Growth and Yield of Appalachian Mixed Hardwoods After Thinning

Publication No. FWS-1-86

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

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by

Wade C. Harrison
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PREFACE

This paper presents an individual tree, distance independent growth and yield model, and software for implementing the model, for Appalachian mixed hardwoods after thinning. Research was funded by the USDA Forest Service Southeastern Forest Experiment Station under Cooperative Agreement 18-962. Those wishing to obtain copies of the software (G-HAT) should write to:

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Indicate whether FORTRAN G-RAT or BASIC G-HAT is desired. To defer the cost of postage and handling, a charge of $20.00 will be made for a card deck of the FORTRAN software **or a** diskette containing the FORTRAN and/or BASIC software. Checks should be made payable to the Department of Forestry, **VPI &** SU.

Although the software presented 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, the U. S. Forest Service, nor the authors claim any responsibility for any errors that do arise.

ACKNOWLEDGEMENT'S

The authors wish to express their gratitude to Westvaco Corporation for allowing the use of its computer facilities in the completion of software development, and to Ernest H. Bowling for substantial contributions in the development of individual tree yield models.

ABSTRACT

G-RAT (growth of Hardwoods After **Thinning**) is a system of computer programs used to predict growth and yield of Appalachian mixed hardwoods after thinning. Given a tree list or stand table, along with inputs of stand age, site index, and stand basal area before thinning, G-RAT software uses species-specific individual tree equations to predict tree basal area increment and total height for the residual stand. Cubic foot volumes, based on desired merchantability standards, may be obtained for thinned trees, the residual stand, and the projected stand. G-RAT is available as a self-contained, interactive program (BASIC G-RAT) or as a library of FORTRAN subroutines (FORTRAN G-RAT). BASIC G-RAT, for personal computers, is designed for interactive, user-friendly sessions with keyboard input and screen output. Its use requires no programming ability. FORTRAN G-BAT is compatible with mainframe computers, minicomputers, and personal computers. It consists of modular subroutines which allow considerable flexibility in application, such as interface with computerized timber inventory systems and stand simulators.

AUTHORS

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TABLE OF CONTENTS

GROWTH AND YIELD
OF APPALACHIAN MIXED HARDWOODS
AFTER THINNING

Wade C. Harrison, Harold E. Burkhart, Thomas E. Burk, and Donald E. Beck

INTRODUCTION

Appalachian mixed hardwoods predominate on an estimated 26 million acres in the eastern United States. The high growth rates and high-value species found in these stands make this forest type more profitable for the management and production of timber than any other in the Appalachian region (Trimble, 1973; Smith and others, 1983). Sound management of Appalachian mixed hardwoods, including thinning for intermediate cash flows and stand improvement, must rely on growth and yield models for evaluating growth response and economic returns. The diverse mixture of species occuring in these stands creates a need for both species and size class resolution in model predictions.

G-HAT (Growth of Hardwoods After Dinning) is a system of computer programs implementing an individual tree, distance independent growth and yield model for Appalachian mixed hardwoods after thinning. Because it is an individual tree model, it provides both species and size class resolution. It operates in a distance independent mode and thus individual tree locations or inter-tree distances are not required. Given a tree list or stand table, 'along with inputs of stand age and site index, G-HAT software applies the species-specific individual tree equations developed by Harrison and others (1986) to predict tree basal area increment and total tree height for the residual stand after thinning. Cubic foot volumes (Burk and others, 1986) based on desired merchantability standards, may be obtained for thinned trees, the residual stand, and the projected stand.

DATA

Data used in model devolopment consisted of two measurements from 66 permanent sample plots. The plots lie within the Blue Ridge physiographic province (Braun, 1950) of Virginia, North Carolina, Tennessee, and Georgia, and are sizes 0.15, 0.20 and 0.25 acre. Criteria for plot selection required that they occur in unharvested, even-aged, mixed-species stands on productive sites such as coves and moist slopes. Smith and others (1983) place such stands in the Appalachian mixed hardwood type.

Site indices for the plots were determined from selected dominants and codominants, and standardized to that of white oak using Doolittle's (1958) species conversions. Site indices for all oaks were computed with the following equation (after Olson, 1959):

$$\ln(S) = \ln(H_d) + 22.0217\ (1/A_s - 1/50)$$

where: S = site index (feet), base age 50
H_d = average height of dominants and codominants (feet)
A_s = stand age (years), assumed to be breast height age plus four years.
ln denotes natural logarithm.

During the first measurement, 62 of the 66 plots were thinned in order to concentrate growth on high-value species and large, high-quality stems, and to improve spacing.' Apart from the removal of wolf trees, these objectives generally resulted in low thinnings. Yields from thinnings were merchantable, but commercial feasibility was not a requirement. Remeasurement of all plots occurred after five growing seasons. Individual tree data recorded at each measurement included species, dbh, and total height for trees of all crown classes competing in the main canopy. Stem profile data (heights and diameters at approximate four-foot intervals along the stem) were determined with a Barr and Stroud dendrometer at the first measurement. More complete descriptions of the data are given by Harrison and others (1986) and Burk and others (1986). A data summary for the 62 thinned plots appears in Table 1.

Table 2 presents the nomenclature and relative importance of all species present in the data, as well as the G-HAT abbreviation and numeric code for each species group.

Table 1. Data summary for 62 thinned plots in stands of Appalachian mixed hardwoods.

VARIABLE	MEAN	MINUMUM	MAXIMUM
Site index, base age 50 (feet).	80	62	96
Breast height age (years)			
at first measurement	40	19	58
at remeasurement	45	24	63
Dominant/codominant height			
at first measurement	72	45	93
at remeasurement	77	53	96
Stand basal area (square feet per acre)			
before thinning	113	83	193
removed in thinning (%)	47	11	74
at first measurement	60	28	107
at remeasurement	71	34	127
net growth	11	-12	26
Trees per acre			
before thinning	407	151	1517
removed in thinning	277	51	1167.
at first measurement	130	40	384
at remeasurement	125	40	384
mortality	5	0	45
Quadratic mean dbh			
before thinning	7.8	3.4	12.6
at first measurement	10.0	4.7	14.9
at remeasurement	11.0	5.9	15.9

Table 2. Species present in Appalachian mixed hardwood data. Number in parentheses is the mean percentage of plot basal area after thinning.

SPECIES	G-RAT ABBREVIATION	G-RAT NUMERIC CODE
Black Cherry Prunus serotina Ehrh. (4.3)	bc	1
Northern red oak Quercus rubra L. (16.9)	no	2
White oak Quercus alba L. (11.9)	wo	3
Yellow-poplar Liriodendron tulipifera L. (14.2)	yp	4
Black oak Quercus velutina Lam. (6.1)	bo	5
Magnolia Magnolia acuminata L. (3.3) Magnolia fraseri Walt. (0.4)	ma	6
Black Locust Robinia pseudoacacia L. (2.3)	lo	7
Basswood Tilia heterophylla Vent. (< 0.1)	bw	8
Birch Betula lenta L. (6.0) Betula allegheniensis Britton (1.1)	bi	9
Chestnut oak Quercus prinus L. (13.8)	co	10
Scarlet Oak Quercus coccinea Muenchh. (4.8)	so	11
Red Maple Acer rubrum L. (5.8)	rm	12
Miscellaneous Carya spp. (1.2) Ralesia monticola Sarg. (0.4) Fraxinus americana L. (0.3) Fagus grandifolia Ehrh. (0.2) Oxydendrum arboreum L. (0.2) Acer sacharrum Marsh. (0.1) Sassafrass albidum (Nutt.) Nees (0.1) Nyssa sylvatica Marsh. (< 0.1)	xx	13

MODEL COMPONENTS

G-HAT uses four types of individual tree equations to compute growth and yield estimates: basal area increment equations, a survival equation, total height equations, and volume prediction equations.

Basal area increment equations

Species-specific multiple linear regression equations were developed to predict individual tree periodic annual basal area increment over a five--year period as a function of original tree basal area, breast height age, and stand basal area. The equations are based on individual tree growth data from the 62 thinned plots. The model form and the coefficients for each species group appear in Appendix 1. Harrison and others (1986) give more information on the development of these equations.

G-HAT software projects tree size by predicting the periodic annual basal area increment for each tree (or dbh class) in the input data and multiplying this predicted annual increment by a desired projection period of one to ten years. (Predicted tree growth is therefore linear with respect to time and will be most accurate for five-year projection periods.)

Survival equation

A single nonlinear regression equation was developed, expressing the five-year probability of survival (S) for a tree of any species as a function of predicted annual basal area increment (G) in square inches. The equation is:

$$S = .90477 + .09523 [1 - \exp(-.7247 G)]$$

The regression model was constrained so that S would lie between some threshold value and 1. The resulting equation specifies the threshold as .90477, implying that at least 9 out of 10 trees will survive over the five-year period. To develop this equation, the individual tree data from the thinned plots (excluding trees that were cut or knocked down) were ranked in terms of G and then grouped into 15 classes, 14 classes of 100 trees each and 1 class (that containing the largest values of G) of 46 trees. S was computed for each class as the proportion of trees in the class surviving over the five-year period. A mean value of G was computed for each class. Weighted least squares was used in the nonlinear regression, since each of the 15 samples were assumed to be from a binomial population, with variance given by $S (1 - S)$.

