ECONHDWD:

A MODEL FOR THE ECONOMIC ASSESSMENT OF REDUCING HARDWOOD COMPETITION IN UNTHINNED LOBLOLLY PINE PLANTATIONS

by

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<u>PREFACE</u>

This bulletin presents a model to aid in making hardwood competition control decisions for unthinned loblolly pine plantations. The model is written for Windows operating systems. Those wishing to obtain copies of the software should contact:

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To defer the cost of development, a charge of $60.00 will be made for the executable code. Checks should be made payable to the Department of Forestry, VPI.

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 Tech nor the authors claim any responsibility for any errors that do arise.

ECONHDWD is based on the original HDWD model of Burkhart and Sprinz (FWS-3-84). Attached to this document is the original HDWD documentation providing details of the original work.

ABSTRACT

A model, called ECONHDWD, for assessing the economic consequences of vegetation management on the pine component of unthinned loblolly pine plantations was developed from the stand model (HDWD) of Burkhart and Sprinz (1984). Input requirements include stand information, utilization conversions and limits, costs, prices and discount rate. Stand and stock tables for the planted pine component are produced for stands with and without reduction in hardwood competition; users can also obtain an estimate of the volume in hardwood pulpwood. In addition, for a specified pulpwood or sawlog regime, an economic analysis can be obtained which includes net and gross harvest value, net present value, internal rate of return and the marginal rate of return on the hardwood reduction operation.

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Dr. Brian Greber, Oregon State University, provided assistance and advice on the economic analysis aspects of program ECONHDWD. We also gratefully acknowledge the assistance of Olga Avila, Graduate Research Assistant at Virginia Tech, for the derivation of equations to predict hardwood volume.

ECONHDWD:
A Model for the Economic Assessment of Reducing Hardwood Competition in Unthinned Loblolly Pine Plantations

Objective

Interest in vegetative management is increasing as the number of established pine plantations on cutover sites increases. Management decisions concerning the amount and timing of early reduction of hardwood competition require information regarding the biological and economic consequences of hardwood reduction on the residual stand over time. The objective of this bulletin is to present and describe a model for assessing the biological and economic consequences of reducing hardwood competition in unthinned loblolly pine (*Pinus taeda* L.) plantations.

Background

Burkhart and Sprinz (1984) presented a model for predicting the biological effects of hardwood competition on pine survival, growth and yield. Using that model as a base, ECONHDWD was developed to assess the economic feasibility of various vegetation management strategies.

ECONHDWD is an interactive program that provides yield and economic predictions for the planted component of unthinned loblolly pine plantations under various vegetative management strategies. Users can also obtain an estimate of hardwood pulpwood in these plantations.

Limitations in the use of ECONHDWD exist due to the data available, modeling methodology used and assumptions made with the underlying model. The limitations are as follows (Burkhart and Sprinz 1984):

1. The levels of hardwood competition cannot be related to specific treatments. The proportion of basal area in hardwoods must be input by the user 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 are 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.

A range of analyses can be performed on reducing hardwood competition at the time of site preparation or after stand establishment. Analyses involving costs from site preparation techniques designed to reduce hardwood competition can be accomplished by assigning those costs to the cost of hardwood reduction. Similarly, analyses of reducing hardwood competition after stand establishment can be performed provided that stand development in the released stand can be assumed to be the same as in a plantation with the same level of hardwood competition that has not received the release treatment. Since hardwood reduction treatments occurring after age 9 may result in the release of pine, only hardwood reduction treatments occurring prior to age 10 can be evaluated using ECONHDWD.

In this bulletin, the inputs required, output obtained and program details for ECONHDWD are discussed. Information on the data and modeling methodology for the stand model (HDWD) can be found in Burkhart and Sprinz (1984).

Modifications to HDWD

Several modifications were made to the growth and yield model HDWD when structuring ECONHDWD. Since HDWD was developed and published, additional plot remeasurement data have been collected and used to reestimate the parameters in the site index equation. The updated parameter estimates, which follow, were incorporated into ECONHDWD:

$$\ln H_d = \ln SI\ (25/A)^{-0.02205}\ e^{-2.83285(1/A-1/25)}$$

where:

H_d = average height of dominant and codominant trees (ft)
S = site index (ft at base age 25 years)
A = age (years)
ln = logarithm base e

Subsequent to the release of HDWD, more appropriate individual tree volume and volume ratio equations from dominant, codominant and intermediate trees in cutover, site-prepared loblolly pine plantations have been developed (Amateis and Burkhart 1987). These equations were incorporated into ECONHDWD.

