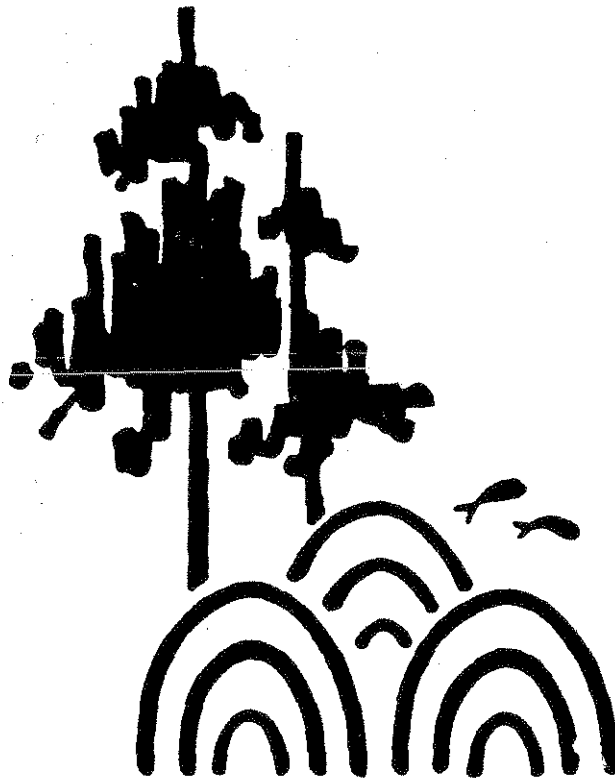


# **A Model for Assessing Hardwood Competition Effects on Yields of Loblolly Pine Plantations**



**Publication No. FWS-3-84**

**School of Forestry and Wildlife Resources  
Virginia Polytechnic Institute and State University  
Blacksburg, Virginia 24061**

**1984**

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A MODEL FOR ASSESSING HARDWOOD COMPETITION  
EFFECTS ON YIELDS OF  
LOBLOLLY PINE PLANTATIONS

by

Harold E. Burkhart  
Peter T. Sprinz

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## PREFACE

This bulletin presents a model to predict pine survival, growth and yield for unthinned loblolly pine plantations with varying levels of hardwood competition in the main canopy. Those wishing to obtain copies of the software should write the authors at:

School of Forestry and Wildlife Resources  
Virginia Polytechnic Institute and State University  
Blacksburg, Virginia 24061

To defer the cost of postage and handling, a charge of \$25.00 will be made for a card deck of the FORTRAN program or a diskette containing the BASIC program. Checks should be made payable to "Department of Forestry, VPI & SU".

Although the software presented here has been extensively tested and checked for accuracy and, to the best of our knowledge, contains no errors, neither Virginia Polytechnic Institute and State University, the Department of Forestry, nor the authors claim any responsibility for any errors that do arise.

## ACKNOWLEDGMENTS

This project has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement CR809002020 to Oregon State University (with Subcontract No. 2-4229-02 to Virginia Polytechnic Institute and State University). The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Support for this work was also provided by the Loblolly Pine Growth and Yield Research Cooperative at Virginia Polytechnic Institute and State University. We gratefully acknowledge the Department of Forestry at Auburn University for use of data to validate the model described herein.

## ABSTRACT

A model was developed to predict pine survival, growth and yield for unthinned loblolly pine plantations with varying levels of hardwood competition in the main canopy. Inputs for the model are number of loblolly pine trees per acre planted, site index for loblolly pine, percent of hardwood basal area in the main canopy of the stand, and age(s) at which output is desired. From these inputs the model computes, by 1-inch dbh classes, the number of trees surviving, basal area, and volumes per acre.

The model, which was constructed using sample plot data from old-field and cutover-site plantations, was validated with independent data from a hardwood conversion/site preparation study. Overall, there was close agreement between the observed values and the model predictions.

## AUTHORS

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## TABLE OF CONTENTS

|                                      | <u>Page</u> |
|--------------------------------------|-------------|
| List of Tables                       | v           |
| List of Figures                      | vi          |
| INTRODUCTION                         | 1           |
| MODEL INPUTS-OUTPUTS                 | 1           |
| DATA BASE                            | 2           |
| Old-field Plantation Plots           | 3           |
| Cutover-site Plantation Plots        | 3           |
| Conversion-study Plots               | 6           |
| MODEL STRUCTURE                      | 7           |
| Approach                             | 7           |
| Height-age Development               | 7           |
| Height-diameter Curves               | 8           |
| Individual Tree Volume Relationships | 8           |
| Diameter Distribution                | 9           |
| Pine Survival                        | 13          |
| Projection of Stand Composition      | 14          |
| MODEL VALIDATION                     | 17          |
| LIMITATIONS                          | 19          |
| LITERATURE CITED                     | 24          |
| APPENDIX                             | 25          |

LIST OF TABLES

| <u>Table</u> |                                                                                                                                                                        | <u>Page</u> |
|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 1            | Summary of characteristics of sample plot data used to model hardwood competition effects on loblolly pine plantation yields.                                          | 4           |
| 2            | Stand and stock tables for the planted component of unthinned loblolly pine plantations at age 30 with 800 trees per acre planted on site index 60 (base age 25) land. | 20          |

## LIST OF FIGURES

| <u>Figure</u> |                                                                                                                                                                                                                                         | <u>Page</u> |
|---------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 1             | Map showing distribution of sample plots used to model hardwood competition effects on loblolly pine plantation yields.                                                                                                                 | 5           |
| 2             | Surviving loblolly pine trees per acre as related to percent of basal area in hardwood. Figure is for 800 trees per acre planted.                                                                                                       | 15          |
| 3             | Relationship between percent basal area composed of hardwoods in the main canopy of loblolly pine plantations at ages 11 and 24 in a hardwood conversion/site preparation study, Fayette County, Alabama.                               | 16          |
| 4             | Total yield of loblolly pine versus percent of total stand basal area in hardwood from plot observations in a hardwood conversion/site preparation study in Fayette County, Alabama. The line represents predictions from program HDWD. | 18          |
| 5             | Pine dbh distribution for 0, 20, and 40 percent of the total stand basal area in hardwood. These histograms are for age 30 with 800 trees per acre planted on site index 60 (base age 25 years) land.                                   | 22          |



# A MODEL FOR ASSESSING HARDWOOD COMPETITION

## EFFECTS ON YIELDS OF LOBLOLLY PINE PLANTATIONS

Harold E. Burkhart and Peter T. Sprinz

### INTRODUCTION

It is generally recognized that hardwood competitors significantly affect yields of pine stands. A model which predicts pine survival, growth and yield for stands with varying levels of competing vegetation is needed to assess the feasibility of various vegetation management strategies. In this bulletin, a model for the growth and yield of unthinned loblolly pine (*Pinus taeda* L.) plantations with varying levels of hardwood competition is presented. The inputs required, outputs obtained, data base used, modeling methods employed, assumptions made and limitations of the model are discussed.

### MODEL INPUTS-OUTPUTS

To operate the loblolly pine model, called HDWD, the user must specify:

- Number of loblolly pine trees per acre planted ( $T_p$ )
- Site index for loblolly pine (feet at base age 25 years) (SI)
- Percent of hardwood basal area in the main canopy of the stand ( $\%B_H$ )
- Ages at which output is desired (A)

From these input parameters, the model computes, by 1-inch diameter at breast height (dbh) classes, estimates for the pine components of:

- Number of trees surviving per acre
- Total height (feet)
- Basal area (square feet per acre)
- Total stem volume, outside bark (cubic feet per acre)
- Pulpwood volume, outside bark, to a 4-inch top diameter (ob) of the trees in the 5-inch dbh class and above (cubic feet per acre)
- Sawlog volume, outside bark, to a 6-inch top diameter (ob) of the trees in the 8-inch dbh class and above (cubic feet per acre)

In addition to the values by dbh class, total numbers of trees, basal area and volumes and arithmetic mean dbh are also shown.

With the complete stand table (numbers of trees by dbh class) provided, one can evaluate the impact of competing vegetation on product yields as well as on overall survival and volume. Such flexibility is needed when performing economic analyses.

The model components were implemented through an interactive computer program called HDWD. The program was written in standard FORTRAN for mainframe computers and in BASIC for the IBM Personal Computer. A user's guide to this program, an example of a user's session with the program, and a complete listing of the FORTRAN and BASIC code is included in the Appendix.

#### DATA BASE

Three primary data sources were used to construct a model designed to quantify hardwood competition effects on loblolly pine yields:

1. Data from unthinned loblolly pine plantations established on abandoned agricultural land (called "old fields") were used to establish an "upper limit" on hardwood competition control effectiveness for site prepared lands that were supporting forests before being cut and regenerated to loblolly pine plantations. Because these old-field plantations developed almost virtually free of competition from hardwood species, the survival and growth can be regarded as an upper limit for plantations established on cutover, site-prepared areas, which are the areas of primary concern in contemporary plantation management in the South. (Pine seedlings for many of these old-field plantations experienced considerable herbaceous and grass competition in the early years; however, due to limitations in data bases, it was not possible to model these effects.)
2. Measurements from unthinned loblolly pine plantations on cutover, site-prepared areas were used, where possible, to estimate the effects of competing hardwoods on pine survival and growth. The data available included a wide variety of site preparation methods, with varying degrees of effectiveness and thus varying levels of competing vegetation.
3. Observations from a site conversion study that was installed and maintained by Auburn University were used to develop basic relationships and evaluate various assumptions. Although this study (commonly referred to as the "Fayette Study") was not designed for the objectives of this analysis, it was the only designed-experiment type data available for this modeling effort. The old-field and cutover-site plantation data came from sample plots in operationally-established plantations.

### Old-field Plantation Plots

Selected old-field loblolly pine plantations were sampled in the Piedmont and Coastal Plain regions of Virginia, and in the Coastal Plain region of Delaware, Maryland and North Carolina. One hundred and twenty-nine of the 189 sample plots were located on Coastal Plain sites, while 60 were in the Piedmont region of Virginia.

Temporary 0.1-acre, circular sample plots were randomly located in selected stands. To be sampled, plantations were required to be unthinned, free of severe insect or disease damage, unburned and unpruned, relatively free of wildlings and contain no interplanting.

On each plot, diameter at breast height (dbh) was recorded to the nearest 0.1 inch for all trees in the 1-inch dbh class and above. Total height was recorded to the nearest 1.0 foot for at least one, but usually two trees per 1-inch dbh class. Six to eight dominant and codominant trees were selected as sample site trees and total age of the stand was determined from planting records or increment borings.

A summary of the sample plot characteristics is shown in Table 1; the geographic distribution of the plots is displayed in Figure 1. Additional information about these plots can be obtained from Burkhardt *et al.* (1972).

### Cutover-site Plantation Plots

During the 1980-81 and 1981-82 dormant seasons, permanent plots were established in cutover, site-prepared plantations throughout the native range of loblolly pine. The initial measurement data from these permanent plots were available for use in this study. To be included in the sample, the plantations had to meet the following specifications: at least eight years in age (defined as years since planting), unthinned, free of evidence of heavy disease or insect attack, not heavily damaged by ice or wind storms, free of interplanting, unpruned, not fertilized within the last four years, not planted with genetically improved stock, contain a minimum of 200-300 planted pine stems per acre which appear "free to grow," not more than 25 percent of the main canopy composed of volunteer pines, and established on a cutover area that received "typical" site preparation treatment for the site conditions and time at which the plantation was established.

The following data were recorded for all planted pines: dbh to the nearest 0.1 inch, total height to the nearest 1.0 foot, height to the base of the live crown, crown class, and a stem quality assessment. In addition, number of trees planted and age were determined.

The following information was recorded for natural pines and hardwoods which were in the main canopy: dbh to the nearest 0.1 inch, total height to the nearest 1.0 foot, and species. Natural pine and hardwood trees not in the main canopy, but greater than 0.5 inches in dbh, were tallied by 1-inch dbh classes only.


Table 1. Summary of characteristics of sample plot data used to model hardwood competition effects on loblolly pine plantation yields.


| Data                                     | No.              | Mean  | Minimum | Maximum |
|------------------------------------------|------------------|-------|---------|---------|
| <u>Old-field Plantation Plots</u> 189    |                  |       |         |         |
| Site index 25 (ft.) <sup>a/</sup>        |                  | 67.0  | 47.4    | 92.3    |
| Age                                      |                  | 16.6  | 9       | 35      |
| Surviving pine (trees/ac)                |                  | 751.9 | 300     | 2900    |
| Basal area pine (sq.ft./ac)              |                  | 151.8 | 72.0    | 277.3   |
| <u>Cutover-site Plantation Plots</u> 186 |                  |       |         |         |
| Site index 25 (ft.) <sup>a/</sup>        |                  | 62.8  | 33.5    | 97.3    |
| Age                                      |                  | 15.2  | 8       | 25      |
| Surviving pine (trees/ac)                |                  | 558.3 | 275     | 950     |
| % Basal area in hardwood                 |                  | 4.8   | 0.0     | 27.8    |
| Basal area pine (sq.ft./ac)              |                  | 150.1 | 22.9    | 230.9   |
| <u>Conversion Study</u>                  |                  |       |         |         |
| <u>Age 11</u>                            |                  |       |         |         |
| Surviving pine (trees/ac)                | 25 <sup>b/</sup> | 486.5 | 40.8    | 673.5   |
| % Basal area in hardwood                 | 25               | 39.7  | 3.7     | 100.0   |
| Basal area pine (sq.ft./ac)              | 25               | 40.4  | 0.0     | 90.6    |
| <u>Age 24</u>                            |                  |       |         |         |
| Site index 25 (ft.) <sup>a/</sup>        | 29               | 58.8  | 44.3    | 69.1    |
| Surviving pine (trees/ac)                | 33               | 316.0 | 0       | 531     |
| % Basal area in hardwood                 | 33               | 33.1  | 0.0     | 100.0   |
| Basal area pine (sq.ft./ac)              | 33               | 97.6  | 0.0     | 174.9   |


<sup>a/</sup> All site index values were computed using the equation for combined coastal plain and piedmont data from Amateis and Burkhart (in press).


<sup>b/</sup> The number of usable observations for each characteristic varied somewhat between measurement times. Two of the original 35 plots were cut in early 1980 during a southern pine beetle salvage operation, leaving a maximum of 33 plots for measurement.

# LEGEND

 CUTOVER SITE PLOTS

 OLD-FIELD & CUTOVER SITE PLOTS

 OLD-FIELD PLOTS

 SITE CONVERSION STUDY PLOTS

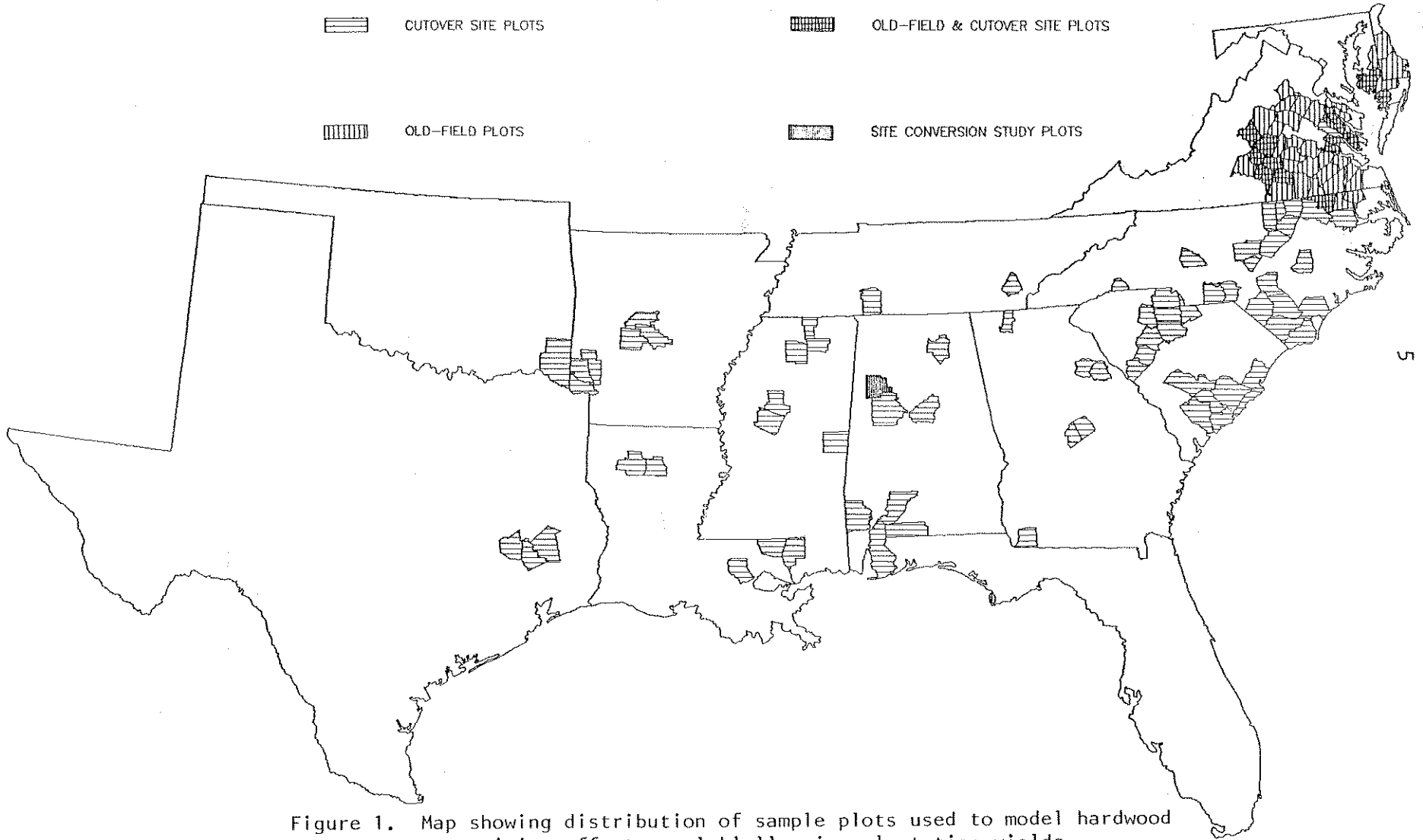


Figure 1. Map showing distribution of sample plots used to model hardwood competition effects on loblolly pine plantation yields.