For a desired projection period (t) of one to ten years, G-HAT software computes the predicted survival probability (St) with the following convention:

$$S_t = S^{t/5}$$

This convention implies that the survival probability over any number of years is the product of independent annual survival probabilities. All G-HAT software treats the predicted survival probability as a proportion. The number of trees represented by each item in a tree list or stand table is multiplied by this proportion, giving the surviving number of trees.

Total height equations

Species-specific nonlinear regression equations were developed to predict total tree height as a function of diameter at breast height (dbh) and average height of dominant and codominant oaks. These equations are based on all dbh and total height data from both measurements of the 66 plots. The model form and the coefficients for each species group appear in Appendix 1. Harrison and others (1986) give more information on the development of these equations.

Volume prediction equations

A species-specific volume prediction system was developed, expressing (1) total volume as a function of dbh and total height, (2) merchantable volume as a function of total volume, total height and merchantable height, and (3) diameter outside bark at any height on the stem as a function of total height and height on the stem. Coefficients for this system of equations were estimated simultaneously for each of nine species groups, using individual tree stem profile data available from the initial measurement of the 66 plots. The model forms and the coefficients for these species groups appear in Appendix 1. Burk and others (1986) give more information on the development of these equations.

With this volume prediction system, G-HAT software can accept merchantability standards in the form of any desired top limit (upper stem diameter, outside bark, or height to any point on the stem) and any desired stump height. When a top diameter limit is desired, G-HAT solves the taper equation (3) with a bisection algorithm to determine the height on the stem where the specified diameter occurs. Volumes may be computed as either inside or outside bark. Inside bark volumes are computed by using the species-specific ratios of diameter inside bark to diameter outside bark (as observed in the data), taken at, breast height. If the ratio is assumed constant throughout the stem, inside bark volume may be computed by multiplying the squared ratio by outside bark volume.,

MODEL APPLICATION

G-HAT software was designed to facilitate the use of the equations described above. BASIC G-HAT is an interactive program for personal computers which will project a stand table and compute stock tables for thinned stands. FORTRAN G-HAT consists of subroutines for each of the equations. These subroutines can be used as "modules" in other software systems, such as timber inventory systems, economic analysis programs, and long-range planning models. However, G-HAT software is not a requisite for applying these equations. Some users may wish to adapt them to their own software, or apply the growth and survival equations in developing growth-index ratios or move-factors for the stand-table projection technique (Avery and Burkhart, 1983).

Applying the equations to data in which stand conditions lie beyond the range of data used for model development (Table 1) may yield illogical results, particularly in projecting growth and survival. The equations are intended only for even-aged stands of Appalachian mixed hardwoods in which no single species constitutes more than 60 percent of the basal area. Projections should occur immediately after thinning and should not be attempted for stands which have been thinned from above, thinned more than once, or high-graded.

G-HAT SOFTWARE

BASIC G-HAT

BASIC G-HAT is designed for foresters and land managers with stand table data who wish to predict growth and yield after thinning for a single stand (or for several stands, one at a time). It is also useful for computing stock tables, as well as yields produced by various thinning methods. Given an existing stand table (numbers of trees per acre, by dbh class and species), BASIC G-HAT computes the corresponding stock table in terms of cubic foot volume to any merchantability limit. If the stand table represents an unthinned stand, the user may specify which trees to thin or BASIC G-HAT can perform a low thinning automatically. Merchantable cubic foot volumes for the thinned trees and the stand and stock tables for the residual stand are then displayed. After thinning, BASIC G-HAT will project the stand table for a period of one to ten years, displaying the stand's projected basal area, volume, and stand and stock tables.

BASIC G-HAT is an interactive, self-contained program for personal computers. Hardware and software required are:

Computer make and model	IBM PC personal computers or compatibles
Operating system	PC DOS or MS DOS (2.0 or higher)
Additional software	none
Minimum memory	128K
Floppy disk drives	1
Hard disk drive	optional
Printer	optional
Display	monochrome or color

BASIC G--HAT was written in IBM **BASICA** (version 3.0) and then compiled with the Microsoft **QuickBASIC** compiler (version 1.02). Because it is a compiled program (translated into machine language), a BASIC interpreter is not necessary. There are five files on the BASIC G-HAT diskette. The compiled program is in the file **G-HAT.EXE;** four additional files contain species-specific ceofficents for the various equations used by G-HAT: B.CF, **B2.CF,** H.CF, and V.CF. If desired, BASIC G-HAT may be copied onto another diskette, or a fixed disk. All five files must be copied and they must reside in the same directory. No printer is required to run BASIC G-HAT. Screen output may be directed to an **80-column** printer by simultaneously pressing the "Shift" and **"PrtSc"** keys whenever a printed copy is desired.

To run BASIC G-HAT, the diskette containing the software should be in the default disk drive with the computer running under DOS. To start the program, type "G-HAT." First, BASIC G-HAT will search for the four coefficient files on the default drive. If they are not found, the program will abort and return control to DOS. If the files are successfully found and read, the G-HAT title screen will appear, with the message "Press any key to continue." Figure 1 is a flow chart describing the subsequent operation of BASIC G-HAT. Escape from the program at any time by pressing the "Ctrl" and "Break" keys simultaneously.

User-supplied inputs to BASIC G-HAT are volume specifications (merchantability limits), breast height age of the stand (years), oak site index (feet at age 50) or height of dominant and codominant oaks (feet), stand basal area before thinning (square feet per acre) if input data represent a thinned stand or thinning criteria if the input data represent an unthinned stand, a stand table (trees per acre by species and dbh class), and projection period length. The user has considerable freedom in the nature of input data. However, extrapolation beyond the range of the data used in model development causes warning messages. Such extrapolation is not recommended and may yield illogical results. Note that once a stand table has been entered, it can be saved on disk under any filename and recalled later. There are several opportunities to save or recall existing stand tables, so that numerous thinning trials or projection period lengths can be tested without manually re-entering the stand table. Recalling a stand table from disk may take a few seconds to about a minute, depending on the size of the stand table and the speed of the computer. The delay is caused by the disk input and the computation of stock table volumes. During this or any other delay, a flashing message to "Please stand by . . ." is displayed.

Output from BASIC G-HAT includes displays of stand and stock tables after input and after projection. If input data represent an unthinned stand, the program displays merchantable cubic foot volumes removed in the simulated thinning (total and from each cell of the stand table) as well as the residual basal area and the new stand and stock tables. After projection, total stand basal area, basal area growth, merchantable cubic foot volume, and volume growth are displayed. BASIC G-HAT displays all projected information as integers (whole numbers). The model "grows" each original dbh class to a projected dbh with six significant digits, then rounds this projected dbh to the nearest one-inch class for display of projected stand and stock tables. Similarly, surviving number of trees is rounded to the nearest integer (the nearest whole tree per acre) in each cell of the stand table. Apart from these integer displays however, BASIC G-HAT retains six digits of accuracy in its arithmetic. Projected basal area and volume for the stand are computed using un-rounded values for projected diameters and surviving numbers of trees.

Printed screen output from a BASIC G-HAT session, with a detailed description of selected items, appears in Appendix 2. A listing of the source code (498 lines) for BASIC G-HAT is available from the authors upon request.