Information (Burkhart and Bredenkamp 1989) on the proportion of trees by dbh class qualifying as sawtimber was also incorporated into ECONHDWD. For the sawtimber regime, a decreasing proportion of trees in the 8 to 15-inch dbh classes is designated as pulpwood material. This is an attempt to recognize that a varying proportion of trees in these dbh classes are not sawlog quality. The percentage of trees categorized as pulpwood in the sawtimber regime is as follows:

Dbh class (in.)	Percentage
≤7	100.0
8	51.2
9	27.4
10	16.3
11	10.0
12	6.3
13	4.0
14	2.5
≥15	0.0

An estimate of the volume in hardwood, in addition to the stand and stock tables for pine, was added to the growth and yield model. Assuming that hardwoods in cutover-site plantations will be utilized for pulpwood, an estimate of the cubic-foot volume, outside bark, for all hardwood trees in the 5-inch dbh class and above to a 4-inch top diameter (ob) was desired. Volume for hardwoods was computed, by species group, using the equations from Bowling et al. (1989); volumes for volunteer pines were computed using the volume equations in Amateis and Burkhart (1987).

Data from a hardwood conversion/site preparation study at the Fayette Experimental Forest of the Auburn University Agricultural Experiment Station in Fayette County, Alabama, were used to develop an estimate of the basal area of the nonplanted pine component of plantations. We assumed that the basal area for old field loblolly pine plantations represents an upper limit of stand basal area and used the following equation (Burkhart and Sprinz 1984) to estimate this upper limit:

$$\log B = 0.38749 + 1.121332 \log H_d + 0.975619/A - 92.324443/T_s \quad (1)$$

where:

- B = basal area (sq ft/ac) of loblolly pine plantations on old field sites
- H_d = average height of dominants and codominants (ft)
- A = plantation age (years)
- T_s = number of trees/ac surviving
- log = logarithm base 10

Then the following model was postulated:

$$Y = X_1 + ß_1 X_2 + e_i \quad (2)$$

where:

- Y = upper limit of stand basal area (estimated from equation (1))
- X_1 = observed basal area of pine (sq ft/ac)
- X_2 = observed basal area of hardwood (sq ft/ac).
- e_i = random error

Model (2) was fitted to the Fayette data using linear regression techniques and resulted in the following equation:

$$Y - X_1 = 1.5 X_2 \qquad (R^2) = 0.87 \quad (3)$$

Rearrangement leads to:

$$X_2 = \frac{Y - X_1}{1.5} \quad (4)$$

As an independent validation, basal area of hardwood was predicted with equation (4) for the 186 control plots in the VPI & SU Coop Thinning Study data set. In cases where predicted hardwood basal area was less than zero, the value was set equal to zero. Comparing predicted basal area of hardwood to the observed basal area of hardwood gave a mean residual (observed-predicted) of 1.59 square feet per acre. Plots of residuals versus age, site index (for pine), basal area of pine and basal area of hardwood revealed no strong patterns. Thus equation (4) was accepted and incorporated into ECONHDWD.

A stand volume function of the following form was desired:

$$V = ß_0 + ß_1(B_h)(H) + e_i \quad (5)$$

where:

- V = cubic-foot volume per acre of hardwood
- B_h = basal area of hardwood (sq ft/ac)
- H = stand height (ft)
- e_i = random error

Plotting average height of hardwood versus average height of dominant and codominant pines revealed a strong linear relationship. Since average height of dominant and codominant pines is an output of the stand model HDWD, it was used as the predictor variable in equation (5). Fitting equation (5) resulted in the following equation:

$$V = -20.86 + 0.2452(B_h)(H_d) \qquad (R^2 = 0.71) \qquad (6)$$

where:

V = cubic-foot volume per acre (ob) in the 5-inch dbh class and above to a 4-inch top (ob).

Equation (6) is used in ECONHDWD to predict volume per acre in hardwoods given basal area of hardwoods (B_h) in square feet per acre and average height of the dominant and codominant planted pines (H_d) in feet.

THE ECONHDWD ENVIRONMENT

The ECONHDWD software allows the user to quickly and easily setup, execute and analyze various decision scenarios. It can be run on any computer with Windows 95 or newer operating system. Interaction with the model follows the usual Windows conventions. Output from the stand/stock table can be copied to the Windows clipboard and pasted into other applications for additional analyses.

INPUT PARAMETERS TO ECONHDWD

Input parameters to ECONHDWD supplied by the user are entered in the fields to the right of the labels. Parameters must be specified at the start of an ECONHDWD session and can be changed at any time. Saving an ECONHDWD session will save the last set of parameter estimates defined by the user. For details about entering data using the mouse or keyboard, see the online help under "Entering Input Data". Below are brief descriptions of each input parameter.