Summary information on these plots is contained in Table 1, while the geographic location is shown in Figure 1. Additional detail can be obtained from Burkhart *et al.* (in press).

### Conversion-Study Plots

In January, 1959, a hardwood conversion/site preparation study was installed at the Fayette Experimental Forest of the Auburn University Agricultural Experiment Station in Fayette County, Alabama, which is in the Upper Coastal Plain soils region. The objective of this study was to test effects of seven methods of conversion on survival and early growth of planted loblolly pine on a cutover-site.

A randomized block design, consisting of 7 treatments (including an untreated check) with 5 replications per treatment, was installed on a relatively uniform site. Treatment plots were square, 132 feet on each side, with a 46.2 foot x 46.2 foot permanent sample plot located in the center of each treated plot. The treatments were:

1. Check
2. Scarification by bulldozer
3. Injector-applied herbicide
4. Girdle without herbicide
5. Axe frill and herbicide
6. Chain girdle and herbicide
7. Foliage spraying plus axe frill and herbicide

These treatments were widely varying in effectiveness, resulting in sample plots that ranged from essentially pure pine to pure hardwood. A detailed description of the study area, methods, treatments and results at the end of the first 6 years was given by Whipple and White (1965).

Subsequent measurements on both the pine and the hardwood components at ages 11 and 24 were made available for use in these analyses. The age 11 information was on a plot basis with details on the number of surviving trees, average dbh and basal area per acre of the pine and hardwood components provided. The following individual-tree information was provided with the age 24 measurements: dbh to the nearest 0.1 inch, total stem volume in cubic feet, crown class and, on a subsample of trees, total height to the nearest 1.0 foot. Hardwood information at age 24 included the number of trees by species in 2-inch dbh classes and 10-foot total height classes. Table 1 gives summary statistics for the age 11 and 24 measurements; Figure 1 shows the study location.

## MODEL STRUCTURE

Approach

The approach taken to modeling hardwood competition effects on yield was to regard values observed in old-field plantations as upper limits and to compute reduction factors based on the level of hardwood competition. As a first step, the effects of hardwood competition on various stand components were assessed. These assessments were made by: (1) computing regression equations with the data from cutover-site plantations and determining if hardwood variables significantly reduced the error sum of squares, and by (2) comparing regression equations fitted to the old-field data with those fitted to the cutover-site data. Because the level of hardwood competition was relatively low in most of the cutover-site plots (see Table 1), attempts to incorporate hardwood competition variables using these data were generally not successful. Comparisons between regressions fitted to the old-field versus the cutover-site data showed significant differences, however. These differences were examined on the following stand components of the pine portion of the stands:

1. Height over age development
2. Height over diameter curves
3. Individual tree volume relationships
4. Diameter distribution
5. Survival relationships

Height-Age Development

Comparisons of height-age (site index) curves for old-fields versus cutover-sites were made by using data from stem analysis trees collected at the time of plot installation. These comparisons showed statistically significant differences between the two data sets. The differences were not overly large from a practical standpoint, however, and they could not be related to level of hardwood competition. This lack of a significant relationship to level of hardwood in the stand is consistent with the generally small effect of stand density -- over a fairly broad range -- on height growth of loblolly pine. Since the primary purpose of this model is to assess levels of hardwood competition on the yields of loblolly pine plantations on cutover, site-prepared land, we adopted the site index curves from Amateis and Burkhart (in press) which were derived from stem analysis trees taken on the cutover-site plantation plots described previously. The equation for the combined piedmont and coastal plain data is

$$\ln H_d = \ln SI (A/25)^{0.10283} e^{-2.1676(1/A-1/25)}$$

where

$H_d$  = average height of dominants and codominants (feet)

SI = site index, base age 25 years (feet)

A = plantation age (years since planting)

$\ln$  = logarithm base e

Amateis and Burkhart present coefficients for subdivisions of the data; if a user wants to use a site index curve for a specific physiographic region, the appropriate coefficients can be substituted easily.

### Height-Diameter Curves

Height-diameter curves were significantly different for the old-field and cutover-site data. Differences could not be related to levels of hardwood competition, however, and comparisons of the two curves showed predicted values to be almost identical. The large sample sizes (2,452 trees from old-fields and 56,989 from cutover-sites) resulted in a very powerful test that was almost certain to indicate a significant difference. Because the primary objective is to model yields for cutover-site areas, the height-diameter curve fitted to the cutover-site data was incorporated into the model. The equation is

$$\begin{aligned} \log (H_d/H_i) = & -0.040006 + (1/D_i - 1/D_{\max}) \times \\ & (0.428373 - 0.497483 \log T_s + 0.363755/A \\ & + 1.095404 \log H_d) \end{aligned}$$

where

$H_i$  = total tree height (feet) for a tree with dbh  $D_i$  (inches)

$D_{\max}$  = maximum dbh (inches) in the stand (determined from the dbh distribution)

$H_d$  = average height of dominants and codominants (feet)

$T_s$  = number of trees per acre surviving at age A (years since planting)

$\log$  = logarithm base 10

The coefficient of determination ( $R^2$ ) for this equation was 0.64 and the standard error of estimate ( $S_{y.x}$ ) was 0.041.

### Individual Tree Volume Relationships

Data from the stem analysis trees were used to compare individual tree volume relationships for old-fields with those from cutover-sites. Again,



significant differences were detected but the differences were not sufficiently large to be of practical importance and they could not be related to hardwood variables. All stem analysis trees from cutover-site plantations were in the dominant or codominant crown classes, but the data set from old-field plantations contained all crown classes. (When comparing volume relationships between the two data sets, only data from dominant and codominant trees in old-fields were used.) Because of the small differences between the two data sets and because volume predictions are needed for all crown classes, the volume equations from Burkhardt (1977), which were fitted to the old-field data from all crown classes, were used. The total cubic-foot volume equation is

$$V = 0.34864 + 0.00232 D^2 H$$

where

V = cubic-foot volume outside bark of the stem from a 0.5 foot stump to tip

D = dbh (inches)

H = total tree height (feet)

Merchantable cubic volumes are derived by multiplying total volume by the appropriate ratio computed from

$$R = 1 - 0.32354 (D_t^{3.1579} / D^{2.7115})$$

where

R = ratio of merchantable cubic-foot volume to top diameter  $D_t$  with respect to total cubic-foot stem volume

$D_t$  = top diameter, outside bark (inches)

D = dbh (inches)

### Diameter Distribution

Comparisons of dbh distributions in old-field and cutover-site plantations showed substantial differences. In general, cutover-site plantations had a smaller mean diameter and less basal area per acre than old-field plantations with the same age, average height of dominants and codominants, and number of pines surviving. Differences in the two data sets may be partially due to a number of factors, but the most important factor is probably the level of hardwood competition. The relatively large impact of hardwood competition on diameter growth as opposed to height growth is consistent with the general trend of competition effects being more pronounced on diameter than height development. We ascribed all differences in diameter distribution to differences in hardwood competition and developed adjustment factors to account for varying hardwood levels.

The pine diameters were assumed to be Weibull distributed. (For a discussion of the Weibull distribution see Bailey and Dell 1973.) The Weibull probability density function (pdf) for the random variable X can be written

$$f(x) = (c/b) [(x-a)/b]^{c-1} e^{-[(x-a)/b]^c}$$

where

$$x \geq a, b > 0, c > 0$$

This function has three parameters. The a parameter is the "location" parameter; it indicates the lower end of the diameter distribution. "Spread" in the diameter distribution is controlled by the b parameter, while the "shape" of the distribution is determined by c.

There are many different methods for estimating the parameters of the Weibull distribution. In this analysis, the method of moments was applied. The equation for the  $i^{\text{th}}$  non-central moment of x is given by:

$$E(x^i) = \int x^i f(x, \theta) dx$$

where  $f(x, \theta)$  is a probability density function with parameters  $\theta$ . In the case of forest diameter distributions, the first two moments are

$$E(x) = \bar{x} = \text{the average diameter of the stand}$$

$$E(x^2) = \overline{x^2} = B/[0.005454 T_s]$$

where B and  $T_s$  are basal area and number of trees per acre, respectively. Hence, the first two moments of the diameter distribution have stand-level interpretations that are meaningful in forestry practice and they are apparently directly affected by the level of hardwood competition.

Stand average estimates of the first k moments produce a system of k equations with k unknown parameters which can be solved to obtain estimates of the pdf parameters. In model HDWD, the location parameter a was predicted outside the system of equations and expressions for the first two moments were solved to obtain estimates of b and c.

Initially, both moments (mean diameter and mean squared diameter) were adjusted as a function of the level of hardwood competition. These adjustments led to some inconsistent results -- such as an increase, followed by a decrease in the variance of the diameter distribution of pine with an increasing proportion of the stand basal area in hardwood. At this point, we examined the data from the hardwood conversion/site preparation study in Fayette County, Alabama for trends in variance in the pine dbh distribution. The Fayette Study plots are all of the same age on a relatively uniform site, but the percent of stand basal area in hardwood varies from essentially 0 to 100. The Fayette Study plots showed that the

minimum and maximum diameters and the variance of the dbh distribution are not significantly related to the proportion of hardwood. When the predicted minimum diameter was not related to hardwood competition, however, the estimated minimum and average diameters became sufficiently close in stands with a high proportion of basal area in hardwood such that solutions for the  $\underline{b}$  and  $\underline{c}$  parameters could not be obtained. Consequently, it was necessary to adjust the minimum diameter downward as a function of hardwood competition.

The following equation was fitted to the old-field plantation data:

$$D_{\min} = -4.10834 + 0.17828A + 1.04138 H_d/A + 947.466/T_s$$

where

$D_{\min}$  = minimum dbh (inches)

A = plantation age (years)

$H_d$  = average height of dominants and codominants (feet)

$T_s$  = number of pine trees per acre surviving at age A.

For the  $D_{\min}$  equation the  $R^2$  value was 0.75 and the standard error of estimate was 0.60. Estimated minimum diameters for old-field conditions were modified by the following function which was fitted to the plot data from plantations on cutover, site-prepared areas:

$$D_{\min_{CO}} = D_{\min_{OF}} e^{-\left(B_H^{0.000427} (-0.595414 \ln B_L + 6.90102/A + 0.738295 \ln H_d)\right)}$$

where  $D_{\min_{CO}}$  = minimum diameter (inches) for cutover-site plantation

$D_{\min_{OF}}$  = minimum diameter (inches) for old-field plantation

$B_H$  = basal area (square feet per acre) of hardwood in the main canopy

$B_L$  = basal area (square feet per acre) of loblolly pine

A = plantation age (years)

$H_d$  = average height of dominants and codominants (feet)

This equation had a standard error of estimate of 0.625. The location parameter  $\underline{a}$  was set to equal  $D_{\min}/2$  and restricted to be greater than or equal to 0.5. That is, if predicted  $D_{\min}$  is less than 0.5,  $\underline{a}$  is set equal to 0.5.

Noting that the variance ( $S^2$ ) is defined as

$$S^2 = \overline{x^2} - (\bar{x})^2$$

it is clear that holding variance constant and adjusting one moment downward will result in a downward adjustment of the other moment as well. An equation was fitted to the data from old-field plantations to predict the variance of the dbh distribution ( $S_{dbh}^2$ ). The variance values were subjected to logarithmic transformation to insure that predicted values would always be positive. The resulting equation is:

$$\ln(S_{dbh}^2) = 2.8366 - 0.2979 \ln T_s - 20.422/H_d + 0.0003872 A^2$$

where

$T_s$  = number of trees per acre surviving at age A

$H_d$  = average height of dominants and codominants (feet)

This equation had an  $R^2$  value of 0.37 and standard error of estimate of 0.31.

The second moment of the dbh distribution from the old-field situation was adjusted downward as a function of the amount of hardwood competition. (Note that this is equivalent to an adjustment in basal area

because basal area in square feet per acre equals  $(D^2)(T_s)$  (0.005454).) The following function was fitted by nonlinear least squares:

$$\overline{D_{CO}^2} = \overline{D_{OF}^2} e^{-(B_H)^{0.912618} (-0.00009688 B_L + 0.068787/A + .0045984 \ln H_d)}$$

where  $\overline{D_{CO}^2}$  = mean squared dbh for cutover-site plantation

$\overline{D_{OF}^2}$  = mean squared dbh for old-field plantation

$B_H$  = basal area (square feet per acre) of hardwood in the main canopy

$B_L$  = basal area (square feet per acre) of loblolly pine

A = plantation age (years)

$H_d$  = average height of dominants and codominants (feet)

This equation, with a standard error of estimate of 0.241, is conditioned such that when  $B_H$  equals zero,  $\overline{D_{CO}^2}$  equals  $\overline{D_{OF}^2}$ . Values for  $\overline{D_{CO}^2}$ ,  $B_H$ ,  $B_L$ , A, and  $H_d$  came from plot observations in the cutover-site plantations. To compute the value of  $\overline{D_{CO}^2}$  for a given cutover-site plantation, assuming an

old-field plantation of the same age, average height of dominants and codominants and number of pines surviving, an estimate of the total stand basal area is needed. The following equation was fitted to plot data from old-field plantations:

$$\log B = 0.38749 + 1.121332 \log H_d + 0.975619/A - 92.324443/T_s$$

where

B = basal area (square feet per acre)

$H_d$  = average height of dominants and codominants (feet)

A = plantation age (years)

$T_s$  = number of trees per acre surviving

This equation showed an  $R^2$  value of 0.82 and standard error of estimate of 0.046. The value for  $\overline{D_{OF}^2}$  was computed for each of the cutover-site plots

by estimating the total stand basal area in pine for an old-field plantation using the above equation (independent variables are the observed values for  $H_d$ , A, and  $T_s$  on the cutover-site plot) and noting that

$$\overline{D^2} = B / (0.005454 T_s)$$

After computing  $\overline{D_{CO}^2}$  for a cutover-site plantation, the mean diameter ( $\overline{D}_{CO}$ ) is computed as:

$$\overline{D}_{CO} = \sqrt{\overline{D_{CO}^2} - s_{dbh}^2}$$

With this procedure, the variance of the dbh distribution of pine remains constant regardless of the amount of hardwood competition, but the mean diameter and mean squared diameter (and thus basal area) are reduced with increasing levels of hardwood.

### Pine Survival

Hardwood competition effects seemed to be most pronounced on pine diameter growth and pine survival. Seventy-five of the 186 cutover-site plantations had valid observations on the numbers of trees planted per acre in addition to the number surviving at the time of plot installation. None of the old-field plots contained information on the number of trees planted. Thus the literature was searched for an appropriate survival curve for old-field plantations. After evaluating several alternative functions, the survival curve from Coile and Schumacher (1964) was

selected:

$$\log T_{s_{of}} = \log T_p + (A/100) (2.2730 - 1.1103 \log T_p)$$

where  $T_p$  = number of trees per acre planted

$T_{s_{of}}$  = number of trees per acre surviving on an old-field

at age A

Predicted number of trees surviving on an old-field was modified as a function of the amount of hardwood competition by fitting the following function with nonlinear least squares to data from the cutover-site plantation plots:

$$T_{s_{co}} = T_{s_{of}} 10^{-\left(\frac{\%B_H}{100}\right)^{1.781844}}$$

where  $T_{s_{co}}$  = number of trees surviving per acre on a cutover site

$T_{s_{of}}$  = number of trees surviving on an old-field (from survival function of Coile and Schumacher 1964)

$\%B_H$  = percent of total basal area in hardwood in the main canopy

The standard error of estimate for this equation was 98.8. When  $\%B_H$  is zero the modifier function is one and trees surviving on cutover-site is equal to that of an old-field.

