To the Graduate Council:

I am submitting herewith a thesis written by John Eric Kunz entitled "Evaluation of 3-P Sampling as a Midcycle Measurement of CFI (Ames Plantation)." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

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EVALUATION OF 3-P SAMPLING AS A MIDCYCLE MEASUREMENT OF CFI (AMES PLANTATION)

A Thesis

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Degree

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ABSTRACT

The objective of this study was to evaluate 3-P sampling as a midcycle volume estimate of CFI. A two-stage 3-P sampling technique was established for forest lands controlled by The University of Tennessee at Ames Plantation whereby the present fixed area plot CFI system was modified to include a midcycle volume and growth estimate based on 3-P sampling. The two-stage 3-P sampling technique was compared with the present CFI system by evaluating the precision and cost of each method. Using 3-P sampling with volume as a predictor and the same tree volume estimating procedures, 120 trees were selected for remeasurement versus the 2,395 trees required by the present CFI method. The pulpwood volume per acre estimated by 3-P sampling was within 1.11% of that obtained by the present CFI system. Three-P sampling estimated 225.71 cubic feet per acre while 228.23 cubic feet per acre was estimated by CFI. Sawtimber volume per acre estimated by 3-P sampling was within 0.56% of that obtained by the present CFI method. Three-P sampling estimated 4186.90 board feet per acre while 4210.39 board feet per acre was estimated by CFI. The relative standard errors for the 3-P volume per acre were 6.78% for pulpwood and 13.53% for sawtimber; relative standard errors for the CFI volume per acre were 6.91% for pulpwood and 7.67% for sawtimber.

Modification of the present CFI system, by adding a basal area factor prism sample (during the first stage sample) at every plot center for measuring all trees one inch in diameter and larger, was recommended to accommodate 3-P sampling for midcycle volume and growth estimation.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
II.	REVIEW OF LITERATURE	2
	Continuous Forest Inventory	2
	3-P Sampling	3
	3-P Sampling in Combination with CFI	4
	Components of Forest Growth	5
	Mortality	5
	Yield	6
	Ingrowth	6
	Outgrowth	6
	Growing Stock Volumes	7
	Accretion and Survivor Growth	7
	Gross Growth	8
	Net Growth	8
	Net Increase	9
	Standard Error Computation	9
	CFI Volume Error	10
	CFI Growth Error	10
	Volume Error of 3-P Sampling in Combination with CFI	11
III.	DESCRIPTION OF STUDY AREA	14
	Location	14
	Regional Physiography and Topography	14

CHAPTER PAGE

Vegetation 14

Climate 16

Management History 16

IV. METHODS AND PROCEDURES 18

Collection of Data 18

Selection of 3-P Predictors 19

Generating a Computer Random Number List 20

3-P Data Selection 20

3-P Volume Estimates 23

3-P Standard Error Estimates of Volume 23

Comparisons of Volume and Standard Errors 23

V. RESULTS AND DISCUSSION 24

Selection of 3-P Predictors 24

3-P Data Selection 26

3-P Volume Estimate 27

3-P Standard Error of Volume 28

Comparison of Volume and Standard Error 29

VI. CONCLUSIONS AND RECOMMENDATION 31

Conclusions 31

Recommendations 32

LITERATURE CITED 34

APPENDICES 39

Appendix A 40

Appendix B 42

CHAPTER PAGE

Appendix C. 44

VITA. 46

LIST OF FIGURES

FIGURE		PAGE
1.	Location of Ames Plantation	15

CHAPTER I

INTRODUCTION

At present, the method of forest inventory used on forest lands controlled by The University of Tennessee is the continuous forest inventory system (CFI) in which permanent plots were established in 1963 and remeasured every five years thereafter.

This type of inventory gives precise growth estimates and is sensitive to forest change. However, this method is very costly due to the many man-hours spent in gathering detailed and accurate measurements. The cost of field work is a major component of the total forest inventory cost. One way to reduce cost without reducing precision is to apply a more efficient sampling method and thus make field work more efficient. The incorporation into the system of the 3-P sampling method of inventory is one approach.

This experiment is designed to reduce the frequency of CFI remeasurement from five years to ten years and to incorporate the 3-P system of inventory at the five-year midcycle. A 3-P sampling system is in keeping with maintaining a modern inventory system and is rapidly being adopted into timber inventory systems.

CHAPTER II

REVIEW OF LITERATURE

I. CONTINUOUS FOREST INVENTORY

The continuous forest inventory (commonly referred to as CFI), which is used as a forest inventory system in the United States, is an outgrowth of the European "method du control" system of continuous inventory (Husch, 1963; Avery, 1967). Continuous forest inventory is a method of periodic inventory using permanent plots to estimate forest change over time; it is used to measure volume, growth and mortality of a forest stand (Meyer, Recknagel, Stevenson and Bartoo, 1961; Avery, 1967).

Over the past 20 years, several conferences have been held on the implications of continuous forest inventory. Discussions at some of these conferences on the various aspects of forest inventory are presented in: Purdue University (1960), Michigan Technological University (1965) and U. S. Forest Service (1953).

One of the major uses of continuous forest inventory in the United States is the Forest Survey conducted by the U.S. Forest Service. It is designed to cover all forest land in the United States regardless of ownership except for those lands which have permanently been withdrawn from commercial timber use and those lands which are of noncommercial value. This system gives national information on forest resource and a concept of forest change (Davis, 1966).

II. 3-P SAMPLING

The 3-P sampling method (probability proportional to prediction) was first described by Lahiri (1951) and developed for forest inventory by Grosenbaugh (1963, 1964, 1965, 1967). Grosenbaugh (1967) described the benefits of the uses of sampling with unequal probability techniques over techniques with equal probability. Probability proportional to prediction (3-P), and list sampling (all methods of unequal probability) proved to have the greater efficiency. Using 3-P sampling, Grosenbaugh (1971) developed a multistage forest inventory system with the dual capability of accepting both U.S. and metric inputs and outputting summarized results in either type of units.

