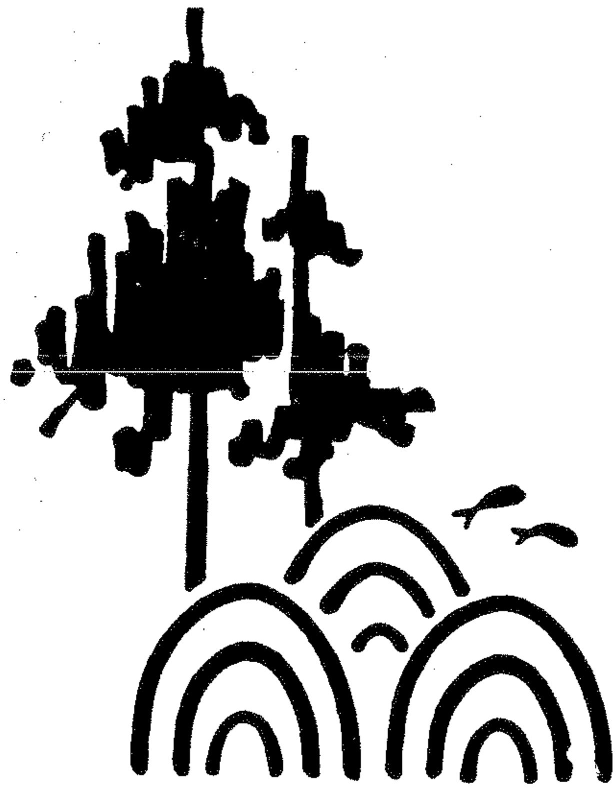
A Model for Assessing Hardwood Competition Effects on Yields of Loblolly Pine Plantations



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

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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
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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

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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.

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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 Burkhart 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
Old-field Plantation Plots	189			
Site index 25 (ft.) [a]		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
Cutover-site Plantation Plots	186			
Site index 25 (ft.) [a]		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
Conversion Study				
Age 11				
Surviving pine (trees/ac)	25 [b]	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
Age 24				
Site index 25 (ft.) [a]	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

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

b/ 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.