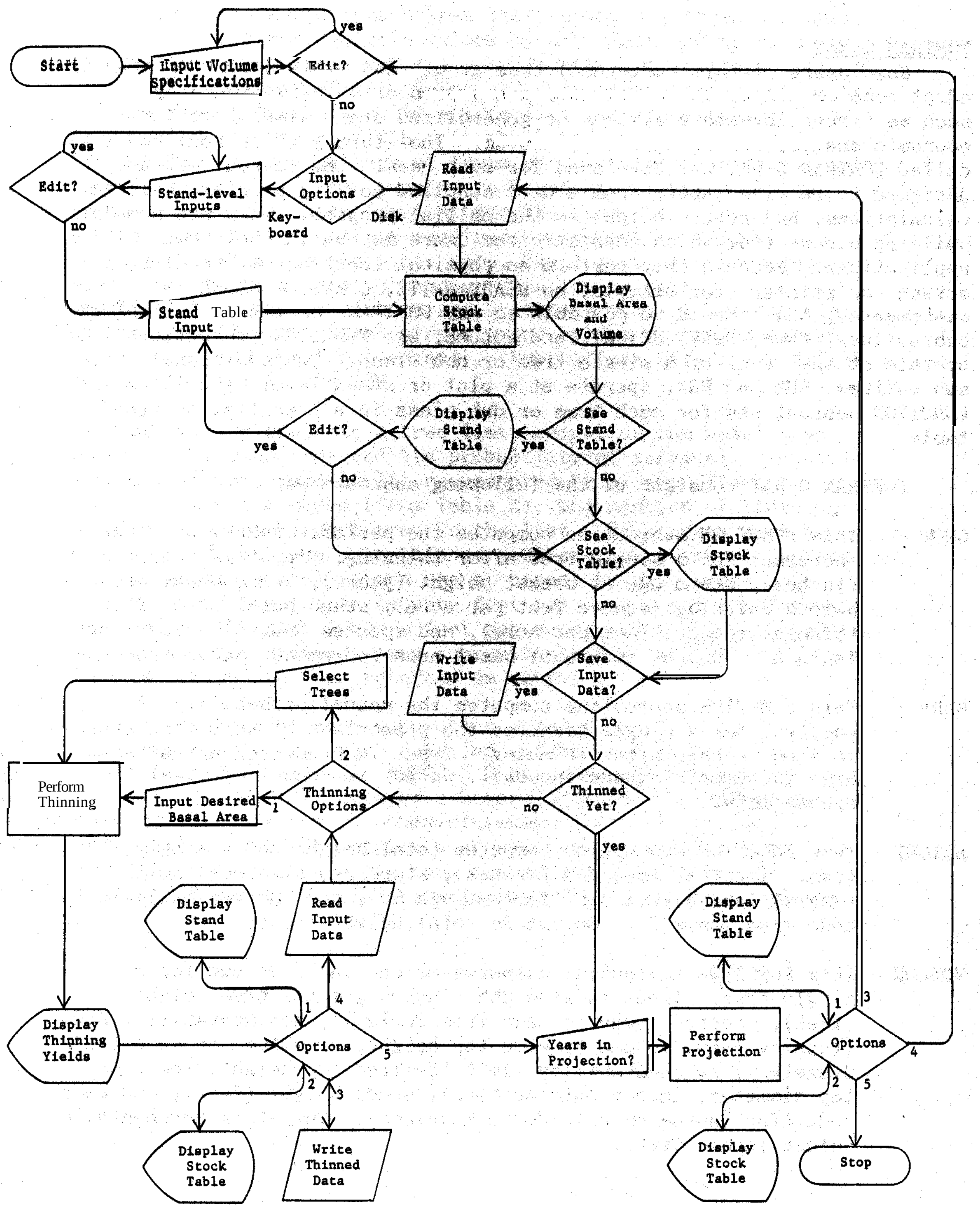

Figure 1. Generalized flow chart for BASIC G-HAT.

FORTRAN G-RAT

Some users of this individual tree growth and yield model may wish to adapt some or all of the model components into existing software systems, such as timber inventory systems or generalized stand simulators for economic analysis or management planning. The library of subroutines called FORTRAN G-RAT was developed for such uses. The subroutines are designed to receive inputs from a user-supplied calling program, perform calculations, and return output to the calling program. They are modular building blocks from which sophisticated users may build their own applications. Because they perform no physical input/output to disk, screen, or printer (for example, no READ, WRITE, OPEN, or CLOSE statements), they should be portable to any FORTRAN compiler. Four of the subroutines, GROW, SURV, HEIGHT, and VOLUME, are FUNCTION subroutines that operate at the level of a single tree or dbh class. Two additional subroutines, SUM and PRJ, operate at a plot or stand level by calling the FUNCTION subroutines for each tree or dbh class in a tree list or stand table.

FORTRAN G-HAT consists of the following subroutines:

GROW - This FUNCTION subroutine computes the periodic annual basal area increment for a single tree after thinning. Input is tree dbh (inches), stand age at breast height (years), stand basal area before thinning (square feet per acre), stand basal area after thinning (square feet per acre), and species (numeric code from Table 2). Output is annual basal area increment (square inches).

SURV - This FUNCTION subroutine computes the annual probability of survival for a single tree (or the proportion of surviving trees in a dbh class) after thinning. Input is predicted annual basal area increment (square inches). Output is annual survival probability.

HEIGHT - This FUNCTION subroutine computes total height for a single tree. Input is tree dbh (inches), stand age at breast height (years), oak site index (feet at age SO), and species (numeric code from Table 2). Output is total height (feet).

VOLUME - This FUNCTION subroutine computes merchantable volume for a single tree. Input is tree dbh (inches), total tree height (feet), species (numeric code from Table 2), merchantability code (total volume, volume to some top height, or volume to some top diameter), merchantability limit (desired top height, feet, or top diameter, inches outside bark), stump height (feet), and bark code (for inside or outside bark volume). Output is merchantable volume (cubic feet).

SUM - This subroutine summarizes a tree list, computing trees per acre, basal area, and merchantable volume by dbh class and species (separately and in combination), and for the entire stand. It is useful for summarizing both input and output data associated with a G-HAT projection. Input is a tree list (or stand table) represented by arrays of dbh's (inches), numeric species codes (from Table 2), and numbers of trees per acre represented by each tree in the list. Other inputs are stand age at breast height (years), oak site index (feet at age SO), and the same merchantability information required by subroutine VOLUME. Output variables are trees per acre, basal area per acre (square feet), and merchantable volume per acre (cubic feet). Additionally, these variables are broken down by l-inch dbh class and species (2-dimensional arrays), and by dbh class and species separately (l-dimensional arrays). Subroutines HEIGHT and VOLUME are called from within SUM.

PRJ - This subroutine projects a tree list, computing the basal area increment of each tree and its probability of survival. Input is a tree list (or stand table) represented by arrays of dbh's (inches), species codes (from Table 2), and numbers of trees per acre represented by each tree in the list. These data must be from a stand that was just thinned. Other inputs are projection period length (years), stand age at breast height (years), current stand basal area (square feet per acre), and stand basal area before thinning (square feet per acre). The original tree list arrays are updated using subroutines GROW and SURV. The updated arrays are then returned as output.

A documented listing of each subroutine appears in Appendix 3. Consult this documentation for more detailed information on input and output, and variable definitions. FORTRAN G-HAT subroutines were programmed in AOS/VS FORTRAN77 on a Data General MV10000 minicomputer. Implementation of the software on other minicomputers or mainframe computers with similar FORTRAN compilers should require little or no modification. The software has also been tested with the Microsoft FORTRAN and IBM Professional FORTRAN compilers on IBM personal computers.

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APPENDICES

Appendix la. Model form and species-specific coefficients for the individual tree periodic annual basal area increment equations.

MODEL: $G = a + b X_1 + c X_2 + d X_3$

where: G = periodic annual basal area increment over five years (square inches)

X_1 = original tree basal area, or original tree basal area divided by breast height age (square inches, or square inches/year)

X_2 = stand basal area after thinning (square feet/acre)

X_3 = stand basal area before thinning (square feet/acre)

a,b,c = species-specific coefficients.

Note: If $G < 0$, then G should be set equal to 0.

G--HAT ABBREVIATION[a]	a	b	c	d
bc	1.844	-1.396	-.0376	.0130
no	1.818	0.034[b]	-.0163	
wo	1.311	1.124	-.0169	
yp	1.332	1.386	-.0402	.0197
bo	1.874	1.299	-.0290	-
ma	0.320	1.441	-.0288	.0187
lo	1.991	1.020	-.0128	.0221
bi	0.305	0.965	-.0137	.0114
co	1.017	1.203	-.0151	-
so	2.155	0.041[b]	-.0313	-
rm	2.305	0.035[b]	-.0345	.0095
xx,bw	0.331	0.950	-.0293	.0188

[a] See Table 2.

[b] X_1 is original tree basal area (square inches).

Appendix lb. Model form and species-specific coefficients for the individual tree total height **equations.**

MODEL: $H = 4.5 + H_d [1 + a \exp(b H_d)] [1 - \exp(c D / H_d)]$

where: H = total height (feet)
H_d = height of dominants and codominant oaks (feet)
D = dbh (inches)
a,b,c = species-specific coefficients
exp denotes the base of the natural logarithm.

G-HAT ABBREVIATION[a]	a	b	c
bc	.0001	.07590	-17.628
no	.1967	-.00107	-10,530
wo	.0026	.04002	-14.601
yp	.1711	.00346	-13.123
bo	.0719	.00029	-16.562
ma	.1254	.00948	- 9.630
lo	.0074	.03738	-15.932
bi	-.0992	-.00930	-17.966
co	.2046	-.00957	“13.621
so	.0021	.04569	-16.322
rm	-.1587	-.04386	-17,833
bw,xx	.3197	-.00066	-9.761

[a] See Table 2.

Appendix lc. Model forms and species-specific coefficients for the individual tree volume prediction system.

MODELS:

(1) $v = (.1104435 / -a\ b.) (D^2 / H) [(H - 4.5) / 4.5]^{b+1} \exp\{ -a [4.5 / (H - 4.5)]^b\}$

(2) $V_m/V = 1 - \exp\{ a [h / (H - h)]^b\}$

(3) $d^2/D^2 = (h / 4.5)^{b-1} [(H - 4.5) / (H - h)]^{b+1} \exp\langle a \{ [h / (H - h)]^b - [4.5 / (H - 4.5)]^b\} \rangle$

where: V = total volume (cubic feet, outside bark)
D = dbh (inches)
H = total height (feet)
Vm = merchantable volume (cubic feet, outside bark)
h = upper stem height (feet)
d = upper stem diameter (inches, outside bark)
a,b = species-specific coefficients
exp denotes the base of the natural logarithm.

G-HAT ABBREVIATION[a]	a	b	dib/dob[b]
bc	-1.9213	.8750	.939
no	-1.7320	.7989	.929
wo	-1.7139	.7489	.937
yp,lo,ma,bw	-1.7427	.8540	.902
bo	-1.8988	.7965	,925
rm,bi	-1.8285	.8416	.934
co	-1.6334	.7959	.909
so	-1.7901	.7993	.939
xx	-1.7854	.8304	.927

[a] See Table 2.

