 20 feet and over in height present 9 years after cutting (February 1972)

Plot number and cutting treatment		Timber species							
		Yellow-poplar	Northern red oak	White oak	Chestnut oak	Scarlet oak	Black oak	Other desirables[1]	Total
		Number per acre							
1	Control	0	0	0	0	0	0	0	0
2	Control	0	0	0	0	0	0	0	0
3	Basal area--66 feet	40	0	0	0	0	0	0	40
4	Basal area--66 feet	24	0	0	2	0	0	0	26
5	Basal area--33 feet	16	0	0	0	0	4	10	30
6	Basal area--33 feet	12	4	0	12	0	0	0	28
7	Clearcut	104	34	0	10	0	6	0	154
8	Clearcut	36	0	4	36	14	4	2	96

[1] Other desirable timber species include black cherry, ash, white pine, other pines, sweet birch, and others.

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USDA Forest Service Research Paper SE-126 March 1975

Biomass and Mineral Elements in a Thinned Loblolly Pine Plantation at Age 16

by

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Biomass and Mineral Elements in a Thinned Loblolly Pine Plantation at Age 16[1]

by

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Since the biomass removed from a forest contains nutrients that trees extract from the soil, any sizable increase in the harvest from a forest increases the quantity of nutrients removed from the site. Short rotations and utilization of whole trees, including small branches, leaves, and roots, are widely proposed to increase fiber supplies, but these actions would also greatly increase nutrient removal rates (Metz and Wells 1965).

Switzer and Nelson (1972) reported that nutrient accumulation rate in the biomass of loblolly pine stands was highest during the first 15 years after planting; therefore, short rotations would remove nutrients faster than long rotations. Depending upon a site's ability to provide nutrients, successive cropping could conceivably deplete the soil to the extent that tree growth would be reduced. However, with sufficient knowledge about soil-tree relationships, reduced growth could be prevented by application of fertilizer or alternative plans could be developed to minimize the nutrient removal impact. For this reason, information about nutrient removal rates is badly needed.

This paper reports the biomass in a loblolly pine (Pinus taeda L.) plantation at age 16, and the contents of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), zinc (Zn), copper (Cu), iron (Fe), and aluminum (Al) in various portions of the biomass. The plantation is on the Duke Forest in North Carolina.

PROCEDURES

A highly productive 16-year-old loblolly pine plantation was selected for the study. The trees were planted at a 1.8- by 2.4-m (6- by 8-ft) spacing. At age 16, there were 2,243 trees/ha averaging 16.6 cm in d.b.h. and 15 m in height (table 1). Site index was 68 feet at age 25 by the curves of Clutter and Lenhart (1968). The soil is Granville coarse sandy loam classified Typic Hapludult; fine loamy, siliceous, thermic.

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[1]Research supported in part by the Eastern Deciduous Forest Biome Project, International Biological Program, funded by the National Science Foundation under Interagency Agreement AG-199, 40-193-69 with the Atomic Energy Commission-Oak Ridge National Laboratory.

Table 1.--Characteristics of the 16-year-old loblolly pine plantation at thinning

Variable	Total	Crop	Pulpwood
Trees/ha	2,243	816	1,427
Basal area/ha (m^2)	49	22.5	26.5
Basal area/tree (cm^2)	218	276	186
Height (m)	15.0	ND[1]	ND[1]

[1]ND = not determined.

For estimates of aboveground biomass, a sample of 16 trees was selected from an area between two 0.1-ha study plots where tree growth, litterfall, and soil investigations were underway. D.b.h. was measured on all trees in the study plots and the area between the plots, a total of about 0.3 ha. All trees were numbered and then stratified by diameter into seven 2.54-cm classes. The 16 sample trees were in the five central classes which contained 97 percent of the trees. Three trees were randomly selected from four classes and four trees from one class.

Two sample trees per day were cut at ground level and felled on a canvas to prevent biomass loss. The trees were cut in September 1968, before major needle fall, and divided into stems, branches, and needles for determination of biomass and mineral element content. On the fallen trees, total height, height to crown, and crown length were measured. Tree stems were then cut into 1-m bolts, branches were removed, and all biomass hauled to the laboratory. Fresh weight of each bolt was determined, and a disk 2 to 5 cm thick was cut from the center of each bolt. The bark was removed from the disk, and bark and wood were weighed separately. The 1-year-old (current) and 2-year-old sections of the branches were clipped off and needles were removed from the respective components. The branch material greater than 2 years old was further divided into components less than 2 cm and greater than 2 cm in diameter. Dead branches were separated into components from within and below the living crown. Subsamples of the stems, needles, and branches were ovendried at 70° C to obtain dry weight.

All ovendried samples were ground in a Wiley mill after further subsampling of the stemwood components and large branches. Nitrogen was determined by the macro-Kjeldahl procedure. For the mineral elements, samples were dry-ashed at 450° C for 6 hours. K, Ca, Mg, Mn, Zn, Fe, Al, and Cu contents were determined by atomic absorption, and the vanadomolybdate method was used for P.

From data for the 16 trees, regressions were developed for each component by the model $Y = a + bx$, where Y = weight of component and x = cm^2 of basal area of the tree at breast height (1.3 m). Using the regression equations ($x = 218$ cm^2) and the tally of total number of trees (2,243 trees/ha), the biomass and nutrient content per hectare were estimated by component. Similar calculations were completed for the trees removed in the pulpwood thinning ($x = 186$ for 1,427 trees). In this thinning, 22.5 m^2 of the original 49 m^2 of basal area and 36 percent of the stems were left as future crop trees. Pulpwood biomass and nutrient content were estimated to an 8-cm diameter top.

To obtain information on root biomass and nutrient content, two trees were excavated to a 1-m depth throughout an area one-half the distance to adjacent trees. The main stump and larger lateral roots were removed by handpicking during excavation. Subsamples of soil were sieved with water to collect quantitative samples of the fine roots. Based upon these two root systems, biomass and element content of root systems per hectare were calculated by a ratio method:

$$\text{Root N (kg/ha)} = \frac{\text{N in roots of the two trees}}{\text{N in stems and live branches of the two trees}} \times$$

N (kg/ha) in stems and living branches for all trees per hectare.

Corresponding calculations were made for biomass, P, K, Ca, and Mg.

RESULTS

Biomass

Biomass in the aboveground part of all trees was 156 metric tons (t)/ha and the total biomass including roots was 192 t/ha in the plantation (table 2). Stemwood made up 57 percent of total biomass including roots. Root biomass was approximately 23 percent of top biomass, and the taproot made up about 66 percent of total root weight (table 3).

Tables giving data for the biomass and nutrients in the 16 sample trees, the regressions for relating the basal area of the trees to biomass and nutrient content, and the calculated biomass and nutrient content per hectare are available from the authors.

Over the 16 years the plantation's net annual biomass accumulation was 11.5 t/ha/yr for stems, branches, and roots. Since needle production was 4.8 t/ha during the 16th year, total biomass production appears to have been as much as 16 t/ha in some years.

Table 2.--Biomass in all trees, crop trees, and pulpwood trees in a 16-year-old plantation when thinned

Component	All trees[1]	Crop trees	Pulpwood trees
	Metric tons/ha		
Needles, current	4.84	2.50	2.45
Needles, total	7.98	3.89	4.12
Branches, living	14.59	7.37	7.30
Branches, dead	8.60	4.86	5.54
Stemwood	109.55	51.45	58.52
Stembark	15.23	7.03	8.25
Aboveground	155.95	74.60	83.73
Roots	36.30	17.19	19.28
Total	192.25	91.79	103.01

[1] Components for all trees, crop trees, and pulpwood trees were calculated independently; therefore, all trees $\neq$ crop trees + pulpwood trees.

Table 3.--Root biomass and N, P, K, Ca, and Mg content by root diameter class

Root class	Biomass	N	P	K	Ca	Mg	N	P	K	Ca	Mg
	kg/tree	Percent (o.d.)					g/tree				
TREE NO. 14, d.b.h. = 20.6 cm											
Taproot											
Wood	12.96	0.080	0.020	0.120	0.064	0.033	10.43	2.59	15.55	8.29	4.28
Bark	1.12	.292	.078	.698	.186	.070	3.28	.88	7.85	2.09	.79
Lateral roots											
> 4 cm	2.25	.103	.020	.055	.035	.016	2.32	.45	1.24	.79	.36
2-4 cm	1.83	.179	.066	.330	.121	.068	3.28	1.21	6.04	2.21	1.24
1-2 cm	1.02	.288	.114	.358	.214	.110	2.94	1.16	3.65	2.18	1.12
0.3-1 cm	.59	.437	.200	.540	.285	.170	2.58	1.18	3.19	1.68	1.00
> 0.3 cm	2.20	.569	.120	.136	.408	.084	12.52	2.64	2.99	8.98	1.85
TREE NO. 4, d.b.h. = 13.7 cm											
Taproot											
Wood	8.61	.059	.013	.106	.036	.056	5.08	1.12	9.13	3.10	4.82
Bark	.55	.217	.095	.783	.093	.090	1.19	.52	4.31	.51	.50
Lateral roots											
> 4 cm	.83	.101	.012	.068	.050	.021	.84	.10	.56	.42	.17
2-4 cm	.51	.210	.022	.148	.050	.031	1.07	.11	.76	.26	.16
1-2 cm	.57	.228	.094	.328	.326	.126	1.30	.54	1.87	1.86	.72
0.3-1 cm	.64	.308	.099	.372	.346	.150	1.97	.63	2.38	2.21	.96
> 0.3 cm	1.86	.580	.098	.146	.369	.104	10.79	1.82	2.72	6.86	1.93

The regressions were used to calculate stem and living branch biomass of the plantation at age 14 when the average basal area per tree was 200 cm^2. The annual change in weight in years 15 and 16 averaged 5.6 t for stems, 1.9 t for branches, and 11.3 t/ha/yr for needles, stems, and branches together. Total annual net production for ages 15 and 16 would exceed this estimate because mortality of branches was not measured and root production was excluded.

A conventional clearcut of all stems, including bark, to an 8-cm top at age 16 would yield 7.2 t/ha/yr (table 4). If the bark from this pulpwood was left in the woods, the yield would be 6.4 t/ha/yr. Harvest of complete trees, including roots greater than 4 cm in diameter, would yield 11.6 t/ha/yr.

Table 4.--Biomass and nutrient removal rates for a clearcut with alternative tree harvest methods at age 16

Harvest method	Biomass		N	P	K	Ca	Mg
	Total t/ha	Annual t/ha/yr	kg/ha/yr				
Complete aboveground + roots > 4 cm	185	11.6	17.6	2.3	12.6	12.8	3.6
Complete aboveground	156	9.8	16.1	1.9	10.3	11.7	2.9
Pulpwood to 8-cm top	116	7.2	6.5	0.9	5.0	6.4	1.6
Debarked pulpwood to 8-cm top	102	6.4	4.6	0.8	3.8	4.3	1.3

The thinning cut 64 percent of the trees, and close to 50 percent of the current needles, living branches, stemwood, and stembark. In this uniform plantation, living branch weight was 12.6 percent of stem weight on residual crop trees and 10.9 percent on cut trees. The thinning removed 61 t/ha of biomass and left 22 t of slash residue and 19 t of roots on the site (table 5). In a thinning with complete aboveground tree harvest, approximately 67 t of stem and 7 t of living branches would have been taken from the site. The 19 t of roots and part of the 4 t of dead branches and 4 t of needles would have been left on the site. Thus, thinning with complete aboveground harvest would take somewhat over 74 t/ha of biomass compared to 61 t in a standard thinning operation.

