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User's Manual for FORAR, A Stand Model for Composition and Growth of Upland Forests of Southern Arkansas

D. L. Mielke
H. H. Shugart
D. C. West

ENVIRONMENTAL SCIENCES DIVISION
Publication No. 1021

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ABSTRACT

MIELKE, D. L., H. H. SHUGART, and D. C. WEST. 1977. User's manual for FORAR, a stand model for composition and growth of upland forests of Southern Arkansas. ORNL/TM-5767. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 44 pp.

This report is a user's manual for FORAR, a computer model simulating stand growth and composition of upland forests of south central Arkansas. The model computes: (1) the number and biomass of each tree species, and (2) the dbh, age, and species of each individual tree on a 1/12-ha circular plot. FORAR was developed from FORET (Shugart and West 1977), a modified version of the JABOWA model developed by Botkin et. at. (1972a, 1972b). The present version of FORAR considers up to 35 species and 700 trees and has been implemented on IBM 360 series computers.

Once a year trees are stochastically killed or grown and new trees are stochastically planted. Individual trees are killed by a probability function scaled according to the maximum age recorded for the appropriate species. Stocking of new seedlings and sprouts in a given year depends on the computed leaf area index of the plot and the condition of five environmental variables: mineral soil, litter layer, temperature (as expressed by degree-days), wildlife populations, and epidemics. Individual trees grow according to a species-specific optimum growth function modified by climate, available light, competition, and soil moisture. The optimum growth function is a function of the maximum known age, the maximum dbh, and the maximum height recorded for each species.

The driving variable is degree-days. Input consists of 19 general characteristics for each species. Normal output shows total biomass and leaf area on a simulated plot and, for each species, the number of trees on the plot, their dbh's, and their biomass. The model also has options to list all the trees that have died from random causes, logging, and fire.

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INTRODUCTION

Because of the relative ease of estimating the necessary input parameters and because the model retains information on both individuals and species, FORAR (FORest in ARkansas stand simulation model) is versatile enough to be used in several different types of ecological studies. Changes in species composition through succession or because of long-term perturbations can be examined and consequences of different timber and wildlife habitat management techniques can be predicted. Changes in tree species abundance (e.g. to dominance or extinction) can be determined. The model provides dynamic simulations of what is classically referred to as the structure and function of ecosystems. The usefulness of different measures of such indices as diversity, productivity, or stability can be studied.

This user's manual describes the FORAR model, which simulates an upland forest of Union County in southcentral Arkansas. The model was developed from FORET (Shugart and West 1977), a modified version of the JABOWA model used by Botkin et al. (1972a, 1972b). The logging subroutine has been expanded in FORAR. A subroutine to burn the plot and probabilities of trees dying from fire damage has been added. Soil competition is computed using basal area instead of biomass. A fifth environmental variable, species-specific epidemics, has been added to subroutine BIRTH to affect seedling establishment. In addition, variables have been added, deleted, renamed, or shifted to other subroutines to make the program more efficient.

FORAR simulates composition and growth of a forest stand on the basis of each tree greater than 1.27 cm in diameter at breast height (dbh) on a 1/12 ha circular plot. The model computes (1) the numbers and biomass of each species and (2) the dbh, age, and species of each individual tree. Once a year, trees are stochastically killed or deterministically grown and new trees are stochastically planted. Individual trees are killed by a probability function that is scaled according to the maximum age recorded for the appropriate species. The probability that a specific tree will die during a given simulated year is increased if its growth rate (expressed as diameter increment) falls below an acceptable minimum (0.1 cm/yr). Stocking of new seedlings and sprouts in a given simulated year depends on the computed leaf-area index of the plot and the condition of five environmental variables discussed below. The tree species to be stocked are chosen randomly from those species which can germinate under the existing conditions for soil, temperature, wildlife populations, and epidemics. Trees grow according to a species-specific optimum growth function that is modified by soil moisture, competition, available light, and climate. The optimum growth function for each species is a function of the maximum known age, the maximum dbh and the maximum height recorded for the species. The driving variable for the model is degree-days, which is randomly chosen at the beginning of each year from a normal distribution with appropriate mean and variance. FORAR is written in FORTRAN IV and has been implemented on IBM 360 series computers. The present version of the model considers up to 35 tree species and up to 700 individual trees and can simulate the forest for any prespecified number of years.

PROGRAM DESCRIPTION

The deck setup of FORAR is shown in Figure 1. The control cards shown are those necessary to run the program on the ORNL IBM 360/91 computer. The program is listed in Appendix A-3. In a typical run the maximum computer core used is 270K. Computer time needed will depend on the size of the run, i.e., how many different plots are wanted, how many species are used, and how many years each plot is run. A run of three plots, each potentially having 33 species and running for 600 years, takes approximately two minutes of CPU time.

INPUT

The program currently reads in parameter values for each tree species using the format:

6A4,F6.0,F5.0,F4.3,F5.2,I1,F4.0,F2.0,F5.1,F2.0,F4.1,F4.0,5L1,I4,F3.1 .

This format can easily be changed in subroutine DATA to suit the user. Table 1 lists and describes the input variable names in the order in which they are entered in the above format. Most of the parameters, such as shade tolerance or maximum age, are relatively straight-forward and can be derived from standard textbooks of dendrology or silvics. Harlow and Harrar (1969) and Fowells (1965) were used in the present case for such parameter estimations.

DMAX and DMIN are the maximum and minimum degree-day values associated with the geographic range of each species. They are calculated (using a sine wave, see Appendix A-1) from the January and July mean temperatures at the northern and southern ends of the range of each species (e.g., Figure 2). B2 and B3 are the coefficients of the following equation relating height to diameter (in cm):

$$H = 137 + B2D - B3D^2 . \quad (1)$$

Solving for B2 and B3, using $H=H_{max}$ and $\frac{dH}{dD} = 0$ when $D=D_{max}$ Botkin et al. 1972a) results in:

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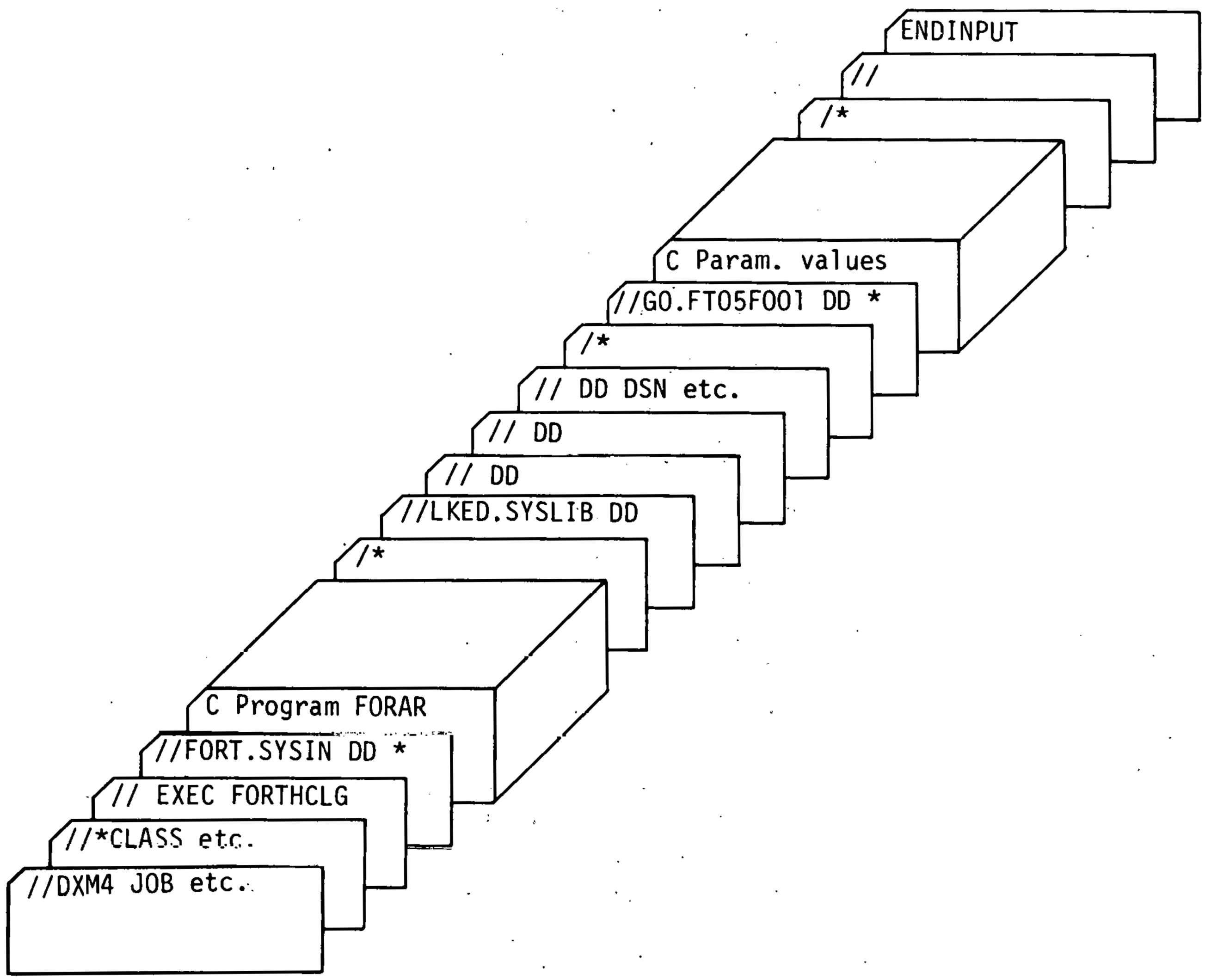

Fig. 1. Deck structure and job setup for program FORAR.

Table 1. Parameters used in the FORAR model. Table 2 lists the values used for each tree species. See text for explanation of variables.