Figure 2 shows survival curves for 800 trees per acre planted and various levels of hardwood competition.

#### Projection of Stand Composition

Percent of total basal area in hardwood in the main canopy is required input for model HDWD. When making projections through time, the behavior of the stand composition in terms of pine and hardwood basal areas needed to be considered. Both pines and hardwoods were measured at ages 11 and 24 in the Fayette Study. These data provided information on stand composition relationships in loblolly pine plantations after crown closure.

Plotting the percent basal area in hardwood at age 24 versus percent at age 11 showed a straight-line relationship with a slope near 1.0 (Figure 3). The fitted regression equation is

$$y = -3.4929 + 0.97107 x$$

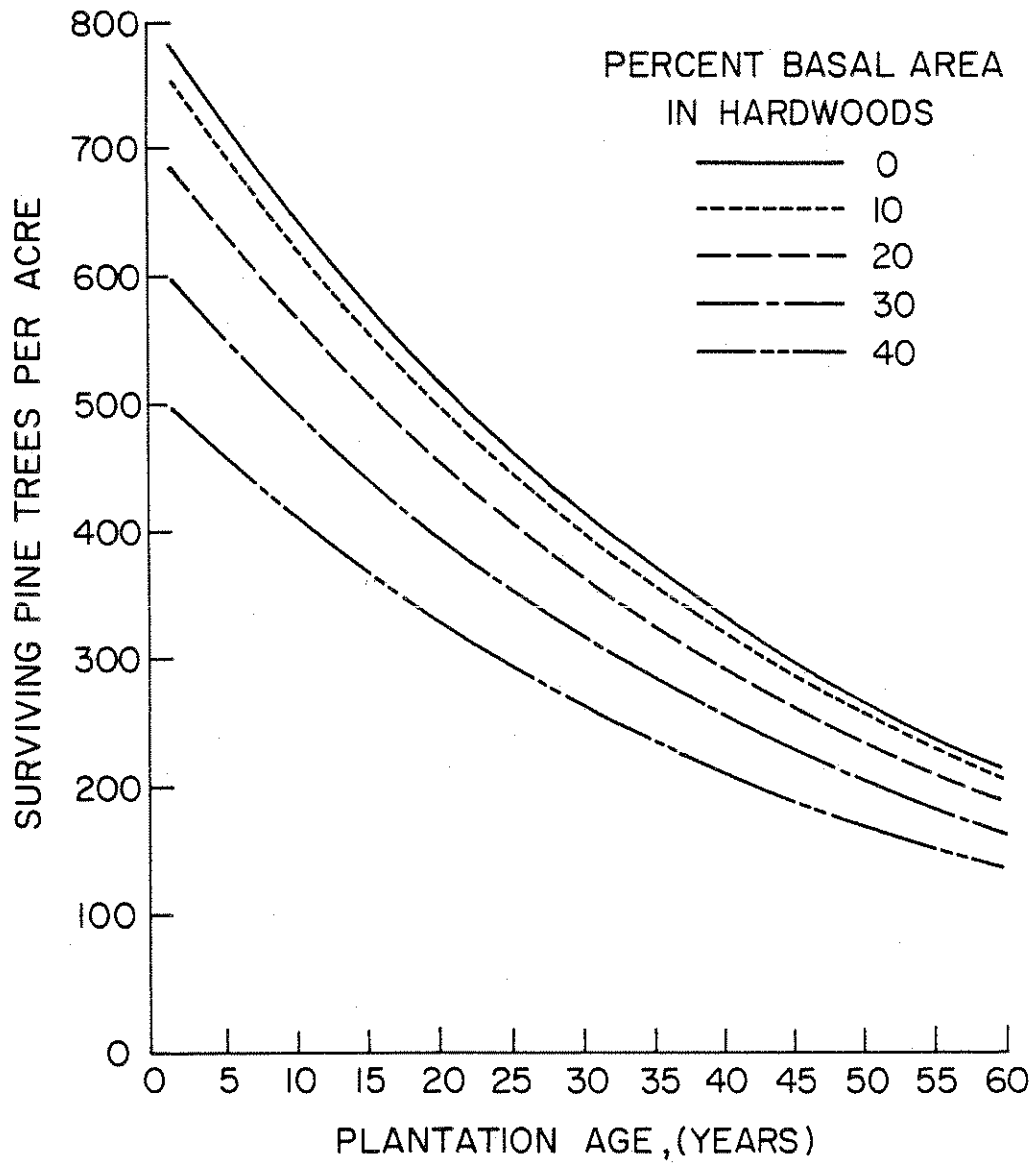


Figure 2. Surviving loblolly pine trees per acre as related to percent of basal area in hardwood. Figure is for 800 trees per acre planted.

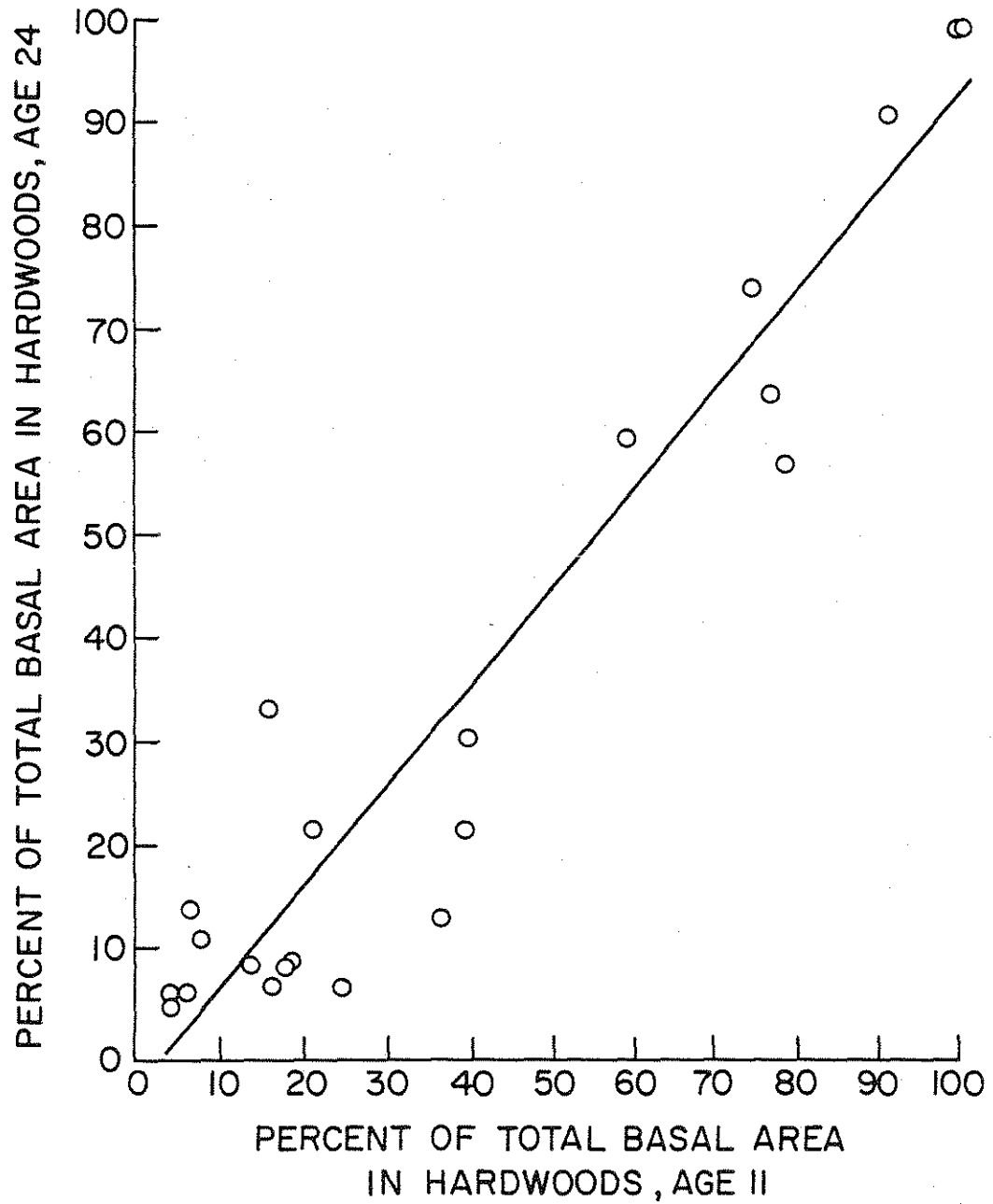


Figure 3. Relationship between percent basal area composed of hardwoods in the main canopy of loblolly pine plantations at ages 11 and 24 in a hardwood conversion/site preparation study, Fayette County, Alabama.



where  $y$  = percent basal area in hardwoods at age 24

$x$  = percent basal area in hardwoods at age 11

The slope coefficient in this regression, which accounts for 92 percent of the variation in the dependent variable, is not significantly different from 1.0. Thus the hypothesis that the stand composition by basal area does not change after crown closure was accepted. A constant ratio of hardwood basal area to total basal area seems reasonable for projection periods of interest for loblolly pine plantations. The stability of this ratio can be observed in data presented in other studies (e.g., Lange 1951).

In model HDWD, the user must specify the percent or amount of basal area in hardwood in the main canopy at any point after crown closure. This percent is then assumed to remain constant.

#### MODEL VALIDATION

Plot observations from the hardwood conversion/site preparation study in Fayette County, Alabama, were used to validate model predictions. The Fayette Study plots are an independent data set (none of the information from the study was used in fitting any of the components of the model) that covers the full spectrum of hardwood competition. Thus, these data provided a rigorous evaluation of model adequacy. Figure 4 is a graph of the total cubic-foot volume in loblolly pine on the Fayette Study plots at age 24 versus percent of total basal area in hardwood. Superimposed on the data points plotted in Figure 4 is a line showing the model behavior for site index 60 feet (base age 25 years), 714 trees per acre planted, age 24 years and percent hardwood 0 to 100. The Fayette Study was planted with 714 trees per acre on an area that averaged 58.8 feet site index.

Overall, there is close agreement between the observed values and the model predictions. There is an apparent bias at very low levels of hardwood competition (less than 10 percent basal area in hardwood). The apparent underprediction for low levels of hardwood competition may be an artifact of the data used in model construction. Old-field data were used as the "zero percent hardwood" base line. These old-field plots represent extremely intensive site preparation. In many of the cutover-site plots very low levels of hardwood were present at the time of plot installation. The history of past hardwood competition levels was, however, not obtainable. Many of these plantations probably developed, prior to the time of plot installation, under considerably more hardwood competition than was present in the old fields. Thus, when temporary plot data from old fields were used as the base and data from cutover-site plantations were used to compute coefficients in the modifier function, there is a rather sharp drop at initial levels of basal area in hardwood. This apparent bias is not large, however, and it should not create any sizeable errors.

It should also be pointed out that the pine survival on the Fayette study plots with low amounts of hardwood was somewhat greater than

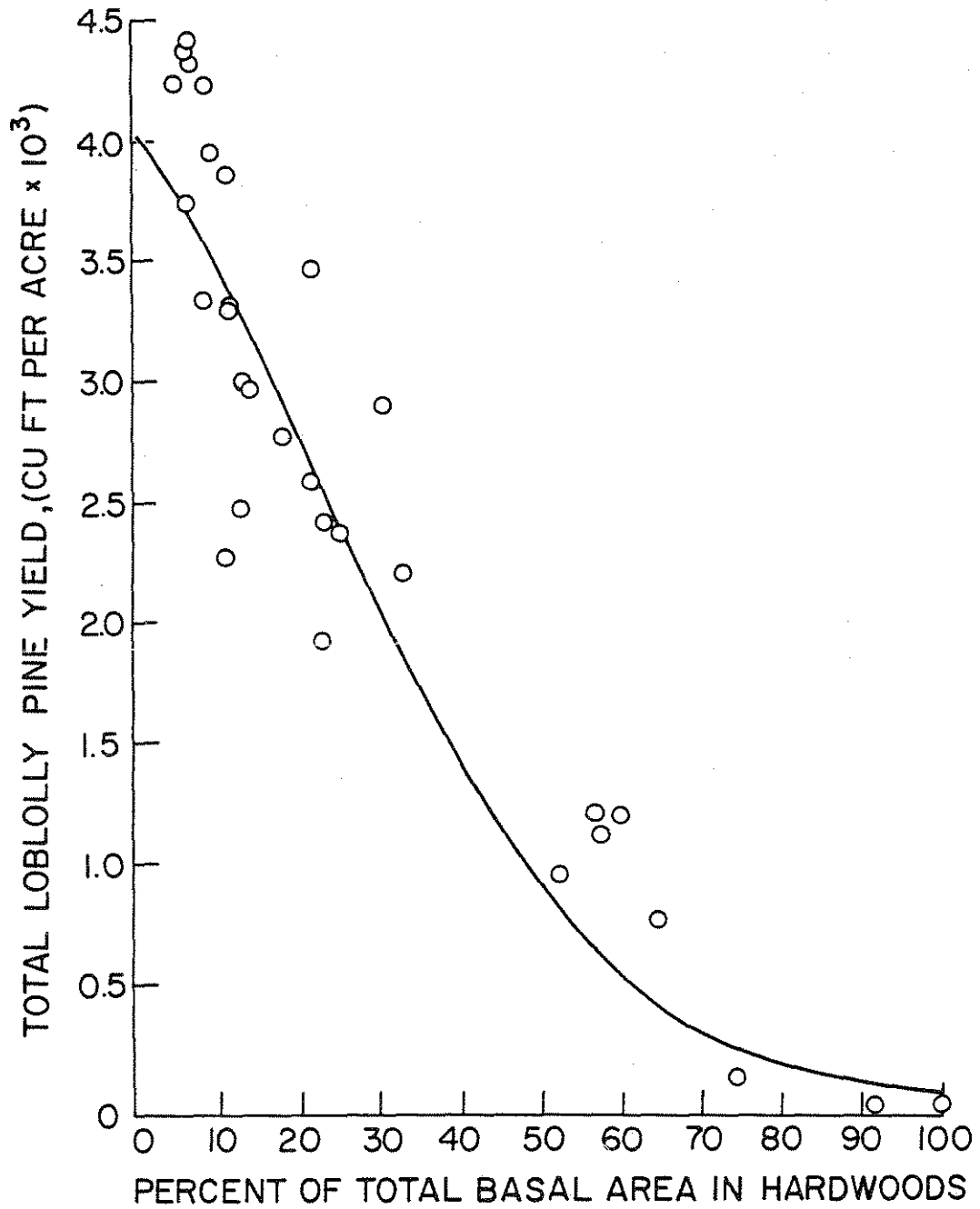


Figure 4. Total yield of loblolly pine versus percent of total stand basal area in hardwood from plot observations in a hardwood conversion/site preparation study in Fayette County, Alabama. The line represents predictions from program HDWD.

expected. The eight plots with less than 10 percent basal area in hardwoods averaged 459 surviving pines per acre at age 24. The average of the predicted values for these eight plots was 427 trees per acre. This difference between observed and predicted survival accounts for some, but not all, of the difference between the average of the observed and predicted yield in the 0 to 10 percent hardwood range.

Program HDWD was used to generate yield tables at age 30 for 800 trees per acre planted on site index 60 land with 0, 20, and 40 percent of the total stand basal area in hardwood (Table 2). From Table 2, one can note that with 20 percent of the basal area in hardwood, the number of trees, basal area and sawlog volume decrease 12, 28 and 40 percent, respectively, from the values for 0 percent basal area in hardwood. At 40 percent of the total basal area in hardwood, the decreases in number of trees, basal area and sawlog volume are 36, 64, and 81 percent, respectively, below that of the figures for 0 percent hardwood. Thus, as the proportion of the total stand basal area in hardwood increased, the decline in pine basal area and volume was even more marked because there were losses in both numbers of pine and in the average diameter of the pine that did survive. The decline in sawlog volume is especially dramatic because the entire pine dbh distribution is shifted to the left as a result of hardwood competition (Figure 5). As the percent basal area in hardwood increases, the variance of the pine dbh distribution remains the same but the mean shifts to the left, resulting in a somewhat more skewed distribution with relatively few trees in the larger diameter classes (Figure 5).