Table 5.--Biomass, N, P, K, Ca, and Mg in wood and bark, in slash residue, and in roots of trees cut for pulpwood thinning

Component	Biomass	N	P	K	Ca	Mg
	t/ha	kg/ha				
Pulpwood wood	53.2	38	5.8	31	37	10.9
Pulpwood bark	7.4	16	1.9	10	21	2.9
Total pulpwood	60.6	54	7.7	41	58	13.8
Slash residue	22.1	83	8.7	46	48	11.3
Roots	19.0	36	11.0	36	25	12.7

Nutrients

Total N in tree biomass including roots was 321 kg/ha at age 16, and the accumulation rate was 20 kg/ha/yr (table 6). Following N, in order of quantity accumulated, were K, Ca, Mg, and P. The needles and stemwood contained about equal quantities of N and P; but more K, Ca, and Mg were in stemwood than needles. All components have sufficient quantities of nutrients to warrant consideration when nutrient relationships of alternative harvesting methods are evaluated.

Table 6.--N, P, K, Ca, and Mg in various components of trees in a 16-year-old loblolly pine plantation

Component	N	P	K	Ca	Mg
	kg/ha				
Needles, current	55	6.3	32	8	4.8
Needles, total	82	10.0	48	17	7.9
Branches, living	34	4.5	24	28	6.1
Branches, dead	26	1.5	4	30	3.0
Stemwood	79	10.7	65	74	22.7
Stembark	36	4.2	24	38	6.5
Aboveground, total	257	30.9	165	187	46.2
Roots	64	16.9	61	52	21.9
Total	321	47.8	226	239	68.1

Alternative harvest methods would remove nutrients from the site at vastly different average annual rates (table 4). For example, an annual biomass yield of 6.4 t of debarked pulpwood to 8-cm top would remove 4.6 kg N/ha/yr. Harvest of the complete aboveground tree would yield 9.8 t of biomass per year, but would remove 16.1 kg N/ha/yr. Thus, harvest of 3.4 t of low-quality biomass per year would remove an additional 11.5 kg N/ha/yr--2½ times as much N as harvest of high-quality pulpwood alone. Similarly, slash harvest removes from 3 to 6 times as much of other nutrients per unit of biomass as does harvest of wood alone.

The pulpwood thinning removed less N, P, and K than was returned to the soil as slash residue (table 5). Slightly more Ca and Mg were removed in the pulpwood than were returned to the soil in the slash. Roots and slash left after thinning are a nutrient source that is made available to crop trees through decomposition. The quantities of N, P, K, Ca, and Mg from these sources would be 119, 20, 82, 73, and 24 kg/ha, respectively. The speed at which they would be made available depends upon the time required for decomposition.

The other elements determined in the study are present in relatively small quantities in comparison with the major elements (table 7). Concentrations of some of these minor elements are high in wood in relation to bark and needles. Harvesting pulpwood, therefore, removed a larger proportion of Mn, Zn, and Cu in the total biomass than it did of N and P. About 64, 62, and 71 percent of the Mn, Zn, and Cu in the biomass were in the wood normally taken for pulpwood. Approximately 50 percent of the Al in the aboveground biomass was in the stembark and about 60 percent of the Na was in the stemwood.

Table 7.--Mn, Zn, Fe, Cu, Al, and Na in aboveground components of trees in a 16-year-old loblolly pine plantation

Component	Mn	Zn	Fe	Al	Na	Cu
	kg/ha					g/ha
Needles, current	1.222	0.166	0.334	2.178	0.258	21.5
Needles, total	2.544	.327	.650	4.116	.356	31.6
Branches, living	1.716	.345	.915	2.519	1.384	63.7
Branches, dead		.289	1.281	2.902	.314	69.5
Stemwood	8.445	1.086	1.830	1.790	3.640	275.0
Stembark	.951	.336	1.126	9.705	.590	59.4
Tree total	13.656	2.383	5.802	21.032	6.284	499.2

Sampling and Data Analysis

Reliable sampling methods and a basis of data comparisons for different studies are essential for the interpretation of results. Ovington, Forrest, and Armstrong (1967) and Madgwick (1971) studied sampling for biomass in *Pinus radiata* and *Pinus virginiana* stands, respectively. They stated that stratified sampling by tree-size classes, similar to the procedure we used, gave better estimates of biomass than random sampling from the population. As in our work, Ovington et al. (1967) found relatively large errors for estimates of the weight of minor components, but because these components made up only a small proportion of the total, the effect on total biomass was small. When minor components, such as small branches, were included in a larger component, as total branches, we found our estimate for branch weight was improved.

Errors in the root/top ratio for estimation of the root component produce relatively small errors in total biomass and mineral estimates, because the ratio is fairly constant and the roots represent less than 30 percent of the total mass. Loblolly pine root biomass of 11- and 12-year-old trees (Nemeth 1972) in the North Carolina Coastal Plain and of 14-year-old trees in the Piedmont (Ralston et al. 1972) was 22 and 24 percent of the stem plus living branches compared with 27 percent for the present study. The ratios of roots to stems and living branches were 0.43 for N, 0.87 for P, 0.54 for K, 0.37 for Ca, and 0.62 for Mg. Corresponding calculated ratios from data of Wheeler (1972) were 0.59 for K, 0.33 for Ca, and 0.48 for Mg. The estimation of root biomass and element weight by the ratio of roots to stems and living branches rather than the ratio of roots to total biomass avoids the errors inherent with variable dead-branch weight, seasonal changes in leaf weight, and the additive effect of errors in root sampling.

Since trees in a plantation vary widely in size and in relative proportions of component parts, and since the number of trees in a practical sample is limited, some error must be accepted in biomass and nutrient determinations. In this study, standard errors of estimates expressed as percents of the mean were 1.8 for total stems, 6.7 for living branches, and 5.6 for 1-year-old needles. Larger standard errors were found for biomass of certain minor components, and extreme variability was found for Ca in stembark, and Zn and Al in general. Error in estimating the dead branch component is relatively large because the rate of branch mortality varies and loss from the tree depends upon tree and branch size as well as occurrence of ice and windstorms. The dead branches were not classed by diameter, and nutrient content varied widely from tree to tree.

So far, we have tried only simple regression models in our estimates. There are indications that alternative estimation models which might provide more reliable estimates should be considered (Schreuder and Swank 1971).

DISCUSSION

Since yield and net primary production for a species are affected by environmental factors and stand conditions such as growing space and age, it is not surprising that total biomass and annual production for loblolly pine have varied widely in different studies. Results of the various studies with loblolly pine are summarized in table 8. In 10-, 15-, and 20-year-old stands from natural regeneration in Mississippi, biomass accumulation rates were lower than in all the other stands, which were planted.

Table 8.--Aboveground net accumulations of biomass and nutrients in loblolly pine stands at various locations and ages

Location and reference	Age	Biomass			N	P	K	Ca	Mg
		Total	Annual	Current					
		t/ha	- t/ha/yr -		- - - - - kg/ha - - - - -				
Miss., Smith et al. (1971)	4	6.3	1.6		38				
	5	15.7	3.1	9.4	72				
Miss., Switzer and Nelson (1972)	10	28.0	2.8		85	9.5	49	33	10.5
	15	63.0	4.2	7.0	140	15.8	82	62	17.3
	20	90.0	4.5	5.4	174	19.3	99	91	24.2
Japan, Akai et al. (1968)	7	45.8	6.5		235	21.0	51	100	44.0
	7	6.1	0.9						
Japan, Akai et al. (1972)	34	197.0	5.8		422	142.0	238	445	75.0
N.C., Nemeth (1972) and Wheeler (1972)	11	77.4	7.0				56	138	29.0
	12	90.6	7.6	12.2			59	158	33.0
N.C., Ralston et al. (1972)	14	75.5	5.4						
	15	91.1	6.1	15.6					
N.C. (present study)	16	155.0	9.7	7.5	257	31.0	165	187	46.0

In Japan, at age 7, the total biomass was 46 t/ha for fertilized low-density (2,100 stems/ha) and for high-density (3,700 stems/ha) plantings. At the same location without fertilization, total biomass at age 7 was 6.1 t/ha with 3,700 stems/ha. The 34-year-old plantation in Japan produced at a slightly lower annual rate than the 7-year-old stand; however, current annual increment of stems was estimated at 7.4 t/ha.

In North Carolina studies, annual biomass accumulation rate since planting was greatest in our 16-year-old plantation, but both the Nemeth (1972) and Ralston et al. (1972) data show a larger current accumulation rate. This result suggests that our stand had passed the peak of productivity. Our stand had 2,243 and the other stands had about 1,500 trees/ha; this difference probably affected comparative production. The 1968 growing season, one of the two years used to estimate current biomass accumulation in the 16-year-old stand, was unusually dry. Annual growth rings were noticeably small and late wood was not found when the trees were cut in September.

Elemental concentrations vary by tree component, and the amount of element in a component is affected by tree age and treatment. In estimating the quantity of nutrients removed from a site, therefore, treatments such as thinning and fertilization, as well as age and amount of biomass removed, must be considered. Boggess (1959) reported increased N concentration in the needles of shortleaf pine following thinning and suggested that nutritional effects of silviculture should be considered. Plantation management by thinning procedures, in contrast to a single-crop harvest in a short rotation, releases nutrients from slash for crop trees, prevents large single-time nutrient removals or releases, and thus more evenly matches nutrient supply with the tree requirements.

The quantities of nutrients in various tree components have important implications for forest managers. Harvest of complete trees for any reason would remove nutrients from the soil at unprecedented rates for forestry. In contrast, harvest of only wood would remove N at approximately the same rate as it is added from the atmosphere (Gambell and Fisher 1966; Wells, Whigham, and Lieth 1972). The impact of nutrient removal on fertility depends upon the supply in the soil and the available means of nutrient restoration. Fertilization, when better developed, will be a method for replenishing or increasing nutrient supply. N could be replenished by planting N-fixing plants. If harvesting systems lead to nutrient removal at rates near or above natural means of restoration, understanding of tree nutrition and its interaction with timber production will prove very important indeed.

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Weighing and analysis of aboveground components of 16 trees and roots of 2 trees indicated a tree biomass, including roots, of 192 metric tons (t)/ha in a 16-year-old loblolly pine plantation. This biomass contained 321 kg N, 48 kg P, 226 kg K, 239 kg Ca, and 68 kg Mg. A pulpwood thinning removed 61 t/ha of wood and bark which contained 54 kg N, 8 kg P, 41 kg K, 58 kg Ca, and 14 kg Mg/ha. The 22 t/ha of logging residue contained more N than the pulpwood, and other elements in the residue were similar in quantities to that in the pulpwood. The slash will be a useful source of nutrients for crop trees as the residue decomposes. Clearcutting the plantation at age 16 and removing all aboveground tree components would remove biomass at the rate of 9.8 t/ha/yr and N, P, K, Ca, and Mg at the rates of 16, 2, 10, 12, and 3 kg/ha/yr. Such a removal rate might exceed the annual replenishment rate for some nutrients and might therefore deplete nutrients and fertility on some sites.