Parameter Name	Meaning	Field
AAA	Scientific name (up to 24 letters)	xxxxxxxxxxxxxxxxxxxxxxxx
DMAX	Maximum degree-days for species range (see text)	xxxxx.
DMIN	Minimum degree-days for species range (see text)	xxxx.
B3	Derived growth parameter (see text)	.xxx
B2	Derived growth parameter (see text)	xx.xx
ITYPE	Shade tolerance 1 = tolerant 3 = intolerant	x
AGEMX	Maximum age recorded for the species	xxx.
C	Leaf area constant 1 = deciduous 2 = coniferous	x.
G	Derived Growth constant (see text)	xxx.x
STEND	Tendency to sprout Value of 0.,1.,2.,or 3.	x.
SPTMIN	The minimum dbh of a tree that will sprout	xx.x
SPTMAX	The maximum dbh of a tree that will sprout	xxx.
S(1)	Must the seed have a litter layer to germinate? value of T of F	x
S(2)	Must the seed have mineral soil to germinate? value of T or F	x
S(3)	Is the seedling susceptible to hot years? value of T or F	x
S(4)	Is the seedling a highly-preferred food for wildlife? value of T or F	x
S(5)	Is an epidemic seriously damaging the species? value of T or F	x
KTIME	Number of years after a bare plot that a species is liable to be present	xxx
SOIM	The fraction of maximum recorded dbh the species will attain on an upland site	x.x

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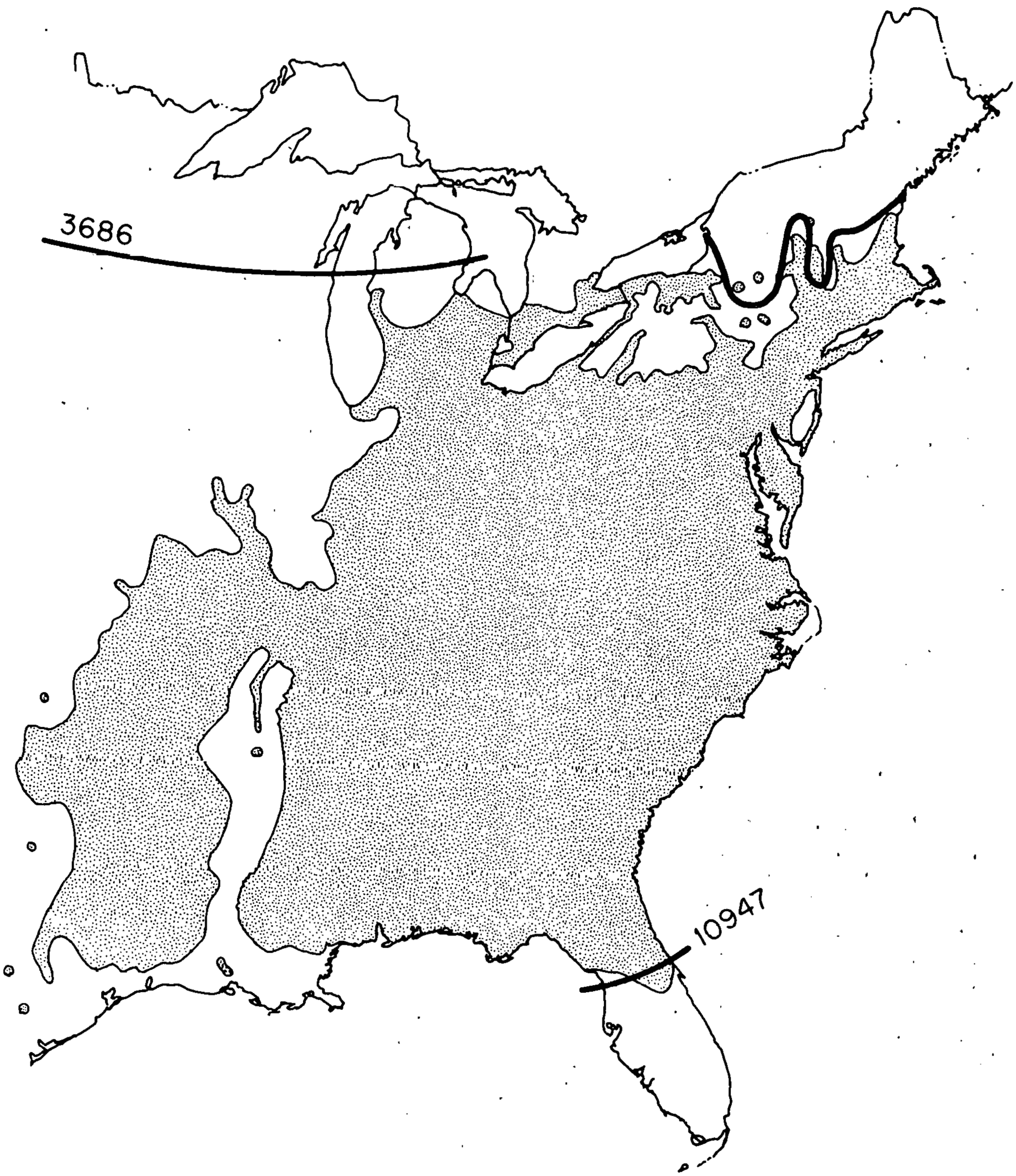

Fig. 2. Growing degree-day limits DMAX and DMIN for the geographic range of flowering dogwood (Cornus florida). Isopleths for growing degree days are calculated from U.S. Geological Survey (1965) and from program DATGEN (Appendix A-1).

$$B2 = \frac{2(H_{max} - 137)}{D_{max}} \quad , \quad B3 = \frac{(H_{max} - 137)}{(D_{max})^2} \quad . \qquad (2)$$

The growth constant G is derived from Equation (4) below and the assumption that 2/3 of the maximum dbh of the tree is reached at 1/2 the maximum age. G can be solved for directly (see Botkin et al. 1972b) or found by using a simple program of tree growth on an interactive computer (see Appendix A-2). The variable KTIME is an attempt to handle variation in seed source availability. If there is no parent tree on the plot and if the variable IMYR (the number of years that have passed since the plot had no trees and mineral soil) is greater than KTIME, then it is assumed there is no seed source for the species and that it can not be established by seeding. The input values used in the present version of FORAR are listed in Table 2.

The model usually starts a plot with no trees; however, subroutine LOAD can be used to input any desired initial conditions. If a litter layer is wanted at the beginning of a plot, IMYR should be given an initial value greater than 15.

Subroutines

The flowchart for FORAR is shown in Figure 3. There are 14 subroutines in addition to the main program; however, KILL, BIRTH, and GROW are the main elements in terms of actual computation.

Whenever a random number is needed for any model computation, a call to subroutine RANDOM returns a random number drawn from a flat distribution between 0 and 1. In subroutine DATA the user declares the number of plots wanted, the number of tree species, the number of years each plot will be run, the interval of time between successive outputs, the annual insolation, the maximum basal area a plot can attain, and the mean for DEGD. Subroutines PLOTIN and INIT initialize variables, and PLOTIN also updates and prints the plot number.

Subroutine GAUSS randomly chooses a value for DEGD — total degree-days for a year, based on a growing degree-day temperature of 42°F — from a normal distribution. The mean and standard deviation of DEGD can be calculated from data available from the National Climatic Center, Asheville, North Carolina.

Table 2. Parameter values used in the FORAR model. Scientific binomials follow Little (1971).