Several trials of various aspects of 3-P sampling have been published; all have been favorable. Hartman (1966), Johnson, Dahms and Hightree (1967), Steber and Space (1972), and Space (1973a,b,c,d) considered the method superb. Johnson et al. (1967) considered it superior to other forms of volume samples showing that 3-P estimates of total sale volume and total sale value were notably free of sampling error. Three-P sampling appeared to be less exposed to bias if the dendrometer was used. Space (1973) explained the opportunity of 3-P sampling to eliminate volume tables, conversion factors, overrun factors, and conventional log rules.

Johnson (1972) found 3-P sampling to be efficient and brought out an important point that 3-P applications need not be associated with the use of dendrometers and computers. Sharpnack (1964) staged

a computer trial simulation of 3-P which gave highly satisfactory results and proved to be an efficient design of unbiased estimates and reliable confidence statements.

Schreuder et al. (1968, 1971) compared 3-P sampling to systematic and random p.p.s. (probability proportional to size), and random equal probability. The results indicated that the unequal probability sampling procedures were superior to equal probability sampling. Systematic sampling with p.p.s. appeared better than 3-P but both proved better than random p.p.s. procedures (with replacement). It was concluded that a precise 3-P volume estimator was biased but reliable.

Bonnor (1972) compared 3-P with fixed and variable plot methods and found 3-P to be most efficient.

III. 3-P SAMPLING IN COMBINATION WITH CFI

Van Hooser (1972) simulated a 3-P sample in combination with CFI data to estimate midcycle volumes. The simulated 3-P sample predicted the total cubic foot volume for five counties in Southern Alabama to within 0.7 percent of that predicted by the latest Forest Survey of that area. Only 259 trees were needed to measure the volume of those counties as compared to the 6,500 trees used in the standard CFI sample. The use of 3-P sampling as a midcycle estimate of CFI appears very attractive in forest surveys, especially where CFI methods have already been established.

IV. COMPONENTS OF FOREST GROWTH

Growth is an important factor in forest management. It is this natural phenomenon which adds size to forest stands and income to the forest owner. Growth is defined by Husch (1963) as "the gradual increase in the size of an organism, population, or object over a period of time." Here we are interested in stand growth: the summation of the growth of individual trees in accordance with the changes in stand structure (Husch, 1963).

In order to understand the results and computations of the 3-P sampling and CFI forest inventories, it is necessary to define the basic components of growth and to understand which of these components make up the growth terms. The components of forest growth covered here are mortality, yield, ingrowth, outgrowth, volume at beginning of growth period, and volume at the end of the growth period. These, in turn, make up the growth terms of gross growth, net growth, net increase, and accretion.

The term "growing stock" as used in the following definitions refer to sound, merchantable trees which are in the stand at a given point in time.

Mortality

Mortality is the volume of trees that were measured at the beginning of the growth period but died some time during that growth period and were not utilized. It is the initial trees which drop out

of the growing stock due to natural causes such as old age, insects, disease, and climatic disturbances (Avery, 1967; Husch, 1963).

Yield

Yield refers to the volume of those trees in the growing stock which are cut or salvaged during the growth period. It may be termed cut (Husch, 1963).

Ingrowth

Besides growth on trees already in the growing stock, additional trees may enter into the stand which at the beginning of the growth period were too small to be measured but by the end of the growth period had attained measurable size (Husch, 1963). Not only does this growth enter the stand but the volume of these trees at the time they became merchantable also enters the volume growth of the stand. Frequently, the distinction is made between the former, called growth on ingrowth and the latter called simply ingrowth (Frayer, 1967).

Outgrowth

Outgrowth is defined as the threshold volume in terms of pulpwood of trees which change status from pulpwood to sawtimber during the growth period. Threshold volume is calculated using the tree height at the beginning of the period and the maximum pulpwood DBH (8.9 inches for pine and 10.9 inches for hardwoods).

Growing Stock Volumes

V1 and V2 are merely the growing stock volumes at the beginning of the growing period and at the end of the growing period, respectively. They include all merchantable trees, regardless of species.

Stand growth is described by Husch (1963) as being gross growth, net growth, net increase and accretion. Any of these growth terms may or may not include ingrowth. The definitions of these growth terms as depicted by Husch (1963) are given below using the symbols which follow:

V2 = stand volume at end of growth period

V1 = stand volume at beginning of growth period

M = mortality volume

Y = yield volume

I = ingrowth

A = accretion

Gg = gross growth excluding ingrowth

Gg+i = gross growth including ingrowth

Gn = net growth excluding ingrowth

Gn+i = net growth including ingrowth

Gd = net increase excluding ingrowth

Gd+i = net increase including ingrowth

Accretion and Survivor Growth

Gilbert (1954) described accretion as the summation of individual growth of all trees which were present at the beginning of a growth period. Avery (1967) states that accretion includes the growth on trees

which were cut during this period and those trees which have died but utilized. Husch, Miller and Beers (1972) suggests that if the volume of utilized mortality and cut is taken at the time of their death or cut that the term accretion be used but that if the volume of the utilized mortality and cut is taken at the time of first inventory (beginning of growth period) the term survivor growth be used.