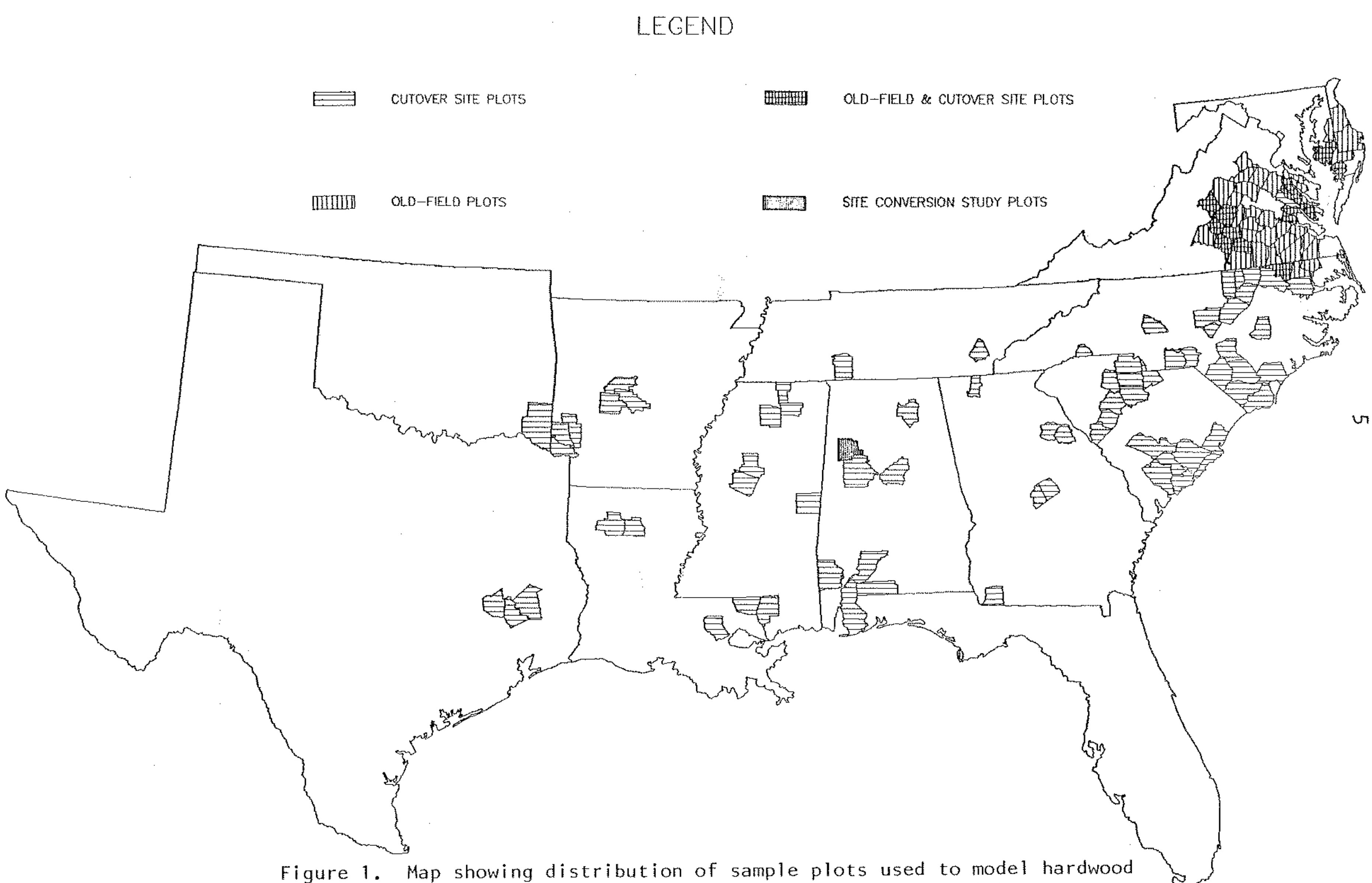

Figure 1. Map showing distribution of sample plots used to model hardwood competition effects on loblolly pine plantation yields.

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

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

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 Burkhart (1977), which were fitted to the old-field data from all crown classes, were used. The total cubic-foot volume equation is

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

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^{th} non-central moment of x is given by:

$$E(x^i) = \int x^i f\ (x_i,\ \underline{\theta})\ dx$$

where $f(x_i, \underline{\theta})$ is a probability density function with parameters $\underline{\theta}$. 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 b and 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:

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

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 a was set to equal $D_{min}/2$ and restricted to be greater than or equal to 0.5. That is, if predicted $D_{min}/2$ is less than 0.5, 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^2_{dbh}). The variance values were subjected to logarithmic transformation to insure that predicted values would always be positive. The resulting equation is:

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

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 ($\overline{D^2}$) (T_S) (0.005454).) The following function was fitted by nonlinear least squares:

$$\overline{D^2_{CO}} = \overline{D^2_{OF}}\ e^{-(B_H^{0.912618}(-.00009688\ B_L + 0.068787/A + .0045984 \ln H_d))}$$

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

$\overline{D^2_{OF}}$ = 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, $\overline{D^2_{CO}}$ equals $\overline{D^2_{OF}}$. Values for $\overline{D^2_{CO}}$, B_H, B_L, A, and H_d came from plot observations in the cutover-site plantations. To compute the value of $\overline{D^2_{OF}}$ 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 $\overline{D^2_{OF}}$ 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 $\overline{D^2_{CO}}$ for a cutover-site plantation, the mean diameter ($\bar{D}_{CO}$) is computed as:

$$\bar{D}_{CO} = \sqrt{\overline{D^2_{CO}} - S^2_{dbh}}$$

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

$$y = -3.4929 + 0.97107\ x$$

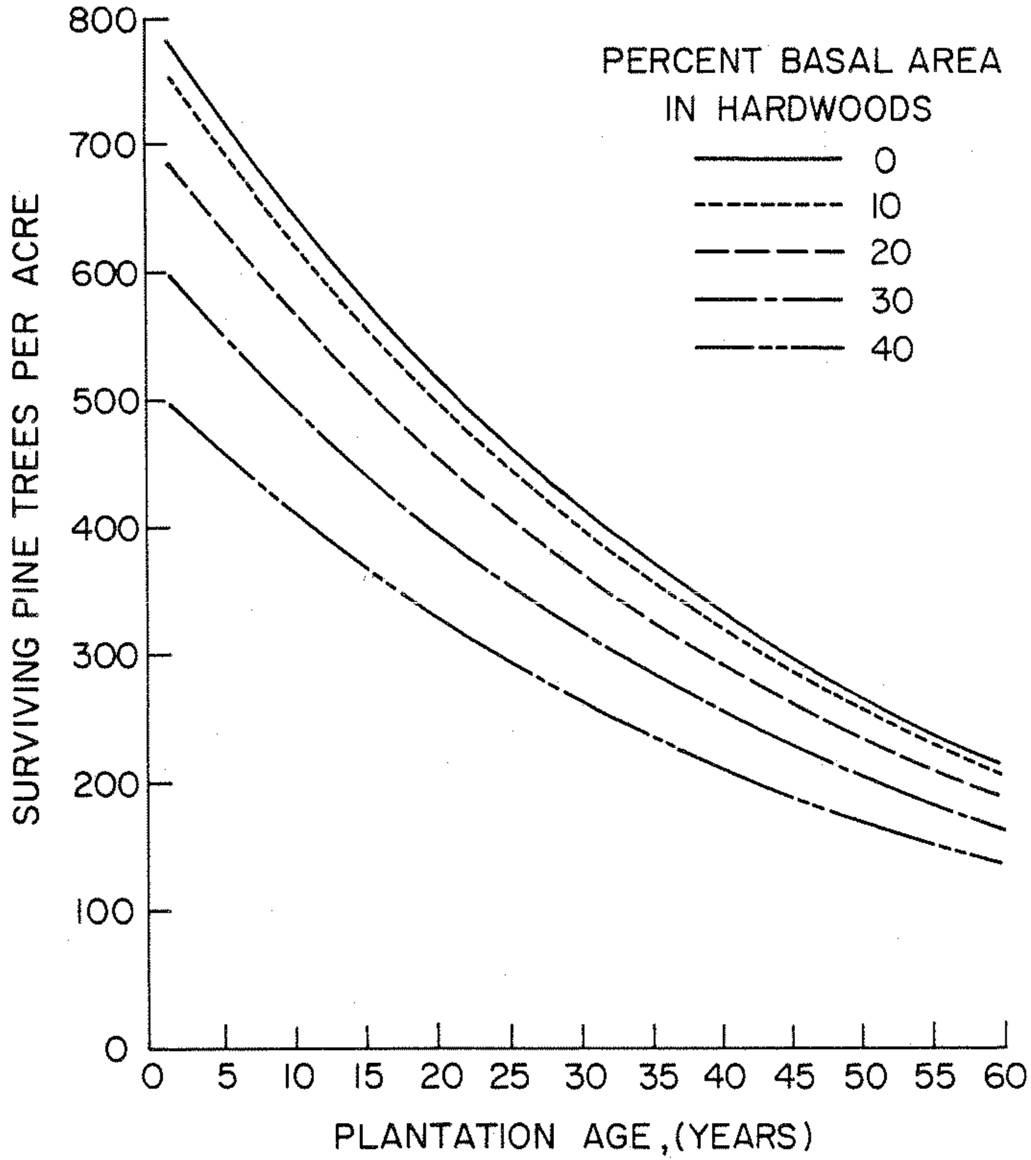

Figure 2. Surviving loblolly pine trees per acre as related to percent of basal area in hardwood. Figure is for 800 trees per acre planted.