Species	DMAX[3]	DMIN[3]	B3	B2	ITYPE	AGEMX	C[8]	G	STEND	SPTMIN	SPTMAX	S					KTIME	SOIM
Acer rubrum	13395	1810	0.173	52.58	1[8]	150[2]	1	240.2	2[1]	12.0[8]	150[11]	F[1]	T[1]	T	F[10]	F[8]	9999	0.5
Carpinus caroliniana	10947	2097	0.228	33.56	1[2]	100	1	129.9	2	6.0	70[11]	F	F	F	F[10]	F	9999	0.4
Carya cordiformis	9461	3686	0.306	69.21	3[1]	300[8]	1	117.2	2[5]	12.0[8]	110[11]	T[8]	F[2]	T[8]	F[1]	F[8]	30	0.8
Carya glabra	12652	3686	0.158	49.65	1[1]	300[8]	1	111.3	2[5]	12.0[8]	145[11]	T[1]	F[2]	T[8]	F[10]	F[8]	30	0.5
Carya laciniosa	8718	5081	0.318	72.46	1[1]	300	1	123.2	2[5]	12.0	90[11]	T	F	T	F[10]	F[5]	9999	0.4
Carya ovata	12652	4105	0.312	69.66	1[1]	300[2]	1	116.5	2[5]	2.0[1]	110[11]	T[8]	F[2]	T[8]	F[10]	F[8]	9999	0.7
Carya texana	9461	5526	0.318	57.56	1	300	1	79.6	2[5]	12.0	110[11]	T	F	T	F[10]	F[5]	9999	0.5
Carya tomentosa	10947	3686	0.190	49.41	3[1]	300[8]	1	98.6	2[5]	12.0[2]	130[11]	T[1]	F[2]	T[8]	F[10]	F[8]	9999	0.8
Castanea ozarkensis	7756	5526	0.085	21.72	1	60	1	250.9	2[12]	12.0	125[11]	T	F	T	F[10]	T[5]	9999	0.8
Celtis laevigata	12652	5526	0.336	71.26	1[1]	350	1	112.7	2[1]	6.0[1]	115[11]	T[1]	F	F	F[10]	F	9999	0.6
Cornus florida	10947	3686	0.536	40.81	1[1]	100[8]	1	88.7	3[1]	12.0	35[11]	F[8]	F[1]	T[1]	F[10]	F[8]	9999	0.9
Diospyros virginiana	13395	5526	0.084	35.84	1[1]	150[8]	1	234.1	2[1]	12.0[8]	210[8]	F[1]	F[2]	T[8]	F[10]	F[8]	30[5]	0.3
Fagus grandifolia	10204	2097	0.151	46.20	1[1]	400[2]	1	80.7	2[1]	6.0[8]	30[8]	F[1]	F[2]	T[8]	F[10]	F[8]	9999	0.5
Fraxinus americana	10947	2414	0.080	34.43	3[1]	300[8]	1	113.3	2[1]	6.0[1]	20	F[1]	T[2]	T[8]	F[10]	F[8]	9999	0.9
Ilex opaca	10947	5526	0.156	42.61	1[2]	200[2]	1	133.5	1[5]	6.0	35[11]	F[8]	F	F	F[10]	F	9999	0.5
Juglans nigra	8499	3686	0.074	36.37	3[1]	250	1	161.5	1[1]	6.0[1]	40	T[3]	F[2]	T[8]	F[10]	F[8]	20[5]	0.7
Juniperus virginiana	10204	2966	0.236	57.75	3[1]	300[1]	2	107.1	0[1]	12.0[1]	120[11]	F[1]	T[1]	F[1]	F[10]	F[8]	20[5]	0.9
Liquidambar styraciflua	10947	5526	0.191	55.20	3[1]	300[2]	1	119.4	2[1]	12.0[1]	80[1]	F[1]	F[1]	F[1]	F[10]	F[8]	9999	0.7
Morus rubra	13395	3686	0.061	22.15	1[4]	75[5]	1	260.6	0[5]	12.0[1]	180[11]	T[5]	F[5]	T	F[10]	F	30[5]	0.3
Nyssa sylvatica	12652	3686	0.202	37.00	1[5]	300[8]	1	54.8	1[1]	60.0[1]	90[1]	F[8]	T[8]	F[8]	F[10]	F[8]	9999	0.7
Ostrya virginiana	10204	1810	0.266	49.50	1[7]	100	1	219.1	1	6.0	90	F	F	F	F[10]	F	9999	0.4
Pinus echinata	9461	5526	0.290	70.75	3[1]	300	2	128.4	2[1]	6.0[1]	20[1]	F[1]	T[1]	F[1]	F[10]	F	9999	1.0
Pinus taeda	10947	6391	0.189	60.81	3[1]	350[2]	2	174.6	0[1]	12.0[1]	160[11]	F[1]	T[1]	F[1]	F[10]	F[8]	9999	1.0
Prunus serotina	10947	3899	0.083	35.57	3[2]	250[1]	1	139.5	2[1]	6.0[1]	210[1]	F[1]	T	F[8]	T[10]	F[8]	9999	0.7
Quercus alba	10204	2966	0.074	36.37	1[1]	400[9]	1	100.7	2[1]	12.0[1]	40[1]	T[1]	F[1]	F[1]	T[10]	F[8]	9999	0.8
Quercus falcata	10947	5526	0.078	33.57	1[6]	400	1	82.9	2[1]	12.0[1]	30[1]	T[8]	F[8]	F[8]	F[10]	F[8]	9999	0.9
Quercus marilandica	10204	5081	0.111	24.86	3[5]	400	1	36.3	2	12.0	40	F[5]	F	F	F[10]	F	9999	1.0
Quercus shumardii	10947	5081	0.199	65.19	3[2]	400	1	115.9	2[1]	12.0[1]	160[1]	F[1]	F[1]	F	F[10]	F	30[5]	0.7
Quercus stellata	10947	5526	0.195	47.75	3[1]	400	1	67.9	2[1]	12.0[1]	40[1]	T[1]	F[1]	F[8]	T[10]	F[8]	9999	1.0
Quercus velutina	9461	3313	0.097	41.57	1[2]	200[9]	1	100.1	2[1]	12.0[1]	40[1]	F[1]	T[1]	F[8]	F[10]	F[8]	9999	0.8
Sassafras albidum	10947	3686	0.519	75.51	3[2]	200[8]	1	108.1	3[1]	6.0[1]	60[1]	T[1]	F[1]	F[8]	F[10]	F[8]	20[5]	0.8
Ulmus alata	10947	5526	0.230	51.81	3[1]	125[5]	1	212.5	1	6.0	110	F	F[5]	F	F[10]	F	9999	0.4
Ulmus americana	12652	1522	0.082	39.35	3	300[1]	1	141.8	1[1]	6.0[1]	240[1]	F[1]	F[1]	T[1]	F[5]	T[10]	9999	0.4

[1]From Fowells (1965)
[2]From Harlow and Harrar (1969)
[3]From Little (1971) and U.S. Geological Survey (1965)
[4]From Wigginton (1964)
[5]From Carl Amason (personal communication, 1975)
[6]From Baker (1949)
[7]From Peattie (1950)
[8]From Shugart and West (1977)
[9]From Northeastern Forest Experiment Station (1971)
[10]From Martin et al. (1971)
[11]From Pardo (1973)
[12]From Moore (1960)
[13]All other values not otherwise referenced were developed during the course of this project.

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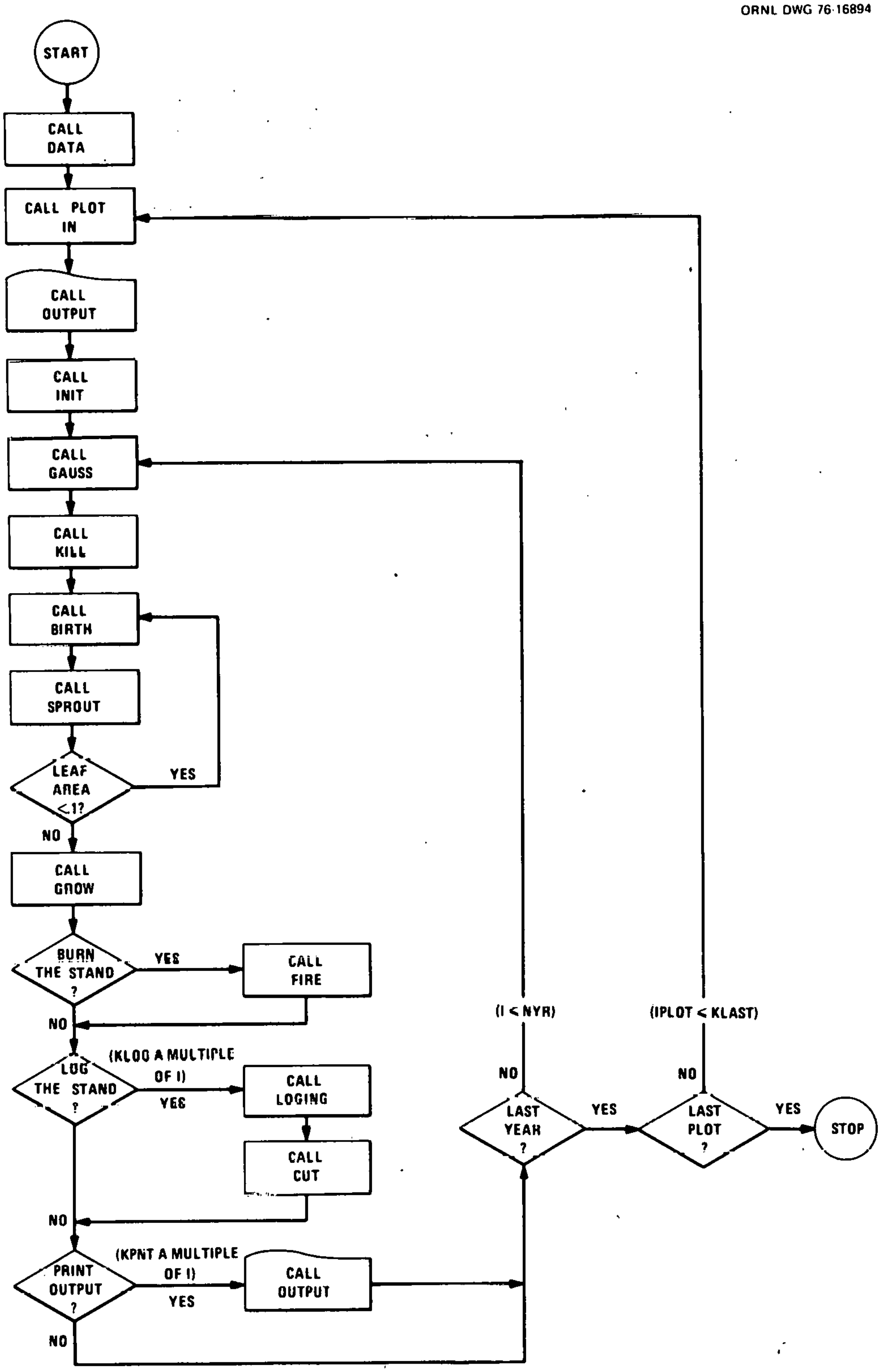

Fig. 3. Flow diagram of the FORAR model.

Subroutine KILL

FORAR, like the Botkin model, assumes that individual tree death can be viewed as a stochastic process, rather than delineating all the different and complex causes of mortality. The probability that a tree will be killed in any one year is $p = 1-(1-\varepsilon)^n$ (Botkin et al. 1972b). The model assumes that 1% of all seedlings of a species will live to reach the maximum age for that species (Figure 4). Setting p equal to 0.99 and n equal to AGEMX (the maximum known age a species can attain) results in:

$$\varepsilon = 4.605/\text{AGEMX} \quad . \tag{3}$$

Once a year KILL generates a random number for every tree, and the tree is killed if the random number generated is less than ε.

In the present version of FORAR, there are two cases in which the kill probabilities of a tree are changed from the above statement. First, the model uses the array NOGRO to keep track of those trees that grow less than 0.1 cm dbh per year. A tree has only one chance in a hundred of surviving 10 years if such a growth rate is maintained (Botkin et al. 1972b). Accordingly, the random number generated has to be less than 0.368 to kill such a tree. Secondly, a moderate fire (described below) will "damage" those species that are susceptible to fire. In the present version of FORAR, a susceptible tree that is present on the plot when a moderate fire occurs is given a 20% chance of living 5 years (J. Warren Ranney, personal communication 1976); thus, the random number generated must be less than 0.275 to kill the tree.