[b] Average of observed ratio of dbh inside bark to dbh outside bark for each species group. If the ratio is assumed constant throughout the stem, inside bark volume may be computed by squaring this ratio and multiplying it by the outside bark volume.

Appendix 2. Example session of BASIC G-BAT.

Printed screen displays from an example session of BASIC G-BAT appear at the end of this appendix. The numbers below correspond to those found circled on the printed displays. (Each page of the example session contains 2 screen displays. To avoid repetition, some of the displays that would actually appear in this session have been omitted.)

1. Volume specifications. These specifications are applied to every tree in the input data. Merchantable volume outside bark to I-inch top diameter above a 6-inch (0.5 foot) stump has been indicated. If "h" rather than "d" had been entered for merchantability limit, the next response would have been for a height on the stem in feet. Total stem volume could have been requested by specifying outside bark volume to a O-inch top diameter above a O-foot stump. Stump height may be set as high as desired, if upper stem volumes are of interest. If BASIC G-HAT were to encounter a tree in which the specified top diameter was larger than 1.3 times dbh, or whose total height or specified top height was less than or equal to stump height, zero volume would be computed for that tree.

2. Input options. The first time BASIC G-BAT is run for any stand, the input data should be entered interactively at the keyboard. Later runs can utilize'data previously saved on disk.

3. Thinned or unthinned. If the stand table to be projected represents an unthinned stand, it must be thinned prior to projection. In this example, data from an unthinned stand will be entered and two methods of thinning will be explored.

4. Stand-level inputs. Necessary inputs are stand age (years at breast height) and oak site index (feet at age 50). If site index is unknown but height of dominant and codominant oaks is available, the user may give a null entry (just press "Return" or "Enter") for site index. The program will then request height of dominant and codominant oaks (feet). If a thinned stand had been specified above, stand basal area before thinning (square feet per acre) would be requested. This information is required for projecting tree growth for non-oak species. If the thinned stand table to be projected were predominantly oak, this information would be of little importance and the word "unknown" could be entered in response to this item. (CAUTION: if stand basal area before thinning is omitted prior to entering a thinned stand table, predictions of individual tree growth for non-oak species are computed using an alternate set of coefficients, estimated with a model form which lacks this predictor variable. Such predictions are likely to be biased.)

5. Stand table entry. As indicated on the stand table entry screen, the user enters a species code (abbreviation from Table 2), a dbh class (inches), and the number of such trees per acre at the arrow. Dbh classes should not exceed 30 inches and trees per acre should not exceed 999 (both should be entered as integers). Species codes must be one of the 13 listed on the screen. The "Return" or "Enter" key should not be pressed until all three items have been typed, separated by a space. After entering one such line, another arrow appears and the next entry may be typed. Any number of entries will be accepted; after a screen fills up (8 entries), another one appears and input may continue. While typing any entry, the backspace key may be used to back up and replace characters (this is true at any point in the program), but after an entry is completed, it cannot be edited until later in the program (see Additions and corrections below). Do not type in an entry that specifies the same species and dbh class as one already entered. Conclude entry of the stand table by typing the word "end." In the example, 3 screens were required to enter the stand table.

6. Summary of input data. After the stand table data are entered, the stand's basal area and cubic foot volume are displayed, and the stand table may be examined. The stock table has been computed and may also be examined, as shown on the next screens. If a table should have too many dbh classes to fit on the screen, a message to "Press any key" appears prior to displaying the bottom of the table. If a stock table contains more than 10 of the 13 species, it will be too wide to fit on the screen and will be displayed improperly. In the example, the stand and stock tables are small enough to fit on a single screen.

7. Additions and corrections. After displaying the stand table just entered, the user may elect to make changes or additions to the stand table. By answering "y" to the question ("n" was entered in the example), another stand table entry screen would appear, where the user could re-specify any entries that were incorrect, and include any additional ones that were left out. (Corrections are by replacement, not addition. For an incorrect entry "yp 12 10" that should have been "yp 12 25", the correct procedure would be to enter "yp 12 25" on the new entry' screen, rather than "yp 12 15".) Entering "0" for trees per acre will remove that entry from the stand table. Any stand table entries not respecified will remain as originally input. Exit the stand table entry screen with "end" just as before. Additions and corrections can be made as many times as necessary. Note that additions and corrections cannot be made if the user does not elect to view the stand table after concluding stand table entry. It is a good practice to examine a new stand table for this purpose. Some invalid entries, such as diameters or numbers of trees containing too many digits, may slip by the error-traps and result in errors in the stand table. Such errors can be identified and corrected at this stage of the program.

8. Saving the stand table. In the example, the currently unthinned stand table has been saved under filename "plotl.' This file will be created on whatever diskette is in the default drive. To place the file elsewhere, a more complete DOS file specification could have been entered (e.g. "c:\data\plotl" for a subdirectory on a fixed disk). If saving the stand table is not desired, a null entry (pressing "Return" or "Enter") will continue the program. If the input stand table had represented a stand already thinned, program control would now proceed to item 11 below (Projection period).

9. Thinning options - automatic thinning. In this example, the stand table will first be thinned by "automatic thinning.' (Later in the session, after reloading the data from disk, it will be thinned selectively. This options is described in item 13 below.) With "automatic thinning", the user inputs a desired residual basal area (in this example, 70 square feet per acre). A thinning algorithm within the program effectively removes one tree (per acre) at a time until the desired residual basal area is achieved. BASIC G-HAT assumes that the red maple and 'miscellaneous" species groups are undesirable; it removes all undesirables before the other species are considered for removal. Apart from this species criterion, thinning is from below. The thinning algorithm begins with the lowest dbh class in the stand table and first removes undesirables until this dbh class has been removed. Then the next higher dbh class is considered and the process is repeated. The algorithm continues through all dbh classes containing undesirables, lowest to highest. If the desired basal area has not been reached, the algorithm then returns to the lowest dbh class and begins removing desirable species (in reverse order of the species list in Table 2). Again, the dbh classes are thinned lowest to highest. Whenever the stand's residual basal area is computed as equal to or below the desired residual basal area, the thinning procedure stops, and a list of thinned trees by species and dbh class, with associated cubic foot volumes, is displayed.

10. Options after thinning. After thinning, the user may examine the current stand and stock tables, save the thinned stand table to disk, recall the unthinned stand table and thin a different way, or begin the growth projection. In the example, the current stand and stock tables are displayed,. then "Begin projection" is selected.

11. Projection period. Projection periods may vary from one to ten years, but dbh class projections are linear with respect to the predicted periodic annual increment. Hence, a one-year projection will indicate one-fifth of the tree growth in a five-year projection, and a ten-year projection will indicate twice the tree growth in a five-year projection. Mortality projections are compounded annually. In this example, five years has been chosen (the basis for model development).

12. **Options after projection.** After projection, the user may examine the projected stand and stock tables, recall a previously saved stand table for another projection, restart the program, or stop the program. Note that further projections are not allowed for a stand that has already been projected. The growth equations are inappropriate for this purpose. In this example, the user examines the stand and stock tables, then recalls the unthinned stand table for an alternative thinning and projection. Recalling the unthinned stand table from disk involves a short delay.

13. **Thinning options - selection.** The idealized thinning carried out above may not be appropriate for many stands, particularly if the user has information on stem quality, spacing, or species-specific market values unique to the area. Should this be the case, the second thinning option would be more appropriate. (CAUTION: Thinning criteria which differ drastically from those of a low thinning with some selection for species and stem quality constitute an extrapolation and may yield unreliable results.) In this example, the unthinned stand table (file "plotl") was reloaded, after which program control returned to item 6 above (Summary of input data). As before, the session proceeds to the pictured screen (thinning options). Option 2 is now selected. This option begins by allowing re-examination of the current (unthinned) stand table. At this point the user should make decisions on which trees to thin. In the example, the decision was to remove all trees with dbh under 7 inches, all black oak and chestnut oak under 8 inches, and also 10 of the 8-inch chestnut oaks (leaving 20 in the 8-inch class). Also, the 13-inch scarlet oaks are considered wolf trees and will also be removed. After examining the stand table, the 'Ready to begin thinning" option is selected. This thinning algorithm simply loops through the stand table, beginning with the least desirable species and the lowest dbh class. The user enters the number of such trees that should remain. (A null entry - pressing "Return" or "Enter" - leaves all of the trees in that species and dbh class). A running total of the stand's residual basal area is displayed as each stand table entry is thinned. The user may loop through the entire stand table as many times as necessary until the desired stand structure is achieved. In the example, only the first and last screens from this procedure are illustrated. Typing the word "end" stops the procedure. At this point, the program is displaying the 'I-inch dbh class for white oak. These trees are unaffected as the procedure is ended. The simulated thinning has reduced stand basal area to 64 square feet per acre. After the thinning, the list of thinned trees is displayed and the session continues as before with projection of the thinned stand.

14. **Stop.** Normal termination of BASIC G-RAT is by selection of option 5 on the "projection complete" screen. The program may be stopped at any other time by pressing the "Ctrl" and "Break" keys simultaneously. .