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FUSIFORM RUST: Forest Survey Incidence Data and Financial Impact in the South

by
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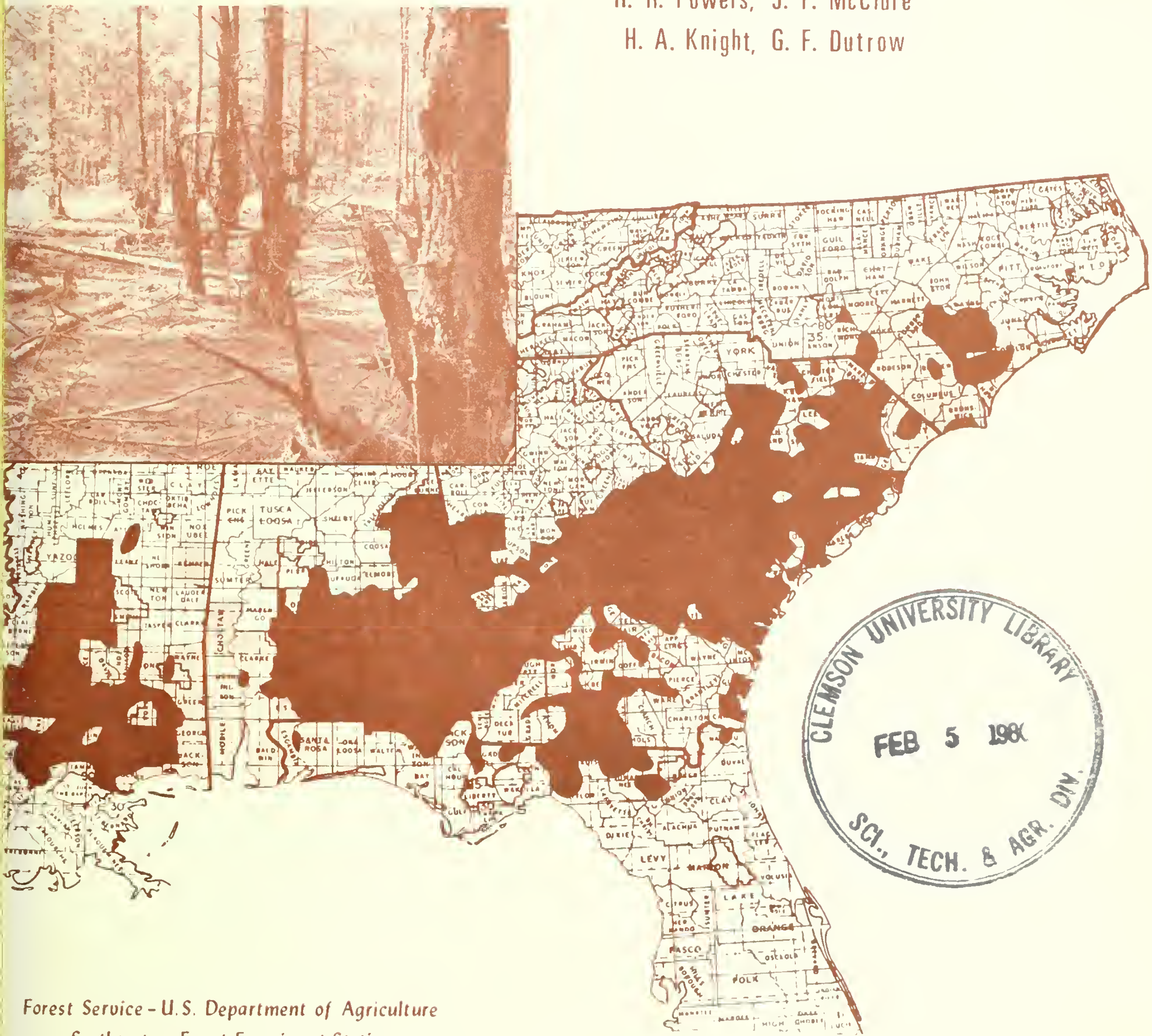
H. A. Knight, G. F. Dutrow



Forest Service - U.S. Department of Agriculture
Southeastern Forest Experiment Station
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FUSIFORM RUST: Forest Survey Incidence Data and Financial Impact in the South

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Fusiform rust (caused by Cronartium fusiforme Hedgc. & Hunt ex Cumm.) is recognized as the most damaging disease of forest trees in the South (fig. 1), but little information has been published relating incidence rates to financial impact of the disease. This Paper reports data obtained in the Forest Surveys of South Carolina, Georgia, and Florida on relative incidence of the disease in natural and planted stands of loblolly (Pinus taeda L.) and slash (P. elliottii var. elliottii Engelm.) pine. The disease is equally serious in Alabama, Mississippi, and Louisiana (figs. 2 and 3). Data from the three Southeastern States, therefore, were expanded to estimate current financial impact of fusiform rust on slash and loblolly pine in the entire South. These species were chosen because they are the most commonly planted southern pines and because they are highly susceptible to the disease (8). More than 90 percent of the damage by fusiform rust occurs on these two species.

Figure 1.--Heavy fusiform rust damage in a 14-year-old slash pine plantation in southeastern South Carolina.

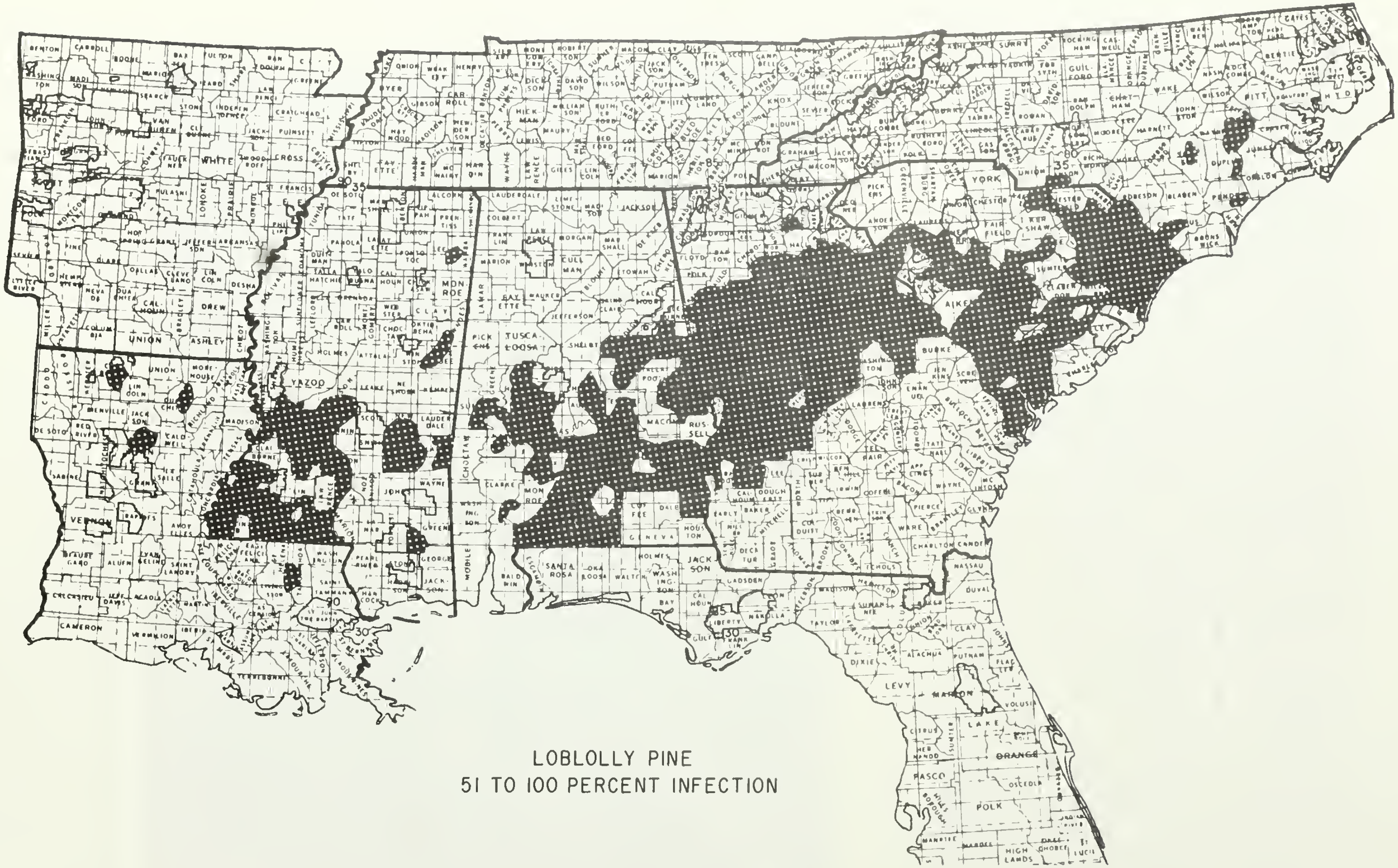

Figure 2.--Areas where 8- to 12-year-old loblolly pine plantations were 51 to 100 percent infected by fusiform rust in 1971-73. (From report by Phelps (6).)