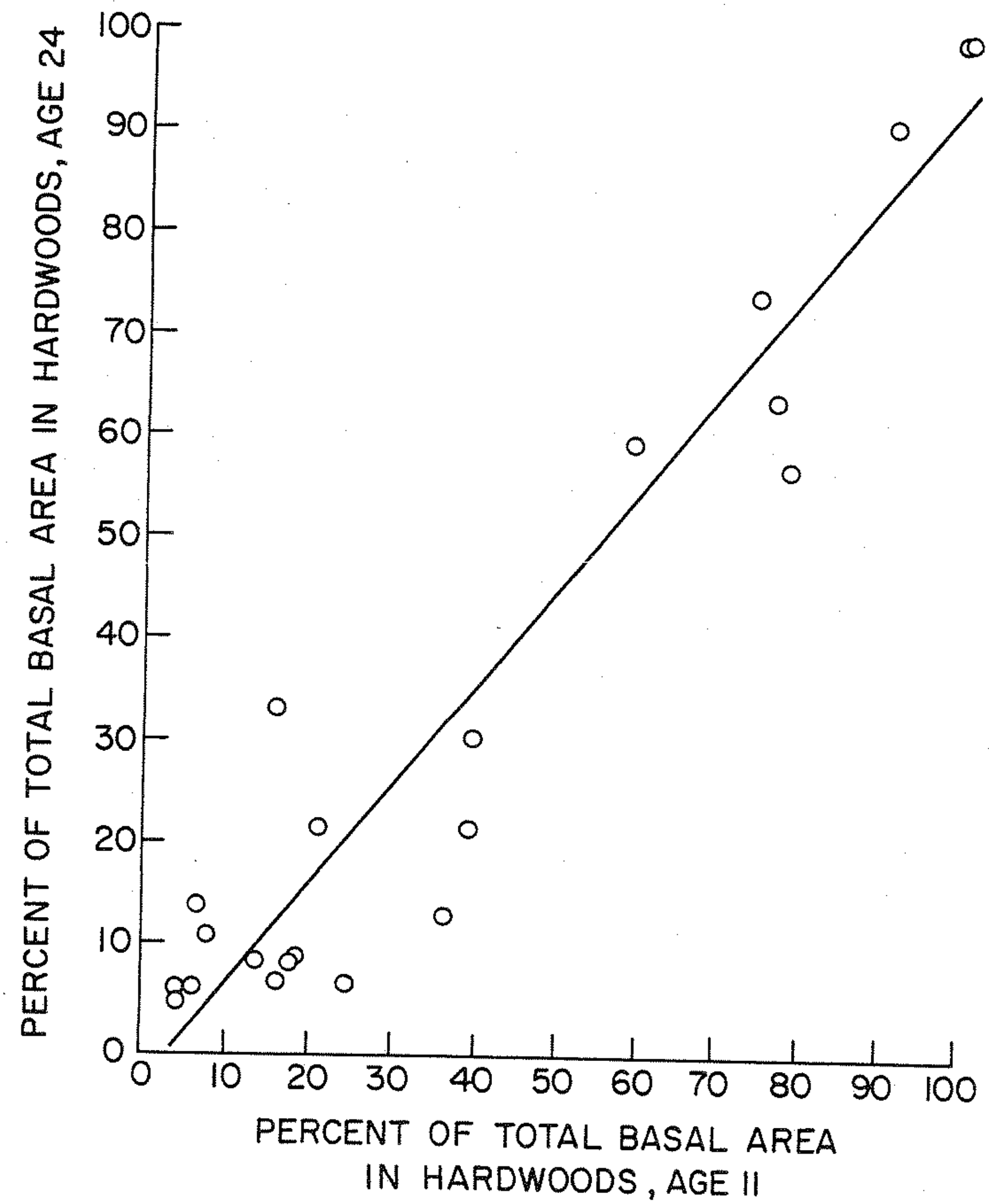

Figure 3. Relationship between percent basal area composed of hardwoods in the main canopy of loblolly pine plantations at ages 11 and 24 in a hardwood conversion/site preparation study, Fayette County, Alabama.

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

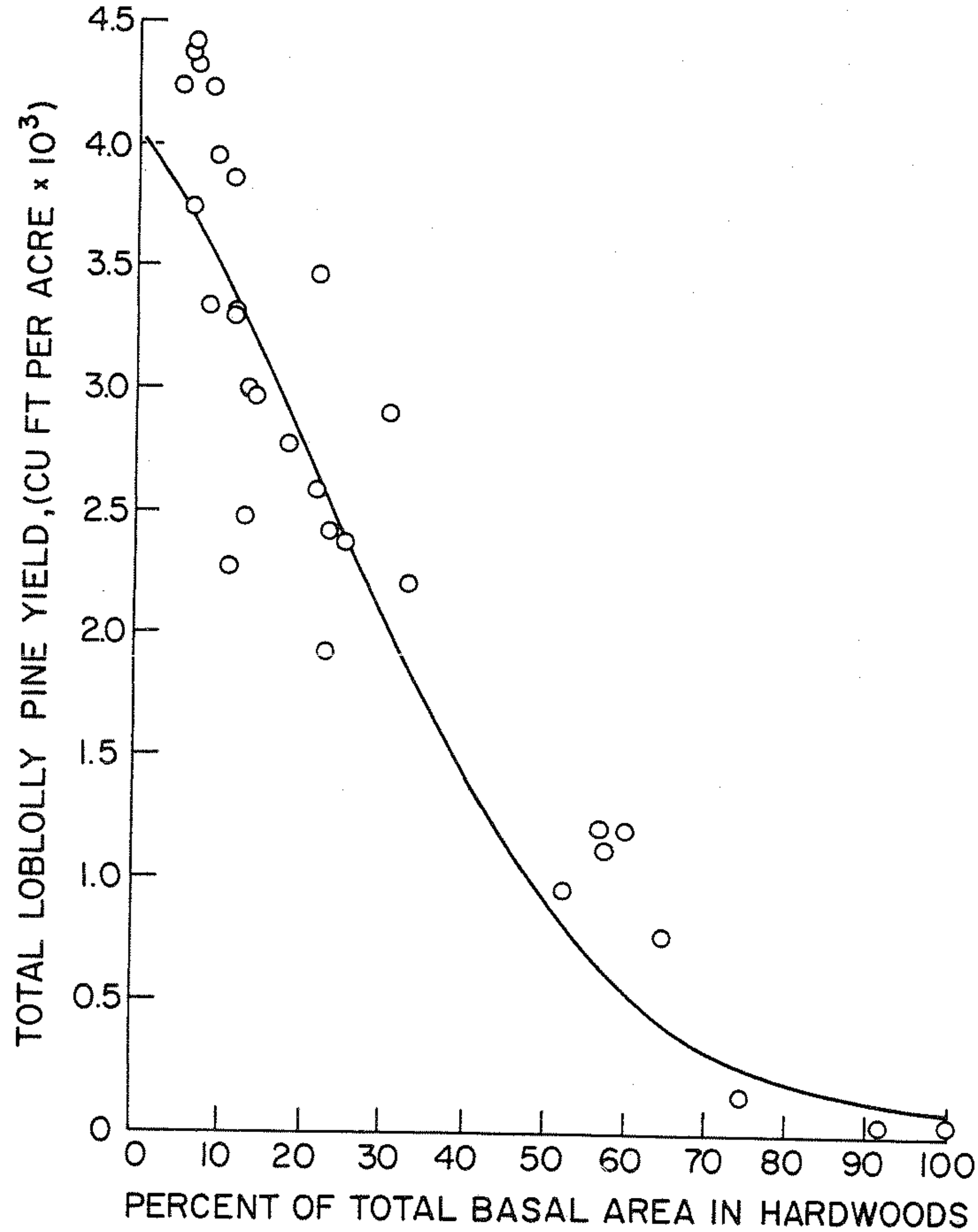

Figure 4. Total yield of loblolly pine versus percent of total stand basal area in hardwood from plot observations in a hardwood conversion/site preparation study in Fayette County, Alabama. The line represents predictions from program HDWD.