G-HAT - Growth of Hardwoods After Thinning

Version 3.0

An individual-tree based stand simulator for predicting the growth and yield of Appalachian mixed hardwoods after thinning,

Developed by

Virginia Polytechnic Institute and State University, Blacksburg VA.

USDA Forest Service Southeastern Forest Experiment Station, Asheville NC.

PRESS ANY KEY TO CONTINUE

VOLUME SPECIFICATIONS:

Cubic foot volumes may be inside bark or outside bark.
Enter 'ib' or 'ob': ob

Volumes may be estimated to *any* merchantability limit.
Enter 'd' to specify a top diameter,
or 'h' to specify a top height: d

Top diameter (inches, o. b.) for volume estimates? 4

Stump height (feet) for volume estimates? .5

```
Volumes (ob) estimated for a 4 - inch (ob) top.
Stump height .5 ft.


You may either (1) change the above, or
               (2) proceed with the program.


(Enter 1 or 2): 2
```

```
Stand table input choices:                          (2)

1.  Keyboard input - unthinned  stand.

2. Keyboard input - thinned  stand.       (3)

3. Disk input - thinned  or  unthinned  stand.

(Enter 1, 2, or 3): 1
```

Stand age (years at breast height)? 36

Oak site index (feet, base age 50)? 91

Stand about to be thinned:

Stand age: 36 years at breast height

Oak site index: 91 feet @ 50 years

Height of dominant/codominant oaks: 82 feet

You may either (1) change the above, or
(2) proceed with the program.

(Enter 1 or 2): 2

05

To input your stand table, enter the species code, dbh class,
and number of such trees per acre at each arrow.
Dbh class may not exceed 30. Please do not exceed 10 species.

(Separate the 3 entries by a space.)

For example: **==>yp** 10 20 means 20 lo-inch yellow-poplars per acre.
When finished, just enter the word 'end'.

SPECIES CODES:

bc=bl.cherry bi=birch **bo=bl.oak** bw=basswood co=chest.oak
lo=bl.locust ma=magnolia **no=n.red** oak rm=red maple **so=sc.oak**
wo=w. oak yp=y.poplar xx=other

==>xx 4 10
==>rm 5 15
==>co 5 50
==>co 6 20
==>co 7 15
==>co 8 30
==>co 9 10
==>bo 5 10

To input your stand table, enter the species code, dbh class,
and number of such trees per acre at each arrow.
Dbh class may not exceed 30. Please do not exceed 10 species.

(Separate the 3 entries by a space.)

For example: **==>yp** 10 20 means 20 lo-inch yellow-poplars per acre.
When finished, just enter the word 'end'.

SPECIES CODES:

bc=bl.cherry bi=birch bo=bl.oak bw=basswood co=chest.oak
lo=bl.locust **ma=magnolia** **no=n.red** oak rm=red maple **so=sc.oak**
wo=w . oak yp=y.poplar xx=other

SCREEN 2 (Continue input)

==>bo 6 20
==>bo 7 20
==>bo 8 15
==>bo 9 15
==>bo 10 10
==>yp 7 20
==>yp 8 30
==>yp 9 15

To input your stand table, enter the species code, dbh class, and number of such trees per acre at each arrow. Dbh class may not exceed 30. Please do not exceed 10 species.

(Separate the 3 entries by a space.)

For example: ==>yp 10 20 means 20 lo-inch yellow-poplars per acre. When finished, just enter the word 'end'.

SPECIES CODES:

bc=bl. cherry	bi=birch	bo=bl.oak	bw=basswood	co=chest.oak
lo=bl. locust	ma=magnolia	no=n.red oak	rm=red maple	so=sc.oak
wo=w. oak	yp=y.poplar	xx=other		

SCREEN 3 (Continue input)

```
==>yp 10 5
==>wo 6 10
==>wo 7 25
==>wo 8 10
==>so 6 20
==>so 13 5
==>end
```

Current stand basal area (square feet per acre): 106
Current stand volume (cubic feet per acre): 2984

Would you like to see your present stand table (y or n)? y

06

PRESENT STAND TABLE (**BEFORE** THINNING): BA = 106 , AGE = 36 , SI = 91

DBH CLASS (in)	TREES PER ACRE BY SPECIES							
	wo	**yp**	bo	co	so	rm	xx	TOTAL
4	0	0	0	0	0	0	10	10
5	0	0	10	50	0	15	0	75
6	10	0	20	20	20	0	0	70
7	25	20	20	15	0	0	0	80
8	10	30	15	30	0	0	0	85
9	0	15	15	10	0	0	0	40
10	0	**5**	**10**	0	0	0	0	**15**
13	0	0	0	0	5	0	0	5
TOTAL	45	70	90	125	25	15	**10**	380

Make a note of any changes you need to make to the table!
Do you want to make any changes or additions (y or n)? n

Would you like to see the present stock table (**y** or n)? y

PRESENT STOCK TABLE (BEFORE TRINNING): BA = 106 , AGE = 36 , SI = 91

DBH CLASS (in)	**CU.FT.VOLUME** PER ACRE (ob) BY SPECIES (TOP DIAMETER 4 IN)							
	wo	YP	bo	co	so	rm	kx	**TOTAL**
4	0	0	0	0	0	0	4	4
5	0	0	20	118	0	35	0	172
6	41	0	83	95	91	0	0	311
7	170	164	136	113	0	0	0	583
8	97	351	145	321	0	0	0	913
9	0	236	194	143	0	0	0	573
10	0	101	166	0	0	0	0	268
13	0	0	0	0	160	0	0	160
TOTAL	308	852	745	790	251	35	4	2984

PRESS ANY KEY TO CONTINUE

Do you want to save the stand table on disk? 8

Enter a filename for your stand table,

or press Enter to go on.

FILENAME: plot1

STAND TABLE SAVED IN FILE plot1

PRESS ANY KEY TO CONTINUE

You have 2 options for thinning your stand:

1. Automatic thinning

2. Your choice of trees to remove

(Enter 1 or 2): 1 9

Initial stand basal area (square feet per acre): 106

Desired residual stand basal area (square feet per acre)? 70

Basal area reduced to 70 square feet per acre:

TREES REMOVED

SPECIES	DBH	TREES/ACRE	VOLUME
wo	6	10	41
yp	7	9	74
bo	5	10	20
bo	6	20	83
bo	7	20	136
co	5	50	118
co	6	20	95
co	7	15	113
so	6	20	91
rm	5	15	35
xx	4	10	4
	TOTALS	199	810

PRESS ANY KEY TO CONTINUE

READY FOR GROWTH PROJECTION?

(10)

1. Display present stand table.
2. Display present stock table.
3. Save present stand table on disk
4. Recall original stand table and re-thin
5. Begin projection.

(Enter 1, 2, 3, 4, or 5): 1

PRESENT STAND TABLE (AFTER THINNING): BA = 70 , AGE = 36 , SI = 91

DBH CLASS (in)	TREES PER ACRE BY SPECIES wo	yp	bo	co	so	TOTAL
7	25	11	0	0	0	36
8	10	30	15	30	0	85
9	0	15	15	10	0	40
10	0	5	10	0	0	15
13	0	0	0	0	5	5
TOTAL	35	61	40	40	5	181

PRESS ANY KEY TO CONTINUE

PRESENT STOCK TABLE (AFTER THINNING): BA = 70 , AGE = 36 , SI = 91

DBH CLASS (in)	CU.FT.VOLUME PER ACRE (ob) BY SPECIES (TOP DIAMETER 4 IN)					
	wo	YP	bo	co	so	TOTAL
7	170	90	0	0	0	260
8	97	351	145	321	0	913
9	0	236	194	143	0	573
10	0	101	166	0	0	268
13	0	0	0	0	160	160
TOTAL	266	770	506	463	160	2174

PRESS ANY KEY TO CONTINUE

This model was based on 5 year growth periods.
Please restrict your growth projection to 10 years or less.

Desired projection period (years): 5

5 - **YEAR** PROJECTION COMPLETE:
Predicted stand basal area (square feet per acre): 82
Predicted **stand** basal area growth (square feet per acre): 12

Predicted stand volume (cubic feet per **acre):** 2666
Predicted stand volume growth (cubic **feet per** acre): 492

1. Display projected stand **table.**
2. Display projected **stock table.**
3. Read a stand table file and m-project.
4. Restart.,
5. stop.

(Enter 1, 2, 3, 4, or 5): 1

12

PROJECTED STAND TABLE AFTER 5 **YEARS** - BA = 82 , **AGE** = 36 , SI = 91

DBH CLASS (in)	TREES PER ACRE BY SPECIES					
	wo	yp	bo	co	so	TOTAL
8	24	11	0	0	0	35
9	10	30	15	29	0	84
10	0	15	15	10	0	40
11	0	5	10	0	0	15
14	0	0	0	0	5	5
TOTAL	34	61	40	39	5	179

PRESS ANY KEY TO CONTINUE

PROJECTED STOCK TABLE AFTER 5 YEARS - BA = 82 , AGE = 36 , SI = 91

DBH CLASS (in)	CU.FT.VOLUME PER ACRE (ob) BY SPECIES (TOP DIAMETER 4 IN)					
	wo	yp	bo	co	so	TOTAL
8	203	122	0	0	0	324
9	115	458	171	376	0	1121
10	0	303	229	168	0	700
11	0	129	197	0	0	326
14	0	0	0	0	195	195
TOTAL	318	1011	598	544	195	2666

PRESS ANY KEY TO CONTINUE

Enter the filename for your stand table.