Accretion, by formula, is defined as:

$$A = V2 - V1 + M + Y - I \tag{1}$$

Gross Growth

Gross growth is defined as a measure of the volume increment of the total stand. When it does not include ingrowth it is synonymous with accretion. If ingrowth is included it becomes:

$$Gg+i = V2 - V1 + Y + M \tag{2}$$

or

$$Gg+i = A + I \tag{3}$$

Net Growth

Net growth is the increase of the total stand over a growth period excluding mortality and including yield. If ingrowth is included then:

$$Gn+i = V2 - V1 + Y \tag{4}$$

or

$$Gn+i = A - M + I \tag{5}$$

If ingrowth is not included then:

$$Gn = V2 - V1 + Y - I \quad (6)$$

or

$$Gn = A - M \quad (7)$$

Net Increase

Net increase is the increase of the total stand excluding mortality and yield. If it includes ingrowth then it is merely the difference between two successive inventories:

$$Gd+i = V2 - V1 \quad (8)$$

or

$$Gd+i = A - M - Y + I \quad (9)$$

If net increase excludes ingrowth then:

$$Gd = V2 - V1 - I \quad (10)$$

or

$$Gd = A - M - Y \quad (11)$$

There is no provision made for the separation of sound and defective wood in these definitions and, unless otherwise stated, all volumes in growth estimates will include both cull and sound wood.

V. STANDARD ERROR COMPUTATION

Sampling cannot depict exact population characteristics. In order to make sound inferences about a population estimated from samples, it is necessary to compute the amount of variance that exists

between repeated samples drawn from the population (Husch, 1963). This variance among samples makes it necessary to compute sampling errors which are the differences between the sample estimates and the parameters. It allows us to make estimates as to the reliability of the sample estimate.

CFI Volume Error

The standard error of the CFI mean volume per acre in the year of inventory can be estimated by the standard formula:

$$S_{\left(\frac{\text{Av Vol}}{\text{Ac}}\right)_x} = \sqrt{\frac{\sum_{1}^{K} (\text{Vol/Ac})^2_{xi} - \left[\sum_{1}^{K} (\text{Vol/Ac})\right]^2_{xi}}{K}}{K\,(K-1)} \qquad (12)$$

where: $S_{\left(\frac{\text{Av Vol}}{\text{Ac}}\right)_x}$ = standard error of the mean volume per acre in year x

$(\text{Vol/Ac})_{xi}$ = volume per acre of CFI plot i in year x

K = number of CFI plots in sample

CFI Growth Error

The standard error of the mean difference between two inventories with paired observations of trees or plots is given by Husch (1963) as:

$$S_{\bar{d}} = \sqrt{S^2_{x1} + S^2_{x2} - 2r_{12}S_{x1}S_{x2}} = \sqrt{S^2_{x1} + S^2_{x2} - 2W_{x1x2}} \qquad (13)$$

where: $\bar{S}_d$ = standard error of a mean difference between two inventories

S^2_{xi} = variance of average volume per plot (first inventory)

S^2_{x2} = variance of average volume per plot (second inventory)

S_{x1} = standard error of average volume per plot (first inventory)

S_{x2} = standard error of average volume per plot (second inventory)

r_{12} = correlation coefficient between plot volumes of first and second inventories

W_{x1x2} = covariance between plot volumes of first and second inventories

Volume Error of 3-P Sampling in Combination with CFI

To aid in the comparison between 3-P and CFI inventory methods, a standard error for the 3-P samples were calculated. Space (1973a) suggests that the formula for a two-staged sampling scheme be:

$$E_t = \sqrt{E_1^2 + E_2^2} \qquad (14)$$

where: E_t = relative sampling error for combined stages

E_1 = relative sampling error of the first stage (plots)

E_2 = relative sampling error of the second stage (3-P subsample)

Space (personal communication, 1974) suggested that the covariance of the two stages should not be ignored and that it should

be added to E_1 and E_2 in the formula above. Grosenbaugh (1973b) suggested the formula found below which includes the covariance between the plots and 3-P samples.

$$\text{Rel.S.E}_{\text{3-P Vol/Ac}_{1973}} = \sqrt{\left[\frac{S^2_{\left(\frac{\text{Av Vol}}{\text{Ac}}\right)_{68}}}{N_1 * \left(\frac{\text{Av Vol}}{\text{Ac}}\right)^2_{68}}\right] + \left[\frac{S^2_{\left(\frac{\overline{\text{Vol 73}}}{\overline{\text{Vol 68}}}\right)}}{N_2 * \left(\frac{\overline{\text{Vol 73}}}{\overline{\text{Vol 68}}}\right)^2}\right] + \frac{2\left[\frac{W_{\left(\frac{\overline{\text{Vol 73}}}{\overline{\text{Vol 68}}}\right)\left(\frac{\text{Av Vol}}{\text{Ac}}\right)_{68}}}{N_2 * \left(\frac{\text{Av Vol}}{\text{Ac}}\right)_{68} * \left(\frac{\overline{\text{Vol 73}}}{\overline{\text{Vol 68}}}\right)}\right]}{} \qquad (15)$$

where: $\text{Rel.S.E}_{\text{3-P}}$ = relative standard error of the 3-P volume per acre in 1973

$S^2_{\left(\frac{\text{Av Vol}}{\text{Ac}}\right)_{68}}$ = variance of the average volume per acre in 1968

N_1 = number of sample plots in CFI inventory

$\left(\frac{\text{Av Vol}}{\text{Ac}}\right)_{68}$ = average volume per acre in 1968 CFI inventory

$S^2_{\left(\frac{\overline{\text{Vol 73}}}{\overline{\text{Vol 68}}}\right)}$ = variance of volume ratios of 3-P selected trees

N_2 = number of trees selected by 3-P sample excluding sure-to-be measured trees

$\left(\frac{\overline{\text{Vol 73}}}{\overline{\text{Vol 68}}}\right)$ = average volume ratio of 3-P selected trees

$W_{\left(\frac{\overline{\text{Vol 73}}}{\overline{\text{Vol 68}}}\right)\left(\frac{\text{Av Vol}}{\text{Ac}}\right)_{68}}$ = the covariance of 3-P tree ratios and average volume per acre of plots from which the 3-P selected trees were picked

The covariance was calculated with each 3-P tree growth ratio as one variable and the 1968 CFI volume per acre of the plot from which that 3-P sample tree was selected as the other variable.