Stand Condtions

The six stand parameters are: (1) number of loblolly pine planted, (2) site index (base age 25), (3) stand age (age at which a yield prediction is desired and it is also used as the harvest age for the economic analysis), (4) Hardwood control (selecting NO produces only one stand/stock table which does not reflect controlling any hardwoods; selecting YES produces two stand and stock tables in the output. The first reflects no control and the second reflects the effect of controlling hardwoods by the percent of hardwood basal area removed due to control), (5) percent of the total stand basal area in hardwoods, (6) percent of the hardwood basal area reduced due to hardwood control, (7) age of hardwood control.

Merchantability / Conversions

There are eight merchantability and conversion parameters for ECONHDWD. They are: (1) cubic feet (outside bark) per cord for pine, (2) cubic feet (outside bark) per cord for hardwood, (3) board feet per cubic foot (outside bark), (4) minimum dbh for total yield (inches), (5) minimum dbh for pulpwood (inches), (6) minimum dbh for sawtimber (inches), (7) minimum outside bark top diameter for pulpwood (inches), (8) minimum outside bark top diameter for sawtimber (inches).

Economic Choices

In the Options menu, selecting the "Include Economic Analysis" option displays the ECONOMIC CHOICES parameter list. This parameter list consists of two user defined variables. The first is Saw/Pulp analysis. This variable is for deciding whether the economic analysis will be performed for a pulpwood or sawtimber product objective. If pulpwood is selected, all merchantable volume is assumed to be pulpwood and only pulpwood prices and costs are applied. If sawtimber analysis is selected, the stand volume is merchandized into both solid wood products and pulpwood according to the specified dbh and top limits of each. Topwood from the sawtimber-sized trees is assumed to be merchandized as pulpwood and included in the pulpwood volume.

The second economic choice is to include or not include the pulpwood-sized value of hardwoods in the analysis. Selecting NO does not include the value of hardwoods. Selecting YES includes the value of hardwoods in the analysis.

Costs

There are eight costs needed by the economic model:

- Site preparation costs ($/acre)
- Seedling costs ($/thousand).
- Planting costs ($/acre).
- Hardwood reduction costs ($/acre)
- Harvest costs for pine pulp ($/cord) - this is the harvesting and hauling costs associated with obtaining the pine pulpwood. If this cost is specified, then prices should be F.O.B. mill price. If this cost is set to zero, then prices should be stumpage prices.
- Harvest costs for hardwood pulp ($/cord) - this is the harvesting and hauling costs associated with obtaining the hardwood pulpwood. Again, prices should be F.O.B. mill price if this cost is specified as other than zero. If it is zero, then prices should be stumpage prices.
- Harvest costs for sawtimber ($/MBF) - this is the harvesting and hauling costs associated with obtaining the pine sawtimber. Prices should be F.O.B. mill price if this cost is specified as other than zero. If it is zero, then prices should be stumpage prices.
- Maintenance costs ($/acre/year) - this is the annual maintenance cost.

Prices and Rates

There are three prices plus the discount rate needed by the economic model:

- Pine pulpwood price ($/cord) - if the harvest cost of pine pulpwood is other than zero, then this price is F.O.B. mill. Otherwise it is a stumpage price.
- Hardwood pulpwood price ($/cord) - if the harvest cost of hardwood pulpwood has been specified as other than zero, then this price is F.O.B. mill. Otherwise it is a stumpage price.
- Pine sawtimber price ($/MBF) - this is the price for pine sawlogs. Again, it is F.O.B. mill when the harvest/haul cost is not zero. If the harvest/haul cost for sawtimber is zero, then this price is a stumpage price. It should be noted that the price per MBF can be modified easily to account for different log rules.
- Discount rate (percent) - this should be the real rate when prices and costs are not adjusted for inflation. Otherwise, a nominal rate should be used.

Graphing Output

By selecting the "Include Diameter Graph" menu option the user can view graphically the results from the growth model. It is possible to view the distribution of number of trees, total height, total volume, pulpwood volume or sawtimber volume by dbh class. To view a comparison graph of the control versus the no control for the chosen distribution, select the overlay option.

Stand/stock table output

Stand and stock tables are displayed for unthinned pine stands without and with (if specified) reduction in hardwood competition. Stand summary information, including number of planted pine (trees/ac), site index, percent basal area in hardwood and stand age is presented at the top of the stand and stock table. Then stand and stock tables, using 1- inch dbh classes and totals where appropriate, are given with the following information:

Number of surviving pine (tree/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)

For a pulpwood economic analysis regime, the pulpwood yield of planted pine according to the minimum dbh and maximum top diameter specified (cu ft/ac) is shown.