Trees are also killed deterministically if there is logging or a fire. To log the circular plot, the user specifics in subroutine LOGING the upper and lower diameter limits of each species of the trees to be logged. Subroutine CUT then removes all trees on the plot within these diameter limits. In subroutine FIRE the user has a choice of specifying a light, a moderate, or a severe burn. A light fire sets the logging limits of each species to a minimum of 0 cm and a maximum of 12.7 cm and then calls subroutine CUT to remove the trees. A severe fire removes all trees from the plot and resets the bare plot counter IMYR to zero, allowing the pioneer species with small values of KTIME to reenter the plot. A moderate fire uses subroutine CUT in the same way as a light burn to remove all the trees of species that are extremely susceptible to fire damage, all the trees less than 25.4 cm dbh of species that are moderately susceptible to fire damage, and all the trees less than 17.8 cm dbh of resistant species. The susceptibility of each species to fire damage is established in the COMPUTED GO TO statements in subroutine FIRE. The values used in FORAR were taken from Davis (1959), Fowells (1965), Harlow and Harrar (1969), or developed in the course of this project. A moderate fire also resets IMYR

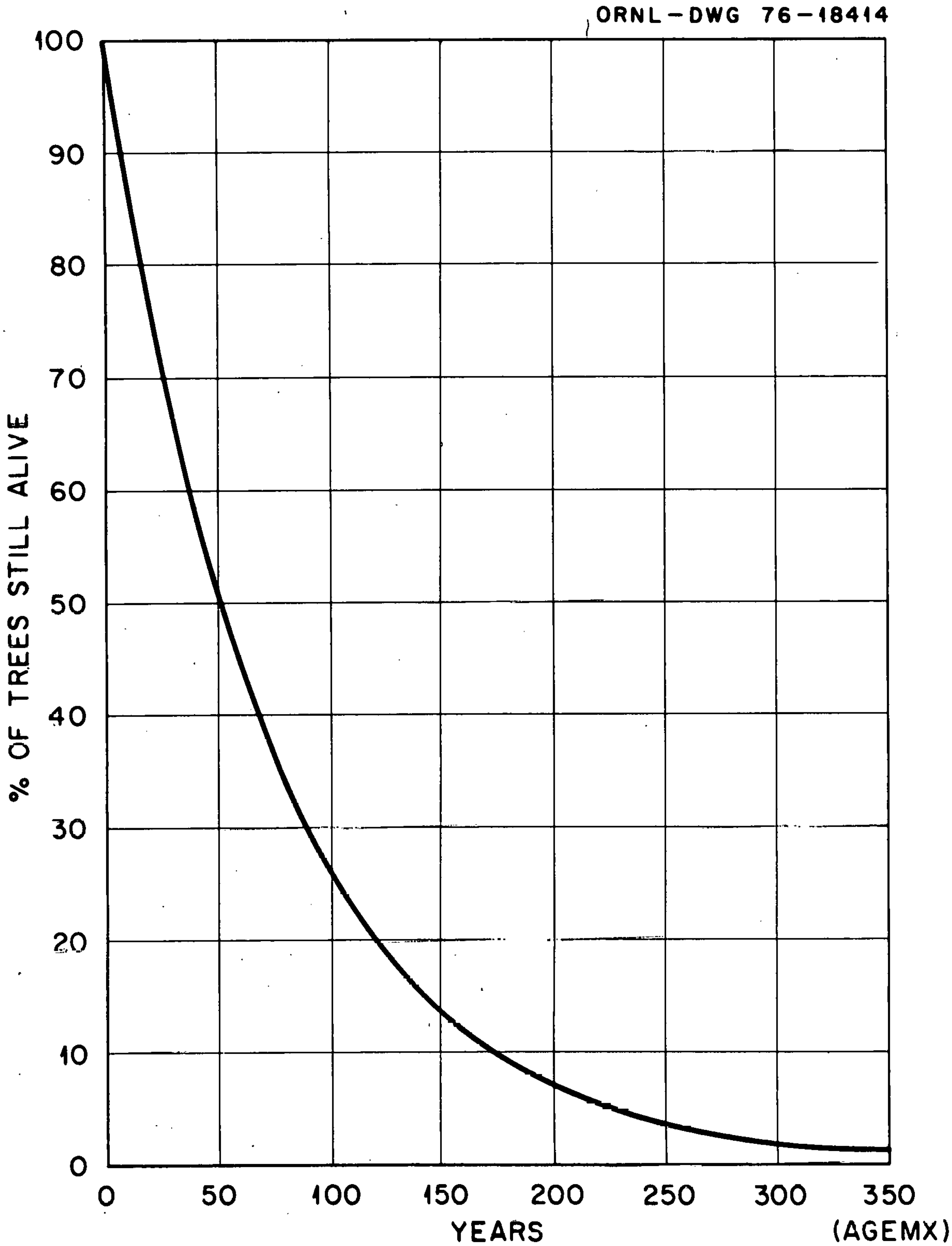

Fig. 4. Functional form for the random death process. The model assumes that 1% of all the seedlings of a species will live to reach the maximum known age. In the example shown, the maximum age of loblolly pine is 350 years.

to zero and changes the survival probabilities of those damage-susceptible trees that were large enough to survive the fire, as discussed above.

Subroutine BIRTH

BIRTH calculates the biomass already on the plot and sets the correct values for the year for the five environmental variables corresponding to the S array in Table 1. As in the FORET model (Shugart and West 1977), the soil is considered to be mineral soil if the biomass on the plot is less than 0.2 metric ton/ha and if IMYR (an additional parameter in the FORAR model) is less than 15. The soil is considered to have a litter layer if the plot biomass is greater than 0.1 metric ton/ha. It is a hot year if DEGD has a value greater than its mean. Wildlife populations are randomly chosen half the time to be large enough to consume the entire seed source of a preferred food species. In the FORAR model, an epidemic is randomly present half the time to destroy the seedlings of certain host species.

BIRTH then separates out those species capable of germinating under existing environmental conditions. For instance, we assume that a species requiring a litter layer to germinate (i.e. S(1) - .TRUE.) cannot be stocked when there is no litter layer on the ground (i.e. when the biomass on the plot is less than 0.1 metric ton/ha). From the subset of possible species, the program randomly chooses from one to three species to actually stock in a given year. A random number of seedlings between zero and eight are then "born" for each of the one to three species and randomly assigned a dbh around 1.27 cm (Tree seedlings are established 137 cm tall in the model in order to have a nonzero dbh.).

After the new seedlings are established, subroutine BIRTH calls subroutine SPROUT, which checks to see if any trees of a species capable of sprouting have died since the last year. If they have, and if their diameter was within the sprouting range of that species (SPTMIN<dbh< SPTMAX), a random number of sprouts between zero and three are randomly given dbh's around 0.1 cm and are added to the plot. Where a maximum of three species of seedlings can enter the plot in one pass through subroutine BIRTH, only one randomly chosen tree can sprout in one pass through subroutine SPROUT.

Subroutine BIRTH then calculates whether the biomass on the plot is less than 0.1 metric ton/ha. If it is, the program returns to the top of subroutine BIRTH to go through the process again. Before returning to MAIN, BIRTH updates the age of all the trees.

Subroutine GROW

The basic growth function used by FORAR, FORET (Shugart and West 1977), and JABOWA (Botkin et al. 1972a, 1972b) is:

$$\delta(D^2H) = R\ LA\ \ (1 - \frac{D\ H}{D_{max}\ H_{max}})\ , \qquad (4)$$

where

D = dbh,
H = height,
D_{max} = maximum dbh recorded for the species (Pardo 1973),
H_{max} = maximum height recorded for the species,
R = a constant, and
LA = leaf area.

This equation considers the trunk of a tree to be a cylinder and assumes that the change in volume of a tree in one year is proportional to the amount of sunlight the leaves receive times a factor for maintenance of the volume of living tissue already present (Botkin et al. 1972b). The assumptions of the model are as follows (For more details, see Botkin et al. 1972b):

$$H = 137 + B2D - B3D^2\ , \qquad (5)$$

$$LA \ \alpha \ \text{leaf weight}\ , \qquad (6)$$

$$\text{leaf weight} = CD^2\ ,$$

and

$$G = RC\ , \qquad (7)$$

where

$$C = \text{leaf area constant}\ ,$$

$$G = \text{a growth constant}\ .$$

Using the above equations in Equation (4) to solve for D, the annual increment of growth, we find:

$$\delta D = GD\ \frac{(1 - \frac{D\ H}{D_{max}\ H_{max}})}{274 + 3B2D - 4B3D^2}\ . \qquad (8)$$

This is the basic equation for optimum growth on a good site with no competitors. An example of this function for two species is shown in Figure 5.

FORAR modifies the annual growth equation by factors for shading, climate, competition, and soil moisture. In order to modify growth according to the amount of light each tree is receiving, subroutine GROW calculates the amount each tree is shaded, in 0.1 meter increments, by those trees on the plot that are taller. This is done using the equation:

$$AL = PHI\ e^{0.25SLA} , \tag{9}$$

where

AL = available light for a given tree,
PHI = annual insolation (in appropriate units), and
SLA = shading leaf area (Botkin et al. 1972a).

SLA is calculated using Equation (6) as the leaf biomass above a given height (Shugart and West 1977, Sollins et al. 1973). Kramer and Kozlowski (1960) give equations to relate AL to r(AL), the photosynthetic rate:

$$r(AL) = 1 - e^{-4.64(AL-0.05)} \text{ for tolerant species ,} \tag{10}$$

$$r(AL) = 2.24(1 - e^{-1.136(AL-0.08)}) \text{ for intolerant species .} \tag{11}$$

The factor r(AL) is then used as the shading factor multiplying the growth equation. Figure 6 shows r(AL) as a function of AL for tolerant and intolerant species.

FORAR assumes a parabolic functional form for the effect of climate upon tree growth, T(DEGD). Figure 7 shows the relationship between the range of the species and T(DEGD). Optimum climatic effect occurs in the middle of the climatic range of the species. DEGD values at the range extremes reduce T(DEGD), and thus the growth of the trees of that species, to near zero.