To further evaluate the "reasonableness" of model predictions, we computed the Relative Yield Total (RYT) using data from the Fayette Study. RYT is defined as (Harper 1977):

$$\text{RYT} = \frac{\text{Yield of species A in mixture}}{\text{Yield of A in pure stand}} + \frac{\text{Yield of species B in mixture}}{\text{Yield of B in pure stand}}$$

Plots with pure pine and pure hardwood in the Fayette Study were used to estimate yield of Species A and B in pure stands, respectively. A RYT value was then computed for all other plots with a pine-hardwood mixture. The average RYT value for the data at age 11 was 0.75; at age 24 the average was 0.80. Since these RYT values are less than 1.0 they imply mutual antagonism. Consequently, the model characteristic of pine basal area and volume decreases being greater than a proportional increase in hardwood basal area seems plausible. Langdon and Trousdell (1974) observed impacts of competing hardwoods on the growth of loblolly pine in natural stands that were of the same general order of magnitude as those predicted by model HDWD for loblolly pine plantations.

#### LIMITATIONS

Model HDWD should prove valuable for analyzing the biological and economic implications of controlling hardwood competition to various levels

Table 2. Stand and stock tables for the planted component of unthinned loblolly pine plantations at age 30 with 800 trees per acre planted on site index 60 (base age 25) land.

\*\*\*\*\*  
 STAND AND STOCK TABLE FOR THE PLANTED PINE COMPONENT OF  
 AN UNTHINNED LOBLOLLY PINE PLANTATION  
 -----

TREES PLANTED = 800.0 /AC      SITE INDEX = 60.0 FT (BASE 25)  
 % BASAL AREA IN HARDWOOD = 0.0      AGE = 30

CUBIC FOOT VOLUMES PER ACRE  
 -----

| DBH<br>INCHES | NUMBER<br>TREES<br>/ACRE | TOTAL<br>HEIGHT<br>FEET | BASAL<br>AREA<br>SQ FT/ACRE | CUBIC FOOT VOLUMES PER ACRE |                            |                          |        |        |
|---------------|--------------------------|-------------------------|-----------------------------|-----------------------------|----------------------------|--------------------------|--------|--------|
|               |                          |                         |                             | TOTAL<br>1" +               | PULPWOOD<br>5" +<br>4" TOP | SAWLOG<br>8" +<br>6" TOP |        |        |
| 3             | 0.0                      | 37.7                    | 0.0                         | 0.1                         |                            |                          |        |        |
| 4             | 1.9                      | 47.0                    | 0.2                         | 4.3                         |                            |                          |        |        |
| 5             | 10.4                     | 53.7                    | 1.5                         | 37.9                        | 25.5                       |                          |        |        |
| 6             | 29.0                     | 58.7                    | 5.8                         | 156.5                       | 125.2                      |                          |        |        |
| 7             | 56.0                     | 62.5                    | 15.2                        | 424.0                       | 368.1                      |                          |        |        |
| 8             | 81.8                     | 65.5                    | 28.7                        | 830.6                       | 754.4                      | 556.5                    |        |        |
| 9             | 91.3                     | 68.0                    | 40.4                        | 1199.8                      | 1119.8                     | 912.1                    |        |        |
| 10            | 76.1                     | 70.0                    | 41.3                        | 1255.7                      | 1192.8                     | 1029.4                   |        |        |
| 11            | 45.2                     | 71.7                    | 29.5                        | 915.7                       | 880.3                      | 788.3                    |        |        |
| 12            | 18.1                     | 73.2                    | 14.0                        | 441.1                       | 427.7                      | 392.7                    |        |        |
| 13            | 4.6                      | 74.4                    | 4.1                         | 131.6                       | 128.4                      | 120.0                    |        |        |
| 14            | 0.7                      | 75.5                    | 0.7                         | 22.6                        | 22.1                       | 21.0                     |        |        |
| TOTALS        |                          |                         |                             | 414.9                       | 181.4                      | 5419.9                   | 5044.3 | 3819.9 |

ARITHMETIC MEAN = 8.78 IN.

\*\*\*\*\*  
 STAND AND STOCK TABLE FOR THE PLANTED PINE COMPONENT OF  
 AN UNTHINNED LOBLOLLY PINE PLANTATION  
 -----

TREES PLANTED = 800.0 /AC      SITE INDEX = 60.0 FT (BASE 25)  
 % BASAL AREA IN HARDWOOD = 20.0      AGE = 30

CUBIC FOOT VOLUMES PER ACRE  
 -----

| DBH<br>INCHES | NUMBER<br>TREES<br>/ACRE | TOTAL<br>HEIGHT<br>FEET | BASAL<br>AREA<br>SQ FT/ACRE | CUBIC FOOT VOLUMES PER ACRE |                            |                          |        |        |
|---------------|--------------------------|-------------------------|-----------------------------|-----------------------------|----------------------------|--------------------------|--------|--------|
|               |                          |                         |                             | TOTAL<br>1" +               | PULPWOOD<br>5" +<br>4" TOP | SAWLOG<br>8" +<br>6" TOP |        |        |
| 3             | 1.3                      | 37.6                    | 0.1                         | 1.7                         |                            |                          |        |        |
| 4             | 7.9                      | 47.2                    | 0.7                         | 17.8                        |                            |                          |        |        |
| 5             | 23.0                     | 54.1                    | 3.2                         | 83.3                        | 56.0                       |                          |        |        |
| 6             | 46.0                     | 59.2                    | 9.2                         | 248.7                       | 198.9                      |                          |        |        |
| 7             | 69.5                     | 63.2                    | 18.7                        | 528.3                       | 458.7                      |                          |        |        |
| 8             | 80.3                     | 66.3                    | 28.1                        | 820.2                       | 745.0                      | 549.6                    |        |        |
| 9             | 69.5                     | 68.8                    | 30.5                        | 918.3                       | 857.1                      | 698.1                    |        |        |
| 10            | 43.0                     | 70.9                    | 23.2                        | 714.4                       | 678.6                      | 585.7                    |        |        |
| 11            | 18.0                     | 72.7                    | 11.7                        | 366.3                       | 352.1                      | 315.3                    |        |        |
| 12            | 4.7                      | 74.2                    | 3.6                         | 116.0                       | 112.4                      | 103.2                    |        |        |
| 13            | 0.7                      | 75.5                    | 0.6                         | 21.0                        | 20.5                       | 19.2                     |        |        |
| TOTALS        |                          |                         |                             | 364.0                       | 129.7                      | 3836.2                   | 3479.5 | 2271.1 |

ARITHMETIC MEAN = 7.90 IN.

\*\*\*\*\*

Table 2. (continued).

\*\*\*\*\*  
 STAND AND STOCK TABLE FOR THE PLANTED PINE COMPONENT OF  
 AN UNTHINNED LOBLOLLY PINE PLANTATION  
 -----

TREES PLANTED = 800.0 /AC      SITE INDEX = 60.0 FT (BASE 25)  
 % BASAL AREA IN HARDWOOD = 40.0      AGE = 30

| DBH<br>INCHES | NUMBER<br>TREES<br>/ACRE | TOTAL<br>HEIGHT<br>FEET | BASAL<br>AREA<br>SQ<br>FT/ACRE | CUBIC FOOT VOLUMES PER ACRE |                            |                          |
|---------------|--------------------------|-------------------------|--------------------------------|-----------------------------|----------------------------|--------------------------|
|               |                          |                         |                                | TOTAL<br>1" +               | PULPWOOD<br>5" +<br>4" TOP | SAWLOG<br>8" +<br>6" TOP |
| 2             | 0.8                      | 23.3                    | 0.0                            | 0.5                         |                            |                          |
| 3             | 8.1                      | 37.6                    | 0.4                            | 10.2                        |                            |                          |
| 4             | 23.8                     | 47.8                    | 2.2                            | 52.9                        |                            |                          |
| 5             | 42.9                     | 55.2                    | 5.9                            | 155.4                       | 104.4                      |                          |
| 6             | 56.1                     | 60.8                    | 11.1                           | 306.5                       | 245.1                      |                          |
| 7             | 55.6                     | 65.1                    | 14.8                           | 429.9                       | 373.2                      |                          |
| 8             | 41.7                     | 68.5                    | 14.4                           | 434.5                       | 394.7                      | 291.1                    |
| 9             | 23.2                     | 71.3                    | 10.1                           | 313.9                       | 293.0                      | 238.7                    |
| 10            | 9.3                      | 73.6                    | 5.0                            | 159.0                       | 151.0                      | 130.3                    |
| 11            | 2.6                      | 75.5                    | 1.7                            | 55.0                        | 52.8                       | 47.3                     |
| -----         |                          |                         |                                |                             |                            |                          |
| TOTALS        | 264.0                    |                         | 65.7                           | 1917.8                      | 1614.4                     | 707.5                    |

ARITHMETIC MEAN = 6.53 IN.

\*\*\*\*\*

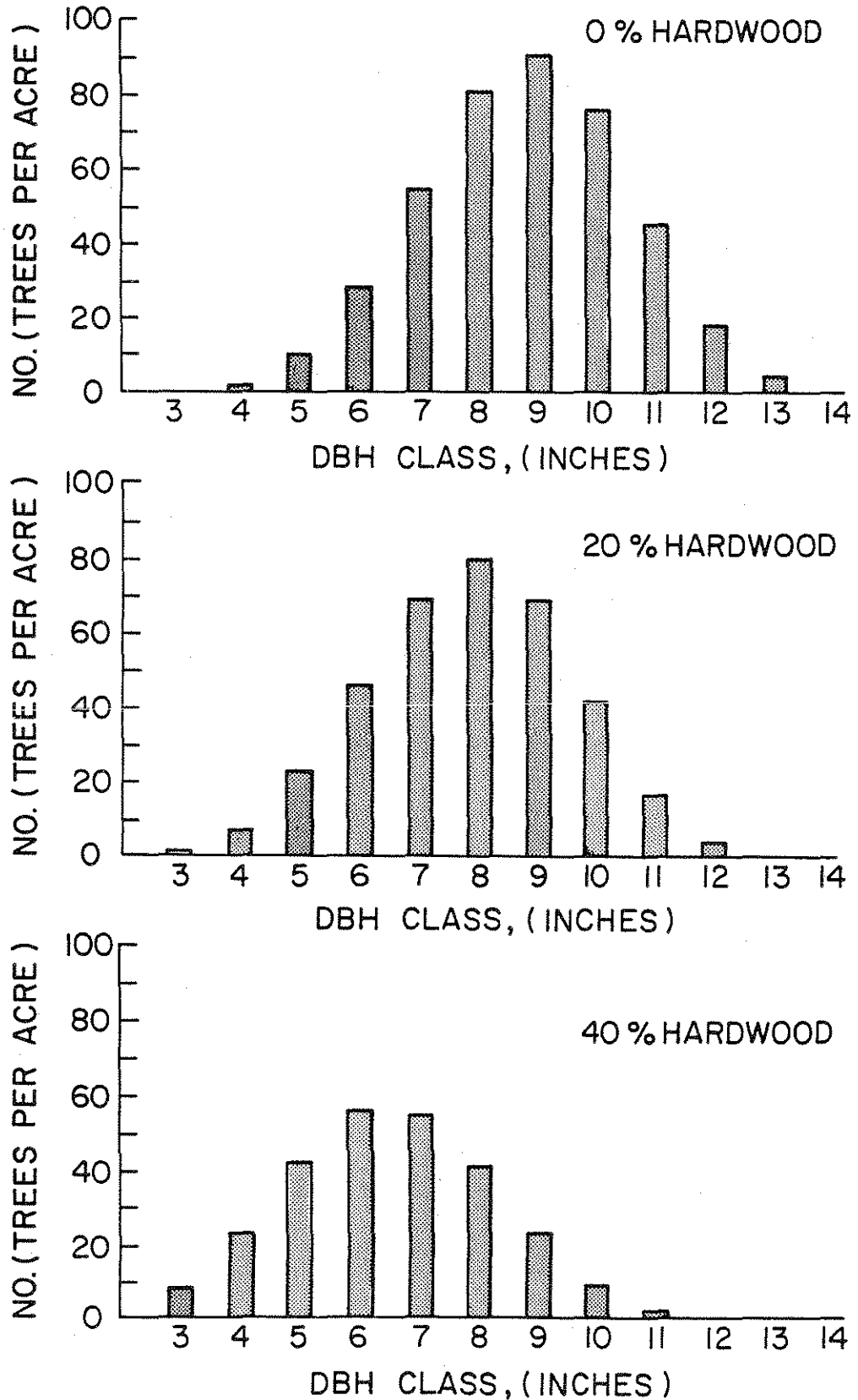


Figure 5. Pine dbh distribution for 0, 20, and 40 percent of the total stand basal area in hardwood. These histograms are for age 30 with 800 trees per acre planted on site index 60 (base age 25 years) land.

in loblolly pine plantations. There are several limitations regarding the types of analyses that can be performed. Specifically:

1. The levels of hardwood competition cannot be related to specific treatments. The proportion of basal area in hardwoods must be input by the users based on past experience and judgment.
2. The model does not account for hardwood species composition. Differential effects from competing hardwood vegetation might result from variations in species composition.
3. The model applies only to unthinned stands. If thinnings were carried out, some of the assumptions of the model (such as a constant ratio of hardwood basal area to total stand basal area) may not be valid.
4. Only analyses of hardwood competition in the main canopy can be performed. The effects of controlling understory vegetation and of controlling grasses and herbs at the time of seedling establishment cannot be evaluated. (It may be possible to model these effects through a shift in stand age, but more data are needed before recommendations can be made.)
5. Release treatments cannot be evaluated unless they are performed early in the life of the stand so that stand development in the released stand can be assumed to be the same as in a plantation that has the same level of hardwood competition but has not been released. If the release treatment has a direct effect on the pine -- such as causing mortality, a loss of a portion of a season's growth, or acting as a growth stimulant -- then adjustment in the pine variables (trees surviving, age, site index) should be made to reflect these effects.

Although much work remains to be done, model HDWD should be satisfactory for a wide range of analyses of the effects of hardwood competition on the growth and yield of loblolly pine plantations.

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APPENDIX

## USERS GUIDE FOR THE PROGRAM HDWD

HDWD is an interactive program providing yield predictions for the planted component of unthinned loblolly pine plantations containing competing hardwood vegetation. Versions of HDWD are written in BASIC for the IBM Personal Computer and FORTRAN for mainframe computers.

SYSTEM INFORMATION: The FORTRAN program is written in standard FORTRAN IV language and is acceptable with VS FORTRAN, H-EXTENDED FORTRAN, and FORTRAN G1 compilers. There is one IMSL routine, DGAMMA, that is needed from outside the program. Designated files are 10 for terminal prompts, questions and output, and 11 for storage of program output.

INPUT REQUIREMENTS: The input information required for HDWD is as follows: (1) number of loblolly pine planted (trees/ac), (2) site index base age 25 (ft), (3) percent of basal area in hardwood in the main canopy of the stand, and (4) age. Questions and prompts are given asking for each of the above information. Values from each response are checked for being within a reasonable range of the data on which the model is based. The bounds associated with each variable are as follows:

|                                    |          |
|------------------------------------|----------|
| number of planted pine (trees/ac): | 200-1600 |
| site index base age 25 (ft):       | 40-90    |
| % basal area in hardwood:          | 0-90     |
| age:                               | 10-45    |

Warning messages and prompts are given when an individual item or some combinations of input information is outside the ranges specified. The program allows predictions outside the above bounds if a feasible solution for the Weibull parameters exists. The program does not allow predictions for ages less than 10 years or for extreme input values.

After a stand and stock table is given for a set of input, the user is asked if another prediction is desired and what input information is to be saved or changed. Any response of 9999 terminates the program and 8888 restarts the program.

OUTPUT INFORMATION: After a set of input information is given, a stand and stock table is printed with the following information pertaining to the planted pine component of an unthinned stand:

|                       |                                   |
|-----------------------|-----------------------------------|
| <u>Initial Input:</u> | NUMBER OF PLANTED PINE (trees/ac) |
|                       | SITE INDEX base age 25 (ft)       |
|                       | % BASAL AREA IN HARDWOOD          |
|                       | AGE                               |

Subsequent Output: by 1 in. dbh classes and totals where appropriate,

NUMBER OF SURVIVING PINE (trees/ac)

TOTAL HEIGHT (ft)

TOTAL BASAL AREA of pine (sq ft/ac)

TOTAL YIELD of planted pine 1 in. dbh and greater (cu ft/ac)

PULPWOOD YIELD of planted pine 5 in. dbh and greater to a 4 in. top outside bark diameter (cu ft/ac)

SAWLOG YIELD of planted pine 8 in. dbh and greater to a 6 in. top outside bark diameter (cu ft/ac)

ARITHMETIC MEAN dbh (in.)