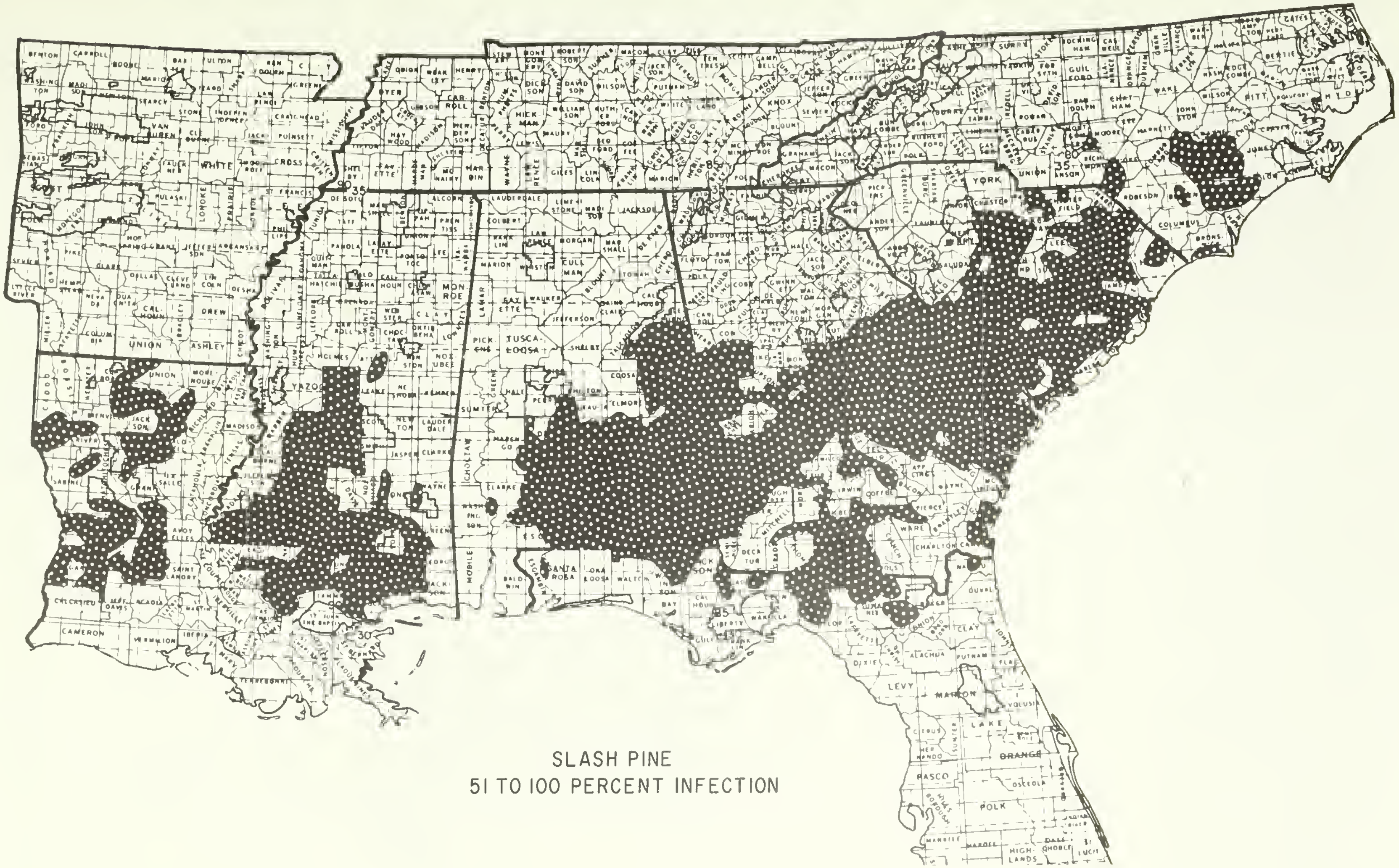

Figure 3.--Areas where 8- to 12-year-old slash pine plantations were 51 to 100 percent infected by fusiform rust in 1971-73. (From report by Phelps (6).)

SURVEY METHODS

In standard Forest Surveys by the USDA Forest Service in the Southeastern States, data are collected on disease incidence as well as on tree growth, timber volume, timber removal, and land use. States are divided into survey units, and the survey units in South Carolina, Georgia, and Florida included in this report cover the primary range of fusiform rust in these States (fig. 4). Data upon which this report was based were from the most recent surveys of these States during the years 1966 to 1972.

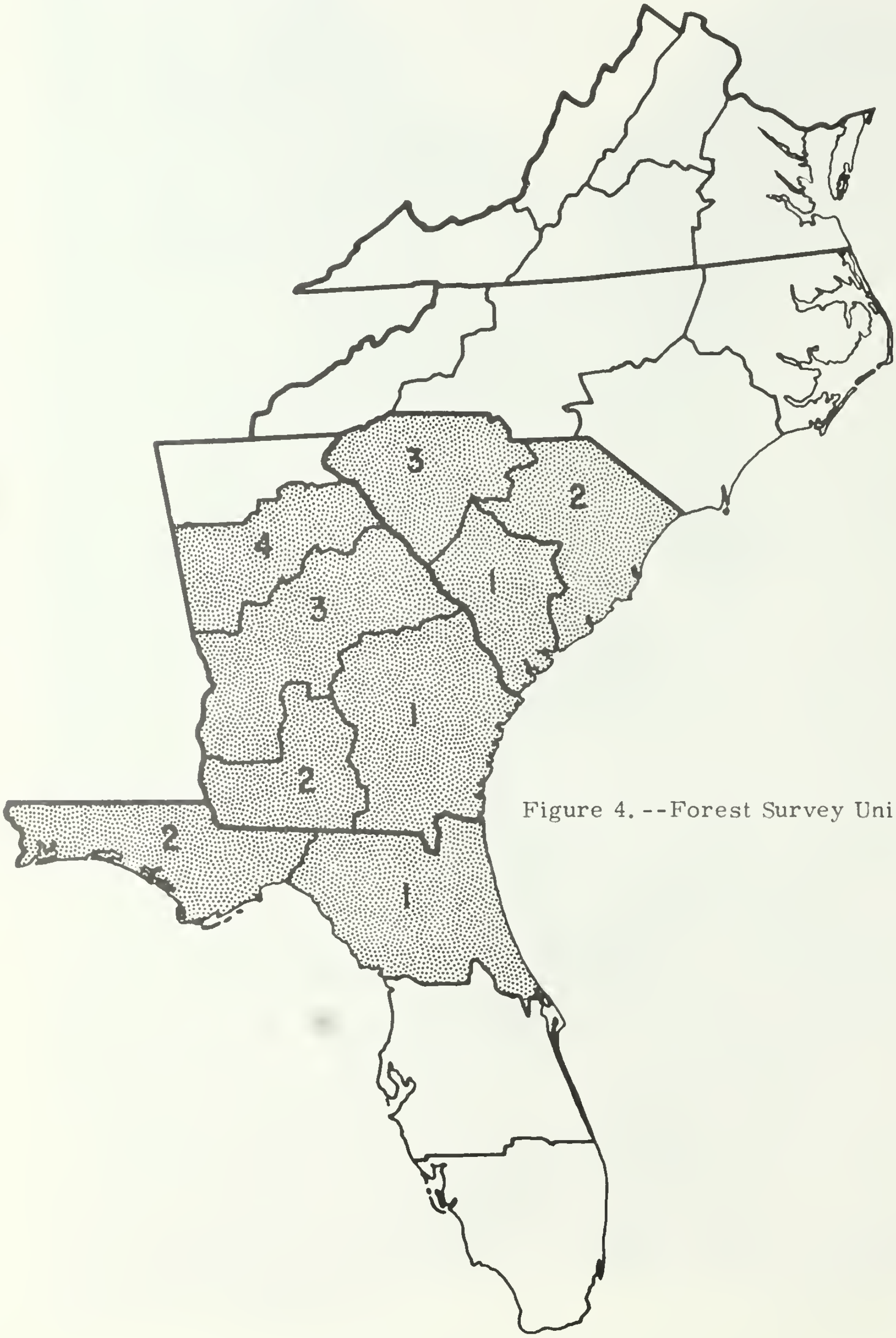

Figure 4. --Forest Survey Units included in study.

Data were taken on standard survey plots, which are made up of a 10-point cluster of sample areas systematically distributed from a random start on 1 acre. At each of the 10 points, sample trees 5.0 inches d.b.h. and larger were selected using a basal area factor of 37.5 square feet per acre. Trees smaller than 5.0 inches d.b.h. were tallied on plots with a radius of 6.8 feet around the point centers. More than 13,000 plots were measured in the 9 study survey units. All are on land classified as commercial forest, regardless of forest condition or ownership. Forest type was determined at each sample location, and stands were identified as natural or plantations.[1]

All living loblolly and slash pines 1 inch d.b.h. and larger were examined for fusiform rust stem infections, which are easy to recognize. No branch galls, even those very close to the stem, were included unless the infection actually involved stem tissue. The techniques used did not estimate seedling infection, and it was impossible to estimate rust-caused mortality because trees that had died since the previous survey were often decomposed.

On the survey units loblolly and slash pine occupy more than 17.5 million acres of commercial forest. Acreages and numbers of loblolly and slash pines are listed by stand origin and species in table 1. These are by far the most widely planted species in the South and provide the bulk of southern pine pulpwood, saw logs, veneer logs, poles, and piles. These pines are most often selected for intensive management; i.e., site preparation, planting, fertilization, and thinning. These practices, which require large investments, substantially increase growth, but they also make the trees more susceptible to rust (2, 4, 9).

Table 1.--Acreage and number of trees 1 inch d.b.h. and over represented in the Forest Survey inventory, by stand origin and species, for the areas included in the study

State	Stand origin and species	Acreage and number of trees 1 inch d.b.h. and over represented in inventory	
		Acres	Thousands of trees
South Carolina	Natural loblolly	2,500,800	1,228,481
	Natural slash	98,100	55,056
	Planted loblolly	410,100	197,222
	Planted slash	476,100	213,613
Georgia	Natural loblolly	4,004,600	2,045,979
	Natural slash	2,439,000	1,153,792
	Planted loblolly	632,400	276,414
	Planted slash	2,088,600	704,433
Florida	Natural loblolly	296,000	108,064
	Natural slash	2,335,100	912,665
	Planted loblolly	40,700	16,470
	Planted slash	2,197,800	771,841
Total		17,519,300	7,684,030

[1]Complete definitions of survey terms and descriptions of methods are in: Forest Survey Manual for the Southeast. Parts I through V. 1968. USDA For. Serv. Southeast. For. Exp. Stn., Asheville, N.C.

RESULTS

Planted pines generally had higher percentages of infection than those in natural stands. The ratio of infection was almost 2 to 1 for planted vs. natural loblolly, and over 3 to 1 for planted vs. natural slash pine. In plantations, 21 percent of the loblolly pines and 15 percent of the slash pines have stem infections. However, 15 percent infection of all planted slash pines is the more meaningful figure because planted slash pines made up 44 percent of the total slash pine inventory, while planted loblolly made up only 13 percent of the total loblolly inventory. Approximately 2.5 times as many planted slash pines were infected as loblolly pines (249 million to 101 million) in these three States.

For both species, incidence levels were lowest in the smallest d.b.h. class, gradually increased to a peak in the 8-inch d.b.h. class, and then declined in the larger diameter classes (fig. 5). The incidence of stem galls dropped very sharply in slash pines between the 8- and 12-inch d.b.h. classes.

Rates of stem infection on living trees 1.0 inch d.b.h. and larger are shown by 2-inch d.b.h. classes in table 2.