The crude competition factor in the model is simply:

$$S(BAR) = 1 - BAR/SOILQ , \tag{12}$$

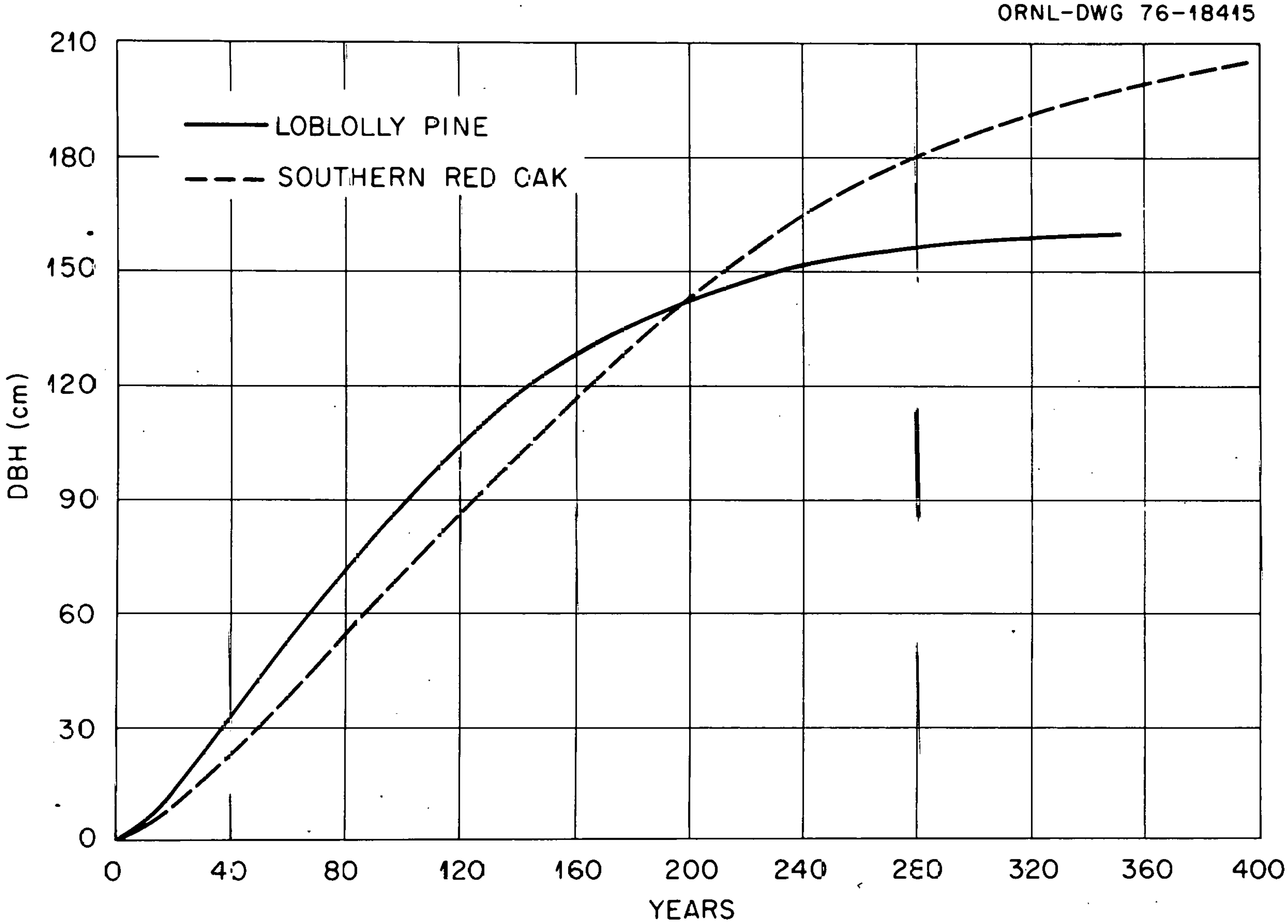

Fig. 5. Functional form for the optimum growth equation. The slope of the curve is a function of AGEMX. The height of the curve is a function of the maximum dbh recorded for the species (Pardo 1973).

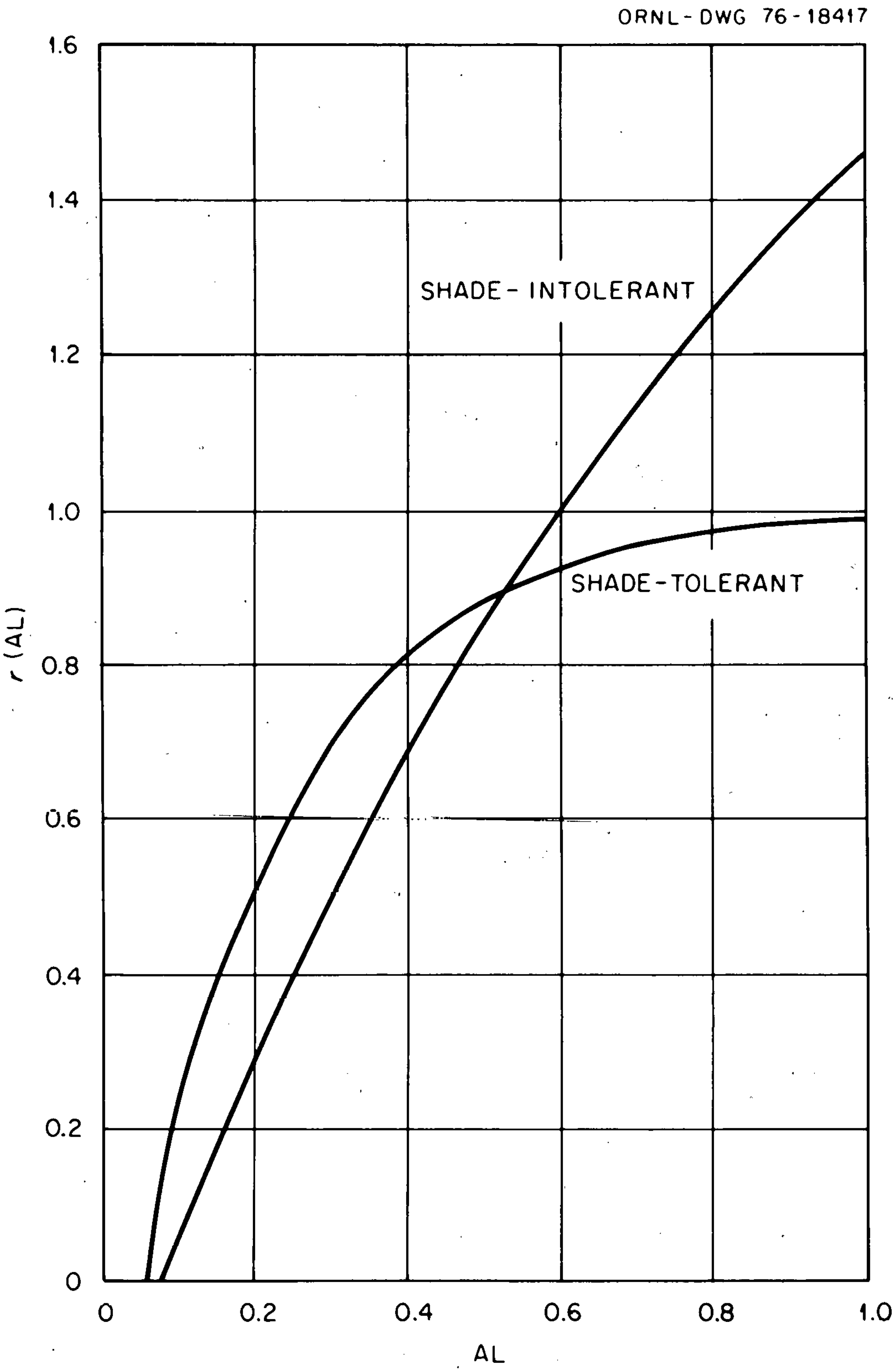

Fig. 6. Functional form relating available light AL to photosynthetic rate r(AL). Equations are from Kramer and Kozlowski (1960).