There will be minor differences between the BASIC and FORTRAN versions in output format and in actual basal area and yield estimates. The BASIC version uses dbh class midpoints for calculation of basal area and volume by class, while the FORTRAN version uses integration over the class bounds.

EXAMPLE:

Case 1: Given the following input:

|                                    |     |
|------------------------------------|-----|
| number of planted pine (trees/ac): | 800 |
| site index base age 25 (ft):       | 60  |
| % basal area in hardwood:          | 20  |
| age:                               | 25  |

the beginning output, questions, responses and subsequent output are given in Table 1.

Case 2: Another prediction is desired with basal area in hardwood changed to 40 %.

Case 3: Another prediction is desired with age changed to 30.

Case 4: Another prediction is desired with the number of planted pine changed to 900 and percent basal area in hardwood changed to 20%, but a prediction after that is not desired.

Table 1. Example input and output for program HDWD. (using FORTRAN version).  
Case 1.

\*\*\*\*\*  
A GROWTH AND YIELD PREDICTION MODEL FOR THE PLANTED COMPONENT  
OF UNTHINNED LOBLOLLY PINE PLANTATIONS CONTAINING HARDWOOD.  
\*\*\*\*\*

VALUES FOR RESPONSES NEED TO BE IN ENGLISH UNITS (I.E., FEET AND TREES/ACRE).

A RESPONSE CAN BE ENTERED AS EITHER INTEGER- OR REAL-VALUED.

ENTER : 9999 AT ANY TIME TO TERMINATE THE PROGRAM,  
8888 AT ANY TIME TO RESTART THE PROGRAM.

-----  
> ENTER THE NUMBER OF LOBLOLLY PLANTED (TREES/ACRE).  
> 800  
  
> ENTER SITE INDEX BASE AGE 25 (FEET).  
> 60  
  
> ENTER PERCENT OF BASAL AREA IN HARDWOODS (E.G., 10,20).  
> 20  
  
> ENTER STAND AGE.  
AGE MUST BE GREATER THAN OR EQUAL TO 10 YEARS.  
> 25

\*\*\*\*\*  
STAND AND STOCK TABLE FOR THE PLANTED PINE COMPONENT OF  
AN UNTHINNED LOBLOLLY PINE PLANTATION  
-----

TREES PLANTED = 800.0 /AC SITE INDEX = 60.0 FT (BASE 25)  
% BASAL AREA IN HARDWOOD = 20.0 AGE = 25

| DBH<br>INCHES | NUMBER<br>TREES<br>/ACRE | TOTAL<br>HEIGHT<br>FEET | BASAL<br>AREA<br>SQ<br>FT/ACRE | CUBIC FOOT VOLUMES PER ACRE |                            |                          |
|---------------|--------------------------|-------------------------|--------------------------------|-----------------------------|----------------------------|--------------------------|
|               |                          |                         |                                | TOTAL<br>1" +               | PULPWOOD<br>5" +<br>4" TOP | SAWLOG<br>8" +<br>6" TOP |
| 2             | 0.2                      | 23.1                    | 0.0                            | 0.1                         |                            |                          |
| 3             | 3.8                      | 35.1                    | 0.2                            | 4.6                         |                            |                          |
| 4             | 17.1                     | 43.3                    | 1.6                            | 35.5                        |                            |                          |
| 5             | 43.2                     | 49.1                    | 6.1                            | 142.4                       | 95.7                       |                          |
| 6             | 75.9                     | 53.3                    | 15.1                           | 370.2                       | 296.2                      |                          |
| 7             | 97.1                     | 56.6                    | 26.0                           | 661.8                       | 574.6                      |                          |
| 8             | 88.5                     | 59.2                    | 30.8                           | 805.6                       | 731.7                      | 539.7                    |
| 9             | 54.4                     | 61.3                    | 23.7                           | 637.6                       | 595.1                      | 484.7                    |
| 10            | 20.9                     | 63.1                    | 11.2                           | 306.0                       | 290.6                      | 250.8                    |
| 11            | 4.5                      | 64.5                    | 2.9                            | 81.5                        | 78.3                       | 70.1                     |
| 12            | 0.5                      | 65.8                    | 0.4                            | 10.9                        | 10.5                       | 9.7                      |
| TOTALS        | 406.1                    |                         | 117.9                          | 3056.2                      | 2672.8                     | 1355.1                   |

ARITHMETIC MEAN = 7.12 IN

\*\*\*\*\*

Table 1. (continued)

Case 2.

THE PREVIOUS INPUT WAS AS FOLLOWS:

|   |                             |       |
|---|-----------------------------|-------|
| 1 | TREES PER ACRE .....        | 800.0 |
| 2 | SITE INDEX .....            | 60.0  |
| 3 | % BASAL AREA IN HARDWOOD .. | 20.0  |
| 4 | AGE .....                   | 25    |

IF ANOTHER PROJECTION IS DESIRED,  
 ENTER THE NUMBERED ITEM TO BE CHANGED,  
 ENTER THE NUMBER 5 IF MORE THAN 1 ITEM IS TO BE CHANGED,  
 OTHERWISE, ENTER THE NUMBER 6 TO TERMINATE THE PROGRAM.

&gt; 3

ENTER PERCENT OF BASAL AREA IN HARDWOODS (E.G., 10,20).

&gt; 40

\*\*\*\*\*  
 STAND AND STOCK TABLE FOR THE PLANTED PINE COMPONENT OF  
 AN UNTHINNED LOBLOLLY PINE PLANTATION

TREES PLANTED = 800.0 /AC      SITE INDEX = 60.0 FT (BASE 25)  
 % BASAL AREA IN HARDWOOD = 40.0      AGE = 25

| DBH<br>INCHES | NUMBER<br>TREES<br>/ACRE | TOTAL<br>HEIGHT<br>FEET | BASAL<br>AREA<br>SQ FT/ACRE | CUBIC FOOT VOLUMES PER ACRE |                            |                          |
|---------------|--------------------------|-------------------------|-----------------------------|-----------------------------|----------------------------|--------------------------|
|               |                          |                         |                             | TOTAL<br>1" +               | PULPWOOD<br>5" +<br>4" TOP | SAWLOG<br>8" +<br>6" TOP |
| 2             | 2.3                      | 22.6                    | 0.1                         | 1.5                         |                            |                          |
| 3             | 14.9                     | 35.2                    | 0.8                         | 17.5                        |                            |                          |
| 4             | 37.9                     | 44.0                    | 3.4                         | 78.0                        |                            |                          |
| 5             | 61.3                     | 50.3                    | 8.5                         | 203.8                       | 137.0                      |                          |
| 6             | 70.5                     | 55.0                    | 13.9                        | 349.4                       | 279.5                      |                          |
| 7             | 58.1                     | 58.7                    | 15.4                        | 404.3                       | 351.0                      |                          |
| 8             | 33.5                     | 61.5                    | 11.5                        | 312.7                       | 284.0                      | 209.5                    |
| 9             | 13.0                     | 63.9                    | 5.6                         | 157.2                       | 146.7                      | 119.5                    |
| 10            | 3.3                      | 65.8                    | 1.7                         | 49.3                        | 46.9                       | 40.5                     |
| TOTALS        | 294.7                    |                         | 60.9                        | 1573.8                      | 1245.1                     | 369.5                    |

ARITHMETIC MEAN = 5.95 IN

\*\*\*\*\*

Table 1. (continued)

## Case 3.

THE PREVIOUS INPUT WAS AS FOLLOWS:

|   |                             |       |
|---|-----------------------------|-------|
| 1 | TREES PER ACRE .....        | 800.0 |
| 2 | SITE INDEX .....            | 60.0  |
| 3 | % BASAL AREA IN HARDWOOD .. | 40.0  |
| 4 | AGE .....                   | 25    |

IF ANOTHER PROJECTION IS DESIRED,  
 ENTER THE NUMBERED ITEM TO BE CHANGED,  
 ENTER THE NUMBER 5 IF MORE THAN 1 ITEM IS TO BE CHANGED,  
 OTHERWISE, ENTER THE NUMBER 6 TO TERMINATE THE PROGRAM.

> 4

ENTER STAND AGE.

AGE MUST BE GREATER THAN OR EQUAL TO 10 YEARS.

> 30

\*\*\*\*\*  
 STAND AND STOCK TABLE FOR THE PLANTED PINE COMPONENT OF  
 AN UNTHINNED LOBLOLLY PINE PLANTATION  
 -----

|                          |             |            |                     |
|--------------------------|-------------|------------|---------------------|
| TREES PLANTED            | = 800.0 /AC | SITE INDEX | = 60.0 FT (BASE 25) |
| % BASAL AREA IN HARDWOOD | = 40.0      | AGE        | = 30                |

| DBH<br>INCHES | NUMBER<br>TREES<br>/ACRE | TOTAL<br>HEIGHT<br>FEET | BASAL<br>AREA<br>SQ FT/ACRE | CUBIC FOOT VOLUMES PER ACRE |                            |                          |
|---------------|--------------------------|-------------------------|-----------------------------|-----------------------------|----------------------------|--------------------------|
|               |                          |                         |                             | TOTAL<br>1" +               | PULPWOOD<br>5" +<br>4" TOP | SAWLOG<br>8" +<br>6" TOP |
| 2             | 0.8                      | 23.3                    | 0.0                         | 0.5                         |                            |                          |
| 3             | 8.1                      | 37.6                    | 0.4                         | 10.2                        |                            |                          |
| 4             | 23.8                     | 47.8                    | 2.2                         | 52.9                        |                            |                          |
| 5             | 42.9                     | 55.2                    | 5.9                         | 155.4                       | 104.4                      |                          |
| 6             | 56.1                     | 60.8                    | 11.1                        | 306.5                       | 245.1                      |                          |
| 7             | 55.6                     | 65.1                    | 14.8                        | 429.9                       | 373.2                      |                          |
| 8             | 41.7                     | 68.5                    | 14.4                        | 434.5                       | 394.7                      | 291.1                    |
| 9             | 23.2                     | 71.3                    | 10.1                        | 313.9                       | 293.0                      | 238.7                    |
| 10            | 9.3                      | 73.6                    | 5.0                         | 159.0                       | 151.0                      | 130.3                    |
| 11            | 2.6                      | 75.5                    | 1.7                         | 55.0                        | 52.8                       | 47.3                     |
| -----         |                          |                         |                             | -----                       |                            |                          |
| TOTALS        | 264.0                    |                         | 65.7                        | 1917.8                      | 1614.4                     | 707.5                    |

ARITHMETIC MEAN = 6.53 IN

\*\*\*\*\*

Table 1. (continued)  
Case 1.

THE PREVIOUS INPUT WAS AS FOLLOWS:

```

1 TREES PER ACRE ..... 800.0
2 SITE INDEX ..... 60.0
3 % BASAL AREA IN HARDWOOD .. 40.0
4 AGE ..... 30
    
```

IF ANOTHER PROJECTION IS DESIRED,  
ENTER THE NUMBERED ITEM TO BE CHANGED,  
ENTER THE NUMBER 5 IF MORE THAN 1 ITEM IS TO BE CHANGED,  
OTHERWISE, ENTER THE NUMBER 6 TO TERMINATE THE PROGRAM.

```

> 5
ENTER THE NUMBER OF LOBLOLLY PLANTED (TREES/ACRE).
> 900
ENTER SITE INDEX BASE AGE 25 (FEET).
> 60
ENTER PERCENT OF BASAL AREA IN HARDWOODS (E.G., 10,20).
> 20
ENTER STAND AGE.
AGE MUST BE GREATER THAN OR EQUAL TO 10 YEARS.
> 30
    
```

\*\*\*\*\*  
STAND AND STOCK TABLE FOR THE PLANTED PINE COMPONENT OF  
AN UNTHINNED LOBLOLLY PINE PLANTATION  
-----

TREES PLANTED = 900.0 /AC      SITE INDEX = 60.0 FT (BASE 25)  
% BASAL AREA IN HARDWOOD = 20.0      AGE = 30

| DBH<br>INCHES | NUMBER<br>TREES<br>/ACRE | TOTAL<br>HEIGHT<br>FEET | BASAL<br>AREA<br>SQ FT/ACRE | CUBIC FOOT VOLUMES PER ACRE |                            |                          |
|---------------|--------------------------|-------------------------|-----------------------------|-----------------------------|----------------------------|--------------------------|
|               |                          |                         |                             | TOTAL<br>1" +               | PULPWOOD<br>5" +<br>4" TOP | SAWLOG<br>8" +<br>6" TOP |
| 3             | 1.6                      | 38.0                    | 0.1                         | 2.2                         |                            |                          |
| 4             | 9.6                      | 47.5                    | 0.9                         | 21.7                        |                            |                          |
| 5             | 27.3                     | 54.3                    | 3.8                         | 99.2                        | 66.7                       |                          |
| 6             | 53.4                     | 59.4                    | 10.7                        | 289.5                       | 231.5                      |                          |
| 7             | 78.5                     | 63.3                    | 21.2                        | 598.1                       | 519.3                      |                          |
| 8             | 87.7                     | 66.4                    | 30.6                        | 896.0                       | 813.8                      | 600.3                    |
| 9             | 72.4                     | 68.9                    | 31.8                        | 957.4                       | 893.6                      | 727.9                    |
| 10            | 42.2                     | 71.0                    | 22.8                        | 701.6                       | 666.4                      | 575.1                    |
| 11            | 16.4                     | 72.8                    | 10.6                        | 333.6                       | 320.7                      | 287.2                    |
| 12            | 3.9                      | 74.3                    | 3.0                         | 96.3                        | 93.3                       | 85.7                     |
| 13            | 0.5                      | 75.5                    | 0.5                         | 15.6                        | 15.2                       | 14.2                     |
| -----         |                          |                         |                             | -----                       |                            |                          |
| TOTALS        | 393.8                    |                         | 136.0                       | 4011.2                      | 3620.7                     | 2290.4                   |

ARITHMETIC MEAN = 7.77 IN

\*\*\*\*\*

1

THE PREVIOUS INPUT WAS AS FOLLOWS:

```

1 TREES PER ACRE ..... 900.0
2 SITE INDEX ..... 60.0
3 % BASAL AREA IN HARDWOOD .. 20.0
4 AGE ..... 30
    
```

IF ANOTHER PROJECTION IS DESIRED,  
ENTER THE NUMBERED ITEM TO BE CHANGED,  
ENTER THE NUMBER 5 IF MORE THAN 1 ITEM IS TO BE CHANGED,  
OTHERWISE, ENTER THE NUMBER 6 TO TERMINATE THE PROGRAM.

> 6

THE PROGRAM HAS BEEN TERMINATED BY THE USER.