FILENAME? plot1

Stand table plot1 (before thinning) has been loaded.
PRESS ANY KEY TO CONTINUE

You have 2 options for thinning your stand:

1. Automatic thinning

2. Your choice of trees to remove

(Enter 1 or 2): 2 0 13

You will now thin your stand according to your own criteria,

You may examine your stand table before you begin:

1. Examine current stand table

2. Ready to begin thinning

(Enter 1 or 2): 1

PRESENT STAND TABLE (BEFORE THINNING): BA = 106 , AGE = 36 , SI = 91

DBH CLASS (in)	wo	yp	bo	co	so	rm	xx	TOTAL
4	0	0	0	0	0	0	10	10
5	0	0	10	50	0	15	0	75
6	10	0	20	20	20	0	0	70
7	25	20	20	15	0	0	0	80
8	10	30	15	30	0	0	0	85
9	0	15	15	10	0	0	0	40
10	0	5	10	0	0	0	0	15
13	0	0	0	0	5	0	0	5
TOTAL	45	70	90	125	25	15	10	380

TREES PER ACRE BY SPECIES

PRESS ANY KEY TO CONTINUE

As each stand table entry appears (starting with low priority species), enter new (residual) trees per acre. To leave the same, press Enter.

When finished, just enter the word 'end'

CURRENT STAND BASAL AREA IS 106 SQUARE FEET PER ACRE

SPECIES: xx DBH: 4 TREES/ACRE: 10

THIN TO: 0

As each stand table entry appears (starting with low priority species), enter new (residual) trees per acre. To leave the same, press Enter.

When finished, just enter the word 'end'

CURRENT STAND BASAL AREA IS 64 SQUARE FEET PER ACRE

SPECIES: wo DBH: 7 TREES/ACRE: 25

THIN TO: end

Basal area reduced to 64 square feet per acre:

TREES REMOVED

SPECIES	DBH	TREES/ACRE	VOLUME
wo	6	10	41
bo	5	10	20
bo	6	20	83
bo	7	20	136
co	5	50	118
co	6	20	95
co	7	15	113
co	8	10	107
so	6	20	91
so	13	5	160
rm	5	15	35
xx	4	10	4
	TOTALS	205	1003

PRESS ANY KEY TO CONTINUE

READY FOR GROWTH PROJECTION?

1. Display present stand table.
2. Display present stock table.
3. Save present stand table on disk
4. Recall original stand table and re-thin
5. Begin projection.

(Enter 1, 2, 3, 4, or 5): 5

This model was based on 5 year growth periods.
Please restrict your growth projection to 10 years or less.

Desired projection period (years): 5

5 - YEAR PROJECTION COMPLETE:
Predicted stand basal area (square feet per acre): 76
Predicted stand basal area growth (square feet per acre): 12

Predicted stand volume (cubic feet per acre): 2491
Predicted stand volume growth (cubic feet per acre): 511

1. Display projected stand table.
2. Display projected stock table.
3. Read a stand table file and re-project.
4. Restart.
5. stop.

(Enter 1, 2, 3, 4, or 5): 5

Thank you for using.G-HAT.

For more information on this growth and yield model, contact:

Harold E. Burkhart
School of Forestry and Wildlife Resources
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

Appendix 3a. FORTRAN source code listing for subroutine GROW.

```
      FUNCTIONGROW(DBH,AGE,BA1,BA2,K)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C      ROUTINE TO COMPUTE THE PERIODIC ANNUAL BASAL AREA INCREMENT      C
C      OF AN APPALACHIAN HARDWOOD TREE AFTER THINNING                  C
C      EQUATIONS OF HARRISON ET.AL. 1986.                              C
C                                                                      C
C      WRITTEN BY WADE HARRISON, MAY 1985                              C
C                                                                      C
C      CALLED BY PRJ.                                                  C
C                                                                      C
C      INPUT:  DBH      TREE DBH, INCHES.                              C
C              AGE      STAND AGE, YEARS AT BREAST HEIGHT.             C
C              BA1      STAND BASAL AREA PRIOR TO THINNING, SQ.FT./AC. C
C              BA2      CURRENT STAND BASAL AREA, SQ.FT./AC.           C
C              K        SPECIES CODE (INTEGER).                        C
C                                                                      C
C      OUTPUT:  GROW    ANNUAL BASAL AREA INCREMENT (SQUARE INCHES).   C
C                                                                      C
C        NOTE: IF THE TREE IS ONE OF THE OAK SPECIES, BA1 IS NOT       C
C              NECESSARY AND MAY BE ENTERED AS ZERO. IF BA1=0 AND      C
C              THE TREE IS NOT AN OAK, ALTERNATE COEFFICIENTS          C
C              ARE USED, WHICH WERE ESTIMATED USING A MODEL FORM WHICH C
C              LACKS BA1.  RESULTS MAY BE BIASED IN THIS CASE.         C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
       DIMENSION PAR(5,13)
       DIMENSION ALT(4,13)
C
C      PARAMETERS FOR TREE BASAL AREA GROWTH EQUATIONS:
C      (ORDER IS COEFF. ON TREE BASAL AREA, COEFF. ON TREE BASAL AREA C
DIVIDED BY BREAST HT AGE, COEFF. ON BASAL AREA AFTER THINNING,
C      COEFF. ON BASAL AREA BEFORE THINNING, INTERCEPT, REPEAT FOR NEXT
C      SPECIES.  ORDER OF SPECIES IS BLACK CHERRY, N. RED OAK, WHITE OAK,
C      YELLOW-POPLAR, BLACK OAK, MAGNOLIA, BLACK LOCUST, BASSWOOD, BIRCH,
C      CHESTNUT OAK, SCARLET OAK, RED MAPLE, MISCELLANEOUS.)
C
       DATA PAR/0,1.396,-.0376,.013,1.844,.034,0,-.0163,0,1.818,0,1.124,
     &          -.0169,0,1.311,0,1.386,-.0402,.0197,1.332,0,1.299,-.029,
     &          0,1.874,0,1.441,-.0288,.0187,.32,0,1.02,-.0128,.0221,
     &          -1.991,0,.95,-.0293,.0188,.331,0,.965,-.0137,.0114,.305,
     &          0,1.203,-.0151,0,1.017,.041,0,-.0313,0,2.155,.035,0,
     &          -.0345,.0095,2.305,0,.95,-.0293,.0188,.331/
C
C      PARAMETERS FOR ALTERNATE SET OF TREE BASAL AREA GROWTH EQUATIONS,
C      USED WHEN STAND BASAL AREA BEFORE THINNING IS UNKNOWN (SAME FOR
C      ALL OAKS). SAME ORDER AS ABOVE EXCEPT THAT COEFF. ON BASAL AREA
C      BEFORE THINNING IS OMITTED:
```

Appendix 3a (continued). FORTRAN source code listing for subroutine GROW.

```
C
      DATA ALT/0,1.469,-.0290,2.636,.034,0,-.0163,1.818,0,1.124,-.0169,
     &         1.311,0,1.415,-.0302,2.929,0,1.299,-.029,1.874,0,1.428,
     &         -.0138,1.528,0,1.137,-.004,-0.251,0,.944,-.0160,1.615,
     &         0,1.069,-.0104,1.189,0,1.203,-.0151,1.017,.041,0,-.0313,
     &         2.155,.035,0,-.0308,3.143,0,.944,-.0160,1.615/
C
      DATA BAC/.785376/
C
         TBA=DBH*DBH*BAC
         IF(BA1.GT.0)GROW=PAR(5,K)+PAR(1,K)*TBA+PAR(2,K)*TBA/AGE
     &                      +PAR(3,K)*BA2+PAR(4,K)*BA1
         IF(BA1.EQ.0)GROW=ALT(4,K)+ALT(1,K)*TBA+ALT(2,K)*TBA/AGE
     &                      +ALT(3,K)*BA2
         IF(GHAT.LT.0)GROW=0
      RETURN
      END
```

Appendix 3b. FORTRAN source code listing for subroutine SURV.

```
      FUNCTION SURV(G)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C     INDIVIDUAL TREE SURVIVAL PROBABLITY FUNCTION.                    C
C                                                                      C
C     WRITTEN BY WADE HARRISON, MAY 1985.                              C
C                                                                      C
C     CALLED BY SUBROUTINE PRJ.                                        C
C                                                                      C
C     INPUT: G         PREDICTED ANNUAL TREE BASAL AREA INCREMENT      C
C                      IN SQUARE INCHES (AFTER THINNING).              C
C                                                                      C
C     OUTPUT: SURV     ANNUAL PROBABILITY THAT THE TREE WILL SURVIVE.  C
C                      (SURV SHOULD BE APPLIED AS THE PROPORTION       C
C                      OF TREES REPRESENTED BY THE SUBJECT TREE        C
C                      THAT WILL SURVIVE ANNUALLY.)                    C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     ESTIMATE B-YEAR SURVIVAL PROBABILITY:
C
      SURV=.90477+.09523*(1-EXP(-.72469*G))
C
C     REDUCE TO ANNUAL SURVIVAL PROBABILITY:
C
      SURV=SURV**0.2
      RETURN
      END
```