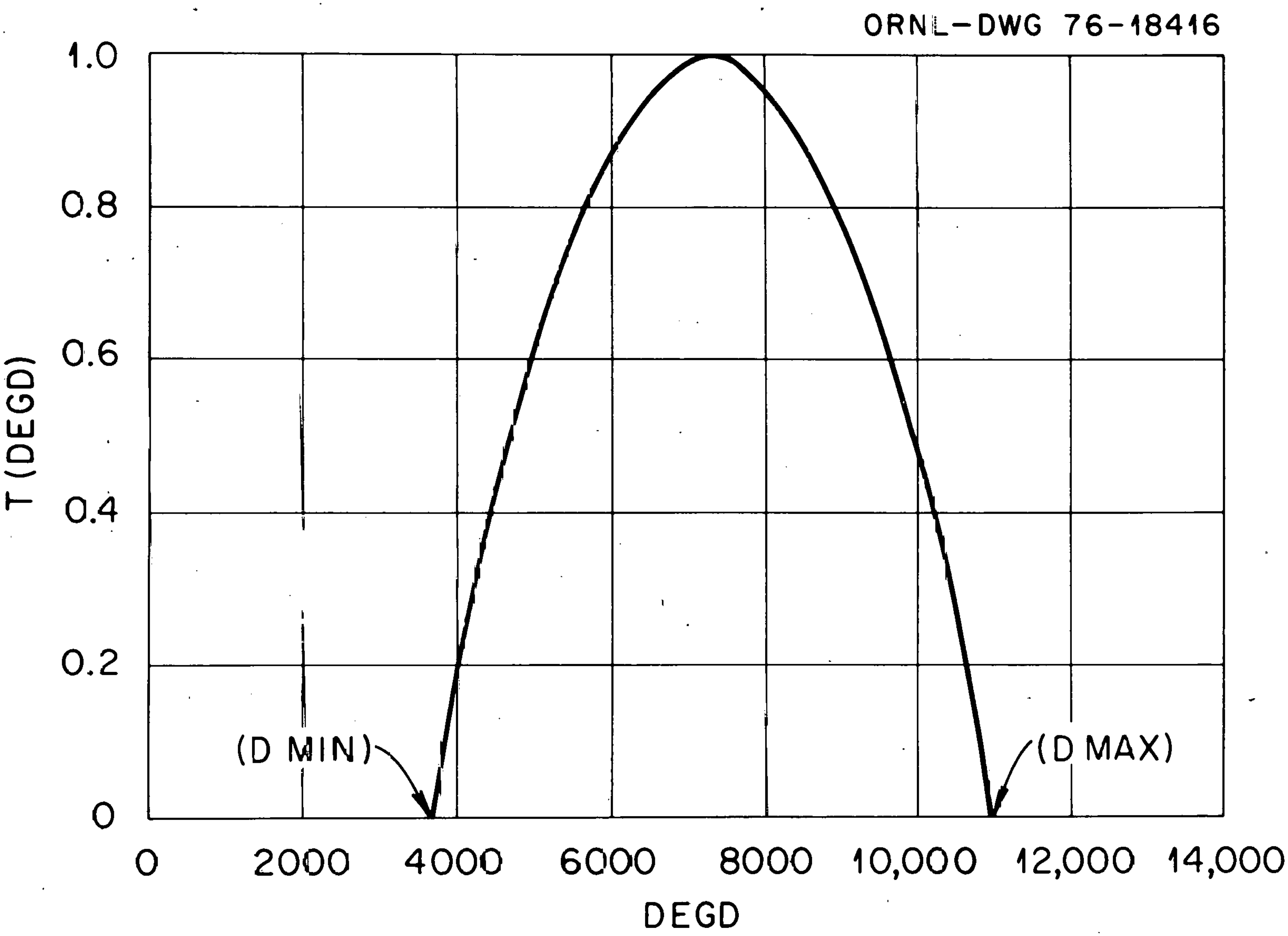

Fig. 7. Functional form relating degree-days DEGD to the effect of climate on the growth of a tree species. In this example, sassafras can not grow if the degree-days are less than 3686 or greater than 10947.

where

S(BAR) = competition factor,
BAR = basal area on the plot, and
SOILQ = maximum basal area the plot can sustain.

A plot of S(BAR) is shown in Figure 8.

The last factor modifying tree growth, soil moisture, was added to FORAR when it was found that primarily-bottomland species were comprising too much biomass on the plot. For simplicity, SOIM was assumed to be a constant factor reducing (usually) the growth of a species on an upland site. A more realistic approach would be to use moisture as another driving variable of the model. This, however, would add another level of resolution to an already complex program. Species that are found primarily on dry, poor soils have values of SOIM near 1.0; whereas species that commonly grow well in bottomlands and grow much more poorly on upland sites may have values of SOIM around 0.5.

The final growth equation for the model is thus:

$$\delta D = G\ D \frac{1 - \frac{D\ H}{D_{max}\ H_{max}}}{274 + 3B2D - 4B3D^2}\ r(AL)\ T(DEGD)\ S(BAR)\ SOIM \quad . \qquad (13)$$

OUTPUT

A sample output of FORAR is shown in Appendix A-4. Normal output of FORAR shows, for each species, the number of trees on the plot, their dbh's, and the biomass. Total biomass and leaf area on the plot are also given at the end of the species list. Output frequency (KPNT) is specified by the user in subroutine DATA. The model has an option to list all the trees that have died from random causes since the last printout, all the trees that have been removed by logging and the diameter limits for each species, and all the trees that have been killed by fire.

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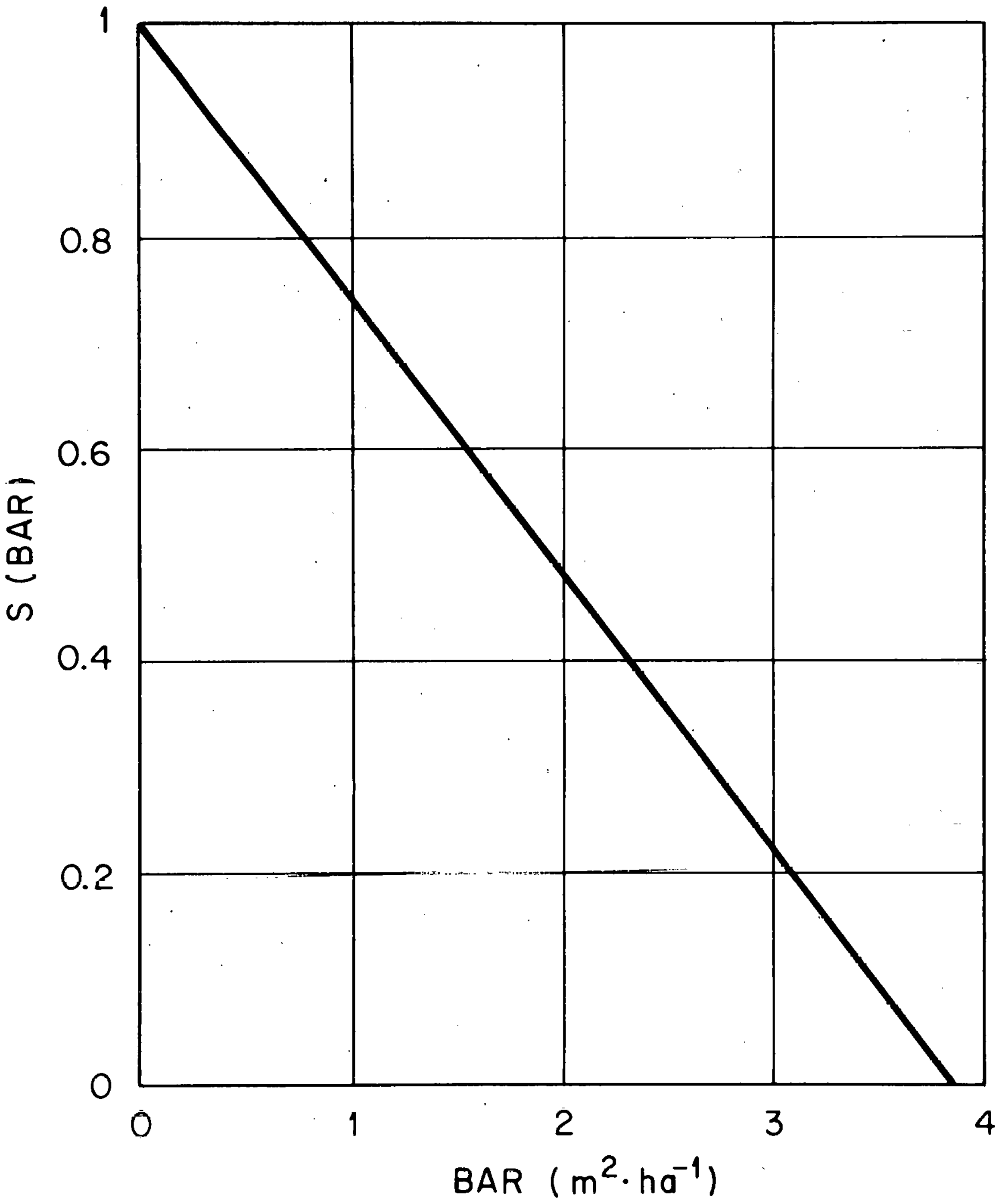

Fig. 8. Linear function relating basal area on the 1/12 ha plot (BAR) to a general competition factor S(BAR). The maximum basal area the plot can maintain is from Dick Williams (personal communication 1975).

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Appendix A-1

Program DATGEN calculates annual degree-days from January and July mean temperatures. A sine function is used to estimate average daily temperature, with the minimum and maximum values equal to the January and July means, respectively. The area under the sine curve and above the 42°F line is then determined by integration and scaled to the proper value for degree-days.

In the listing shown, the degree-days are calculated and printed out for the matrix of January mean temperatures from 0° to 70° and July mean temperatures from 60° to 90°.

```
ISN 0002          DIMENSION DEGD(100,100)
ISN 0003          DO 6 I=1,71,5
ISN 0004         XI=I-1
ISN 0005         DO 4 J=60,90,5
ISN 0006         KK=1
ISN 0007         XJ=J
ISN 0008          AVE=(XJ+XI)/2.
ISN 0009          IF(XI.GE.XJ) GO TO 39
ISN 0011          R=XJ-XI
ISN 0012         R=.5*R
ISN 0013          DO 11 JJ=1,342
ISN 0014           XJJ=JJ
ISN 0015          HEAT=R*SIN(.017214*(XJJ-91.25))+AVE
ISN 0016          IF(KK.EQ.1.AND.HEAT.GE.42.) GO TO 9
ISN 0018          GO TO 10
ISN 0019       9  D1=XJJ
ISN 0020          KK=2
ISN 0021      10  IF (KK.EQ.2.AND.HEAT.LT.42.) GO TO 12
ISN 0023         GO TO 11
ISN 0024      12  D2=XJJ
ISN 0025          KK=1
ISN 0026      11  CONTINUE
ISN 0027         DEGD(I,J)=COS(.017214*(D1-91.25))-COS(.017214*(D2-91.25))
ISN 0028          DEGD(I,J)=.31831*DEGD(I,J)*(D2-D1)*R-(D2-D1)*(42.-AVE)
ISN 0029          GO TO 4
ISN 0030     39   DEGD(I,J)=10000000.
ISN 0031       4  CONTINUE
ISN 0032       6  TYPE 7,(DEGD(I,J),J=60,90,5)
ISN 0033       7  FORMAT(/,7(' ',F8.0))
ISN 0034          STOP
ISN 0035          END
```