## FORTRAN LISTING

```

C*****DHA00010
C*                                     *DHA00020
C*   A GROWTH AND YIELD PREDICTION MODEL FOR THE PLANTED COMPONENT *DHA00030
C*   OF UNTHINNED LOBLOLLY PINE PLANTATIONS CONTAINING HARDWOODS. *DHA00040
C*                                     *DHA00050
C*           BY PETER T. SPRINZ   VPI&SU   FWS-3-84 *DHA00060
C*                                     *DHA00070
C*****DHA00080
C                                     DHA00090
C   QUESTIONS, RESPONSES AND OUTPUT ARE SENT TO TERMINAL BY FILE 10. DHA00100
C   OUTPUT ONLY IS WRITTEN TO FILE 11. DHA00110
C                                     DHA00120
C*****DHA00130
C                                     DHA00140
C   IMPLICIT REAL*8 (Z) DHA00150
C   DIMENSION DCL(50),BCL(50),VCL(50),PCL(50),SCL(50) DHA00160
C   EXTERNAL TREEHT,ZFCV,VDIST,BDIST DHA00170
C   COMMON/AREA1/DAVG,D2AVG,A,B,C DHA00180
C   COMMON/AREA2/HGTD,TWS,TOF,DMAX,AGE DHA00190
C                                     DHA00200
C   WRITE(10,5) DHA00210
C   WRITE(10,6) DHA00220
C   5 FORMAT(/80('*'),/12X, DHA00230
C   &'A GROWTH AND YIELD PREDICTION MODEL FOR THE PLANTED COMPONENT' DHA00240
C   &/13X,'OF UNTHINNED LOBLOLLY PINE PLANTATIONS CONTAINING HARDWOOD.' DHA00250
C   &/,80('*'),// DHA00260
C   &T3,'VALUES TO RESPONSES NEED TO BE IN ENGLISH UNITS (I.E., FEET' DHA00270
C   &,T64,'AND TREES/ACRE).') DHA00280
C   6 FORMAT(/2X, DHA00290
C   &'A RESPONSE CAN BE ENTERED AS EITHER INTEGER- OR REAL-VALUED.',// DHA00300
C   &2X,'ENTER : 9999 AT ANY TIME TO TERMINATE THE PROGRAM,' DHA00310
C   &/,10X,'8888 AT ANY TIME TO RESTART THE PROGRAM.'//,80('-'),/) DHA00320
C                                     DHA00330
C   7 RESP1=5. DHA00340
C                                     DHA00350
C*****DHA00360
C*                                     *DHA00370
C*   INPUT DATA *DHA00380
C*                                     *DHA00390
C*****DHA00400
C                                     DHA00410
C   8 IF(RESPI.GE.2..AND.RESPI.LE.4.)GO TO 20 DHA00420
C   10 WRITE(10,100) DHA00430
C   100 FORMAT(5X,'ENTER THE NUMBER OF LOBLOLLY PLANTED (TREES/ACRE).') DHA00440
C   READ(10,*)TP DHA00450
C   IF(TP.GE.200..AND.TP.LE.1600.)GO TO 20 DHA00460
C   IF(TP.EQ.9999.)GO TO 9999 DHA00470
C   CALL RESPS1(TP) DHA00480
C   WRITE(10,104) DHA00490
C   104 FORMAT(5X,'DATA RANGE IS FROM 200 TO 1600 TREES/ACRE.') DHA00500
C   IF(TP.GE.4000..OR.TP.LE.50.)GO TO 8 DHA00510
C   CALL RESPS2(RESPI) DHA00520
C   IF(RESPI.EQ.1.)GO TO 8 DHA00530
C   IF(RESPI.EQ.2.)GO TO 20 DHA00540
C   IF(RESPI.EQ.9999.)GO TO 9999 DHA00550

```



## FORTRAN LISTING (continued)

```

IF(Resp.EQ.8888.)GO TO 9998
C
20 IF(Resp1.EQ.1..OR.Resp1.EQ.3..OR.Resp1.EQ.4.)GO TO 30
WRITE(10,200)
200 FORMAT(5X,'ENTER SITE INDEX BASE AGE 25 (FEET).')
READ(10,*)SI
IF(SI.GE.40..AND.SI.LE.90.)GO TO 30
IF(SI.EQ.9999.)GO TO 9999
IF(SI.EQ.8888.)GO TO 9998
CALL RESPS1(SI)
WRITE(10,201)
201 FORMAT(5X,'DATA RANGE FOR SITE INDEX IS FROM 40 TO 90 FEET.'//)
IF(SI.GE.200..OR.SI.LE.20.)GO TO 20
CALL RESPS2(Resp)
IF(Resp.EQ.1.)GO TO 20
IF(Resp.EQ.2.)GO TO 30
IF(Resp.EQ.9999.)GO TO 9999
IF(Resp.EQ.8888.)GO TO 9998
C
30 IF(Resp1.LE.2..OR.Resp1.EQ.4)GO TO 50
WRITE(10,301)
301 FORMAT(5X,
&'ENTER PERCENT OF BASAL AREA IN HARDWOODS (E.G., 10,20).')
READ(10,*)PERBAH
IF(PERBAH.GE.0..AND.PERBAH.LE.90.)GO TO 50
IF(PERBAH.EQ.9999.)GO TO 9999
IF(PERBAH.EQ.8888.)GO TO 9998
CALL RESPS1(PERBAH)
WRITE(10,302)
302 FORMAT(5X,'DATA RANGE IS 0 TO 90 PERCENT.')
```

```

IF(PERBAH.GT.100..OR.PERBAH.LT.0.)GO TO 30
31 CALL RESPS2(Resp)
IF(Resp.EQ.1.)GO TO 30
IF(Resp.EQ.2.)GO TO 50
IF(Resp.EQ.9999.)GO TO 9999
IF(Resp.EQ.8888.)GO TO 9998
C
50 IF(Resp1.LE.3.)GO TO 80
WRITE(10,500)
500 FORMAT(5X,'ENTER STAND AGE.',
& /7X,'AGE MUST BE GREATER THAN OR EQUAL TO 10 YEARS.')
```

```

READ(10,*)AGE
AGE=AGE+.5
IF(AGE.GE.10..AND.AGE.LE.45.)GO TO 80
IF(AGE.EQ.9999.)GO TO 9999
IF(AGE.EQ.8888.)GO TO 9998
CALL RESPS1(AGE)
WRITE(10,501)
501 FORMAT(5X,'DATA RANGE IS FROM 10 TO 45 YEARS.')
```

```

IF(AGE.GE.100..OR.AGE.LT.10.)GO TO 50
CALL RESPS2(Resp)
IF(Resp.EQ.1.)GO TO 50
IF(Resp.EQ.2.)GO TO 80
IF(Resp.EQ.9999.)GO TO 9999
IF(Resp.EQ.8888.)GO TO 9998

```

```

DHA00560
DHA00570
DHA00580
DHA00590
DHA00600
DHA00610
DHA00620
DHA00630
DHA00640
DHA00650
DHA00660
DHA00670
DHA00680
DHA00690
DHA00700
DHA00710
DHA00720
DHA00730
DHA00740
DHA00750
DHA00760
DHA00770
DHA00780
DHA00790
DHA00800
DHA00810
DHA00820
DHA00830
DHA00840
DHA00850
DHA00860
DHA00870
DHA00880
DHA00890
DHA00900
DHA00910
DHA00920
DHA00930
DHA00940
DHA00950
DHA00960
DHA00970
DHA00980
DHA00990
DHA01000
DHA01010
DHA01020
DHA01030
DHA01040
DHA01050
DHA01060
DHA01070
DHA01080
DHA01090
DHA01100

```



## FORTRAN LISTING (continued)

```

DMIN=OFMIN*AMIN
DAVG2=D2AVG-VAR
IF(DAVG2.LE.0.)GO TO 91
DAVG=SQRT(DAVG2)
C
C*****CALCULATE ESTIMATES OF THE WEIBULL PARAMETERS
C
90 A = DMIN*0.5
IF(A.LE.0.5) A = 0.5
BL=1.
TL=5.
C
CALL WEIB(DAVG,D2AVG,A,BL,TL,B,C,X1P,X2P,IER)
IF(B.LE.0.)GO TO 91
IF(DAVG.LE.A)GO TO 91
IF(IER.EQ.1.OR.IER.EQ.3)GO TO 91
GO TO 92
91 WRITE(10,901)
901 FORMAT(/5X,
&'THE COMBINATION OF INPUT RESULTED IN EITHER NO SOLUTION OR',/5X,
&'AN ILLOGICAL SOLUTION OF THE B OR C WEIBULL PARAMETERS.'/)
GO TO 99
C
C*****
C*
C* GIVEN THE PARAMETER ESTIMATES, DERIVE THE STAND TABLE
C*
C*****
C
92 I=A+0.5
DL=A+0.01
DU=I+0.5
94 DDCL=TWS*(EXP(-(((DL-A)/B)**C))-EXP(-(((DU-A)/B)**C)))
IF(FLOAT(I).GT.DAVG.AND.DDCL.LT.0.5)GO TO 95
DMAX=FLOAT(I)
I=I+1
DU=I+0.5
DL=I-0.5
GO TO 94
95 CONTINUE
C
WRITE(10,905)TP,SI,PERBAH,IAGE
WRITE(11,905)TP,SI,PERBAH,IAGE
905 FORMAT(/74(' '),/9X,
&'STAND AND STOCK TABLE FOR THE PLANTED PINE COMPONENT OF',/,18X,
&'AN UNTHINNED LOBLOLLY PINE PLANTATION',/,74(' '),/,T2,
&'TREES PLANTED =',F6.1,' /AC',T42,
&'SITE INDEX =',F6.1,' FT (BASE 25)',
&/T2,'% BASAL AREA IN HARDWOOD =',F6.1,T42,' AGE =',I4,/)
C
WRITE(10,907)
WRITE(11,907)

```

```

DHA01660
DHA01670
DHA01680
DHA01690
DHA01700
DHA01710
DHA01720
DHA01730
DHA01740
DHA01750
DHA01760
DHA01770
DHA01780
DHA01790
DHA01800
DHA01810
DHA01820
DHA01830
DHA01840
DHA01850
DHA01860
DHA01870
DHA01880
DHA01890
*DHA01900
*DHA01910
*DHA01920
DHA01930
DHA01940
DHA01950
DHA01960
DHA01970
DHA01980
DHA01990
DHA02000
DHA02010
DHA02020
DHA02030
DHA02040
DHA02050
DHA02060
DHA02070
DHA02080
DHA02090
DHA02100
DHA02110
DHA02120
DHA02130
DHA02140
DHA02150
DHA02160
DHA02170
DHA02180
DHA02190
DHA02200

```

## FORTRAN LISTING (continued)

```

907 FORMAT(1X,T45,'CUBIC FOOT VOLUMES PER ACRE',/,T43,31('-'),/,T12,   DHA02210
&'NUMBER',T23,'TOTAL',T35,'BASAL',T46,'TOTAL',T55,'PULPWOOD',T67,   DHA02220
&'SAWLOG',/,T4,'DBH',T12,'TREES',T23,'HEIGHT',T35,'AREA',T46,   DHA02230
&'1" +',T57,'5" +',T68,'8" +',/,1X,'INCHES',T12,'/ACRE',T24,   DHA02240
&'FEET',T32,'SQ FT/ACRE',T56,'4" TOP',T67,'6" TOP',/)   DHA02250
C   DHA02260
C*****COMPUTE THE PREDICTED DISTRIBUTIONS   DHA02270
C   DHA02280
C   DSUM = 0.   DHA02290
C   BSUM = 0.   DHA02300
C   VSUM = 0.   DHA02310
C   PSUM = 0.   DHA02320
C   SSUM = 0.   DHA02330
C   ASUM = 0.   DHA02340
C   DHA02350
C   I = A + 0.5   DHA02360
C   DL = A + 0.01   DHA02370
C   DU = I + 0.5   DHA02380
96 DCL(I)=TWS*(EXP(-(((DL-A)/B)**C))-EXP(-(((DU-A)/B)**C)))   DHA02390
IF(DCL(I).LT.0.)DCL(I)=0.   DHA02400
DIAM=I   DHA02410
HGT=TREHT(DIAM)   DHA02420
IF (FLOAT(I).GT.DMAX)GO TO 97   DHA02430
BCL(I) = TWS*GAUS(BDIST,DL,DU)   DHA02440
VCL(I) = TWS*GAUS(VDIST,DL,DU)   DHA02450
IF(VCL(I).LT..05)GO TO 98   DHA02460
C   DHA02470
C*****CALCULATE MERCHANTABLE VOLUMES AS A RATIO OF TOTAL VOLUME   DHA02480
C   (BURKHART 1977)   DHA02490
C   DHA02500
C   PCL(I) = VCL(I)*(1.+(-.32354*((4.**3.1579)/(DIAM**2.7115))))   DHA02510
C   SCL(I) = VCL(I)*(1.+(-.32354*((6.**3.1579)/(DIAM**2.7115))))   DHA02520
C   DSUM = DSUM + DCL(I)   DHA02530
C   BSUM = BSUM + BCL(I)   DHA02540
C   VSUM = VSUM + VCL(I)   DHA02550
C   ASUM = ASUM + FLOAT(I)*DCL(I)   DHA02560
C   IF(I.GE.5)PSUM = PSUM + PCL(I)   DHA02570
C   IF(I.GE.8)SSUM = SSUM + SCL(I)   DHA02580
C   DHA02590
C   IF(I.GE.8.)WRITE(10,908)I,DCL(I),HGT,BCL(I),VCL(I),PCL(I),SCL(I)   DHA02600
C   IF(I.GE.8.)WRITE(11,908)I,DCL(I),HGT,BCL(I),VCL(I),PCL(I),SCL(I)   DHA02610
908 FORMAT(1X,14,6(5X,F6.1))   DHA02620
IF(I.GE.5.AND.I.LT.8.)WRITE(10,909)I,DCL(I),HGT,   DHA02630
&   BCL(I),VCL(I),PCL(I)   DHA02640
&   IF(I.GE.5.AND.I.LT.8.)WRITE(11,909)I,DCL(I),HGT,   DHA02650
&   BCL(I),VCL(I),PCL(I)   DHA02660
909 FORMAT(1X,14,5(5X,F6.1))   DHA02670
IF(I.LT.5.)WRITE(10,910)I,DCL(I),HGT,BCL(I),VCL(I)   DHA02680
IF(I.LT.5.)WRITE(11,910)I,DCL(I),HGT,BCL(I),VCL(I)   DHA02690
910 FORMAT(1X,14,4(5X,F6.1))   DHA02700
C   DHA02710
C   98 I = I + 1   DHA02720
C   DU = I + 0.5   DHA02730
C   DL = I - 0.5   DHA02740
C   GO TO 96   DHA02750

```

## FORTRAN LISTING (continued)

```

97 CONTINUE
   ARTH=ASUM/DSUM
   WRITE(10,911) DSUM,BSUM,VSUM,PSUM,SSUM,ARTH
   WRITE(11,911) DSUM,BSUM,VSUM,PSUM,SSUM,ARTH
911 FORMAT(1X,72('-')),/1X,'TOTALS',2X,F7.1,15X,F7.1,4X,F7.1,4X,
   &F7.1,4X,F7.1,/,1X,'ARITHMETIC MEAN =',F5.2,1X,'IN.',/,74('#'),/)
C
99 WRITE(10,912)TP,SI,PERBAH,IAGE
912 FORMAT(/5X,'THE PREVIOUS INPUT WAS AS FOLLOWS:'//8X,
   &' 1 TREES PER ACRE .....',F6.1,/8X,
   &' 2 SITE INDEX .....',F6.1,/8X,
   &' 3 % BASAL AREA IN HARDWOOD ..',F6.1,/8X,
   &' 4 AGE .....',14,//5X,
   &' IF ANOTHER PROJECTION IS DESIRED,'/8X,
   &' ENTER THE NUMBERED ITEM TO BE CHANGED,'/8X,
   &' ENTER THE NUMBER 5 IF MORE THAN 1 ITEM IS TO BE CHANGED,'/5X,
   &' OTHERWISE, ENTER THE NUMBER 6 TO TERMINATE THE PROGRAM.'/)
   READ(10,*)RESP1
   IF(RESP1.EQ.1..OR.RESP1.EQ.5.)GO TO 8
   IF(RESP1.EQ.2.)GO TO 20
   IF(RESP1.EQ.3.)GO TO 30
   IF(RESP1.EQ.4.)GO TO 50
   IF(RESP1.EQ.6..OR.RESP1.EQ.9999)GO TO 9999
   IF(RESP1.EQ.8888.)GO TO 9998
   GO TO 99
C
9998 WRITE(10,914)
914 FORMAT(/5X,'THE PROGRAM HAS BEEN RESTARTED.')
   GO TO 7
C
9999 WRITE(10,913)
913 FORMAT(/5X,'THE PROGRAM HAS BEEN TERMINATED BY THE USER.')
   STOP
   END
C
C*****
C*
C* SUBROUTINES AND FUNCTIONS
C*
C*****
C
C*****COMPUTE TOTAL TREE HEIGHTS
C
   FUNCTION TREEHT(DBH)
   COMMON/AREA2/HGTD,TWS,TOF,DMAX,AGE
   TREEHT=10.**(-.040006+(1./DBH-1./DMAX)*(.428373-.497483*
   & ALOG10(TWS)+.363755/AGE+1.095404*ALOG10(HGTD)))
   TREEHT=HGTD/TREEHT
   RETURN
   END
C
C*****CHECK RESPONSES
C
   SUBROUTINE RESP1(X)
   WRITE(10,102)X

```

## FORTRAN LISTING (continued)

```

102 FORMAT(5X,'WARNING: SPECIFIED VALUE OF',F7.1,2X,
&' IS BEYOND DATA RANGE, '/
&14X,'ILLOGICAL OR INCONSISTENT RESULTS MAY BE OBTAINED.')
```

DHA03310  
DHA03320  
DHA03330  
DHA03340  
DHA03350  
DHA03360  
DHA03370  
DHA03380  
DHA03390  
DHA03400  
DHA03410  
DHA03420  
DHA03430  
DHA03440  
DHA03450  
DHA03460  
DHA03470  
DHA03480  
DHA03490  
DHA03500  
DHA03510  
DHA03520  
DHA03530  
DHA03540  
DHA03550  
DHA03560  
DHA03570  
DHA03580  
DHA03590  
DHA03600  
DHA03610  
DHA03620  
DHA03630  
DHA03640  
DHA03650  
DHA03660  
DHA03670  
DHA03680  
DHA03690  
DHA03700  
DHA03710  
DHA03720  
DHA03730  
DHA03740  
DHA03750  
DHA03760  
DHA03770  
DHA03780  
DHA03790  
DHA03800  
DHA03810  
DHA03820  
DHA03830  
DHA03840  
DHA03850

```

RETURN
END
C
SUBROUTINE RESPS2(RESP)
1 WRITE(10,103)
103 FORMAT(5X,'ENTER: 1 IF YOU WANT TO SPECIFY ANOTHER VALUE, '/
&12X,'2 IF NOT.')
```