For a sawlog economic analysis regime, the merchantable yield (cu ft/ac) is divided between the sawlog and pulpwood (including topwood) portions to the minimum dbh and maximum top diameters specified.

Arithmetic mean dbh of all pine trees 1 in. dbh and greater (in.)

Hardwood pulpwood volume of all hardwood trees in the 5-inch dbh class and above to a 4-inch top diameter (cu ft/ac).

Stand/Economic summary table

Following the stand and stock tables, a table of stand and, if specified in the input, before-tax economic summary characteristics is displayed for the specified management regime. Values for the pine and hardwood component of stands without and with (if specified in the input) reduction in hardwood competition are given for the following:

Stand Characteristics

Arithmetic mean dbh of all trees 1- inch dbh and greater
Number of surviving pine (trees/ac)
Total basal area of pine (sq ft/ac)
Yield according to the management scenarios and limits specified (cu ft/ac)
Hardwood yield (pulpwood, cu ft/ac)

Economic Characteristics

Gross value at the time of harvest ($/ac) of the timber without consideration of harvesting and hauling costs
Net value at the time of harvest ($/ac) of the timber after harvesting and hauling costs have been deducted
Net present value of discounted net costs and revenues to age zero ($/ac)
Internal rate of return (%)
Rate of return (%) on the hardwood control operation

The economic analysis is based on a before-tax comparison of costs and prices associated with and without reducing hardwood competition. The discounted cash flow criteria (i.e., net present value and internal rate of return) are based on a year zero reference point. This means that the net present value of the treated stand is at the time of planting, or year zero. Both planting and site preparation are assumed to occur in year 0. The rate of return on the hardwood control operation is a calculated value based on incremental changes in costs and net value between the control and no control operations. It reflects the marginal rate of return of performing the hardwood reduction operation. All cash flows are on a pre-tax basis. Finally, it should be noted that the economic analysis is for one rotation (not infinite rotations).

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

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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 contact:

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To defer the cost of development, a charge of $60.00 will be made for the software. Checks should be made payable to "Department of Forestry" Virginia Tech".

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 Tech, the Department of Forestry, nor the authors claim any responsibility for any errors that do arise.

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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-sits 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 originally 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. Subsequently, a new computer program with enhanced model components and an economic evaluation component has been developed for Windows operating systems.

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

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.)[2]			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	48.8	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.