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):

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

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

DBH INCHES	NUMBER TREES /ACRE	TOTAL HEIGHT FEET	BASAL AREA SQ FT/ACRE	CUBIC FOOT VOLUMES PER ACRE: TOTAL 1" +	PULPWOOD 5" + 4" TOP	SAWLOG 8" + 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

DBH INCHES	NUMBER TREES /ACRE	TOTAL HEIGHT FEET	BASAL AREA SQ FT/ACRE	CUBIC FOOT VOLUMES PER ACRE: TOTAL 1" +	PULPWOOD 5" + 4" TOP	SAWLOG 8" + 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

				CUBIC FOOT VOLUMES PER ACRE		
DBH INCHES	NUMBER TREES /ACRE	TOTAL HEIGHT FEET	BASAL AREA SQ FT/ACRE	TOTAL 1" +	PULPWOOD 5" + 4" TOP	SAWLOG 8" + 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.

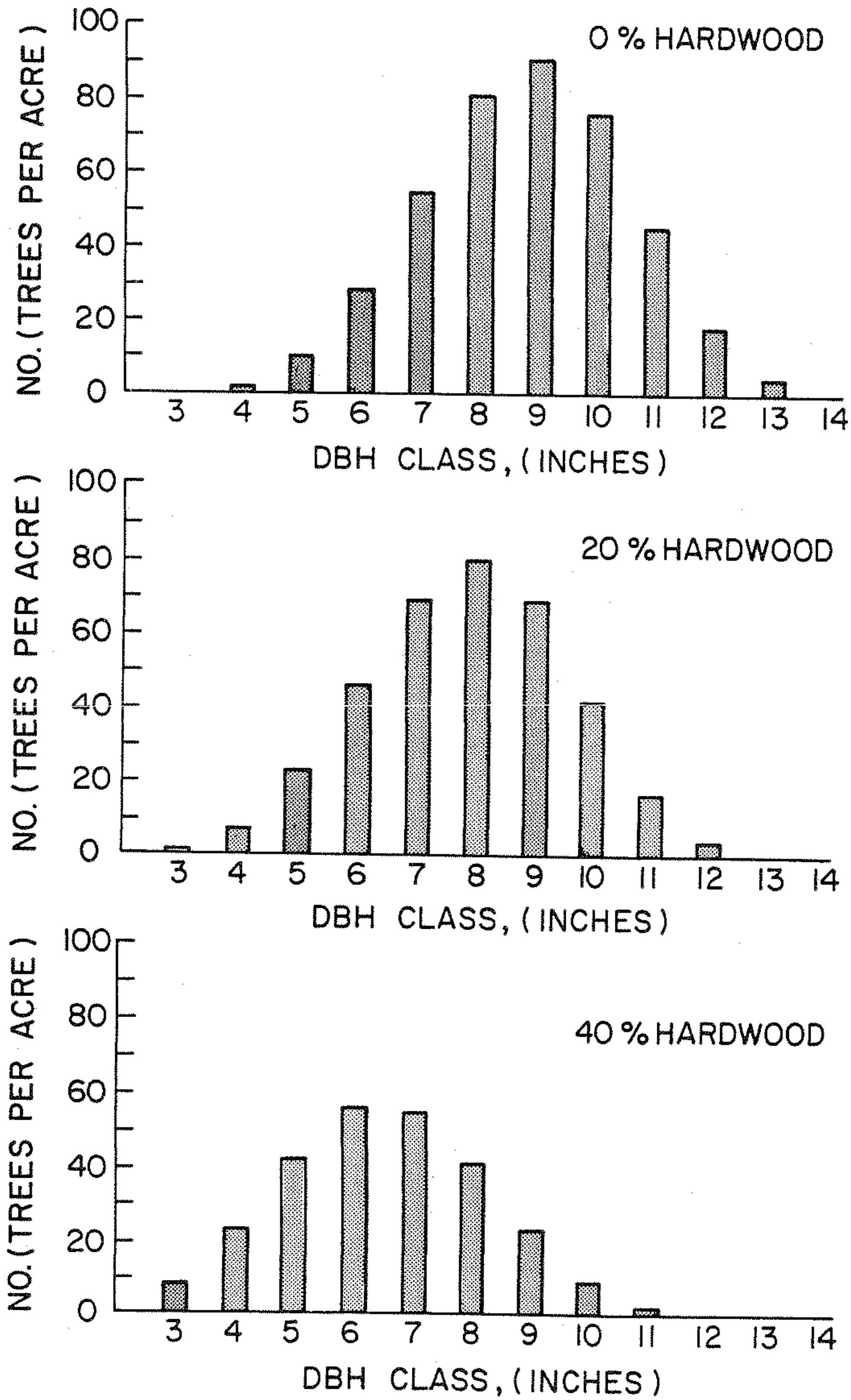

Figure 5. Pine dbh distribution for 0, 20, and 40 percent of the total stand basal area in hardwood. These histograms are for age 30 with 800 trees per acre planted on site index 60 (base age 25 years) land.