DHA03370  
DHA03380  
DHA03390  
DHA03400  
DHA03410  
DHA03420  
DHA03430  
DHA03440  
DHA03450  
DHA03460  
DHA03470  
DHA03480  
DHA03490  
DHA03500  
DHA03510  
DHA03520  
DHA03530  
DHA03540  
DHA03550  
DHA03560  
DHA03570  
DHA03580  
DHA03590  
DHA03600  
DHA03610  
DHA03620  
DHA03630  
DHA03640  
DHA03650  
DHA03660  
DHA03670  
DHA03680  
DHA03690  
DHA03700  
DHA03710  
DHA03720  
DHA03730  
DHA03740  
DHA03750  
DHA03760  
DHA03770  
DHA03780  
DHA03790  
DHA03800  
DHA03810  
DHA03820  
DHA03830  
DHA03840  
DHA03850

```

READ(10,*)RESP
IF(RESP.EQ.9999.)RETURN
IF(RESP.EQ.1..OR.RESP.EQ.2..OR.RESP.EQ.8888.)GO TO 2
GO TO 1
2 RETURN
END
C
C*****CALCULATE B AND C PARAMETERS OF THE WEIBULL DISTRIBUTION
C (BURK AND BURKHART 1984. VPI&SU FWS-1-84).
```

DHA03460  
DHA03470  
DHA03480  
DHA03490  
DHA03500  
DHA03510  
DHA03520  
DHA03530  
DHA03540  
DHA03550  
DHA03560  
DHA03570  
DHA03580  
DHA03590  
DHA03600  
DHA03610  
DHA03620  
DHA03630  
DHA03640  
DHA03650  
DHA03660  
DHA03670  
DHA03680  
DHA03690  
DHA03700  
DHA03710  
DHA03720  
DHA03730  
DHA03740  
DHA03750  
DHA03760  
DHA03770  
DHA03780  
DHA03790  
DHA03800  
DHA03810  
DHA03820  
DHA03830  
DHA03840  
DHA03850

```

C
SUBROUTINE WEIB(X1,X2,LOCA,BL,TL,B,C,X1P,X2P,IER)
IMPLICIT REAL*8 (Z)
REAL LOCA
COMMON/AREA3/ZA,ZB,ZC,ZD1,ZD2
C
IER=0
ZA=DBLE(LOCA)
B=0.0
C=0.0
ZD2=DBLE(X2)
X1P=X1
X2P=X2
IFLAG=0
C
10 ZD1=DBLE(X1P)
ZFN=DBLE(BL)
ZFCV(ZFN)
IF(ZFN.LT.0.DO)GO TO 30
IER=2
IF(IFLAG.EQ.0)GO TO 20
IER=3
RETURN
20 X1P=X1P+.01
GO TO 10
30 ZFN1=DBLE(TL)
ZFCV(ZFN1)
IF(ZFN1.GT.0.DO)GO TO 40
IER=2
IFLAG=1
X1P=X1P-.01
GO TO 10
C
40 DO 60 J=1,5
ZTEMP=(ZFN+ZFN1)/2.DO
ZFCV(ZTEMP)
```

## FORTRAN LISTING (continued)

```

      IF(ZFTEMP*ZFXN.LE.0.D0)GO TO 50
      ZXN=ZTEMP
      ZFXN=ZFTEMP
      GO TO 60
50  ZXN1=ZTEMP
      ZFXN1=ZFTEMP
60  CONTINUE
C
      DO 70 J=1,100
      ZTEMP=ZXN-ZFXN*(ZXN-ZXN1)/(ZFXN-ZFXN1)
      ZXN1=ZXN
      ZFXN1=ZFXN
      ZXN=ZTEMP
      ZFXN=ZFCV(ZXN)
      IF(DABS(ZFXN).LE.0.00001D0)GO TO 80
70  CONTINUE
      IER=1
      X2P=ZD2-ZFXN
80  C=ZC
      B=ZB
      RETURN
      END
C
      DOUBLE PRECISION FUNCTION ZFCV(ZX)
      IMPLICIT REAL*8 (Z)
      COMMON/AREA3/ZA,ZB,ZC,ZD1,ZD2
      ZC=ZX
      ZG1=DGAMMA(1.D0+1.D0/ZC)
      ZG2=DGAMMA(1.D0+2.D0/ZC)
      ZB=(ZD1-ZA)/ZG1
      ZFCV=ZD2-ZA*ZA-2.D0*ZA*ZB*ZG1-ZB*ZB*ZG2
      RETURN
      END
C
C*****CALCULATION OF TOTAL BASAL AREA BY DIAMETER CLASS.
C
      FUNCTION BDIST(DBH)
      COMMON/AREA1/DAVG,D2AVG,A,B,C
      BDIST = 0.
      XX = 1.
      XY = C * ALOG((DBH-A)/B)
      IF(XY.GT.4.) RETURN
      IF(XY.LT.-10.) GO TO 30
      XX = EXP(-(((DBH-A)/B)**C))
30  BDIST = 0.005454154*DBH*DBH*C/B*((DBH-A)/B)**(C-1.)*XX
      RETURN
      END
C
C*****CALCULATION OF TOTAL CUBIC FOOT OUTSIDE BARK VOLUME BY DIAMETER
C CLASS (BURKHART ET AL. 1972).
C
      FUNCTION VDIST(DBH)
      COMMON/AREA1/DAVG,D2AVG,A,B,C
      VDIST = 0.
      XX = 1.

```

DHA03860  
DHA03870  
DHA03880  
DHA03890  
DHA03900  
DHA03910  
DHA03920  
DHA03930  
DHA03940  
DHA03950  
DHA03960  
DHA03970  
DHA03980  
DHA03990  
DHA04000  
DHA04010  
DHA04020  
DHA04030  
DHA04040  
DHA04050  
DHA04060  
DHA04070  
DHA04080  
DHA04090  
DHA04100  
DHA04110  
DHA04120  
DHA04130  
DHA04140  
DHA04150  
DHA04160  
DHA04170  
DHA04180  
DHA04190  
DHA04200  
DHA04210  
DHA04220  
DHA04230  
DHA04240  
DHA04250  
DHA04260  
DHA04270  
DHA04280  
DHA04290  
DHA04300  
DHA04310  
DHA04320  
DHA04330  
DHA04340  
DHA04350  
DHA04360  
DHA04370  
DHA04380  
DHA04390  
DHA04400

## FORTRAN LISTING (continued)

```

XY = C * ALOG((DBH-A)/B)
IF(XY.GT.4.) RETURN
IF(XY.LT.-10.)GO TO 30
XX = EXP(-(((DBH-A)/B)**C))
30 VDIST = (0.34864+0.00232*DBH*DBH*TREEHT(DBH))*C/B
&*(((DBH-A)/B)**(C-1.))*XX
RETURN
END
C
C*****NUMERICAL INTEGRATION (HAFLEY ET AL. 1982. NC STATE UNIV.
C TECH REPORT 1).
C
C FUNCTION GAUS (F,A,B)
C DIMENSION C(10),D(10)
C EXTERNAL F
C
C DATA C/.0765265,.2277858,.3737061,.510867,.6360537,.7463319,
& .8391170,.912234,.9639719,.9931286/
C
C DATA D/.1527534,.1491730,.1420961,.1316886,.1181945,.1019301,
& .0832767,.0626720,.0406014,.0176140/
S=(B-A)/2.
T=A+S
P=0.
DO 200 K=1,10
P=P+D(K)*(F(S*C(K)+T)+F(T-S*C(K)))
200 CONTINUE
GAUS=P*S
RETURN
END
DHA04410
DHA04420
DHA04430
DHA04440
DHA04450
DHA04460
DHA04470
DHA04480
DHA04490
DHA04500
DHA04510
DHA04520
DHA04530
DHA04540
DHA04550
DHA04560
DHA04570
DHA04580
DHA04590
DHA04600
DHA04610
DHA04620
DHA04630
DHA04640
DHA04650
DHA04660
DHA04670
DHA04680
DHA04690
DHA04700

```



## DEFINITIONS OF VARIABLES USED IN THE PROGRAM HDWD

|        |                                                                                                                           |
|--------|---------------------------------------------------------------------------------------------------------------------------|
| A      | location parameter of the Weibull distribution                                                                            |
| AD2AVG | modifies OD2AVG to D2AVG                                                                                                  |
| AGE    | age of plantation                                                                                                         |
| AMIN   | modifies OFMIN to DMIN                                                                                                    |
| ARTH   | arithmetic mean dbh (in.)                                                                                                 |
| ASUM   | weighted sum of dbh (in.)                                                                                                 |
| B      | scale parameter of the Weibull distribution                                                                               |
| BAH    | basal area in hardwood (sq ft/ac)                                                                                         |
| BAL    | basal area in pine on a woods site (sq ft/ac)                                                                             |
| BAP    | basal area in pine on an old field site (sq ft/ac)                                                                        |
| BCL(I) | basal area in pine for diameter class i (sq ft/ac)                                                                        |
| BL     | bottom limit of the shape parameter 'C'                                                                                   |
| BSUM   | sum of BCL (sq ft/ac)                                                                                                     |
| C      | shape parameter of the Weibull distribution                                                                               |
| DAVG   | average stand diameter (in.) of pine as adjusted by BAH                                                                   |
| DBH    | diameter at breast height (in.)                                                                                           |
| D2AVG  | average squared stand diameter (sq in.) of pine as adjusted by BAH                                                        |
| DCL(I) | number of pine for diameter class i (trees/ac)                                                                            |
| DDCL   | same as DCL                                                                                                               |
| DGAMMA | IMSL double precision routine solving for the parameters of the gamma distribution                                        |
| DL     | lower bound of diameter class i (in.)                                                                                     |
| DMIN   | minimum diameter class of pine (in.)                                                                                      |
| DMAX   | maximum diameter class of pine (in.)                                                                                      |
| DSUM   | sum of DCL (trees/ac)                                                                                                     |
| DU     | upper bound of diameter class i (in.)                                                                                     |
| HGT    | total height of pine (ft)                                                                                                 |
| HGTD   | average height of the pine dominants and codominants (ft)                                                                 |
| ODAVG  | old field average stand diameter of pine (in.)                                                                            |
| OD2AVG | old field average squared stand diameter of pine (sq in.)                                                                 |
| OFMIN  | old field minimum stand diameter of pine (in.)                                                                            |
| PERBAH | percent basal area in hardwood                                                                                            |
| PCL(I) | pulpwood yield of planted pine 5 in. dbh and greater to a 4 in. top outside bark diameter (cu ft/ac) for diameter class i |
| PSUM   | sum of PCL (cu ft/ac)                                                                                                     |
| RESPI  | responses to questions                                                                                                    |
| SCL(I) | sawlog yield of planted pine 8 in. dbh and greater to a 6 in. top outside bark diameter (cu ft/ac) for diameter class i   |
| SI     | site index base age 25 (ft)                                                                                               |
| SSUM   | sum of SCL (cu ft/ac)                                                                                                     |
| TL     | top limit of shape parameter 'C'                                                                                          |
| TOF    | number of surviving pine on an old field site (trees/ac)                                                                  |
| TP     | number of planted pine (trees/ac)                                                                                         |
| TREEHT | same as HGT                                                                                                               |
| TWS    | number of surviving pine (trees/ac) as adjusted by BAH                                                                    |
| VAR    | variance of pine dbh                                                                                                      |
| VCL(I) | total yield of planted pine 1 in. dbh and greater (cu ft/ac) for diameter class i                                         |
| VSUM   | sum of VCL (cu ft/ac)                                                                                                     |

## BASIC LISTING

IBM Personal Computer BASIC Formatter and Cross-Reference V 1.00

```

10 REM*****
20 REM    A GROWTH AND YIELD PREDICTION MODEL FOR THE PLANTED COMPONENT
30 REM    OF UNTHINNED LOBLOLLY PINE PLANTATIONS CONTAINING HARDWOODS
40 REM    BY PETER T. SPRINZ    VPI&SU    FWS-3-84
50 REM*****
60 CLS:
  PRINT:
  PRINT:
  PRINT:
  PRINT
70 PRINT
  "    A GROWTH AND YIELD PREDICTION MODEL FOR THE PLANTED COMPONENT
80 PRINT
  "    OF UNTHINNED LOBLOLLY PINE PLANTATIONS CONTAINING HARDWOODS.
90 PRINT:
  PRINT
100 PRINT
  "Values to responses need to be in ENGLISH units (i.e., trees/ac, feet).
110 PRINT:
  PRINT "A response can be entered as either INTEGER- or REAL-valued."
120 PRINT:
  PRINT "ENTER: 9999 at any time to TERMINATE the program,"
130 PRINT "    8888 at any time to RESTART the program."
140 PRINT:
  PRINT "PRESS any key to CONTINUE",A$=INPUT$(1):
  CLS
150 REM*****
160 K=.4342944819#
170 DIM
  DCL(50),
  BCL(50),
  VCL(50),
  PCL(50),
  SCL(50)
180 PRINT:
  PRINT
190 RESP1=5
200 REM*****

```

## BASIC LISTING (continued)

IBM Personal Computer BASIC Formatter and Cross-Reference V 1.00

```
210 IF
    RESP1>=2 AND RESP1<=4
    THEN
        GOTO 350
220 INPUT "ENTER THE NUMBER OF LOBLOLLY PINE PLANTED (trees/acre)....",TP
230 IF
    TP>=200 AND TP<=1600
    THEN
        GOTO 350
240 IF
    TP=9999
    THEN
        GOTO 2060
250 IF
    TP=8888
    THEN
        GOTO 2050
260 ICK=TP:
    GOSUB 2100
270 PRINT "DATA RANGE IS FROM 200 TO 1600 TREES/ACRE."
280 IF
    TP>=4000 OR TP<=50
    THEN
        GOTO 210
290 GOSUB 2140
300 IF
    RESP=1
    THEN
        GOTO 210
310 IF
    RESP=2
    THEN
        GOTO 350
320 IF
    RESP=9999
    THEN
        GOTO 2060
330 IF
    RESP=8888
    THEN
        GOTO 2050
340 REM
350 IF
    RESP1=1 OR RESP1=3 OR RESP1=4
    THEN
        GOTO 490
360 INPUT "ENTER SITE INDEX BASE AGE 25 (feet).....",SI
370 IF
    SI>=40 AND SI<=90
    THEN
```

## BASIC LISTING (continued)

IBM Personal Computer BASIC Formatter and Cross-Reference V 1.00

```

          GOTO 490
380 IF
      SI=9999
      THEN
          GOTO 2060
390 IF
      SI=8888
      THEN
          GOTO 2050
400 ICK=SI:
      GOSUB 2100
410 PRINT "DATA RANGE FOR SITE INDEX IS FROM 40 TO 90 FEET."
420 IF
      SI>=200 OR SI<=20
      THEN
          GOTO 350
430 GOSUB 2140
440 IF
      RESP=1
      THEN
          GOTO 350
450 IF
      RESP=2
      THEN
          GOTO 490
460 IF
      RESP=9999
      THEN
          GOTO 2060
470 IF
      RESP=8888
      THEN
          GOTO 2050
480 REM
490 IF
      RESP1<=2 OR RESP1=4
      THEN
          GOTO 630
500 INPUT
      "ENTER PERCENT OF BASAL AREA IN HARDWOODS (e.g., 4, 20)....",
      PERBAH
510 IF
      PERBAH>=0 AND PERBAH<=90
      THEN
          GOTO 630
520 IF
      PERBAH=9999
      THEN
          GOTO 2060
530 IF
      PERBAH=8888
      THEN
```

## BASIC LISTING (continued)

IBM Personal Computer BASIC Formatter and Cross-Reference V 1.00

```

                GOTO 2050
540  ICK=PERBAH:
      GOSUB 2100
550  PRINT "DATA RANGE IS 0 TO 90 PERCENT."
560  IF
      PERBAH>100 OR PERBAH<0
      THEN
          GOTO 490
570  GOSUB 2140
580  IF
      RESP=1
      THEN
          GOTO 490
590  IF
      RESP=2
      THEN
          GOTO 630
600  IF
      RESP=9999
      THEN
          GOTO 2060
610  IF
      RESP=8888
      THEN
          GOTO 2050

620  REM
630  IF
      RESP1<=3
      THEN
          GOTO 840
640  PRINT "ENTER STAND AGE,"
650  INPUT "  AGE MUST BE GREATER THAN OR EQUAL TO 10 YEARS.....",AGE
660  AGE%=AGE
670  IF
      AGE>=10 AND AGE<=45
      THEN
          GOTO 840
680  IF
      AGE=9999
      THEN
          GOTO 2060
690  IF
      AGE=8888
      THEN
          GOTO 2050
700  ICK=AGE:
      GOSUB 2100
710  PRINT "DATA RANGE IS FROM 10 TO 45 YEARS."
720  IF
      AGE>=100 OR AGE<10
      THEN
          GOTO 630
```