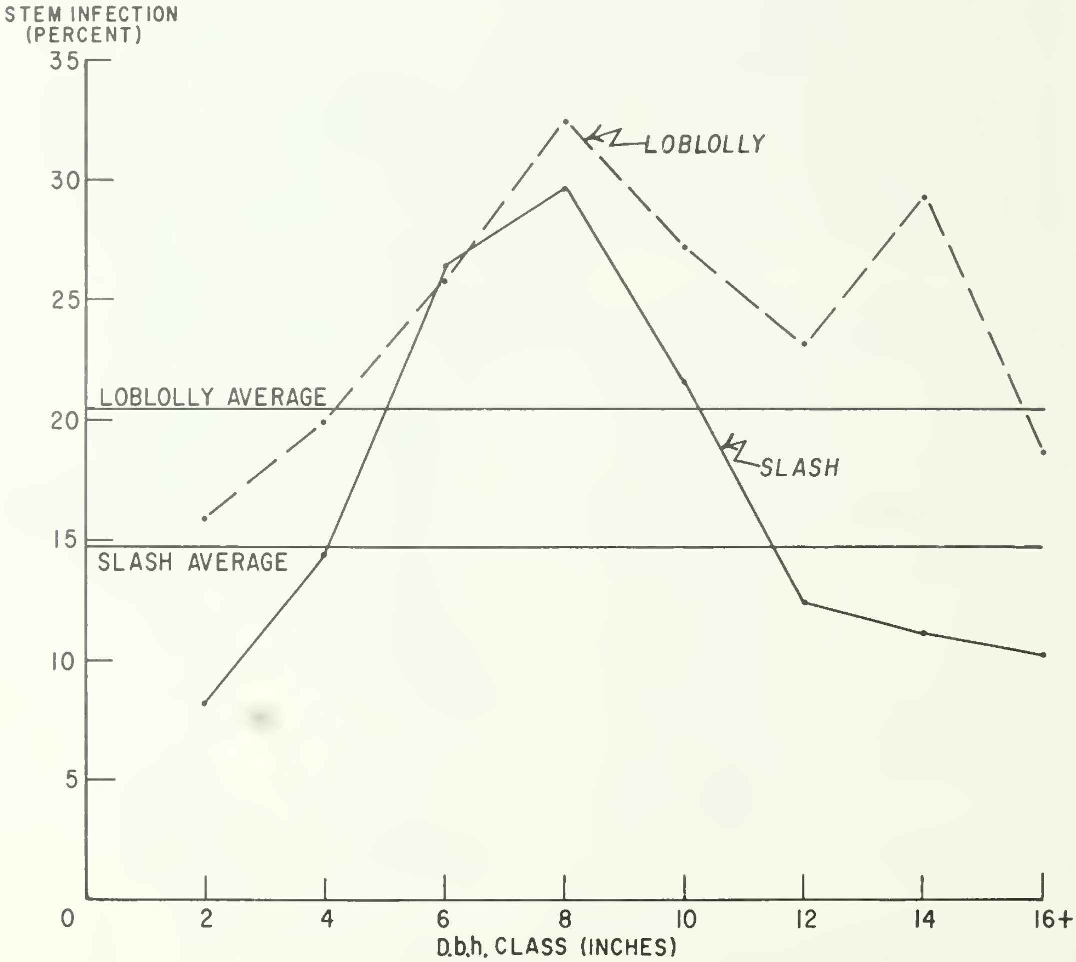

Figure 5.--Fusiform rust incidence, by diameter class, on planted loblolly and slash pines in the study area.

Table 2.--Summary of fusiform rust incidence, by stand, origin, species, and diameter class, for the areas included in the study

Type of stand and species	Total all classes	Diameter class (inches)							
		2	4	6	8	10	12	14	16+
Plantation:									
Slash pine:									
No. of trees in inventory (in thousands)	1,689,887	686,239	603,370	298,102	80,532	15,406	4,438	1,253	547
Proportion infected	14.75%	8.16%	14.36%	26.40%	29.55%	21.55%	12.37%	11.17%	10.24%
Loblolly pine:									
No. of trees in inventory (in thousands)	490,106	185,518	163,817	91,700	33,666	11,029	2,753	962	661
Proportion infected	20.54%	15.91%	19.86%	25.82%	32.45%	27.21%	23.10%	29.31%	18.61%
Natural:									
Slash pine:									
No. of trees in inventory (in thousands)	2,121,513	943,428	568,752	290,132	152,322	84,921	45,489	22,357	14,112
Proportion infected	4.74%	4.68%	4.70%	5.00%	5.15%	4.25%	2.95%	3.22%	2.44%
Loblolly pine:									
No. of trees in inventory (in thousands)	3,382,524	1,653,386	766,427	409,094	227,430	136,005	86,239	53,117	50,826
Proportion infected	11.62%	9.60%	11.70%	14.86%	16.34%	15.52%	14.76%	13.41%	11.52%

RESULTS

Planted pines generally had higher percentages of infection than those in natural stands. The ratio of infection was almost 2 to 1 for planted vs. natural loblolly, and over 3 to 1 for planted vs. natural slash pine. In plantations, 21 percent of the loblolly pines and 15 percent of the slash pines have stem infections. However, 15 percent infection of all planted slash pines is the more meaningful figure because planted slash pines made up 44 percent of the total slash pine inventory, while planted loblolly made up only 13 percent of the total loblolly inventory. Approximately 2.5 times as many planted slash pines were infected as loblolly pines (249 million to 101 million) in these three States.

For both species, incidence levels were lowest in the smallest d.b.h. class, gradually increased to a peak in the 8-inch d.b.h. class, and then declined in the larger diameter classes (fig. 5). The incidence of stem galls dropped very sharply in slash pines between the 8- and 12-inch d.b.h. classes.

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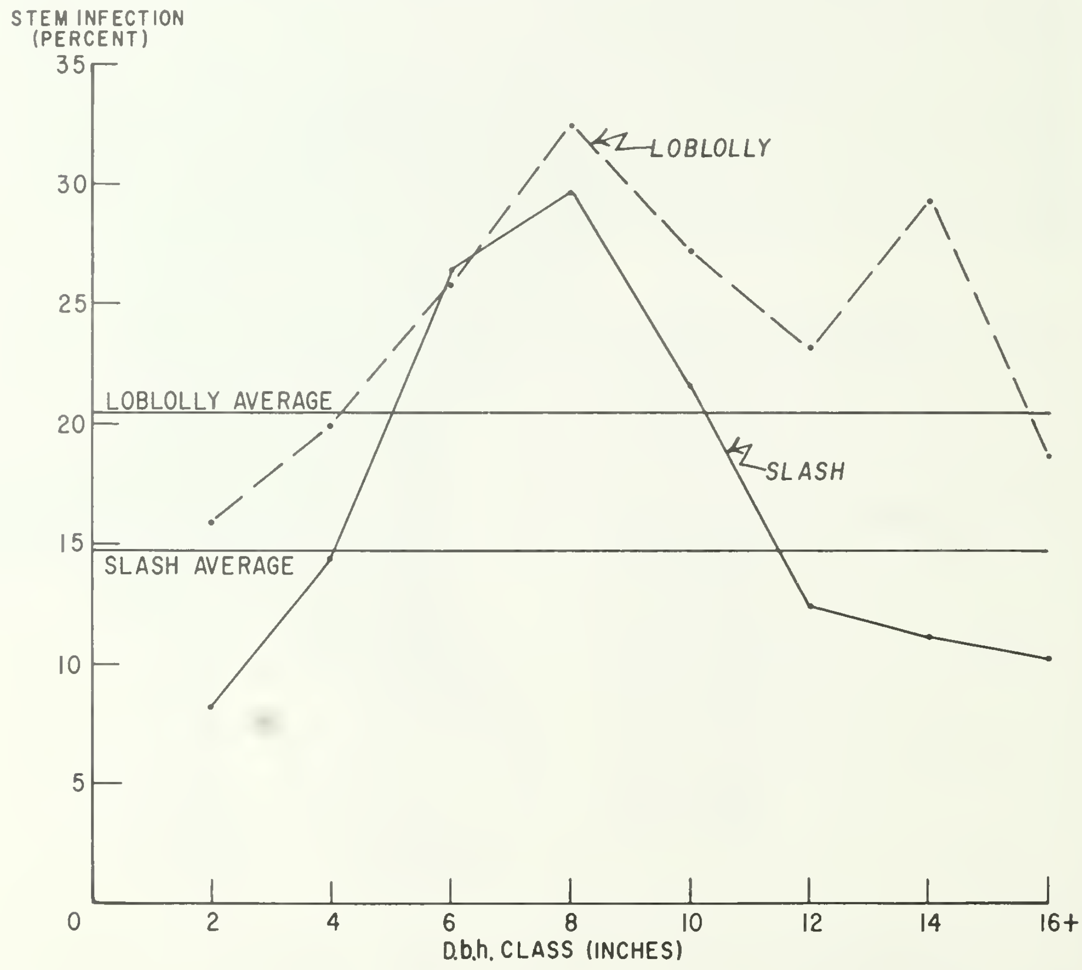

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Survey data and price information from 1970 were used to derive initial cubic-foot values. In 1970, some 3.7 billion cubic feet of softwood products were removed from southern lands (12, table 33). Stumpage price information for southern pine sawtimber and pulpwood were gathered from Forest Farmer (5) statistics as a framework for value calculations.

In blending these volumes and prices into a single representative value, three price x quantity relationships were used. Southwide stumpage prices of $50 per thousand board feet and $6.42 per cord for sawtimber and pulpwood were extracted from Forest Farmer compilations. A $60 per thousand board-feet price was chosen to provide a premium for veneer logs. To compute a blended price, each cubic foot of wood was subdivided into portions assigned prices for veneer logs, saw logs, and pulpwood. The cubic-foot prices would not be applicable to a single owner, but would be valid for the region.

Table 3 shows how 1970 production and Southwide prices were blended for a stumpage value of $0.1836 per cubic foot. Incidence statistics apply only to loblolly and slash pine. Since Southwide removal volumes were not tabulated by species, it was necessary to estimate how much of the total was loblolly and slash pine. Data sources (10, 11) reveal that the two species make up 56 percent of the South's softwood inventory. It was assumed that this percentage also applied to removal volumes. This assumption provides a total loblolly and slash removal of 2,096,987,200 cubic feet in 1970.

Table 3.--Computation of blended 1970 stumpage price

Softwood product removed	Number of units	Price per unit	Total stumpage value	Thousand cubic feet	Value per cubic foot
		- - - Dollars - - -			Dollars
Saw logs	7,949,009 Fbm	50.00	397,450,450	1,330,452	0.2987
Veneer logs	1,562,852 Fbm	60.00	93,771,120	256,854	.3651
Plywood	25,825,882 cords	6.42	165,802,162	1,991,492	.0833
Total			657,023,732	3,578,798	
Blended price					.1836

Because rust infection rates vary by species and method of regeneration, an accurate estimate of rust damage hinges upon further segmenting volumes removed into loblolly or slash, planted or natural. Inventories of the two species furnished the necessary basis for this estimate (table 2), and the following percentages were derived:

a. Trees on slash pine plantations 22

b. Trees on loblolly pine plantations 6

c. Trees on natural stands of slash pine 28

d. Trees on natural stands of loblolly pine 44

Volumes removed for each of these categories were obtained by applying these percentages to the loblolly-slash total of 2,096,987,200 cubic feet. Certainly, 22 percent of the stands harvested in 1970 were not slash plantations, but an exact figure is not available. Furthermore, the issue of importance here is the volume produced, not the average in plantations. Superior productivity of plantations permits greater volume removals than the acreage allotted to plantations would indicate.

Accordingly, harvests of loblolly and slash pine, by species and stand type, in 1970 were:

	Cubic feet
Slash plantations	461,337,184
Loblolly plantations	125,819,232
Natural slash stands	587,156,416
Natural loblolly stands	922,674,368

The rates of stem infection for these categoried, respectively, were 15, 21, 5, and 12 percent.

Ascribing specific volume and value losses to these rates of infection was based on the supposition that removals would have been markedly higher in the absence of rust. However, removals would not have been higher by the full amount of the percentages listed above since stem infection does not imply total volume lost. Only a fraction of the volume of trees with stem infections would fail to qualify for some commercial purpose. Porterfield (7) provides the only known published commitment to a specific value, 40 percent. That is, 40 percent of the volume of stem-infected trees has no market value. This fraction was bracketed by 30- and 50-percent loss estimates to satisfy those who feel that the Porterfield figure is unduly liberal or conservative.