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CHAPTER III

DESCRIPTION OF STUDY AREA

Location

The study area, Ames Plantation, consists of 18,600 acres of land administered by The University of Tennessee as an Agricultural Experiment Station. Ames Plantation is located in southwest Tennessee approximately 50 miles east of Memphis and 10 miles north of the Mississippi State line. The Plantation lies in Fayette and Hardeman Counties near Grand Junction, Tennessee. (Figure 1).

Regional Physiography and Topography

Fayette County and Hardeman County are in the western part of the plateau slope of western Tennessee (Flowers et al. 1964). The soil is characterized by the Lorring and Calloway series with 3.5 to 8 feet of loess structured material layered on top of sandy coastal plain materials sometimes exposed due to heavy erosion (University of Tennessee n. d.). The drainage of this area varies from moderately good to restricted. Topography ranges from moderately dissected to gently rolling hills with the soil very susceptible to erosion. Average elevation is 400 feet above sea level (Flowers et al. 1964).

Vegetation

The native vegetation at Ames Plantation is predominately hardwoods with some natural stands of pine; it is classified in the

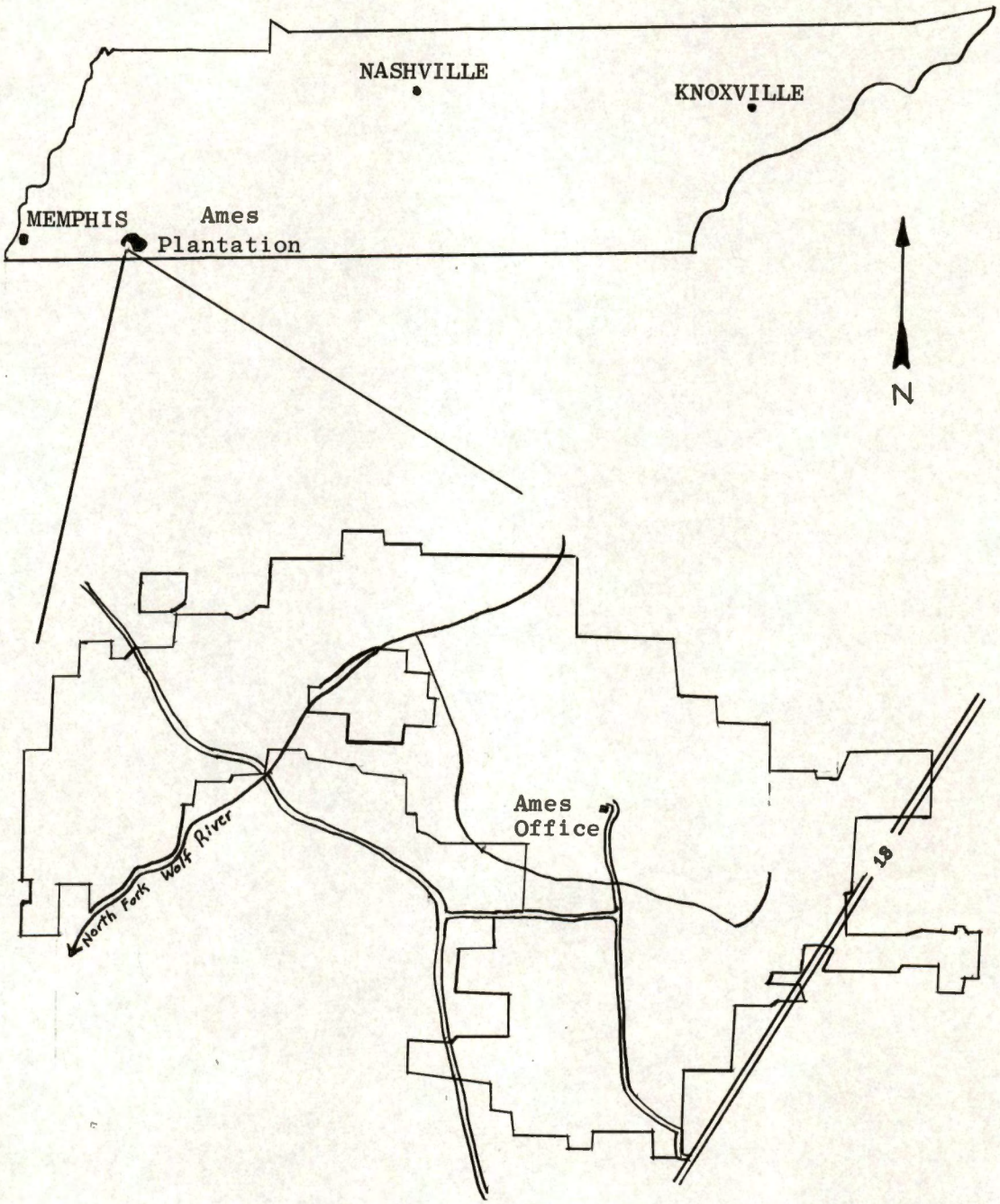


Figure 1. Location of Ames Plantation, taken from Eubanks (1972).

deciduous forest region (Hebb, 1962). Numerous pine plantations have been established for the main purpose of controlling the excessive erosion (Eubanks, 1972).

Eubanks (1972) and Hebb (1960) give detailed descriptions of the vegetation at Ames Plantation.

Climate

Climatic conditions at Ames are classified as being temperate and humid (Eubanks, 1972). The winters have an average temperature of about 40 degrees Fahrenheit with approximately 60 days out of the year in which temperature drops below 32 degrees Fahrenheit. The average daily temperature during the summer months are 65 degrees Fahrenheit and a maximum of 90 degrees Fahrenheit lasting for approximately 69 days out of the year. In spite of the commonly mild temperatures, summer droughts and high temperatures are not uncommon (Flowers et al. 1964).