## BASIC LISTING (continued)

IBM Personal Computer BASIC Formatter and Cross-Reference V 1.00

```

730 GOSUB 2140
740 IF
      RESP=1
      THEN
          GOTO 630
750 IF
      RESP=2
      THEN
          GOTO 840
760 IF
      RESP=9999
      THEN
          GOTO 2060
770 IF
      RESP=8888
      THEN
          GOTO 2050
780 REM

790 REM *****

800 REM COMPUTE STAND ATTRIBUTES

810 REM *****
820 REM-----
830 REM***>> COMPUTE OLD FIELD SURVIVING TREES/AC (COILE & SCHUMACHER 1964)
840 TOF=K*LOG(TP)+(AGE/100)*(2.273-1.1103*K*LOG(TP))
850 TOF=10^TOF
860 REM-----

870 REM***>> COMPUTE AVG HEIGHT OF DOM & CODOMINATES (AMATEIS & BURKHART
      1984)
880 HGTD=LOG(SI)*((AGE/25)^.10283)*EXP(-2.1676*((1/AGE)-(1/25)))
890 HGTD=EXP(HGTD)
900 REM-----

```

## BASIC LISTING (continued)

IBM Personal Computer BASIC Formatter and Cross-Reference V 1.00

910 REM\*\*\*>> COMPUTE OLD FIELD BASAL AREA/ACRE

920 BAP=10^(.38749+1.121332\*K\*LOG(HGTD)+.975619/AGE-92.324443#/TOF)

930 BAH=BAP\*PERBAH/100:

BAL=BAP-BAH

940 IF

BAL<=0

THEN

GOTO 1270

950 REM-----

960 REM\*\*\*>> COMPUTE NUMBER OF TREES/ACRE ADJUSTED BY BASAL AREA IN HARDWOOD

970 TWS=TOF\*10^(-(PERBAH/100)^1.781844)

980 REM\*\*\*\*\*

990 REM\*\*\*>> COMPUTE AVERAGE SQUARED DIAMETER OLD FIELD (OD2AVG), VARIANCE OF DBH (VAR) AND MINIMUM DIAMETER OLD FIELD (OFMIN).

1000 VAR=EXP(2.8366-.2979\*LOG(TOF))-20.422/HGTD+.0003872\*AGE^2)

1010 OD2AVG=BAP/(.005454\*TOF)

1020 OFMIN=-4.10834+.17828\*AGE+1.04138\*HGTD/AGE+947.466/TOF

1030 REM-----

1040 REM\*\*\*>> CALCULATE THE ADJUSTMENT FUNCTIONS BASED ON THE AMOUNT OF BASAL AREA IN HARDWOOD

1050 IF

BAH>0

THEN

AD2AVG=- (BAH^.912618)\*(-9.688E-05\*BAL+.068787/AGE  
+.0045984\*LOG(HGTD))

1060 IF

BAH>0

THEN

AD2AVG=EXP(AD2AVG)

1070 IF

BAH=0

THEN

AD2AVG=1

1080 IF

BAH>0

THEN

AMIN=- (BAH^.000427)\*(-.595414#\*LOG(BAL)+6.90102/AGE  
+.738295\*LOG(HGTD))

## BASIC LISTING (continued)

IBM Personal Computer BASIC Formatter and Cross-Reference V 1.00

```

1090 IF
      BAH>0
      THEN
          AMIN=EXP(AMIN)
1100 IF
      BAH=0
      THEN
          AMIN=1

1110 REM-----

1120 REM***>> MODIFY THE OLD FIELD ESTIMATES OF THE MOMENTS TO REPRESENT
      WOOD SITE CONDITIONS CONTAINING A SPECIFIED AMOUNT OF BASAL
      AREA IN HARDWOOD.

1130 D2AVG=OD2AVG*AD2AVG
1140 DMIN=OFMIN*AMIN
1150 DAVG2=D2AVG-VAR
1160 IF
      DAVG2<=0
      THEN
          GOTO 1270
1170 DAVG=SQR(DAVG2)

1180 REM*****

1190 REM***>> CALCULATE ESTIMATES OF THE WEIBULL PARAMETERS

1200 A=DMIN*.5
1210 IF
      A<=.5
      THEN
          A=.5
1220 GOSUB 2200
1230 IF
      B<=0
      THEN
          GOTO 1270
1240 IF
      DAVG<=A
      THEN
          GOTO 1270
1250 IF
      IER=1 OR IER=3
      THEN
          GOTO 1270
1260 GOTO 1350
1270 CLS:
      PRINT:
      PRINT

```



## BASIC LISTING (continued)

IBM Personal Computer BASIC Formatter and Cross-Reference V 1.00

```

1280 PRINT "THE COMBINATION OF INPUT RESULTED IN EITHER NO SOLUTION OR"
1290 PRINT "AN ILLOGICAL SOLUTION OF THE b OR c WEIBULL PARAMETERS.":
PRINT
1300 GOTO 1870

1310 REM

1320 REM*****

1330 REM GIVEN THE PARAMETER ESTIMATES, DERIVE THE STAND TABLE

1340 REM*****

1350 CLS
1360 PRINT
"          STAND AND STOCK TABLE FOR THE PLANTED PINE COMPONENT OF"
1370 PRINT "          AN UNTHINNED LOBLOLLY PINE PLANTATION"
1380 PRINT
"-----"
1390 PRINT USING
"TREES PLANTED          = ###.# /AC      SITE INDEX = ###.# FEET (B
ASE 25)";TP,SI
1400 PRINT USING
"% BASAL AREA IN HARDWOOD = ###.#      AGE      = #";PERBAH,
AGE%
1410 PRINT
1420 PRINT
"          ---CUBIC FOOT VOLUMES PER ACRE-
--"
1430 PRINT
"          NUMBER TOTAL      BASAL      TOTAL      PULPWOOD      SAWLOG"
1440 PRINT
"          DBH   TREES  HEIGHT  AREA      1in +      5in +      8in + "
1450 PRINT
"          inches /acre  feet    sqft/ac      4in top      6in top
"
1460 REM*****

1470 REM***>> COMPUTE THE PREDICTED DISTRIBUTIONS

1480 REM*****
1490 I%=A:

```

## BASIC LISTING (continued)

IBM Personal Computer BASIC Formatter and Cross-Reference V 1.00

```

DL=A+.01:
DU=I%+.5
1500 DDCL=TWS*(EXP(-(((DL-A)/B)^C))-EXP(-(((DU-A)/B)^C)))
1510 IF
      I%>DAVG AND DDCL<.5
      THEN
          GOTO 1550
1520 DMAX=I%
1530 I%=I%+1:
      DU=I%+.5:
      DL=I%-.5
1540 GOTO 1500
1550 DSUM=0:
      BSUM=0:
      VSUM=0:
      PSUM=0:
      SSUM=0:
      ASUM=0
1560 I%=A:
      DL=A+.01:
      DU=I%+.5
1570 DCL(I%)=TWS*(EXP(-(((DL-A)/B)^C))-EXP(-(((DU-A)/B)^C)))
1580 IF
      DCL(I%)<0
      THEN
          DCL(I%)=0
1590 D1=I%
1600 IF
      D1>DMAX
      THEN
          GOTO 1810
1610 BCLASS=5.454154E-03*D1*D1
1620 HGT=10^(-.040006+(1/D1-1/DMAX)*(.428373-.497483*K*LOG(TWS)+.363755/AGE
      +1.095404*K*LOG(HGTD)))
1630 HGT=HGTD/HGT
1640 REM*****
1650 REM***>> CALCULATE CUBIC FOOT OUTSIDE BARK VOLUME (BURKHART ET AL. 1972)
1660 VCLASS=.34864+.00232*D1*D1*HGT
1670 BCL(I%)=DCL(I%)*BCLASS:
      VCL(I%)=DCL(I%)*VCLASS
1680 IF
      VCL(I%)<.05
      THEN
          GOTO 1790
1690 REM-----

```

## BASIC LISTING (continued)

IBM Personal Computer BASIC Formatter and Cross-Reference V 1.00

```

1700 REM***>> CALCULATE MERCH VOL AS A RATIO OF TOTAL VOLUME (BURKHART 1977).
1710 PCL(I%)=VCL(I%)*(1-.32354*((4^3.1579)/(D1^2.7115)))
1720 SCL(I%)=VCL(I%)*(1-.32354*((6^3.1579)/(D1^2.7115)))
1730 DSUM=DSUM+DCL(I%):
      BSUM=BSUM+BCL(I%):
      VSUM=VSUM+VCL(I%):
      ASUM=ASUM+I%*DCL(I%)
1740 IF
      I%>=5
      THEN
          PSUM=PSUM+PCL(I%)
1750 IF
      I%>=8
      THEN
          SSUM=SSUM+SCL(I%)
1760 IF
      I%>=8
      THEN
          PRINT USING
              "      ##      ###.#      ###.#      ###.#      ###.#      ###.#
              ###.#";I%,DCL(I%),HGT,BCL(I%),VCL(I%),PCL(I%),SCL(I%)
1770 IF
      I%>=5 AND I%<8
      THEN
          PRINT USING
              "      ##      ###.#      ###.#      ###.#      ###.#      ###.#";
              I%,DCL(I%),HGT,BCL(I%),VCL(I%),PCL(I%)
1780 IF
      I%<5
      THEN
          PRINT USING "      ##      ###.#      ###.#      ###.#      ###.#";I%,
              DCL(I%),
              HGT,BCL(I%),VCL(I%)
1790 I%=I%+1:
      DU=I%+.5:
      DL=I%-.5
1800 GOTO 1570
1810 ARTH=ASUM/DSUM
1820 PRINT USING
      "      TOTALS ###.#      ###.#      ###.#      ###.#      ###.#";
      DSUM,BSUM,VSUM,PSUM,SSUM
1830 PRINT:
      PRINT USING "      ARITHMETIC MEAN = ##.## inches";ARTH
1840 PRINT "PRESS any key to CONTINUE",A$=INPUT$(1)
1850 CLS

1860 REM

1870 PRINT "THE PREVIOUS INPUT WAS AS FOLLOWS:":
      PRINT
1880 PRINT USING " 1 TREES PER ACRE ..... ###.#";TP
1890 PRINT USING " 2 SITE INDEX ..... ###.#";SI
1900 PRINT USING " 3 % BASAL AREA IN HARDWOOD .. ###.#";PERBAH

```

## BASIC LISTING (continued)

IBM Personal Computer BASIC Formatter and Cross-Reference V 1.00

```

1910 PRINT USING " 4 AGE ..... ##";AGE%
1920 PRINT:
    PRINT "IF ANOTHER PROJECTION IS DESIRED,"
1930 PRINT " ENTER THE NUMBERED ITEM TO BE CHANGED,"
1940 PRINT " ENTER THE NUMBER 5 IF MORE THAN 1 ITEM IS TO BE CHANGED,"
1950 INPUT "OTHERWISE, ENTER THE NUMBER 6 TO TERMINATE THE PROGRAM...",RESP1
1960 PRINT
1970 IF
    RESP1=1 OR RESP1=5
        THEN
            GOTO 210
1980 IF
    RESP1=2
        THEN
            GOTO 350
1990 IF
    RESP1=3
        THEN
            GOTO 490
2000 IF
    RESP1=4
        THEN
            GOTO 630
2010 IF
    RESP1=6 OR RESP1=9999
        THEN
            GOTO 2060
2020 IF
    RESP1=8888
        THEN
            GOTO 2050
2030 GOTO 1850
2040 REM
2050 PRINT:
    PRINT "THE PROGRAM HAS BEEN RESTARTED.":
    PRINT:
    GOTO 190
2060 PRINT:
    PRINT "THE PROGRAM HAS BEEN TERMINATED BY THE USER."
2070 END
2080 REM*****
2090 REM***>> CHECK RESPONSES
2100 PRINT
2110 PRINT USING
    "WARNING: SPECIFIED VALUE OF ####.# IS BEYOND DATA RANGE,";
    ICK
2120 PRINT:

```

## BASIC LISTING (continued)

IBM Personal Computer BASIC Formatter and Cross-Reference V 1.00

PRINT "ILLOGICAL OR INCONSISTENT RESULTS MAY BE OBTAINED.":  
RETURN

2130 REM

2140 PRINT "ENTER: 1 IF YOU WANT TO SPECIFY ANOTHER VALUE,"

2150 INPUT " 2 IF NOT.",RESP:

PRINT

2160 IF

RESP=1 OR RESP=2 OR RESP=8888 OR RESP=9999

THEN

RETURN

2170 GOTO 2140:

RETURN

2180 REM\*\*\*\*\*

2190 REM\*\*\*>> CALCULATE b AND c PARAMETERS OF WEIBULL DISTRIBUTION  
(BURK & BURKHART 1984 VPI&SU FWS-1-84).

2200 SHAPEL=1:

SHAPEU=5

2210 IER%=0:

A#=A:

B=0:

C=0:

D22#=D2AVG:

D1P=DAVG:

D2P=D2AVG:

IFLAG%=0

2220 D1#=D1P:

XN#=SHAPEL:

C#=XN#:

( THEN )

GOSUB 2410:

FXN#=FVAL#

2230 IF

FXN#<0

THEN

GOTO 2250

ELSE

IER%=2

2240 IF

IFLAG% <> 0

THEN

IER%=3:

RETURN

ELSE

D1P=D1P+.01:

GOTO 2220

2250 XN1#=SHAPEU:

C#=XN1#:

## BASIC LISTING (continued)

IBM Personal Computer BASIC Formatter and Cross-Reference V 1.00

```

GOSUB 2410:
FXN1#=FVAL#
2260 IF
      FXN1#>0
      THEN
          GOTO 2270
      ELSE
          IER%=2:
          IFLAG%=1:
          DIP=DIP-.01:
          ( THEN )
          GOTO 2220
2270 FOR J%=1 TO 5
2280 | TEMP#=(XN#+XN1#)/2#:
| C#=TEMP#:
| GOSUB 2410:
| FTEMP#=FVAL#
2290 | IF
|       FTEMP#*FXN#<=0
|       THEN
|           XN1#=TEMP#:
|           FXN1#=FTEMP#
|       ELSE
|           XN#=TEMP#:
|           FXN#=FTEMP#
2300 NEXT
2310 FOR J%=1 TO 100
2320 | TEMP#=XN#-FXN#*(XN#-XN1#)/(FXN#-FXN1#)
2330 | XN1#=XN#:
| FXN1#=FXN#:
| XN#=TEMP#:
| C#=XN#:
| GOSUB 2410:
| FXN#=FVAL#
2340 | IF
|       FXN#>-.00001# AND FXN#<.00001#
|       THEN
|           GOTO 2370
2350 NEXT
2360 IER%=1:
D2P=D22#-FXN#
2370 B=B#:
C=C#
2380 RETURN
2390 REM-----
2400 REM***>> FUNCTION FOR RECOVERING WEIBULL PARAMETERS
2410 ZX#=1#+1#/C#:
GOSUB 2480:
GI#=GAMMA#

```

## BASIC LISTING (continued)

IBM Personal Computer BASIC Formatter and Cross-Reference V 1.00

```

2420 ZX#=1#+2#/C#:
      GOSUB 2480:
      G2#=GAMMA#
2430 B#=(D1#-A#)/G1#
2440 FVAL#=D22#-A#*A#-2#*A#*B#*G1#-B#*B#*G2#
2450 RETURN

2460 REM-----

2470 REM***>> DOUBLE PRECISION GAMMA FOR AN ARGUMENT >+1

2480 N%=ZX#-.5#:
      XI#=N%:
      N%=XI#-1#
2490 FRAC#=ZX#-XI#
2500 GAMMA#=1#+FRAC#*(-.577191652#+FRAC#*(.988205891#+FRAC#*(-.897056937#
      +FRAC#*(.918206857#))))
2510 GAMMA#=GAMMA#+FRAC#^5*(-.756704078#+FRAC#*(.482199394#+FRAC#*(-
      .193527818# +FRAC#*(.035868343#))))
2520 IF
      N%=0.
      THEN
      RETURN
2530 PROD#=1#
2540 FOR L%=1 TO N%:
      | L#=L%:
      | PROD#=PROD#*(FRAC#+L%):
      NEXT
2550 GAMMA#=GAMMA#*PROD#
2560 RETURN

```