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:

Initial Input: 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 INCHES	NUMBER TREES /ACRE	TOTAL HEIGHT FEET	BASAL AREA SQ FT/ACRE	CUBIC FOOT VOLUMES PER ACRE: TOTAL 1" +	PULPWOOD 5" + 4" TOP	SAWLOG 8" + 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.
```

>   3

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

>   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 INCHES	NUMBER TREES /ACRE	TOTAL HEIGHT FEET	BASAL AREA SQ FT/ACRE	CUBIC FOOT VOLUMES PER ACRE: TOTAL 1" +	PULPWOOD 5" + 4" TOP	SAWLOG 8" + 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

				CUBIC FOOT VOLUMES PER ACRE		
DBH INCHES	NUMBER TREES /ACRE	TOTAL HEIGHT FEET	BASAL AREA SQ FT/ACRE	TOTAL 1" +	PULPWOOD 5" + 4" TOP	SAWLOG 8" + 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 INCHES	NUMBER TREES /ACRE	TOTAL HEIGHT FEET	BASAL AREA SQ FT/ACRE	CUBIC FOOT VOLUMES PER ACRE: TOTAL 1" +	PULPWOOD 5" + 4" TOP	SAWLOG 8" + 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***********************************************************************
C*                                                                     *
C*    A GROWTH AND YIELD PREDICTION MODEL FOR THE PLANTED COMPONENT    *
C*    OF UNTHINNED LOBLOLLY PINE PLANTATIONS CONTAINING HARDWOODS.     *
C*                                                                     *
C*                BY PETER T. SPRINZ    VPI&SU    FWS-3-84             *
C*                                                                     *
C***********************************************************************
C
C     QUESTIONS, RESPONSES AND OUTPUT ARE SENT TO TERMINAL BY FILE 10.
C     OUTPUT ONLY IS WRITTEN TO FILE 11.
C
C***********************************************************************
C
      IMPLICIT REAL*8 (Z)
      DIMENSION DCL(50),BCL(50),VCL(50),PCL(50),SCL(50)
      EXTERNAL TREEHT,ZFCV,VDIST,BDIST
      COMMON/AREA1/DAVG,D2AVG,A,B,C
      COMMON/AREA2/HGTD,TWS,TOF,DMAX,AGE
C
      WRITE(10,5)
      WRITE(10,6)
    5 FORMAT(/80('*'),/12X,
     &'A GROWTH AND YIELD PREDICTION MODEL FOR THE PLANTED COMPONENT'
     &/13X,'OF UNTHINNED LOBLOLLY PINE PLANTATIONS CONTAINING HARDWOOD.'
     &/,80('*'),//
     &T3,'VALUES TO RESPONSES NEED TO BE IN ENGLISH UNITS (I.E., FEET'
     &,T64,'AND TREES/ACRE).')
    6 FORMAT(/2X,
     &'A RESPONSE CAN BE ENTERED AS EITHER INTEGER- OR REAL-VALUED.',//
     &2X,'ENTER : 9999 AT ANY TIME TO TERMINATE THE PROGRAM,'
     &/,10X,'8888 AT ANY TIME TO RESTART THE PROGRAM.'//,80('-'),/)
C
    7 RESP1=5.
C
C***********************************************************************
C*                                                                     *
C*    INPUT DATA                                                       *
C*                                                                     *
C***********************************************************************
C
    8 IF(RESP1.GE.2..AND.RESP1.LE.4.)GO TO 20
   10 WRITE(10,100)
  100 FORMAT(5X,'ENTER THE NUMBER OF LOBLOLLY PLANTED (TREES/ACRE).')
      READ(10,*)TP
      IF(TP.GE.200..AND.TP.LE.1600.)GO TO 20
      IF(TP.EQ.9999.)GO TO 9999
      CALL RESPS1(TP)
      WRITE(10,104)
  104 FORMAT(5X,'DATA RANGE IS FROM 200 TO 1600 TREES/ACRE.')
      IF(TP.GE.4000..OR.TP.LE.50.)GO TO 8
      CALL RESPS2(RESP)
      IF(RESP.EQ.1.)GO TO 8
      IF(RESP.EQ.2.)GO TO 20
      IF(RESP.EQ.9999.)GO TO 9999
```

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
      IAGE=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
```

FORTRAN LISTING (continued)