Appendix 3c. FORTRAN source code listing for subroutine HEIGHT.

```
      FUNCTION HEIGHT(DBH,SI,AGE,KODE)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                    C
C     ROUTINE TO COMPUTE THE TOTAL HEIGHT OF AN                      C
C     APPALACHIAN HARDWOOD TREE.                                     C
C     EQUATIONS OF HARRISON ET.AL. 1985                              C
C                                                                    C
C     WRITTEN BY WADE HARRISON, AUGUST 1985                          C
C                                                                    C
C     CALLED BY SUM.                                                 C
C                                                                    C
C     INPUT: DBH       TREE DBH, INCHES.                             C
C            AGE       STAND AGE, YEARS AT BREAST HEIGHT.            C
C            SI        SITE INDEX (BASE AGE 50) FOR WHITE OAK, FEET. C
C            KODE      SPECIES CODE (INTEGER).                       C
C                                                                    C
C     OUTPUT:  HEIGHT  TOTAL TREE HEIGHT, FEET                       C
C                                                                    C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION PAR(3,13)
C
C     PARAMETERS FOR HEIGHT PREDICTION EQUATIONS (ORDER OF SPECIES
C            SAME AS IN SUBROUTINE PRJ):
C
      DATA PAR/.0001, .07590,-17.528, .1967,-.00107,-10.530,
     &         .0026, .04002,-14.601, .1711, .00346,-13.123,
     &         .0719, .00029,-16.562, .1254, .00948,- 9.630,
     &         .0074, .03738,-15.932, .3197,-.00066,- 9.761,
     &        -.0992,-.00930,-17.966, .2046,-.00957,-13.621,
     &         .0021, .04569,-16.322,-.1587,-.04386,-17.833,
     &         .3197,-.00066,- 9.761/
C
C     SITE INDEX EQUATION OF OLSON (1958) TO COMPUTE DOM/CODOM HT
C            OF OAKS (ASSUME TREES TAKE 4 YRS TO REACH BREAST HT):
C
      HDOM=EXP(ALOG(SI)-22.0217*(1/(AGE+4)-.02))
C
C     HEIGHT  PREDICTION:
C
      HEIGHT=4.5+HDOM*(1+PAR(1,KODE)*EXP(PAR(2,KODE)*HDOM))
     &         *(1-EXP(PAR(3,KODE)*DBH/HDOM))
      RETURN
      END
```

Appendix 3d. FORTRAN source code listing for subroutine VOLUME.

```
      FUNCTIONVOLUME(MERCH,TOP,STUMP,KRAB,DBH,HITE,KODE)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                    C
C     ROUTINE TO COMPUTE THE VOLUME OF AN INDIVIDUAL                 C
C     APPALACHIAN HARDWOOD TREE.                                     C
C     VOLUME PREDICTION SYSTEM OF BURK ET.AL. 1985                   C
C                                                                    C
C     WRITTEN BY WADE HARRISON, AUGUST 1985                          C
C                                                                    C
C     CALLED BY SUM.                                                 C
C                                                                    C
C     INPUT: MERCH    VOLUME MERCHANTABILITY CODE (INTEGER):         C
C                          O= TOTAL VOLUME                           C
C                          1 = VOLUME TO SOME TOP HEIGHT,            C
C                              LESS VOLUME OF STUMP.                 C
C                          2 = VOLUME TO SOME TOP DIAMETER,          C
C                              LESS VOLUME OF STUMP.                 C
C            TOP      MERCHANTABILITY LIMIT:                         C
C                          IF MERCH=1, TOP=TOP HT IN FEET.           C
C                          IF MERCH=2, TOP=TOP DIA. IN INCHES.       C
C            STUMP    HEIGHT OF STUMP IN FEET.                       C
C            DBH      TREE DBH, INCHES.                              C
C            HITE     TOTAL TREE HEIGHT, FEET.                       C
C            KODE     SPECIES CODE (INTEGER).                        C
C            KRAB     INSIDE OR OUTSIDE BARK SPECIFIER (INTEGER):    C
C                          0 = OUTSIDE                               C
C                          1 = INSIDR                                C
C                                                                    C
C     OUTPUT: VOLUME  MERCHANTABLE CUBIC FOOT VOLUME FOR THE TREE.   C
C                                                                    C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION PAR(2,13)
      DIMENSION RAT(13)
C
C     PARAMETERS FOR VOLUME PREDICTION EQUATIONS (ORDER OF SPECIES
C            HERE AND BELOW SAME AS IN SUBROUTINE PRJ):
C
      DATA PAR/-1.9213,.8750,-1.7320,.7989,-1.7139,.7489,-1.7427,.8540,
     &         -1.8988,.7965,-1.7427,.8540,-1.7427,.8540,-1.7427,.8540,
     &         -1.8285,.8416,-1.6334,.7959,-1.7901,.7993,-1.8285,.8416,
     &         -1.7854,.8304/
C
C     DIB/DOB RATIOS BY SPECIES:
C
      DATA RAT/.939,.929,.937,.902,.925,.902,.902,.902,
     &         .934,.909,.939,.934,.927/
C
      DATA BAC/.005454/
C
C     ZERO VOLUME CONDITIONS:
C
```

Appendix 3d (continued). FORTRAN source code listing for subroutine VOLUME.

```
      VOLUME=0
      TVOL=0
      IF(STUMP.GT.HITE)GOTO 100
      IF(DBH.EQ.0.OR.HITE.EQ.0)GOTO 100
      IF(MERCH.EQ.1.AND.TOP.LT.STUMP)GOTO 100
      IF(MERCH.EQ.2.AND.TOP.GT.1.3*DBH)GOTO 100
C
C     VOLUME PREDICTION SYSTEM:
C
      B0=PAR(1,KODE)
      B1=PAR(2,KODE)
      IF(KRAB.EQ.0)THEN
        RATIO=1
      ELSE
        RATIO=RAT(KODE)
      ENDIF
C
C     TOTAL VOLUME:
C
      VOLUME=BAC*4.5*4.5*DBH*DBH/(-B0*B1*HITE)*((HITE-4.5)/4.5)
     &         **(B1+1)*EXP(-B0*(4.5/(HITE-4.5))**B1)
      IF(MERCH.EQ.0)THEN
        VOLUME=TVOL
        GOTO  50
      ENDIF
C
C     VOLUME TO A TOP HEIGHT:
C
      IF(MERCH.EQ.1)THEN
        IF(TOP.GE.HITE)GOTO 40
        TOPH=TOP
        GOTO 30
      ENDIF
C
C     VOLUME TO A TOP DIAMETER:
C
      IF(MERCH.EQ.2)THEN
        IF(TOP.EQ.0)GOTO 40
C
C       PERFORM BISECTION TO LOCATE THE HEIGHT ON THE TREE AT WHICH
C       DIAMETER IS EQUAL TO SPECIFIED TOP DIAMETER:
C
        A=0
        B=HITE
   10   HTRY=(A+B)/2
C
C       FIND DIAMETER (DTRY) AT THIS HEIGHT (HTRY) WITH TAPER FUNCTION:
C
        TAPER=(HTRY/4.5)**(B1-1)*((HITE-4.5)/(HITE-HTRY))**(B1+1)
     &       *EXP(B0*((HTRY/(HITE-HTRY))**B1-(4.5/(HITE-4.5))**B1))
```

Appendix 3d (continued). FORTRAN source code listing for subroutine VOLUME.

```
          DTRY=SQRT(DBH*DBH*TAPER)
          DIF=ABS(DTRY-TOP)
          IF(DIF.LT.0.05)GOTO 20
          IF(DTRY.GT.TOP)THEN
            A=HTRY
            GOTO 10
          ENDIF
          IF(DTRY.LT.TOP)THEN
            B=HTRY
            GOTO 10
          ENDIF
   20     TOPH=HTRY
        ENDIF
C
C       REDUCE VOLUME ACCORDING TO TOP HEIGHT:
C
   30   VOLUME=TVOL*(1-EXP(B0*(TOPH/(HITE-TOPH))**B1))
C
C       REDUCE VOLUME ACCORDING TO STUMP HEIGHT:
C
   40   IF(STUMP.EQ.0)GOTO 50
        VOLUME=VOLUME-TVOL*(1-EXP(B0*(STUMP/(HITE-STUMP))**B1))
C
C       ACCOUNT FOR BARK (DIB/DOB RATIO)
C
   50   VOLUME=VOLUME*RATIO*RATIO
  100   RETURN
        END
```