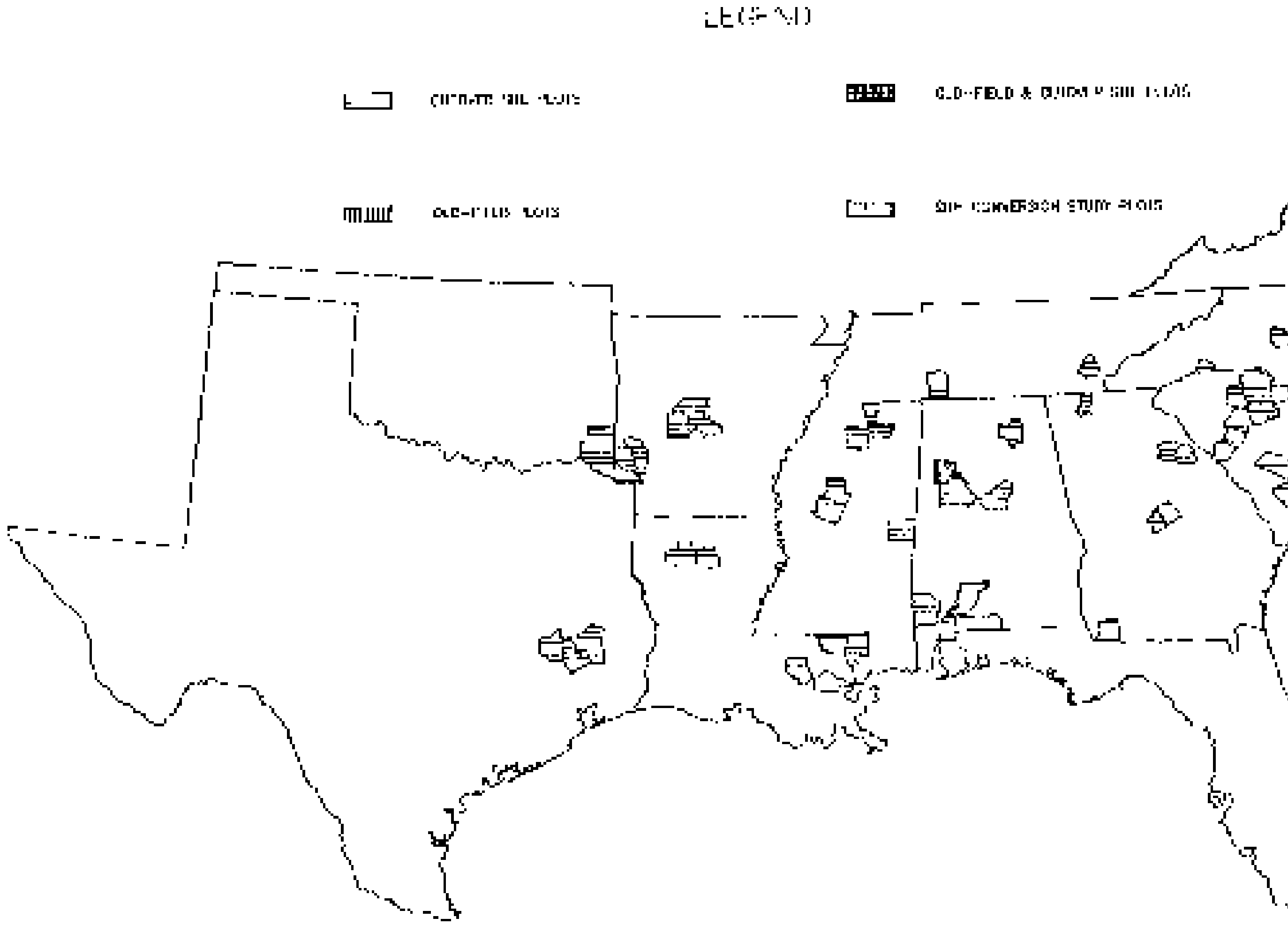

Figure 1. Map showing distribution of sample plots used to model hardwood competition effects on loblolly pine plantation yields.planted pine stems per acre which appear "free to grow," not more than 25 percent of the main canopy composed of volunteer pines, and established on a cutover area that received "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 1inch dbh classes only.

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).

<u>Conversion-Study Plots</u>

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

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

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

where

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
0 = 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)

<u>Diameter Distribution</u>

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 □ 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 <u>a</u> parameter is the "location" parameter; it indicates the lower end of the diameter distribution. “Spread” in the diameter distribution is controlled by the <u>b</u> parameter, while the “shape” of the distribution is determined by <u>c</u>.

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:

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

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

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

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

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:

$$D_{minCO}=D_{minOF}\ \exp(-(B_H^{0.000427}\ (-0.595414 \ln B_L + 6.90102/A + 0.738295 \ln H_d)))$$

where

D_{minCO}= minimum diameter (inches) for cutover-site plantation

D_{minOF}= 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

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

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 (D^2) (T_S) (0.005454).) The following function was fitted by nonlinear least squares:

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

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 ($\overline{D}_{CO}$) is computed as:

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

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:

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

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

$$y = -3.4929 + 0.97107 x$$

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

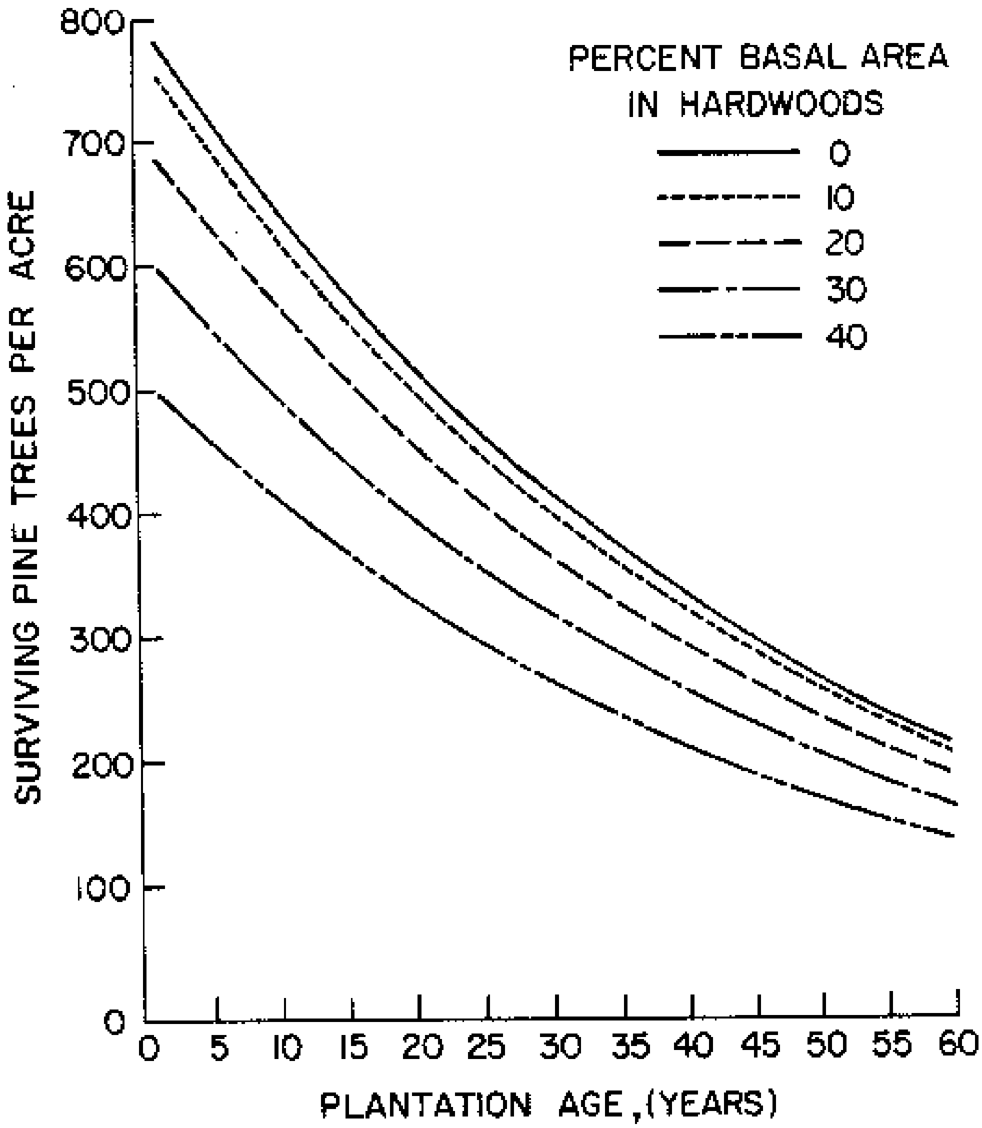

Figure 2. Surviving loblolly pine trees per acre as related to percent of basal area in hardwood. Figure is for 800 trees per acre planted.