The major rainfall comes in the spring and the annual average is 53.1 inches per year. The frost free period runs for approximately 7 months starting about the first of April and continuing to about the end of October. There are 200 days of growing season with most of the tree growth taking place in the early spring. During the months of January through May, evapotransportation is less than the precipitation but during July through September the opposite is true. (Flowers et al. 1964)

Management History

The land which is now known as Ames Plantation belonged to the Chicasaw Indians until the early 1800's at which time the United

States purchased the land and opened it up for settlement (Flowers et al. 1964).

Mr. Hobart Ames began purchasing land in 1903 and by 1937 had acquired the present acreage now known as Ames Plantation. Mr. Ames used the area primarily for hunting and for holding the Annual National Field Trials for bird dogs. He was more interested in preserving the land in its natural state rather than intensive farming and timber production.

Upon her death in 1950, Mrs. Ames, having survived her husband, set the Plantation up in a trust and made The University of Tennessee a beneficiary; the land and facilities at Ames were set aside for education and research thereby providing tax exemption (Ewing, 1956). At the present time Ames Plantation is still used for the National Field Trials. In addition the area is being used for research on cattle production, swine production, and agronomy. Forestry research is also important at Ames and the area provides a great teaching aid to students of The University of Tennessee.

The CFI system of forest inventory was established for the purpose of research and management of the forest resources. CFI plots were placed on cruise lines 20 chains apart and 20 chains along cruise lines. Concentric, circular plots were used as follows: one-fifth acre plots for the sawtimber inventory, 1/10th acre plots for the pulpwood inventory, and 1/100th acre plots were used to collect reproduction information. Detailed information on the CFI method of forest inventory established on University of Tennessee controlled land is found in MacDonald (1964), Martin (1970), Boyd (1970), and Martin et al. (1971).

CHAPTER IV

METHODS AND PROCEDURES

Collection of Data

During the summers of 1963, 1968 and 1973, CFI data were collected at Ames Plantation for the purpose of estimating growing stock and periodic growth. Information concerning sawtimber data were collected from permanent 1/5th acre plots, and pulpwood data from permanent 1/10th acre plots. Merchantable size trees were 5.0 - 10.9 inches DBH for hardwood pulpwood and 5.0 - 8.9 inches for softwood pulpwood. Hardwood trees larger than 10.9 inches and softwood trees larger than 8.9 inches were listed as sawtimber. Plots and sample trees in plots were numbered to allow individual tree records and give reliable growth information. An extensive and detailed description of the methods used in the CFI data collection and analysis for University of Tennessee controlled lands can be found in McDonald (1964) and Martin (1970).

The data collected from these CFI inventories were used as a basis for the 3-P samples. The 3-P samples taken from these CFI inventories were subsamples of the CFI fixed area plot samples. The object of this study was to take a 3-P sample from the 1968 CFI inventory to predict the volume per acre in 1973. This was compared to the volume per acre from the CFI inventory along with standard errors to evaluate 3-P sampling as a midcycle estimate of CFI volume and growth.

Three-P information from the 1968 CFI inventory was used to estimate the volume per acre in 1973 and the growth per acre from 1968 to 1973. Volumes in 1973 for 3-P selected trees were taken from the previously collected 1973 CFI data.

Selection of 3-P Predictors

By placing the greatest probability of selection on the predictor having the highest correlation with growth, the precision of the sample should be greatly increased. For example, it is the larger high-valued trees which add most to the total merchantable volume found in that stand. If these large high-valued trees carried a greater chance of being sampled (greater probability of selection), the estimate should then have greater precision than an estimate with equal probability of selection.

Since growth of the stands at Ames was the factor which was being estimated by the 3-P samples, it became necessary to find which predictors had the highest correlation on growth. From the CFI data collected in 1963, predictors of merchantable height, diameter breast height (DBH), basal area X height, DBH X height, and volume were correlated with both sawtimber and pulpwood growth (growth from 1963 to 1968); this was to see which predictors had the greatest relationship. The selected predictors were also intercorrelated to see what relationship they had to each other. The predictors having the highest correlation with growth were then selected as the criteria for the 3-P samples.

compared to a new random number in the random number list. Those individuals with estimates equal or larger than the random number from the list are selected for the 3-P sample and accurately measured. Also, those individuals with a value greater than K are designated "sure-to-be measured" and are accurately measured. The individuals which have been selected for 3-P sample now have two measurements, one estimate and one accurate measure. By dividing the accurate measure by the estimated measure and finding the average for all the 3-P selected trees, a correction factor may be developed to adjust the estimated values. The procedure for this calculation may be found in Space (1973c) who uses the basic 3-P formula:

$$Vol_T = \left[\sum_{1}^{M} KPI_{est} * \frac{\sum_{1}^{m} \left(\frac{KPIac}{KPI_{est}} \right)}{m} \right] + Vol_{STBM} \qquad (16)$$

where:

Vol_T = total volume of population sampled by 3-P

KPI_{est} = estimated volume of individual trees

KPI_{ac} = accurately measured volume of individual trees

m = number of trees selected for 3-P sampling

M = number of trees in population being sampled by 3-P

Vol_{STBM} = volume of sure-to-be measured trees

The ratios for the 3-P samples in this study were developed a little different than those of the standard 3-P method. The estimates were the 1968 CFI inventory data and the accurate measurements were the 1973 CFI inventory measurements of the 3-P selected trees. This

gave ratios of 1973 volume divided by 1968 volume data. The average ratio multiplied times the average volume per acre in 1968 yielded an average volume per acre estimate in 1973 (formula 17).