Appendix A-2

Program GFIX iteratively determines the value of G, the growth constant, for each tree species. G is calculated using the optimum growth function developed by Botkin et al. (1972a, 1972b) and the assumption that a tree will attain 2/3 of its maximum dbh at 1/2 its maximum age:

$$\delta D = G\,D\,\frac{1 - \dfrac{D\,H}{D_{max}\,H_{max}}}{274 + 3B2D - 4B3D^2}$$

and

$$D = 2/3\ D_{max} \text{ when } t = AGEMX/2 \quad .$$

Any interactive computer system can be used to run this program. The values for DMAX, HMAX, B2, B3, and AGEMX for the species and the initial guess for G are entered in. The value of DBH typed out can then be compared to 2/3 D_{max}, and a better guess for G can be entered for the next iteration. This is repeated until DBH becomes sufficiently close to 2/3 D_{max}.

```
ISN 0002          INTEGER AGEMAX
ISN 0003          TYPE 1
ISN 0004        1 FORMAT (2X,'TYPE IN DMAX,HMAX,B2,B3,AGEMAX,4F10.3,I5')
ISN 0005          ACCEPT 2,DMAX,HMAX,B2,B3,AGEMAX
ISN 0006        2 FORMAT (4F10.3,I5)
ISN 0007        3 TYPE 4
ISN 0008        4 FORMAT (2X,'TYPE IN G, F10.3')
ISN 0009          ACCEPT 5,G
ISN 0010        5 FORMAT (F10.3)
ISN 0011          D=.5
ISN 0012          J=IFIX(AGEMAX/2.)
ISN 0013          DO 10 I=1,J
ISN 0014          H=137.+B2*D-B3*D**2
ISN 0015          DELD=(G*D*(1.-(D-H)/(DMAX*HMAX)))/(274.+3.*B2*D-4.*B3*D**2)
ISN 0016          D=D+DELD
ISN 0017       10 CONTINUE
ISN 0018          TYPE 11,DMAX,HMAX,B2,B3,AGEMAX,G
ISN 0019       11 FORMAT (5X,'DMAX',5X,'HMAX',7X,'B2',9X,'B3',4X,
                 A'AGEMAX',4X,'G',/,4F10.3,I5,F10.3)
ISN 0020          TYPE 12,D
ISN 0021       12 FORMAT (6X,'DBH=',F10.4)
ISN 0022          GO TO 3
ISN 0023          STOP
ISN 0024          END
```