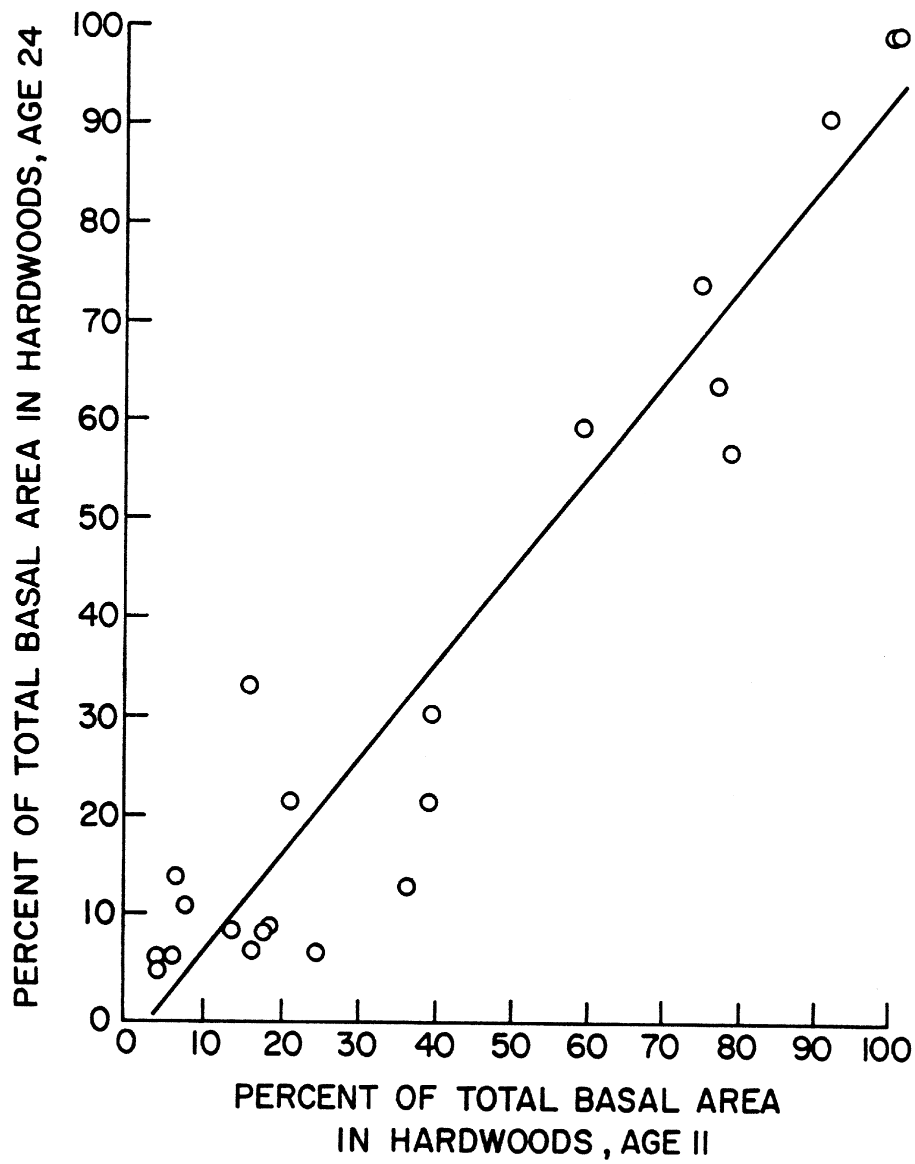

Figure 3. Relationship between percent basal area composed of hardwoods in the main canopy of loblolly pine plantations at ages 11 and 24 in a hardwood conversion/site preparation study, Fayette County, Alabama.

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 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.

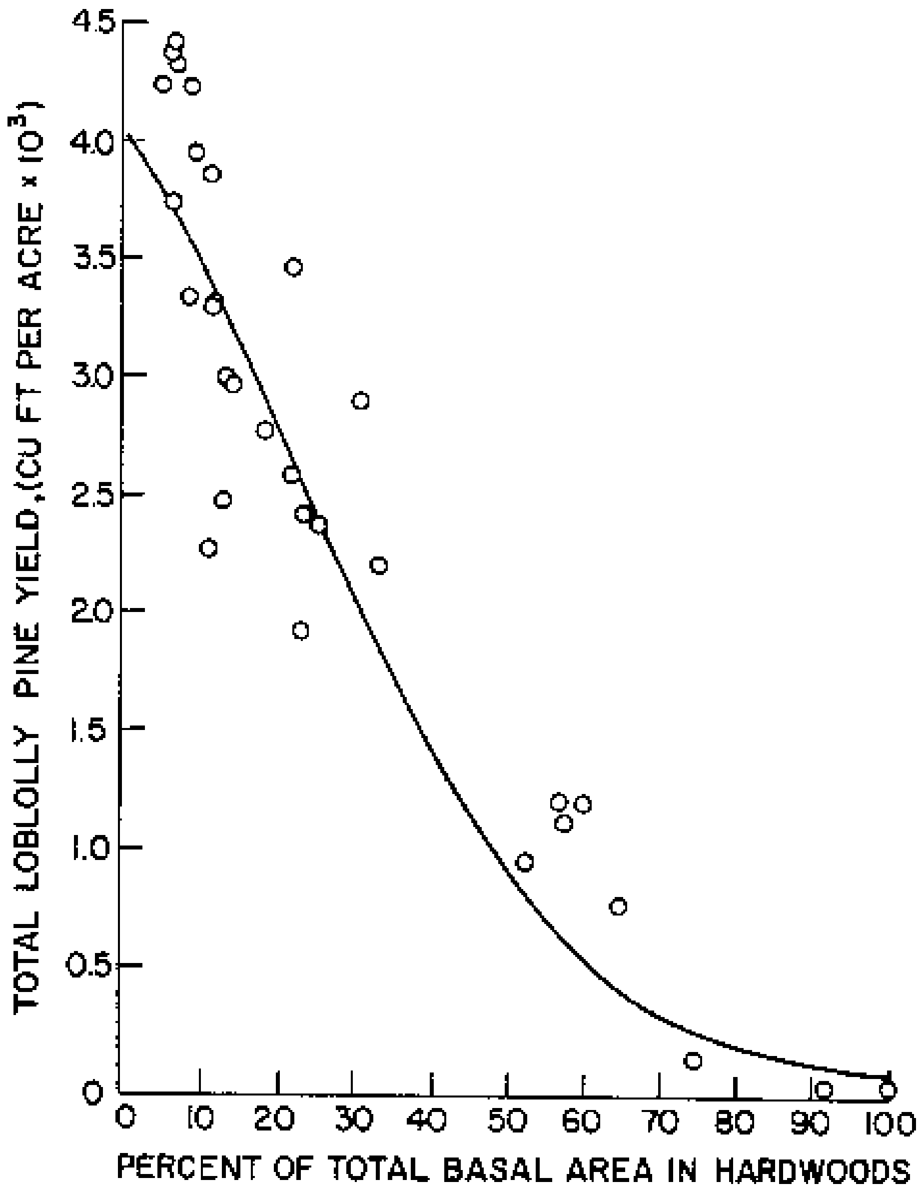

Figure 4. Total yield of loblolly pine versus percent of total stand basal area in hardwood from plot observations in a hardwood conversion/site preparation study in Fayette County, Alabama. This line represents predictions from program HDWD.