$$Vol/Ac_{73} = \frac{PPA}{TNP}\left[\left(\sum_{1}^{K} KPI - Vol_{STBM_{68}}\right) * \left(\frac{\sum_{1}^{K}\left(\frac{Vol\ 73}{Vol\ 68}\right)}{k}\right)\right] + Vol_{STBM_{73}} \qquad (17)$$

where: Vol/Ac_{73} = volume per acre in 1973

PPA = number of plots per acre

TNP = total number of plots on CFI

$\sum_{1}^{K} KPI$ = sum of all individual CFI measured tree volumes in the 1968 inventory excluding sure-to-be measured trees

K = the number of trees, excluding sure-to-be measured trees, in the 1968 inventory

$Vol_{STBM_{68}}$ = 1968 volumes of all trees larger than K

$\left(\frac{Vol\ 73}{Vol\ 68}\right)$ = the 1973 volume of individual 3-P selected trees divided by its 1968 volume

k = number of 3-P selected trees

$Vol_{STBM_{73}}$ = 1973 volumes of all trees larger than K

Samples were picked from the 1968 inventory by matching each successive number from the random number list with each successive net volume in the inventory listing of net volume. Those trees which had equal or larger values than the value in the random number list were selected for the 3-P sample.

3-P Volume Estimates

The volume of the 3-P selected trees from the 1968 CFI inventory along with the corresponding tree volume in the 1973 CFI inventory were entered into the formula found in Appendix B to get a 3-P estimate of the 1973 pulpwood and sawtimber volume per acre.

3-P Standard Error Estimates of Volume

By calculating the variance associated with the volume per acre of 1968 CFI inventory, the variance of the 3-P sample ratios and covariance between the two samples, it was possible to compute the relative standard error of the 3-P estimate of the 1973 volume per acre. The formula and calculations for the relative standard error of the 3-P 1973 volume per acre can be found in Appendix C.

Comparisons of Volume and Standard Errors

The 3-P volume per acre estimates along with their standard error were compared to the volume and standard errors per acre of the standard 1973 CFI inventory. An evaluation of the comparisons and the feasibility of 3-P sampling as a midcycle volume estimate of CFI was accomplished by studying the efficiencies of the samples, the time and costs of conducting each sample, and the types of growth and volume information received from each.

CHAPTER V

RESULTS AND DISCUSSION

Selection of 3-P Predictors

Correlations of merchantable height, DBH, basal area X height, DBH X height, DBH^2, and volume in 1963 to pulpwood and sawtimber growth from 1963 to 1968 indicated that 1963 pulpwood volume is best correlated to pulpwood growth ($r = 0.4802$) and that merchantable height was best correlated to sawtimber growth ($r = 0.1287$). Despite the fact that these predictors, 1963 pulpwood volume to pulpwood growth and merchantable height to sawtimber growth, had the best correlation among the selected variables, the relationship did not account for enough variability to be meaningful. This indicated that tree growth, being dependent on many variables, could not be predicted by selecting only one variable as a predictor. This approach to 3-P sampling of growth was not pursued further.

Examining growth itself, as a predictor for the 3-P samples, seemed to be at first a practical approach. This meant selecting trees based on their 1963 to 1968 growth to predict the growth from 1968 to 1973. Several problems were quickly encountered. Trees which were classified as ingrowth could not be measured. Also nonmerchantable which became merchantable over the growth period could not be measured. Other major problems occurred because of the complications of consolidating standard growth terms. Trees which grew into pulpwood (pulpwood ingrowth) and trees which grew from pulpwood into sawtimber

(sawtimber ingrowth) over the growth period were separated into two growth terms; that of ingrowth and growth on ingrowth. The volume of an ingrowth tree at its threshold diameter was added to the tree class into which it grew, but the extra volume above threshold diameter was added to the growth term called accretion. Because of these complications of separating growth into categories that could be sampled by 3-P sampling, it was considered impractical to proceed further.

The correlation between 1963 and 1968 sawtimber volumes was very high ($r = 0.8468$). The correlation between 1963 and 1968 pulpwood volumes was considerably less ($r = 0.2642$) because of the large number of trees becoming sawtimber. However, it was still significant at the .05 level of probability. This indicated that predicting 1973 volumes from 1968 CFI volumes, i. e. using 1968 individual CFI tree volumes as the selection criterion, would be the best alternative in approaching a growth estimate through 3-P sampling. Several problems were encountered. Ingrowth into pulpwood could not be sampled nor could those trees which went from non-merchantable to merchantable status. However the CFI inventory analysis was altered so that meaningful comparisons could be evaluated between the CFI method and the 3-P method.

By subtracting the volume per acre at the beginning of the growth period (V1), obtained from the CFI, from the volume per acre at the end of the period (V2), obtained from the 3-P sample, it was possible to arrive at the net increase per acre excluding ingrowth.

3-P Data Selection

After selecting volume as the criterion of 3-P samples for estimating 1973 volume, it was necessary to see how many trees were needed from the pulpwood and sawtimber CFI data to serve as an adequate 3-P sample. Between tree and between plot variability was evaluated for the 1968 pulpwood volumes and the 1968 sawtimber volumes. By selecting 100 trees from both sawtimber and pulpwood tree volumes, coefficients of variation were calculated to be 51.2% for among trees in sawtimber and 64.7% among trees for pulpwood. Based on the 1968 CFI data, coefficients of variation (among plots) for sawtimber was 95.5% while that for pulpwood was 85.1%. These coefficients of variation and a desired coefficient of variation of 10% for the 3-P sample were entered into the formula in Appendix A. Sample sizes (N) of 66 sawtimber trees and 49 pulpwood trees were calculated as the desired number of trees to be selected by the 3-P samples.

A K value (maximum KPI) had to be selected before random number lists for selecting the 3-P samples could be obtained. Frequency distribution of sawtimber and pulpwood volumes from the 1968 CFI inventory were examined to determine this value. Selection of K is important because if it is too high too few trees will be selected for the 3-P samples and if too low, too many trees will be selected. If a stand is of predominately small trees with only a very few large trees, selecting the largest tree as the maximum KPI would be improper. It would be far better to designate those few large trees as "sure-to-be measured" trees (trees with a KPI greater

than K) and select a maximum KPI at a point that is more representative of the population.