Infection rates and volume-lost factors were combined to indicate what could have been harvested without fusiform rust. An example of how the natural loblolly volume potential was calculated follows:

> Since such stands were found to be infected at a 12-percent rate and 40 percent of this amount is unmarketable, the volume of a stand that is actually lost is the product of these figures, 4.8 percent. Conversely, the multiplier for potential volume removed would be 100/(100-4.8) = 100/95.2 = 1.0504. Applying this to the actual volume of loblolly removed, 922,674,368 cubic feet, the total is increased to 969,177,156 cubic feet. The difference in these two volumes is the amount of loblolly pine lost to rust rather than harvested and used.

This procedure was applied to each of the species and stand categories, and the total potential volumes were summed (table 4).

Table 4.--Potential 1970 removal volume of slash and loblolly pines in the absence of fusiform rust

Species and stand type	Volume-lost factor	1970 volume removed	Multiplier	Potential volume without rust
	Percent	Cubic feet		Cubic feet
Slash plantations	30	461,337,184	1.0471	483,066,165
	40	461,337,184	1.0638	490,770,496
	50	461,337,184	1.0811	498,751,630
Loblolly plantations	30	125,819,232	1.0672	134,274,284
	40	125,819,232	1.0917	137,356,856
	50	125,819,232	1.1173	140,577,828
Natural slash	30	587,156,416	1.0152	596,081,194
	40	587,156,416	1.0204	599,134,407
	50	587,156,416	1.0256	602,187,620
Natural loblolly	30	922,674,368	1.0373	957,090,122
	40	922,674,368	1.0504	969,177,156
	50	922,674,368	1.0638	981,540,993

The total foregone volumes associated with each volume-lost factor are:

Volume-lost factor	Potential volume	Actual volume removed	Volume foregone
(percent)	(cubic feet)	(cubic feet)	(cubic feet)
30	2,170,511,765	2,096,987,200	73,524,565
40	2,196,438,915	2,096,987,200	99,451,715
50	2,223,058,071	2,096,987,200	126,070,871

The rust impact takes on even greater significance when we apply the blended price of $0.1836 per cubic foot. In ascending order of volume-lost factor, dollars lost to rust in 1970 range from $13,499,110 to $23,146,612. In addition, 1970 dollars were far more valuable than current dollars. Updating volumes removed and price levels in accordance with Forest Service (3) and Forest Farmer (5) data, the 1972 cost of rust was:

Volume-lost factor	Volume foregone	Dollars foregone (1972)
(percent)	(cubic feet)	
30	81,244,644	20,693,011
40	109,894,145	27,990,039
50	139,308,312	35,481,827

Regardless of the criterion, the cost of rust is formidable and mounting.

DISCUSSION

The most significant biological result of this extensive survey of fusiform rust incidence was the high percentage of stem infections in plantations. Infection in natural stands, while involving millions of trees, does not represent as great an impact because natural stands frequently are overstocked and do not require the high initial investment of plantations. Planted stands are frequently on the better sites, installed with intensive site preparation, thinned, fertilized, and, in general, subjected to intensive forest management. These are the stands where investments and expected returns are greatest, and where extensive losses due to disease are most costly. The damage from fusiform rust is particularly severe in slash pine plantations, which represent about 44 percent of the total slash pine inventory in these three States.

Overall, incidence of stem infection was higher on loblolly than on slash pines. In the three-State survey area, however, planted loblolly accounts for less than one-fifth of the total plantation acreage. Only in Georgia was a relatively high loblolly pine acreage figure combined with a high incidence of rust that would produce a problem as serious as with the slash pines.

Although infection is not as serious in natural stands as in plantations, such infection is a problem. In natural loblolly stands, the incidence rate of 12 percent means that almost 400 million trees have stem infections. Loss of sawtimber potential in these trees is substantial. Furthermore, eventual control of the disease is less likely in natural stands than in plantations, where disease-resistant strains of pine will soon be planted.

Geographic variation in susceptibility should be considered when a species is chosen for planting. In the areas to the north of its natural range, primarily Georgia survey units 3 and 4, slash pine was more heavily diseased than loblolly pine (fig. 6). In Florida survey units 1 and 2, however, loblolly pine had a higher incidence of rust. It is clear that slash pine should be favored for planting in northern Florida, and loblolly pine in northern Georgia.

In general, fusiform rust is not too serious in the Upper Coastal Plain and Piedmont of South Carolina and areas to the north. There are pockets within these areas where serious losses are caused by the disease, but it is not the major problem that it is to the south and west of this area.

Incidence of infection in plantations increased with tree diameter in each diameter class through 8 inches d.b.h. (fig. 5). This increase probably reflects both the exposure to several heavy infection years and the spread of branch infections into the main stem. The incidence of stem galls decreases in the larger diameter classes, with a particularly sharp drop in slash pine. This decrease may be a reflection of a lower tolerance for the disease by slash pine. Once infected by rust, slash pines are more severely damaged and show a higher mortality rate than loblolly pines (8). The fact that slash pine seems to be less tolerant than loblolly once infection takes place probably is responsible for the higher incidence percentages on loblolly pine shown in figure 5, since by age 5 many stem-infected slash pines are already dead. In both species, the relatively low percentage of stem galls in the 16+ d.b.h. class probably results both from increasing mortality and removal of severely infected trees in thinnings.

Conversion of the incidence data to financial impact values is important in evaluating the fusiform rust problem in the South. However, there are no established procedures for such conversions, and some arbitrary decisions were necessary. The blended price concept and tying the rust incidence figures to cubic feet of wood removed probably give an accurate picture of the financial impact of a disease. Costs were not included for protective fungicidal spraying used in all southern forest tree nurseries, infection on high-value seed orchard trees, or the loss when rust-infected trees are downgraded from a high-value product to one of lower value. Also excluded are expenditures necessary when a heavily infected plantation must be prematurely cut and reestablished and the costs associated with additional acreage necessary to satisfy wood demands where rust is severe.

The reported incidence values are also conservative. Mortality was not estimated, and no attempt was made to determine the losses in trees less than 1 inch d.b.h. Small trees, particularly in plantations less than 4 or 5 years old, are often killed by fusiform rust. Many foresters think that if a stand escapes heavy rust infection for the first 5 years, the chances are good that it will not be too severely damaged after that time. Also, survey incidence figures were based on stem infections only. This means that a tree with a branch infection, even if the gall is very close to the stem, was not counted as a diseased tree. In all probability such an infection would spread into the stem, especially in a young tree.

Thus, the incidence figures and financial estimates reported in this Paper, as severe as they are, do not include many very important elements of damage. When all of these factors are considered, it is easy to understand why fusiform rust is the most damaging forest tree disease in the South.

SUMMARY

The primary points emphasized by the forest survey data on rust incidence from Florida, Georgia, and South Carolina are:

1. Fusiform rust infections on the main stems of both planted and natural slash and loblolly pines 1 inch d.b.h. and larger is high enough to cause major economic losses, with the most serious damage occurring in central Georgia.

2. Over 800 million trees have stem infections.

3. Slash pines in plantations have more than three times as many stem infections as those in natural stands; the ratio of infection for planted vs. natural loblolly is almost 2 to 1.

4. Loblolly pines have a higher percentage of stem infections than slash pine in both planted and natural in the three States.

5. The planted slash pine infection figures, while somewhat lower than those of loblolly pine, are particularly significant because plantations account for almost half of the slash pine acreage in the Southeast.

6. The incidence of rust increases with increasing stem diameter up to the 8-inch d.b.h. class, and then declines in the larger diameter classes.

7. Slash pine has a higher rust incidence than loblolly pine where it is grown north of its natural range.

8. Loblolly pine shows a higher rust incidence than slash in north Florida, which is the southern part of the natural range of loblolly.

9. Fusiform rust is a serious problem in much of the three-State area included in this survey but is less important in the northern sections of South Carolina.

10. A very conservative estimate of annual financial loss due to fusiform rust in the South, based on Forest Survey incidence data, is $28 million.

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The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

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Predicted Green Lumber and Residue Yields from the Merchantable Stem of Shortleaf Pine

by

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Traditionally, sawtimber has been bought and sold on the basis of its lumber-producing potential, with little or no regard for the residues that are produced. In the early years of the sawmilling industry this practice was acceptable because sawmill residues had little or no value. In fact, they often caused expensive disposal problems. Today the situation is different. Solid wood residues (slabs, edgings, and end trims) are chipped at the sawmill and sold to the paper industry for pulping. Bark residues and sawdust are used as a fuel at the mill, or sold for an increasing number of uses (particles for particle board, mulching material, bedding material, ground covers, etc.).

As sawmill residues gain in value, the need for accurate yield information, by species and tree size, increases. Early research of sawmill residues dealt primarily with chip yields and in all cases was directed to saw logs (King 1952; Applefield 1956, 1960; Kramer 1957; Lehman 1958). Only recently has there been an effort to measure southern pine residue yields for trees (Taras et al. 1974).

In the study described here, we developed regression equations to predict the yields of lumber, chippable residue, bark residue, and sawdust of shortleaf pine (*Pinus echinata* Mill.) trees in Mississippi. Stem weights and stem cubic volumes are also predicted.

PROCEDURE

Sample trees were obtained from the Holly Springs National Forest near Tupelo, Mississippi. In an effort to determine the influence of differing stand conditions on lumber and residue yields from trees, we selected our sample trees from two stand types. One area was a mature natural stand with trees that averaged 87 years of age and had a form class of 81 (table 1). The other site, which was adjacent to the first, was an old field that had reverted to pines 37 years prior to sampling. The average form class of the old-field trees was 76 (table 1).

This study was conducted by the Southeastern Forest Experiment Station in cooperation with and through the financial assistance of the Range, Timber, and Wildlife Program Area of Region 8 of the National Forest System. Field personnel were provided by the Holly Springs National Forest. Assistance was also received from the T. F. Evans Lumber Company, Fulton, Miss.

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Table 1.--Physical characteristics of sample trees from two stand types

Item and unit of measure	Mature stand (36 trees)		Old-field stand (21 trees)	
	Mean	Range	Mean	Range
D.b.h. (inches)	15.0	9.8 - 19.5	13.9	9.7 - 20.4
Total height (feet)	80	63 - 97	61	41 - 73
Merchantable height (feet)	50	34 - 72	35	15 - 46
Age (years)	87	35 - 114	37	20 - 57
Form class	81	74 - 86	76	68 - 84

Thirty-six trees 10 to 19 inches d.b.h. were selected from the mature stand; 21 trees 10 to 20 inches d.b.h. were chosen from the old-field stand. The distribution of sample trees by stand type and d.b.h. is given in table 2.

Table 2.--Distribution of sample trees by stand type and tree d.b.h.

D.b.h. (inches)	Number of trees		
	Mature stand	Old field	Combined
10	6	4	10
12	5	5	10
14	6	4	10
16	5	5	10
18	9	1	10
19	5	0	5
20	0	2	2
Total	36	21	57

Sample trees were felled, limbed, and bucked into logs 8 to 16 feet long. Minimum merchantable top diameter was 6 inches inside bark, but heavy branching often prevented us from reaching this level. Average merchantable top for all trees was 8.6 inches. Maximum and minimum d.i.b. and d.o.b. measurements were made at both ends of each log to the nearest 0.1 inch. Log length was measured to the nearest 0.1 foot. Above the saw-log portion of the stem, pulpwood to a 4-inch top d.i.b. and topwood from 4 to 2 inches d.i.b. were cut, measured, and weighed separately.