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	1119.6	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

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	0.8	25.3	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	65.3	14.8	429.9	373.2	
8	41.7	68.5	14.4	434.5	394.7	291.1
9	23.2	71.3	10.7	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.

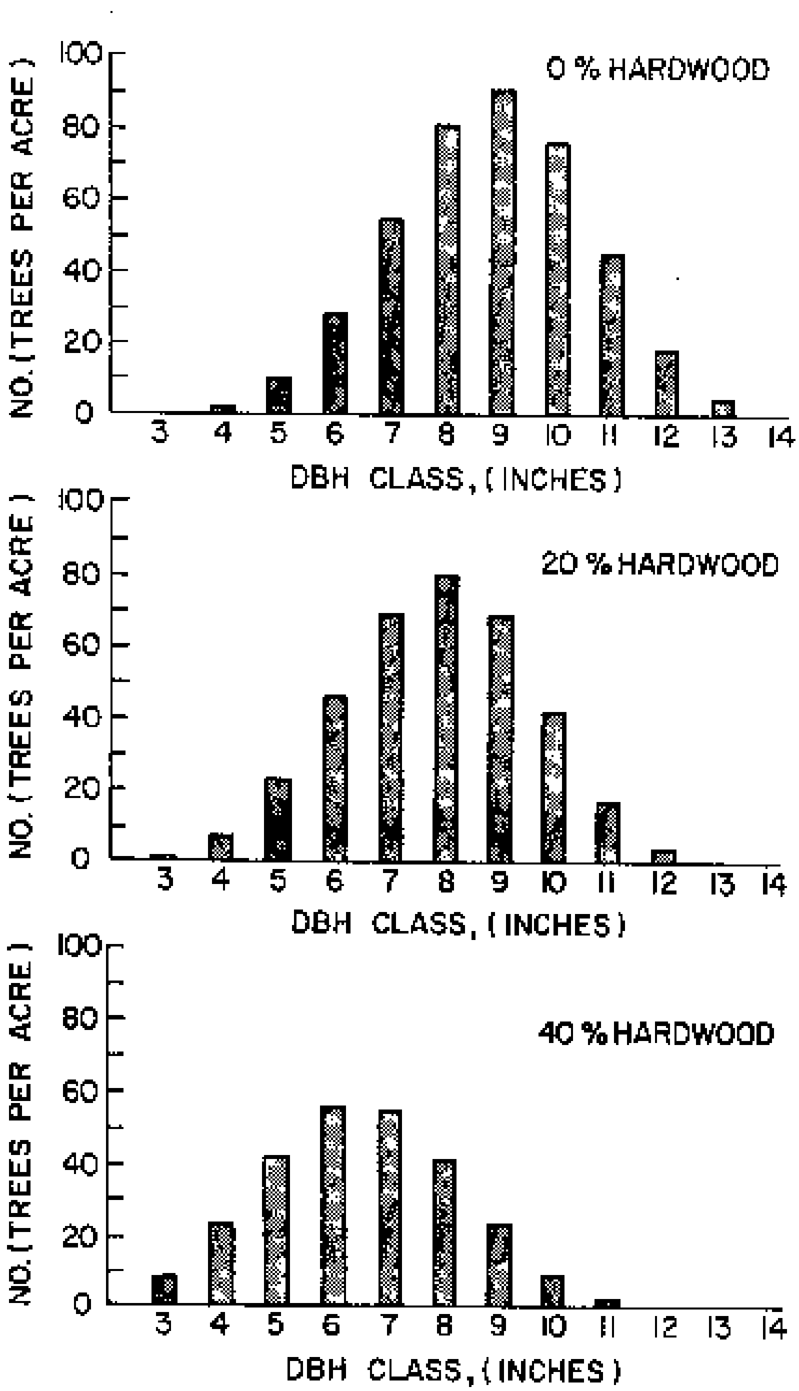

Figure 5. Pine dbh distribution for 0, 20, and 40 percent of the total stand basal area in hardwood. These histograms are for age 30 with 800 trees per acre planted on site index 60 (base age 25 years) land.

LIMITATIONS

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