ΣKPI for both sawtimber and pulpwood were simply a sum of all 1968 CFI volumes excluding those trees with volumes larger than K.

Using random number lists generated with the RN3P computer program and this information, the 3-P sample trees were selected from the 1968 CFI inventory. Sixty-seven trees were picked for the sawtimber sample and 42 trees for the pulpwood sample. There were 6 sure-to-be measured trees in sawtimber and 5 in pulpwood. Since these trees had already been remeasured in the 1973 CFI inventory, the volumes were picked directly from the CFI listing. The 3-P selected trees were trees which had some positive volume in the 1968 CFI inventory; thus, they did not include ingrowth or cull trees which obtained merchantability over the growth period.

3-P Volume Estimate

The 1968 CFI inventory volume and the 1973 volumes for the 3-P selected trees were entered into the formula 17.

Each 1973 volume was divided by the corresponding 1968 volume giving a ratio of its volumes over the growing period. An average of these ratios gave an estimate of average growth (1968 to 1973). Sawtimber trees had an average growth ratio of 1.11 of the 1968 volume while pulpwood had an average growth ratio of 1.17 of the 1968 volume. These ratios were small because ingrowth was not included; trees which were listed as outgrowth, mortality or cut in pulpwood and trees listed as mortality or cut in sawtimber were recorded as

zero volume in the remeasurement. These growth ratios were multiplied by their respective 1968 average volume per acre to calculate the average volume per acre in 1973. The average volume per acre of sawtimber in 1973 came to 4186.90 board feet per acre while the pulpwood average volume per acre 1973 came to 225.71 cubic feet per acre.

3-P Standard Error of Volume

To aid in the comparison between 3-P sampling and CFI inventory methods, a relative standard error for the combined system was calculated using equation 15. These calculations revealed that the relative standard error for pulpwood was less than the corresponding relative standard error from the CFI inventory. The 3-P relative standard error for sawtimber was slightly larger than that of the CFI inventory. A relative standard error of 6.78% for 3-P estimated pulpwood volume per acre was calculated versus 6.91% for CFI estimated pulpwood volume per acre. A relative standard error of 13.53% for 3-P estimated sawtimber volume per acre was calculated versus 7.67% for CFI estimated sawtimber volume per acre.

Grosenbaugh (1973b) explained why a slightly lower relative standard error may occur using the 3-P subsample. A negative covariance, such as the ones estimated here, reduces the standard error of a product $(KPI * \frac{Vol\ 73}{Vol\ 68})$. The volumes in 1973, in essence, were inflated over the 1968 volumes in the 3-P sample resulting in a negative covariance. This negative covariance tended to reduce the effect of the inflation giving a standard error which is sometimes

lower than the standard error found in the CFI inventory. This is a bonus benefit of 3-P sampling which does not always happen and one reason why the covariance term in the standard error computation should not be ignored.

Comparison of Volume and Standard Error

The 3-P volume estimate of 4186.90 board feet per acre was within 0.56% of the CFI sawtimber volume estimate of 4210.39 board feet per acre. A 3-P pulpwood volume estimate of 225.71 cubic feet per acre was within 1.11% of the CFI pulpwood volume estimate of 228.23 cubic feet per acre. The same inventory instruments were used in each method. Both 3-P relative standard errors were lower than the corresponding CFI relative standard errors. These comparisons clearly enforce previous findings of the superb efficiency of 3-P sampling. The cost of measuring 120 trees in the 3-P sampling method versus measuring over 2,000 trees by the CFI method, plus the fact that all CFI plots would not have to be revisited for remeasurement with 3-P sampling, would be considerably lower than total remeasurement. In this study only 77 plots out of 151 would have had to been revisited. These include 48 plots with one remeasure tree, 18 plots with 2 remeasure trees, 9 plots with 3 remeasure trees, and 2 plots with 4 remeasure trees.

The types of information received from the 3-P samples suffered some drawbacks when compared to the CFI system. No information was obtained on ingrowth or trees changing from nonmerchantable status

to merchantable trees over the growth period. These drawbacks can be overcome if the procedures of administering the CFI inventory are altered to accommodate the 3-P sampling.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATION

Conclusions

Use of 3-P sampling for midcycle volume and growth estimate in a CFI system is very efficient. Its use as a forest sampling method ranks very high among modern forest sampling techniques.

Although several problems were encountered in the establishment of a 3-P sample in combination with the present CFI system of The University of Tennessee, the savings in time and cost plus the high efficiency of 3-P sampling compensates for the problems encountered.

The problems of not being able to sample pulpwood ingrowth or to sample trees which move from nonmerchantable to merchantable status over the growth period can be solved by changing the CFI method of forest inventory to gather a small amount of additional information. This may be accomplished in several ways. One method would be to record all trees on the CFI 1/10th acre permanent plot which are larger than one inch in diameter during the standard CFI measurement taking DBH and height information. This would give a record of all trees one inch and greater and a source of information concerning pulpwood ingrowth. Another method of modifying the CFI inventory to accommodate a 3-P sample, would be to take a basal area factor variable plot sample of all trees one inch and above at each plot center

during the standard CFI sample taking DBH, height and cull information and using height as the criterion for 3-P selections. This variable plot sample would then be used as the source of data used to select the 3-P samples.

Regardless of the methods used to modify the CFI inventory to accommodate 3-P sampling as a midcycle volume estimate, spending a few dollars more for additional information, collected from standard CFI, would more than be paid for by the low cost of the 3-P midcycle estimate and its comparable accuracy.