At the millyard, individual logs were weighed with electronic load cells and a digital reader to the nearest pound. The logs were debarked with a rosser-head debarker and immediately reweighed. The difference between log weights before and after debarking is a measure of bark residue, which we define after Wartluft (1971) as all the material removed during debarking, including wood fiber.

The logs were sawn in a mill with a 3/16-inch-kerf band headsaw and in-line circular edger and end-trim saws. The mill's sawing bill was somewhat unusual in that 1 by 5 and 1 by 3 inch boards were cut. Most southern pine sawmills cut only even-width boards. As each log was sawn, lumber, slabs, edgings, and end trims were collected and weighed on platform scales to the nearest one-fourth pound. Sawdust weight was determined by subtracting the weights of lumber and solid wood residue from log weight without bark. Lumber dimensions and board-foot volumes were recorded, and actual board widths and thicknesses were measured on a subsample of boards.

In the woods, sample disks were cut at each bucking point from the stump to a 2-inch top. Wood and bark samples from the disks were weighed in the field on a top-loading balance to the nearest 0.1 gram. Samples were returned to the laboratory where wood and bark moisture content and specific gravity were determined on each sample. Moisture content was computed on an ovendry weight basis after samples were dried at 103° C. Specific gravity was determined on a green volume-ovendry basis. Weighted tree moisture content and specific gravity were computed by weighting each disk sample according to its basal area. Pulpwood and topwood bark weights were computed from disk bark percentages sampled at the 6-, 4-, and 2-inch diameters in the stem. The cubic volume of the saw log and upper stem sections were computed by Smalian's formula:

$$\text{Stem cubic foot volume } V = \left(\frac{B + b}{2}\right) L$$

where:

V = volume in cubic feet

B = area of disk from base of log in square feet

b = area of disk from top of log in square feet

L = length of log in feet

ANALYSIS

Study yields were summarized by trees, and standard regression analyses were performed on these data. Independent variables examined were tree d.b.h., merchantable height, total height, and form class. After testing these variables individually and in various combinations, we found D^2Mh (d.b.h.^{2} x merchantable height) to be our best single independent variable combination. Form class made a significant addition (at the 0.05 level) to some of the equations, such as those for stem weight and lumber volume, but the improvement realized was small and was judged less than worth the extra effort required for measurement.

After examining the variance associated with weight and volume predictions and a plot of residuals, we chose the linear form of the equations. The variance did not show a definite trend to increase with increasing tree size, and plots of residuals of the linear equations showed no abnormalities. The general equation used for all predictions is:

$$Y = b_o + b_1 (D^2Mh) + e$$

where:

Y = weight or volume of item to be predicted

b_o, b_1 = regression coefficients

D = diameter at breast height (d.b.h.) in inches

Mh = merchantable height in feet

e = experimental error

Regression equations were developed for the mature stand (36 trees), the old-field stand (21 trees), and all trees combined (57 trees). The difference between the mature-stand equations and the old-field equations was tested by a method described by Snedecor and Cochran (1967, p. 432). We found no significant difference in the slope and intercept of all comparable pairs of equations with the exception of lumber weight. The slopes of the lumber-weight equations were just significantly different at the 0.05 level. However, a plot of individual-tree yields around the combined prediction line showed no trends by stand type, nor did a plot of residuals. Based on these observations, and for the sake of additivity, we chose the combined equations for all predictions including lumber weight.

RESULTS AND DISCUSSION

Lumber and Residue Yields

The 57 shortleaf study trees weighed a total of 128,301 pounds from stump height to a 2-inch top. Eighty-seven percent of this amount was saw-log material, 12 percent was pulpwood, and 1 percent was topwood left in the woods.

The saw-log portion of the stem yielded an average of 54 percent lumber by weight, 26 percent chippable residue, 10 percent bark residue, and 10 percent sawdust (table 3). Lumber yield increased from 43 percent in samll-diameter trees to as much as 58 percent in larger trees. Residue yields decreased or remained constant with increasing diameter. Chippable residue decreased from 32 to 22 percent, while bark residue decreased from 12 to 9 percent. Sawdust varied from 9 to 13 percent without showing a definite trend with increasing d.b.h. The percentage yields in the 20-inch class are not very representative because we only had two sample trees.

Lumber and residue yields are influenced by a mill's sawing bill and by its ability to cut minimum rough lumber widths and thicknesses. Sixty-two percent of the lumber in this study was cut into dimension (8/4), and 38 percent was cut into boards (4/4). Average thicknesses of rough green dimension and boards were 1.9 and 0.9 inches, respectively. Average green lumber width was 0.6 inch above dry surface minimum standards.

A rosser-head debarker, such as the one used in this study, affects the yield of both chippable residue and bark residue. Wood fiber removed by the cutting action of the rosser head increases bark residue yield and decreases chippable residue yield. Based on bark yields determined from disk samples, we estimate our bark residue is 75 to 80 percent bark and 20 to 25 percent wood fiber.

Table 3.--Average recovery percentages of lumber, chippable residue, bark residue, and sawdust for shortleaf sawtimber trees

D.b.h. class (inches)	Sample trees	Merchantable height (6-inch top)	Merchantable stem weight (6-inch top)	Primary product recovery				Volume, lumber tally
				Lumber	Chippable[1] residue	Bark[2] residue	Sawdust	
	Number	Feet	Pounds	- - - - - - Percent - - - - - -				Board feet
10	10	34	730	43	32	12	13	66
12	10	43	1,302	46	31	12	11	122
14	10	44	1,822	50	29	11	10	186
16	10	45	2,458	54	26	11	9	262
18	10	53	3,681	57	23	10	10	434
19	5	52	4,229	58	22	10	10	484
20	2	44	3,616	53	26	9	12	390
Weighted study average			2,251	54	26	10	10	244

[1] Includes slabs, edgings, and end trim.

[2] Includes wood fiber removed during debarking.

Regression Equations

Equations to predict lumber and residue yields, stem weights, and stem cubic-foot volumes are given in table 4. The coefficients of determination (R^2) range from 0.93 for bark residue prediction to 0.98 for stem weight and stem cubic-foot volume predictions. The coefficients of variation (CV) indicate our stem weight with bark predictions are the least variable (7.2 percent) and our lumber weight predictions are the most variable (12.9 percent).

Table 4.--Regression equations and associated statistics for shortleaf trees

Item and unit of measure	Equation	Coefficient of determination (R^2)	Standard error of estimate ($S_{y \cdot x}$)	Coefficient of variation (CV)
				Percent
Primary product weight (pounds)				
Lumber	$Y = -188.84680 + 0.13406\ D^2Mh$	0.96	155.8	12.9
Chippable residue	$Y = 112.75512 + 0.04449\ D^2Mh$	0.95	56.8	9.8
Bark residue	$Y = 39.00682 + 0.01908\ D^2Mh$	0.93	29.1	12.2
Sawdust	$Y = 3.25218 + 0.02165\ D^2Mh$	0.95	28.3	12.4
Lumber volume (board feet)	$Y = -39.71101 + 0.02722\ D^2Mh$	0.96	30.8	12.6
Stem weight with bark (pounds) to				
6-inch top d.i.b.	$Y = -33.83268 + 0.21928\ D^2Mh$	0.98	162.5	7.2
4-inch top d.i.b.	$Y = 48.68601 + 0.24091\ D^2Mh$	0.96	292.6	11.4
2-inch top d.i.b.	$Y = 77.97197 + 0.24027\ D^2Mh$	0.96	292.4	11.3
Stem weight without bark (pounds) to				
6-inch top d.i.b.	$Y = -72.83950 + 0.20020\ D^2Mh$	0.98	151.5	7.5
4-inch top d.i.b.	$Y = -4.43311 + 0.21963\ D^2Mh$	0.96	264.3	11.6
2-inch top d.i.b.	$Y = 20.87330 + 0.21910\ D^2Mh$	0.96	264.4	11.5
Stemwood cubic volume (cubic feet) to				
6-inch top d.i.b.	$Y = -0.75786 + 0.00327\ D^2Mh$	0.98	2.6	7.7
4-inch top d.i.b.	$Y = 0.21756 + 0.00359\ D^2Mh$	0.96	4.2	11.2
2-inch top d.i.b.	$Y = 0.57805 + 0.00358\ D^2Mh$	0.96	4.2	11.2

Efforts were made to predict stem pulpwood yields (6- to 4-inch top) and topwood yields (4- to 2-inch top) using d.b.h. and merchantable height as independent variables. The equations were poor predictors because pulpwood yields varied with merchantability limits, and topwood yields remained nearly constant with increasing tree sizes. As a result, prediction lines had zero slope and coefficients of determination were low.

Pulpwood and topwood yields can be estimated from the differences between predicted values to 6-, 4-, and 2-inch tops. The small difference between the slopes of the equations for 4- and 2-inch tops indicates one average value for all trees would be an adequate measure of yields in most cases. Topwood stem weights with and without bark for our trees averaged 23 and 20 pounds, respectively. Topwood cubic volume averaged 0.27 cubic foot.

Wood Properties

Whenever possible, stem specific gravity and moisture content should be measured before predicting stem weights, because these properties directly affect the efficiency of prediction equations. A large difference in weight per cubic foot between a test sample and an applied sample could result in poor predictions.

Weighted average wood specific gravity in the merchantable stem of our sample trees was 0.475 with a standard deviation of 0.029. Average wood moisture content was 108.0 percent with a standard deviation of 13.5 percent. Based on moisture content and specific gravity, wood weight per cubic foot averaged 61.7 pounds and was constant, with only random variation, across tree d.b.h. classes.

Bark specific gravity averaged 0.339 with a standard deviation of 0.035 for the 57 sample trees. Bark moisture content averaged 61.8 percent with a standard deviation of 15.0 percent. Bark weight per cubic foot averaged 34.9 pounds and showed no trend with increasing tree size.

Yield Tables

Regression equations in table 4 were used to develop tables of primary product weights (Appendix tables 5-8), lumber volumes (Appendix table 9), stem weights with and without bark (Appendix tables 10-13) and stem cubic volumes (Appendix tables 14-15). Since the yield from a 4- to a 2-inch top is essentially constant, tables to a 2-inch top are not given. Yields are tabulated by 1-inch classes from 1 to 22 inches and by the number of 16-foot logs from 1 to 5. The blocked-in areas indicate the range of our data.

Data presented in this paper should not be used indiscriminately across the range of shortleaf pine or where major differences in mill processing occur. For optimum performance, predictions should be made on timber with properties similar to our trees processed in a bandmill.