Appendix 3e. FORTRAN source code listing for subroutine SUM.

```
      SUBROUTINE SUM(N,DBH,TREES,KODE,MERCH,TOP,STUMP,KRAB,AGE,SI,
     &                DMAX,TTAB,BTAB,VTAB,SPTR,DTR,SPBA,DBA,SPVOL,DVOL,
     &                BA,TPA,VOL)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C     ROUTINE TO SUMMARIZE A GIVEN TREE LIST.                         C
C                                                                     C
C     WRITTEN BY WADE HARRISON, MAY 1985                              C
C                                                                     C
C     CALLED BY MAIN.                                                 C
C                                                                     C
C     CALLS FUNCTION VOLUME.                                          C
C     CALLS FUNCTION HEIGHT.                                          C
C                                                                     C
C     INPUT: N        NUMBER OF ITEMS IN LIST, IF KNOWN (ELSE N=100).C
C            DBH      LIST OF DBH'S IN INCHES INDEXED BY TREE NUMBER.C
C            TREES    LIST OF TREES/ACRE REPRESENTED BY EACH ITEM     C
C                          IN THE TREE LIST, INDEXED BY TREE NUMBER. C
C            KODE     LIST OF SPECIES CODES (INTEGERS), INDEXED BY    C
C                          TREE NUMBER.                               C
C            MERCH    VOLUME MERCHANTABILITY CODE (INTEGER):          C
C                          0 = TOTAL VOLUME                           C
C                          1 = VOLUME TO SOME TOP HEIGHT,             C
C                              LESS VOLUME OF STUMP.                  C
C                          2 = VOLUME TO SOME TOP DIAMETER,           C
C                              LESS VOLUME OF STUMP.                  C
C            TOP      MERCHANTABILITY LIMIT:                          C
c                          IF MERCH=1, TOP=TOP HT IN FEET.            C
C                          IF MERCH=2, TOP=TOP DIA. IN INCHES.        C
C            STUMP    HEIGHT OF STUMP, FEET.                          C
C                                                                     C
C            KRAB     INSIDE OR OUTSIDE BARK SPECIFIER (INTEGER):     C
C                          0 = OUTSIDE                                C
C                          1 = INSIDE                                 C
C            AGE      STAND AGE (YEARS AT BREAST HEIGHT).             C
C            SI       SITE INDEX (BASE AGE 50) FOR WHITE OAK.         C
C                                                                     C
C     OUTPUT: DMAX    LARGEST DBH IN TREE LIST, INCHES.               C
C            TTAB     TREES/AC FOR EACH l-INCH DBH CLASS IN EACH      C
C                          SPECIES, INDEXED BY l-INCH DBH CLASS       C
C                          AND SPECIES CODE.                          C
C            BTAB     BASAL AREA/AC FOR EACH l-INCH DBH CLASS IN      C
C                          EACH SPECIES, INDEXED BY l-INCH DBH CLASS C
C                          AND SPECIES CODE, SQ.FT.                   C
C            VTAB     CU.FT. VOL/AC FOR EACH l-INCH DBH CLASS IN      C
C                          EACH SPECIES, INDEXED BY l-INCH DBH CLASS C
C                          AND SPECIES CODE.                          C
C            SPTR     TREES/AC FOR EACH SPECIES, INDEXED BY SPECIES C
C                          CODE.                                      C
C            DTR      TREES/AC FOR EACH l-INCH DBH CLASS, INDEXED BY C
C                          l-INCH DBH CLASS.                          C
```

Appendix 3e (continued). FORTRAN source code listing for subroutine SUM.

```
C              SPBA      BASAL AREA/AC FOR EACH SPECIES, INDEXED BY     C
C                             SPECIES CODE, SQ.FT.                      C
C              DBA       BASAL AREA/AC FOR EACH 1-INCH DBH CLASS,       C
C                             INDEXED BY 1-INCH DBH CLASS, SQ.FT.       C
C              SPVOL     CU.FT.VOLUME/AC FOR EACH SPECIES, INDEXED BY   C
C                             SPECIES CODE.                             C
C              DVOL      CU.FT.VOLUME/AC FOR EACH 1-INCH DBH CLASS,     C
C                             INDEXED BY 1-INCH DBH CLASS.              C
C              BA        TOTAL BASAL AREA/AC, SQ.FT.                    C
C              TPA       TOTAL NUMBER OF TREES/AC                       C
C              VOL       TOTAL CU.FT.VOLUME/AC                          C
C                                                                       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION DBH(N),TREES(N),KODE(N),SPTR(13),DTR(30),
     &          SPBA(13),DBA(30),SPVOL(13),DVOL(30),
     &          TTAB(13,30),BTAB(13,30),VTAB(13,30)
      DATA BAC/.005454/
C
C     INITIALIZE:
C
      BA=0
      TPA=0
      VOL=0
          DO 10 J=1,13
          SPTR(J)=0
          SPBA(J)=0
          SPVOL(J)=0
               DO 15 K=1,30
               TTAB(J,K)=0
               BTAB(J,K)=0
               VTAB(J,K)=0
   15          CONTINUE
   10     CONTINUE
          DO 20 K=1,30
          DTR(K)=0
          DBA(K)=0
          DVOL(K)=0
   20     CONTINUE
C
C     COMPUTE STAND CHARACTERISTICS:
C
      DMAX=0
          DO 30 I=1,N
          IF(DBH(I).GT.DMAX)DMAX=DBH(I)
          TBA=TREES(I)*DBH(I)*DBH(I)*BAC
          HITE=HEIGHT(DBH(I),SI,AGE,KODE(I))
          TVOL=TREES(I)*VOLUME(MERCH,TOP,STUMP,KRAB,DBH(I),HITE,KODE(I))
          IDBH=DBH(I)+.499
          TTAB(KODE(I),IDBH)=TTAB(KODE(I),IDBH)+TREES(I)
          BTAB(KODE(I),IDBH)=BTAB(KODE(I),IDBH)+TBA
```

Appendix 3e (continued). FORTRAN source code listing for subroutine SUM.

```
      VTAB(KODE(I),IDBH)=VTAB(KODE(I),IDBH)+TVOL
      BA=BA+TBA
      TPA=TPA+TREES(I)
      VOL=VOL+TVOL
      SPTR(KODE(I))=SPTR(KODE(I))+TREES(I)
      DTR(IDBH)=DTR(IDBH)+TREES(I)
      SPBA(KODE(I))=SPBA(KODE(I))+TBA
      DBA(IDBH)=DBA(IDBH)+TBA
      SPVOL(KODE(I))=SPVOL(KODE(I))+TVOL
      DVOL(IDBH)=DVOL(IDBH)+TVOL
30    CONTINUE
   RETURN
   END
```

Appendix 3f. FORTRAN source code listing for subroutine PRJ.

```
      SUBROUTINE PRJ(N,DBH,TREES,KODE,PP,BA1,BA2,AGE)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C     ROUTINE TO PROJECT A GIVEN TREE LIST OF APPALACHIAN MIXED        C
C     HARDWOODS, WITH EQUATIONS OF HARRISON ET.AL. 1985.               C
C                                                                      C
C     WRITTEN BY WADE HARRISON, MAY 1985                               C
C                                                                      C
C     CALLED BY MAIN.                                                  C
C                                                                      C
C     CALLS FUNCTIONS GROW, SURV.                                      C
C                                                                      C
C     INPUT: N        NUMBER OF ITEMS IN LIST, IF KNOWN (ELSE N=100).C
C            DBH      LIST OF DBH'S IN INCHES INDEXED BY TREE NUMBER.C
C            TREES    LIST OF TREES/ACRE REPRESENTED BY EACH ITEM      C
C                          IN THE TREE LIST, INDEXED BY TREE NUMBER.   C
C            KODE     LIST OF SPECIES CODES (INTEGERS), INDEXED BY     C
C                          TREE NUMBER.                                C
C            BA1      STAND BASAL AREA PRIOR TO THINNING, SQ.FT./AC.   C
C            BA2      CURRENT STAND BASAL AREA, SQ.FT./AC.             C
C            AGE      STAND AGE IN YEARS AT BREAST HEIGHT.             C
C            PP       PROJECTION PERIOD LENGTH (0 TO 10 YRS).          C
C                                                                      C
C     OUTPUT: DBH     LIST OF DBH'S IN INCHES INDEXED BY TREE NUMBER.C
C             TREES   LIST OF TREES/ACRE REPRESENTED BY EACH ITEM      C
C                          IN THE TREE LIST, INDEXED BY TREE NUMBER.   C
C                                                                      C
C       NOTE: BA1 IS UNNECESSARY INFORMATION IF THE INPUT DATA         C
C             CONSIST OF OAK SPECIES.  IN THIS CASE, IT MAY BE SET     C
C             TO ZERO.  TREE GROWTH PROJECTIONS FOR ANY NON-OAK        C
C             SPECIES WHEN BA1=0 WILL BE BIASED (AN ALTERNATE SET      C
C             OF COEFFICIENTS ARE USED).  SEE FUNCTION GROW.           C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION DBH(N),TREES(N),KODE(N)
C
      DATA BAC/.785376/
C
C     LOOP TO PROCESS EACH TREE:
C
         DO 10 I=1,N
         G=GROW(DBH(I),AGE,BA1,BA2,KODE(I))
         TBA=DBH(I)*DBH(I)*BAC+PP*G
         TREES(I)=TREES(I)*SURV(G)**PP
         DBH(I)=SQRT(TBA/BAC)
   10    CONTINUE
      RETURN
      END
```