```
C                                                                        DHA01110
C***********************************************************************DHA01120
C*                                                                      *DHA01130
C*    COMPUTE STAND ATTRIBUTES                                          *DHA01140
C*                                                                      *DHA01150
C***********************************************************************DHA01160
C                                                                        DHA01170
C*****COMPUTE OLD FIELD SURVIVING TREES/ACRE(COILE AND SCHUMACHER 1964)  DHA01180
C                                                                        DHA01190
   80 TOF=ALOG10(TP)+(AGE/100.)*(2.1346+.1384-1.1103*ALOG10(TP))         DHA01200
      TOF=10.**TOF                                                       DHA01210
C                                                                        DHA01220
C*****COMPUTE AVERAGE HEIGHT OF THE DOMINANTS AND CODOMINANTS            DHA01230
C     (AMATEIS AND BURKHART 1984)                                        DHA01240
C                                                                        DHA01250
      HGTD=ALOG(SI)*((AGE/25.)**0.10283)*                                DHA01260
     &      EXP(-2.1676*((1./AGE)-(1./25.)))                             DHA01270
      HGTD=EXP(HGTD)                                                     DHA01280
C                                                                        DHA01290
C*****COMPUTE OLD FIELD BASAL AREA/ACRE                                  DHA01300
C                                                                        DHA01310
      BAP=10.**(.38749+1.121332*ALOG10(HGTD)+.975619/AGE-92.324443/TOF)  DHA01320
      BAH=BAP*PERBAH/100.                                                DHA01330
      BAL=BAP-BAH                                                        DHA01340
      IF(BAL.LE.0.)GO TO 91                                              DHA01350
C                                                                        DHA01360
C*****COMPUTE NUMBER OF TREES/ACRE ADJUSTED BY BASAL AREA IN HARDWOOD    DHA01370
C                                                                        DHA01380
      TWS=TOF*10.**(-(PERBAH/100.)**1.781844)                            DHA01390
C                                                                        DHA01400
C*****COMPUTE VARIANCE OF DBH (VAR), AVERAGE SQUARED DIAMETER (OD2AVG),  DHA01410
C     AND MINIMUM DIAMETER (OFMIN) FROM OLD FIELD INFORMATION; AND THEN  DHA01420
C     ADJUST OD2AVG AND OFMIN BY THE AMOUNT OF BASAL AREA IN HARDWOOD.   DHA01430
C                                                                        DHA01440
      VAR=EXP(2.8366-.2979*ALOG(TOF)-20.422/HGTD+.0003872*AGE**2.)       DHA01450
      OD2AVG=BAP/(.005454*TOF)                                           DHA01460
      OFMIN=-4.10834+0.17828*AGE+1.04138*HGTD/AGE+947.466/TOF            DHA01470
C                                                                        DHA01480
C*****CALCULATE THE ADJUSTMENT FUNCTIONS BASED ON THE AMOUNT OF BASAL    DHA01490
C     AREA IN HARDWOOD.                                                  DHA01500
C                                                                        DHA01510
      IF(BAH.GT.0.) AD2AVG=-(BAH**.912618)*(-.00009688*BAL               DHA01520
     &                +.068787/AGE+.0045984*ALOG(HGTD))                  DHA01530
      IF(BAH.GT.0.) AD2AVG=EXP(AD2AVG)                                   DHA01540
      IF(BAH.EQ.0.) AD2AVG=1.                                            DHA01550
      IF(BAH.GT.0.) AMIN=-(BAH**.000427)*(-.595414*ALOG(BAL)             DHA01560
     &                +6.90102/AGE+.738295*ALOG(HGTD))                   DHA01570
      IF(BAH.GT.0.) AMIN=EXP(AMIN)                                       DHA01580
      IF(BAH.EQ.0.) AMIN=1.                                              DHA01590
C                                                                        DHA01600
C*****MODIFY THE OLD FIELD ESTIMATES OF THE MOMENTS TO REPRESENT WOOD    DHA01610
C     SITE CONDITIONS CONTAINING A SPECIFIED AMOUNT OF BASAL AREA IN     DHA01620
C     HARDWOOD.                                                          DHA01630
C                                                                        DHA01640
      D2AVG=OD2AVG*AD2AVG                                                DHA01650
```

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
C*****DETERMINE THE LARGEST DIAMETER CLASS(DMAX) AS THE LAST
C     DIAMETER CLASS CONTAINING AT LEAST .5 TREE PER ACRE.
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)
```