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APPENDIX

Table 5.--Lumber weight from the saw-log portion of shortleaf pine trees[1] [2]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	39	146	254	361	468	575	683		
11	87	217	346	476	606	736	866		
12	139	294	448	603	757	912	1,066	1,220	
13	196	378	559	740	921	1,103	1,284	1,465	
14	258	468	678	888	1,099	1,309	1,519	1,729	1,939
15	324	565	807	1,048	1,289	1,530	1,772	2,013	2,254
16	395	669	944	1,218	1,493	1,767	2,042	2,316	2,591
17	470	780	1,090	1,400	1,710	2,020	2,329	2,639	2,949
18	550	897	1,245	1,592	1,939	2,287	2,634	2,982	3,329
19	634	1,021	1,408	1,795	2,183	2,570	2,957	3,344	3,731
20	723	1,152	1,581	2,010	2,439	2,868	3,297	3,726	4,155
21		1,289	1,762	2,235	2,708	3,181	3,654	4,127	4,600
22			1,952	2,471	2,991	3,510	4,029	4,548	5,067

[1] $Y = -188.84680 + 0.13406 D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 6.--Chippable residue weight from the saw-log portion of shortleaf pine trees[1] [2]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	188	224	260	295	331	366	402		
11	204	247	290	333	377	420	463		
12	222	273	324	375	427	478	529	580	
13	241	301	361	421	481	541	601	662	
14	261	331	401	470	540	610	680	749	819
15	283	363	443	523	603	683	763	844	924
16	306	397	489	580	671	762	853	944	1,035
17	331	434	537	640	743	846	948	1,051	1,154
18	358	473	588	704	819	934	1,050	1,165	1,280
19	386	514	643	771	900	1,028	1,157	1,285	1,414
20	415	558	700	842	985	1,127	1,269	1,412	1,554
21		603	760	917	1,074	1,231	1,388	1,545	1,702
22			823	996	1,168	1,340	1,512	1,685	1,857

[1] $Y = 112.75512 + 0.04449 D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 7.--Bark residue weight from the saw-log portion of shortleaf pine trees[1] [2]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	71	87	102	117	132	148	163		
11	78	97	115	134	152	171	189		
12	86	108	130	152	174	196	218	240	
13	94	120	145	171	197	223	249	274	
14	103	132	162	192	222	252	282	312	342
15	112	146	181	215	249	284	318	352	387
16	122	161	200	239	278	317	356	396	435
17	133	177	221	265	309	353	397	442	486
18	144	194	243	292	342	391	441	490	540
19	156	211	266	321	377	432	487	542	597
20	169	230	291	352	413	474	535	596	657
21		249	317	384	451	519	586	653	721
22			344	418	492	565	639	713	787

[1] $Y = 39.00682 + 0.01908 D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 8.--Sawdust weight from the saw-log portion of shortleaf pine trees[1] [2]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	40	57	75	92	109	127	144		
11	48	69	90	111	132	153	174		
12	56	81	106	131	156	181	206	231	
13	65	95	124	153	183	212	241	270	
14	75	109	143	177	211	245	279	313	347
15	86	125	164	203	242	281	320	359	398
16	97	142	186	230	275	319	364	408	452
17	110	160	210	260	310	360	410	460	510
18	123	179	235	291	347	403	459	515	571
19	136	199	261	324	386	449	511	574	636
20	150	220	289	358	428	497	566	635	705
21		242	318	395	471	547	624	700	777
22			349	433	517	601	684	768	852

[1] $Y = 3.25218 + 0.02165 D^2Mh$.

[2] Blocked-in area indicates the range of our data.

[3] Includes a 1-foot stump allowance.

Table 9.--Lumber volume from the saw-log portion of shortleaf pine trees[1] [2]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Board feet								
10	7	28	50	72	94	115	137		
11	16	43	69	95	122	148	174		
12	27	58	90	121	152	184	215	246	
13	38	75	112	149	186	222	259	296	
14	51	94	136	179	222	264	307	350	392
15	64	113	162	211	260	309	358	407	456
16	79	134	190	246	302	357	413	469	525
17	94	157	220	283	346	409	472	535	597
18	110	181	251	322	392	463	534	604	675
19	127	206	285	363	442	520	599	678	756
20	145	232	320	407	494	581	668	755	842
21		260	356	452	548	645	741	837	933
22			395	500	606	711	817	922	1,027

[1] $Y = -39.71101 + 0.02722 D^2Mh$.

[2] Blocked-in area indicates the range of our data.

[3] Includes a 1-foot stump allowance.

Table 10.--Stem weight with bark of shortleaf pine trees to a 6-inch top diameter inside bark[1] [2]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	339	514	690	865	1,041	1,216	1,391		
11	417	629	842	1,054	1,266	1,479	1,691		
12	503	756	1,008	1,261	1,513	1,766	2,019	2,271	
13	596	893	1,189	1,486	1,782	2,078	2,375	2,671	
14	697	1,041	1,384	1,728	2,072	2,416	2,760	3,104	3,447
15	805	1,200	1,594	1,989	2,384	2,778	3,173	3,568	3,963
16	920	1,370	1,819	2,268	2,717	3,166	3,615	4,064	4,513
17	1,043	1,550	2,057	2,564	3,071	3,578	4,085	4,592	5,099
18	1,174	1,742	2,311	2,879	3,447	4,016	4,584	5,153	5,721
19	1,312	1,945	2,578	3,212	3,845	4,478	5,112	5,745	6,378
20	1,457	2,159	2,861	3,562	4,264	4,966	5,667	6,369	7,071
21		2,384	3,157	3,931	4,705	5,478	6,252	7,025	7,799
22			3,469	4,318	5,167	6,016	6,865	7,714	8,563

[1] $Y = -33.83268 + 0.21928\ D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 11.--Stem weight with bark of shortleaf pine trees to a 4-inch top diameter inside bark[1] [2]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	458	651	844	1,036	1,229	1,422	1,615		
11	544	777	1,011	1,244	1,477	1,710	1,943		
12	638	916	1,193	1,471	1,749	2,026	2,304	2,581	
13	741	1,067	1,392	1,718	2,044	2,369	2,695	3,021	
14	851	1,229	1,607	1,985	2,362	2,740	3,118	3,496	3,873
15	970	1,404	1,837	2,271	2,705	3,138	3,572	4,006	4,439
16	1,097	1,591	2,084	2,577	3,071	3,564	4,057	4,551	5,044
17	1,232	1,789	2,346	2,903	3,460	4,017	4,574	5,131	5,688
18	1,376	2,000	2,624	3,249	3,873	4,498	5,122	5,747	6,371
19	1,527	2,223	2,919	3,614	4,310	5,006	5,702	6,397	7,093
20	1,687	2,458	3,229	4,000	4,771	5,541	6,312	7,083	7,854
21		2,705	3,555	4,405	5,255	6,104	6,954	7,804	8,654
22			3,897	4,829	5,762	6,695	7,628	8,561	9,493

[1] $Y = 48.68601 + 0.24091\ D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 12.--Stem weight without bark of shortleaf pine trees to 6-inch top diameter inside bark[1] [2]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	268	428	588	748	908	1,068	1,228		
11	339	533	727	920	1,114	1,308	1,502		
12	417	648	879	1,109	1,340	1,570	1,801	2,032	
13	502	773	1,044	1,314	1,585	1,856	2,126	2,397	
14	594	908	1,222	1,536	1,850	2,164	2,478	2,792	3,106
15	693	1,053	1,414	1,774	2,134	2,495	2,855	3,215	3,576
16	798	1,208	1,618	2,028	2,438	2,848	3,258	3,668	4,079
17	911	1,374	1,836	2,299	2,762	3,225	3,688	4,151	4,614
18	1,030	1,549	2,068	2,587	3,106	3,624	4,143	4,662	5,181
19	1,156	1,734	2,312	2,890	3,468	4,047	4,625	5,203	5,781
20	1,289	1,929	2,570	3,210	3,851	4,492	5,132	5,773	6,414
21		2,134	2,841	3,547	4,253	4,960	5,666	6,372	7,079
22			3,125	3,900	4,675	5,450	6,225	7,001	7,776

[1] $Y = -72.83950 + 0.20020\ D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 13.--Stem weight without bark of shortleaf pine trees to a 4-inch top diameter inside bark[1] [2]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	369	545	720	896	1,072	1,247	1,423		
11	447	660	873	1,085	1,298	1,510	1,723		
12	533	786	1,039	1,292	1,545	1,798	2,051	2,304	
13	627	924	1,220	1,517	1,814	2,111	2,408	2,705	
14	727	1,072	1,416	1,761	2,105	2,449	2,794	3,138	3,482
15	836	1,231	1,626	2,022	2,417	2,812	3,208	3,603	3,998
16	951	1,401	1,851	2,301	2,751	3,200	3,650	4,100	4,550
17	1,075	1,582	2,090	2,598	3,106	3,614	4,121	4,629	5,137
18	1,205	1,775	2,344	2,913	3,482	4,052	4,621	5,190	5,760
19	1,343	1,978	2,612	3,246	3,881	4,515	5,149	5,783	6,418
20	1,489	2,192	2,895	3,597	4,300	5,003	5,706	6,409	7,112
21		2,417	3,192	3,967	4,742	5,516	6,291	7,066	7,841
22			3,503	4,354	5,204	6,055	6,905	7,756	8,606

[1] $Y = -4.43311 + 0.21963\ D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 14.--Stem cubic volume of shortleaf pine trees to a 6-inch top diameter inside bark[1 2]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Cubic feet								
10	5	7	10	13	15	18	20		
11	6	9	12	15	19	22	25		
12	7	11	15	19	22	26	30	34	
13	9	13	17	22	26	31	35	40	
14	10	15	20	26	31	36	41	46	51
15	12	18	24	29	35	41	47	53	59
16	13	20	27	34	40	47	54	60	67
17	15	23	30	38	46	53	61	68	76
18	17	26	34	43	51	60	68	77	85
19	19	29	38	48	57	67	76	85	95
20	21	32	42	53	63	74	84	95	105
21		35	47	58	70	81	93	105	116
22			51	64	77	89	102	115	127

[1] $Y = -0.75786 + 0.00327\ D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Table 15.--Stem cubic volume of shortleaf pine trees to a 4-inch top diameter inside bark[1 2]

D.b.h. (inches)	Merchantable height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Cubic feet								
10	6	9	12	15	18	21	24		
11	8	11	15	18	22	25	28		
12	9	13	17	21	26	30	34	38	
13	11	15	20	25	30	35	40	45	
14	12	18	23	29	35	40	46	52	57
15	14	20	27	33	40	46	53	59	66
16	16	23	31	38	45	53	60	67	75
17	18	26	34	43	51	59	68	76	84
18	20	29	39	48	57	67	76	85	94
19	22	33	43	53	64	74	84	95	105
20	25	36	48	59	71	82	94	105	117
21		40	52	65	78	90	103	116	128
22			58	71	85	99	113	127	141

[1] $Y = 0.21756 + 0.00359\ D^2Mh$.
[2] Blocked-in area indicates the range of our data.
[3] Includes a 1-foot stump allowance.

Phillips, Douglas R., and James G. Schroeder
1975. Predicted green lumber and residue yields from the merchantable stem of shortleaf pine. USDA For. Serv. Res. Pap. SE-128, 12 p. Southeast. For. Exp. Stn., Asheville, N.C.

Fifty-seven shortleaf pine trees from two stand types in Mississippi were processed in a bandmill. Merchantable stems produced an average of 54 percent lumber, 26 percent chippable residue, 10 percent bark residue, and 10 percent sawdust. Regression equations developed to predict stem and primary product yields produced coefficients of determination ($\underline{R}^2$) ranging from 0.93 to 0.98. Tables constructed from the equations provide weight and volume yields by tree size.

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The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.