Recommendations

It is recommended that 3-P sampling be incorporated into the CFI system of sampling presently used by The University of Tennessee. It is suggested that during future CFI remeasurements a basal area factor prism sample be taken at each permanent plot center. Information which is normally taken for CFI trees would also be taken for the prism selected trees. This would mean sampling only a few extra trees since most of the trees will have already been sampled by previously established permanent plots and will, in most cases, only necessitate transferring the needed data.

ΣKPI, K, K + Z, and N would be selected from the variable plot data. Since volumes tend to be proportional to basal area X height (D^2H), a predictor of height would be used to select the 3-P samples. N would be selected using coefficients of variation for D^2H among prism plots and coefficients of variation for ratios of actual volumes of individual trees to their D^2H. Once a list of 3-P trees is

selected, all that remains to be done at the next inventory cycle is to remeasure the selected trees. Computations for the 3-P samples at midcycle would be handled in the manner described in Van Hosser (1972).

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APPENDICES

APPENDIX A

Calculation of desired sampling size (N) for 3-P sampling using formula:

$$N_{ST} = \frac{(51.2)^2}{(10)^2 - \frac{(95.46)^2}{151}}$$

where: N_{ST} = desired number of sawtimber trees to be selected for 3-P sample

51.2% = the coefficient of variation in percent among a sample of individual sawtimber tree ratios taken from CFI data (1968/1963)

10% = desired coefficient of variation for 3-P sample

95.46% = the coefficient of variation in percent among sawtimber plot volumes per acre taken from CFI

151 = number of plots in CFI

$$N_{pw} = \frac{(64.7)^2}{(10)^2 - \frac{(85.1)^2}{151}}$$

where: N_{pw} = desired number of pulpwood trees to be selected for 3-P sample

64.7% = the coefficient of variation in percent among a sample of individual pulpwood tree ratios taken from CFI data (1968/1963)

10% = desired coefficient of variation for 3-P sample

85.1% = the coefficient of variation in percent among sawtimber plot volumes per acre taken from CFI

151 = number of plots in CFI

APPENDIX B

Three-P calculation of sawtimber volume per acre in 1973 (bd. ft.) using formula 17:

$$Vol/Ac_{ST} = \frac{5}{151}\left(\left[\left(115{,}244.2 - 3{,}349.07\right) * \frac{74.32}{67}\right] + 2{,}237.64\right)$$

where: Vol/Ac_{ST} = sawtimber volume per acre in 1973 (3-P)

5/151 = blow up factor (1/5th acre plots; 151 plots)

115,244.2 = sum of all individual CFI measured tree volumes in the 1968 inventory excluding sure-to-be measured trees

3,349.07 = 1968 volumes of all trees larger than K

74.32 = sum of individual 3-P selected tree ratios (vol. 73/vol. 68)

67 = number of 3-P selected trees

2,237.64 = 1973 volumes of all trees larger than K

Three-P calculation of pulpwood volume per acre in 1973 (cu. ft.) using formula 17:

$$Vol/Ac_{pw} = \frac{10}{151}\left(\left[\left(2{,}935.23 - 55.87\right) * \frac{48.93}{42}\right] + 39.37\right)$$

where: Vol/Ac_{pw} = pulpwood volume per acre in 1973 (3-P)

10/151 = blow up factor (1/10th acre plots; 151 plots)

2,935.23 = sum of all individual CFI measured tree volumes in the 1968 inventory excluding sure-to-be measured trees

55.87 = 1968 volumes of all trees larger than K

48.93 = sum of individual 3-P selected tree ratios

(vol. 73/vol. 68)

42 = number of 3-P selected trees

39.37 = 1973 volumes of all trees larger than K

APPENDIX C

Three-P calculation of sawtimber relative standard error (bd. ft.) with formula 15:

$$\text{Rel. S.E.}_{\text{3-P Vol/Ac}_{73}} = \sqrt{\left(\frac{12{,}527{,}635.51}{151 * (3816.03)^2}\right) * \left(\frac{.25}{67 * (1.11)^2}\right) + 2\left(\frac{-586.14}{67 * 3816.03 * 1.11}\right)}$$

where: $\text{Rel. S.E.}_{\text{3-P}}$ = relative standard error of 3-P volume per acre in 1973

12,527,635.51 = variance of the average plot volume per acre in 1968

151 = number of sample plots in CFI inventory

3,816.03 = average volume per acre in 1968 CFI inventory

.25 = variance of volume ratios of 3-P selected trees

67 = number of trees selected by 3-P sample excluding sure-to-be measured trees

.25 = average volume ratio of 3-P selected trees

-586.14 = the covariance of 3-P tree ratios and average volume per acre of plots from which 3-P selected trees were picked.

Three-P calculation of pulpwood relative standard error (bd. ft.) with formula 15:

$$\text{Rel. S.E.}_{\text{3-P Vol/Ac 73}} = \sqrt{\left(\frac{26{,}817.34}{151 * (194.39)^2}\right) + \left(\frac{1.04}{42 * (1.17)^2}\right) + 2\left(\frac{-21.44}{42 * 194.39 * 1.17}\right)}$$

where: $\text{Rel. S.E.}_{\text{3-P}}$ = relative standard error of 3-P volume per acre in 1973

26,817.34 = variance of the average plot volume per acre in 1968

151 = number of sample plots in CFI inventory

194.39 = average volume per acre in 1968 CFI inventory

1.04 = variance of volume ratios of 3-P selected trees

42 = number of trees selected by 3-P sample excluding sure-to-be measured trees

1.17 = average volume ratio of 3-P selected trees

-21.44 = the covariance of 3-P tree ratios and average volume per acre of plots from which 3-P selected trees were picked

VITA

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Upon graduation from the University of the South in 1968, the author entered into active duty with the United States Navy where he spent four years as an Aviation Electronics Technician. He was honorably separated from the Navy in July of 1972 and enrolled at The University of Tennessee to pursue a Master of Science degree in Forestry. As a graduate student he worked as a teaching assistant in Forestry.

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