FORTRAN LISTING (continued)

```
  907 FORMAT(1X,T45,'CUBIC FOOT VOLUMES PER ACRE',/,T43,31('-'),/,T12,
     &'NUMBER',T23,'TOTAL',T35,'BASAL',T46,'TOTAL',T55,'PULPWOOD',T67,
     &'SAWLOG',/,T4,'DBH',T12,'TREES',T23,'HEIGHT',T35,'AREA',T46,
     &'1" +',T57,'5" +',T68,'8" +',/,1X,'INCHES',T12,'/ACRE',T24,
     &'FEET',T32,'SQ FT/ACRE',T56,'4" TOP',T67,'6" TOP',/)
C
C*****COMPUTE THE PREDICTED DISTRIBUTIONS
C
      DSUM = 0.
      BSUM = 0.
      VSUM = 0.
      PSUM = 0.
      SSUM = 0.
      ASUM = 0.
C
      I =  A + 0.5
      DL = A + 0.01
      DU = I + 0.5
   96 DCL(I)=TWS*(EXP(-(((DL-A)/B)**C))-EXP(-(((DU-A)/B)**C)))
      IF(DCL(I).LT.0.)DCL(I)=0.
      DIAM=I
      HGT=TREEHT(DIAM)
      IF (FLOAT(I).GT.DMAX)GO TO 97
      BCL(I) = TWS*GAUS(BDIST,DL,DU)
      VCL(I) = TWS*GAUS(VDIST,DL,DU)
      IF(VCL(I).LT..05)GO TO 98
C
C*****CALCULATE MERCHANTABLE VOLUMES AS A RATIO OF TOTAL VOLUME
C     (BURKHART 1977)
C
      PCL(I) = VCL(I)*(1.+(-.32354*((4.**3.1579)/(DIAM**2.7115))))
      SCL(I) = VCL(I)*(1.+(-.32354*((6.**3.1579)/(DIAM**2.7115))))
      DSUM = DSUM + DCL(I)
      BSUM = BSUM + BCL(I)
      VSUM = VSUM + VCL(I)
      ASUM = ASUM + FLOAT(I)*DCL(I)
      IF(I.GE.5)PSUM = PSUM + PCL(I)
      IF(I.GE.8)SSUM = SSUM + SCL(I)
C
      IF(I.GE.8.)WRITE(10,908)I,DCL(I),HGT,BCL(I),VCL(I),PCL(I),SCL(I)
      IF(I.GE.8.)WRITE(11,908)I,DCL(I),HGT,BCL(I),VCL(I),PCL(I),SCL(I)
  908 FORMAT(1X,I4,6(5X,F6.1))
      IF(I.GE.5.AND.I.LT.8.)WRITE(10,909)I,DCL(I),HGT,
     &                            BCL(I),VCL(I),PCL(I)
      IF(I.GE.5.AND.I.LT.8.)WRITE(11,909)I,DCL(I),HGT,
     &                            BCL(I),VCL(I),PCL(I)
  909 FORMAT(1X,I4,5(5X,F6.1))
      IF(I.LT.5.)WRITE(10,910)I,DCL(I),HGT,BCL(I),VCL(I)
      IF(I.LT.5.)WRITE(11,910)I,DCL(I),HGT,BCL(I),VCL(I)
  910 FORMAT(1X,I4,4(5X,F6.1))
C
   98 I =  I + 1
      DU = I + 0.5
      DL = I - 0.5
      GO TO 96
```

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 ....................... ',I4,//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 RESPS1(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.')
      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.')
      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).
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)
      ZXN=DBLE(BL)
      ZFXN=ZFCV(ZXN)
      IF(ZFXN.LT.0.D0)GO TO 30
      IER=2
      IF(IFLAG.EQ.0)GO TO 20
      IER=3
      RETURN
   20 X1P=X1P+.01
      GO TO 10
   30 ZXN1=DBLE(TL)
      ZFXN1=ZFCV(ZXN1)
      IF(ZFXN1.GT.0.D0)GO TO 40
      IER=2
      IFLAG=1
      X1P=X1P-.01
      GO TO 10
C
   40 DO 60 J=1,5
      ZTEMP=(ZXN+ZXN1)/2.D0
      ZFTEMP=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.
```

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*****NUMBERICAL INTEGRATION (HAFLEY ET AL. 1982.  NC STATE UNIV.
C     TECH REPORT 1).
C
      FUNCTION GAUS (F,A,B)
      DIMENSION C(10),D(10)
      EXTERNAL F
C
      DATA    C/.0765265,.2277858,.3737061,.510867,.6360537,.7463319,
     &           .8391170,.912234,.9639719,.9931286/
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
```

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, fe
           t)."
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)

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```
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)

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```
               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)

```
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               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
```

```
     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-------------------------------------------------------------------------
```

```
      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)

```
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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
```

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```
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:
```

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```
      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)

```
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1700  REM***>> CALCULATE MERCH VOL AS A RATIO OF TOTAL VOLUME (BURKHART 1977).

1710  PCL(I%)=VCL(I%)*(1-.32354*((4^3.1579)/(DL^2.7115)))
1720  SCL(I%)=VCL(I%)*(1-.32354*((6^3.1579)/(DL^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
```

```
     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:
```

```
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      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#:
```

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```
      GOSUB 2410:
      FXN1#=FVAL#
2260  IF
         FXN1#>0
            THEN
               GOTO 2270
            ELSE
               IER%=2:
               IFLAG%=1:
                  D1P=D1P-.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:
      G1#=GAMMA#
```

BASIC LISTING (continued)

```
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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
```