Appendix A-3

Listing of Program FORAR

```
C       STAND SIMULATOR MODIFIED FROM:
C
C            BOTKIN,D.B.,J.F.JANAK,J.R.WALLIS. 1970. A SIMULATOR FOR
C        NORTHEASTERN FOREST GROWTH; A CONTRIBUTION OF THE HUBBARD BROOK
C        ECOSYSTEM STUDY AND IBM RESEARCH. RC 3140. IBM THOMAS J. WATSON
C        RESEARCH CENTER, YORKTOWN HEIGHTS, NEW YORK. 21P.
      DIMENSION DBH(700),NTREES(35)
      DIMENSION DBHK(250),NTREEK(35)
      COMMON /FDATA/ FARDAM(500),ALIMIT(35),BLIMIT(35),IMYR
      LOGICAL SWITCH(5),S(35,5),LOGS
      DIMENSION KTIME(35)
      COMMON /LOGBLK/ SWITCH,KTIME,S
      COMMON /RUNNR/ NYR,INYR,KPNT,KAGE,KTIMES,KLAST
      COMMON /HDATA/ B2(35),B3(35),PHI,SOILQ,DEGD
       CALL DATA
      IPLOT=0
   11 CONTINUE
      CALL PLOTIN(IPLOT,DBH,NTREES)
      IMYR=0
      INYR=0
      CALL OUTPUT(DBH,NTREES)
      DO 9 J=1,KTIMES
      JJ=J
      IF (JJ .GT. 1) PRINT 13,IX
   13 FORMAT (/,'   PLOT NUMBER   ',I4)
      CALL INIT(DBH,NTREES,DBHK,NTREEK,JJ)
      DO 1 I=1,NYR
      IMYR=IMYR+1
      INYR=I
      CALL GAUSS(IX,700.0,8700.0,DEGD)
       CALL KILL(DBH,NTREES,IX)
       CALL BIRTH(IX,NTREES,DBH)
      CALL GROW(DBH,NTREES)
C     IF (R.LT..048) CALL FIRE (DBH,NTREES)
      IF (I.NE.35) GO TO 5
      CALL LOGING (LOGS)
C     CALL CUT (DBH,NTREES,LOGS)
    5 IF(I-KPNT*(I/KPNT).EQ.0) CALL OUTPUT(DBH,NTREES)
    1 CONTINUE
    9 CONTINUE
      IF(IPLOT .EQ. KLAST) GO TO 99
      GO TO 11
   99 CONTINUE
      STOP
      END
```

```
      SUBROUTINE LOAD(DBH,NTREES)
      DIMENSION DBH(700),NTREES(25)
      COMMON /IRUN/ INDEX
      DO 1 I=1,INDEX
    1 NTREES(I)=0.
       RETURN
       END
```

```
      SUBROUTINE LOGING (LOGS)
      COMMON /IRUN/ INDEX
      LOGICAL LOGS
      COMMON /FDATA/ FARDAM(500),ALIMIT(35),BLIMIT(35),IMYR
      DO 10 J=1,INDEX
      ALIMIT(J)=25.4
      BLIMIT(J)=200.
   10 CONTINUE
      LOGS=.TRUE.
      RETURN
      END
```

```
ISN 0002          SUBROUTINE SPROUT(IX,NTREES,DBH)
ISN 0003          COMMON /SDATA/ KSPRT(35),STEND(35),SPTMIN(35),SPTMAX(35)
ISN 0004          COMMON /IRUN/ INDEX
ISN 0005          DIMENSION NTREES(35),ANEW(700),DBH(700),NAGE(700)
ISN 0006          DIMENSION NEW(35)
ISN 0007          COMMON /TRAGE/ IGES(700),IDGE(500)
           C      SMALLEST STUMP SPROUT IS .1 CM ON THE AVERAGE.
ISN 0008          SIZE=.1
ISN 0009          NU=1
ISN 0010          DO 230 LL=1,INDEX
ISN 0011          L=LL
ISN 0012          IF(NTREES(L).EQ.0) GO TO 230
ISN 0014          NNU=NU+NTREES(L)-1
ISN 0015      230 NU=NU+NTREES(L)
ISN 0016          KEND=NU-1
ISN 0017          NIX=0
ISN 0018          DO 205 LL=1,INDEX
ISN 0019          L=LL
ISN 0020          IF(STEND(L).LE.0.) GO TO 205
ISN 0022          IF(KSPRT(L).GE.0) GO TO 205
ISN 0024          NIX=NIX+1
ISN 0025          NEW(NIX)=L
ISN 0026      205 CONTINUE
ISN 0027          IF (NIX .EQ.0) GO TO 74
ISN 0029          DO 2 J=1,KEND
ISN 0030          NAGE(J)=IGES(J)
ISN 0031          ANEW(J)=DBH(J)
ISN 0032        2 CONTINUE
ISN 0033          CALL RANDOM(IX,R)
ISN 0034          NIX=NIX*R+1.0
ISN 0035          N=NEW(NIX)
ISN 0036          KSUM=0
ISN 0037          DO 51 I=1,N
ISN 0038       51 KSUM=KSUM+NTREES(I)
           C      STEND(I) IS THE TENDENCY FOR THE ITH SPECIES TO STUMP
           C OR ROOT SPROUT. THE VALUE OF STEND(I) IS THE AVERAGE
           C NUMBER OF SPROUTS (VIABLE) THAT MIGHT OCCUR WITH A GIVEN TREE DEATH.
ISN 0039          CALL RANDOM(IX,R)
ISN 0040          M=R*STEND(N)+1
ISN 0041           IF(M.EQ.0) GO TO 74
ISN 0043          DO 70 J=1,M
ISN 0044          KSUM=KSUM+1
ISN 0045          NTREES(N)=NTREES(N)+1
ISN 0046          NAGE(KSUM)=0
ISN 0047          CALL RANDOM(IX,R)
ISN 0048          ANEW(KSUM)=SIZE+0.1*(1.0-R)**3
ISN 0049          KEND=KEND+1
ISN 0050          K1=KSUM+1
ISN 0051          DO 60 II=K1,KEND
ISN 0052          I=II
ISN 0053          ANEW(I)=DBH(I-1)
ISN 0054          NAGE(I)=IGES(I-1)
ISN 0055       60 CONTINUE
ISN 0056          IF(KEND .LT.701) GO TO 61
ISN 0058          PRINT 98
ISN 0059          STOP
ISN 0060       61 CONTINUE
ISN 0061       98 FORMAT (' <<<<<<<<<<<<LOOK OUT THE NTREES VECTOR GOT TOO BIG>>>
                *>>>',13I4/' <<<<<<<<<<<<TRY COMPATIBLE SPECIES AND CLIMATE>>>>>>')
ISN 0062          DO 65 I=1,KEND
ISN 0063          IGES(I)=NAGE(I)
ISN 0064       65 DBH(I)=ANEW(I)
ISN 0065       70 CONTINUE
ISN 0066          N=0
ISN 0067       74 CONTINUE
ISN 0068          DO 9998 I=1,INDEX
ISN 0069     9998 KSPRT(I)=1
ISN 0070          RETURN
ISN 0071          END
```

```
ISN 0002          SUBROUTINE CUT(DBH,NTREES,LOGS)
ISN 0003          DIMENSION DBH(700),NTREES(35),ANEW(100)
ISN 0004          COMMON /FDATA/ FARDAM(500),ALIMIT(35),BLIMIT(35),IMYR
ISN 0005          DIMENSION KAGES(100),NCUT(35),DBHCUT(100),KKAGE(100)
ISN 0006          COMMON /SDATA/ KSPRT(35),STEND(35),SPTMIN(35),SPTMAX(35)
ISN 0007          COMMON /TRAGE/ IGES(700),IDGE(500)
ISN 0008          COMMON /IRUN/ INDEX
ISN 0009          COMMON /TITLE/ AAA(35,6)
ISN 0010          LOGICAL CUTT,CUTSP,LOGS
ISN 0011          NTOT=0
ISN 0012          DO 1 I=1,INDEX
ISN 0013          NTOT=NTOT+NTREES(I)
ISN 0014        1 CONTINUE
ISN 0015          IF (NTOT.EQ.0) RETURN
ISN 0017          CUTT=.FALSE.
ISN 0018          NEW=0
ISN 0019          NFW=0
ISN 0020          KBEG=1
ISN 0021          KEND=0
ISN 0022          IF (.NOT.LOGS) GO TO 18
ISN 0024          PRINT 15
ISN 0025       15 FORMAT (12X,'DIAMETER LIMITS FOR LOGGING, BY SPECIES'/)
ISN 0026          PRINT 14,(J,ALIMIT(J),BLIMIT(J),J=1,INDEX)
ISN 0027       14 FORMAT (12X,I5,2(2X,F5.1))
ISN 0028       18 DO 2 I=1,INDEX
ISN 0029          IF (NTREES(I).EQ.0) GO TO 2
ISN 0031          CUTSP=.FALSE.
ISN 0032          KEND=KEND+NTREES(I)
ISN 0033          DO 5 JJ=KBEG,KEND
ISN 0034          J=JJ
ISN 0035          IF (DBH(J).LT.ALIMIT(I).OR.DBH(J).GT.BLIMIT(I)) GO TO 6
ISN 0037          NTREES(I)=NTREES(I)-1
ISN 0038          NCUT(I)=NCUT(I)+1
ISN 0039          NFW=NFW+1
ISN 0040          DBHCUT(NFW)=DBH(J)
ISN 0041          KKAGE(NFW)=IGES(J)
ISN 0042          IF (DBH(J).GT.SPTMIN(I).AND.DBH(J).LT.SPTMAX(I)) KSPRT(I)=-1
ISN 0044          CUTT=.TRUE.
ISN 0045          CUTSP=.TRUE.
ISN 0046          GO TO 5
ISN 0047        6 NEW=NEW+1
ISN 0048          ANEW(NEW)=DBH(J)
ISN 0049          KAGES(NEW)=IGES(J)
ISN 0050        5 CONTINUE
ISN 0051          IF (CUTSP.EQ.(.FALSE.)) GO TO 72
ISN 0053          II=I
ISN 0054          IF (.NOT.LOGS) GO TO 65
ISN 0056          PRINT 70,II,NFW,(AAA(I,L),L=1,6)
ISN 0057       70 FORMAT (10X,/,2X,'SPECIES',I2,2X,I3,2X,6A4/,X,'DBH LOGS CUT'/)
ISN 0058          GO TO 74
ISN 0059       65 PRINT 71,II,NFW,(AAA(I,L),L=1,6)
ISN 0060       71 FORMAT (/,12X,'SPECIES ',I2,2X,I3,2X,6A4/,X,'   DBH TREES BURNED'/)
ISN 0061       74 PRINT 29,(DBHCUT(K),K=1,NFW)
ISN 0062       29 FORMAT (20X,4F8.2)
ISN 0063          DO 80 K=1,NFW
ISN 0064          DBHCUT(K)=0.
ISN 0065       80 CONTINUE
ISN 0066          NFW=0
ISN 0067       72 KBEG=KEND+1
ISN 0068        2 CONTINUE
ISN 0069          IF (CUTT.EQ.(.FALSE.)) GO TO 13
ISN 0071          IF (NEW.EQ.0) GO TO 10
ISN 0073          GO TO 8
ISN 0074       13 PRINT 20
ISN 0075       20 FORMAT (5X,'NO TREES CUT'/)
ISN 0076        8 DO 7 I=1,NEW
ISN 0077          DBH(I)=ANEW(I)
ISN 0078          IGES(I)=KAGES(I)
ISN 0079        7 CONTINUE
ISN 0080          RETURN
ISN 0081       10 CONTINUE
ISN 0082          PRINT 11
ISN 0083       11 FORMAT (10X,/10X,'ALL TREES WERE CUT'/)
ISN 0084          DO 12 J=1,700
ISN 0085          DBH(J)=0.0
ISN 0086          IGES(J)=0
ISN 0087       12 CONTINUE
ISN 0088          RETURN
ISN 0089          END
```

```
ISN 0002          SUBROUTINE OUTPUT(DBH,NTREES)
ISN 0003          COMMON /TITLE/ AAA(35,6)
ISN 0004          DIMENSION DBH(700),BDH(500),NTREES(35),IDM(500),BAR(35)
ISN 0005          COMMON /KILD/ NOGRO(100),DDBH(500),KDEAD(35),AREA,KD
ISN 0006          COMMON /TRAGE/ IGES(700),IDGE(500)
ISN 0007          COMMON /RUNNR/ NYR,INYR,KPNT,KAGE,KTIMES,KLAST
ISN 0008          COMMON /HDATA/ B2(35),B3(35),PHI,SOILQ,DEGD
ISN 0009          COMMON /IRUN/ INDEX
ISN 0010           PRINT 11
ISN 0011       11 FORMAT(//' YEAR SPEC.    NUM.              NAME                     BIOMA
              ZSS')
ISN 0012          PRINT 21,INYR
ISN 0013       21 FORMAT(I5)
ISN 0014       96 NDEAD=0
ISN 0015          NTOT=0
ISN 0016          DO 1 I=1,INDEX
ISN 0017          NDEAD=NDEAD+KDEAD(I)
ISN 0018        1 NTOT=NTOT + NTREES(I)
ISN 0019          IF(NTOT.EQ.0) GO TO 100
ISN 0021          N=1
ISN 0022          AREA=0.0
ISN 0023          TBAR=0.0
ISN 0024          DO 20 II=1,INDEX
ISN 0025          I=II
ISN 0026          BAR(I)=0.0
ISN 0027          IF(NTREES(I).EQ.0) GO TO 20
ISN 0029          NN=N+NTREES(I) - 1
ISN 0030          N1=NTREES(I)
ISN 0031          DO 50 JJ=N,NN
ISN 0032          J=JJ
ISN 0033       50 AREA=AREA+1.9283295E-4*DBH(J)**2.129
ISN 0034          DO 97 J=1,N1
ISN 0035          N2=J+N-1
ISN 0036          BDH(J)=DBH(N2)
ISN 0037          BAR(I)=BAR(I)+.1193*DBH(N2)**2.393
ISN 0038       97 CONTINUE
ISN 0039          TBAR=TBAR+BAR(I)
ISN 0040          N2=MIN0(12,N1)
ISN 0041          PRINT 2, I,NTREES(I),(AAA(I,K),K=1,6),BAR(I),(BDH(J),J=1,N2)
ISN 0042          IF(N1.GT.12) PRINT 5,(BDH(J),J=13,N1)
ISN 0044        5 FORMAT(20X, 4F8.3,/,20X,4F8.3,/,20X,4F8.3)
ISN 0045          N=N+NTREES(I)
ISN 0046       20 CONTINUE
ISN 0047           TBAR=TBAR*.012
ISN 0048          PRINT 7, NTOT,TBAR,AREA
ISN 0049        7 FORMAT(10X/10X,I7,E12.3,' METRIC TON/HA. LEAF AREA =',F 9.3)
ISN 0050        2 FORMAT(/,5X,I5,'    ',I3,'     ',6A4,'   ',E9.3,'    ',
             Z(/,/,15X,'DBH   ',4F8.3,/,20X,4F8.3,/,20X,4F8.3))
ISN 0051          GO TO 200
ISN 0052      100 PRINT 3,INYR
ISN 0053        3 FORMAT(10X,'YEAR',I5,' NO TREES LIVING')
ISN 0054          THEEND=1810.
ISN 0055          IF (DEGD .GT. THEEND) GO TO 296
ISN 0057      298 PRINT 297
ISN 0058      297 FORMAT(10X,'NONE OF THE SPECIES YOU ARE USING CAN EXIST WITH TH
             *IS CLIMATE')
ISN 0059          STOP
ISN 0060      296 THEEND=13395.
ISN 0061          IF (DEGD.GT.THEEND) GO TO 298
ISN 0063      200 KD=1
ISN 0064          IF(NDEAD .EQ.0) RETURN
ISN 0066          PRINT 201
ISN 0067      201 FORMAT(' DEAD TREES SINCE LAST PRINTOUT')
ISN 0068          N=1
ISN 0069          DO 99 II=1,INDEX
ISN 0070          I=II
ISN 0071          IF(KDEAD(I).EQ.0) GO TO 99
ISN 0073          NN=N+KDEAD(I) - 1
ISN 0074          N1=KDEAD(I)
ISN 0075          DO 98 J=1,N1
ISN 0076          N2=J+N-1
ISN 0077          BDH(J)=DDBH(N2)
ISN 0078          IDM(J)=IDGE(N2)
ISN 0079       98 CONTINUE
ISN 0080          N2=MIN0(7,N1)
ISN 0081          PRINT 4, I,KDEAD(I),(BDH(J),IDM(J),J=1,N2)
ISN 0082          IF(N1.GT.7)  PRINT 6,(BDH(J),IDM(J),J=8,N1)
ISN 0084        6 FORMAT(27X,F9.3,I4,F9.3,I4,F9.3,I4,F9.3,I4,F9.3,I4,F9.3,I4,F9.3
             *,I4)
ISN 0085        4 FORMAT(5X,I5,I7,10X,7(F9.3,I4))
ISN 0086          N=N+KDEAD(I)
ISN 0087       99 CONTINUE
ISN 0088          DO 299 I=1,INDEX
ISN 0089          KDEAD(I)=0
ISN 0090      299 CONTINUE
ISN 0091          RETURN
ISN 0092          END
```

```
ISN 0002           SUBROUTINE GROW(DBH,NTREES)
ISN 0003           DIMENSION DBH(700),NTREES(35),PROF(1000)
ISN 0004           COMMON /IRUN/ INDEX
ISN 0005           COMMON /TDATA/ G(35),C(35),ITYPE(35),AGEMX(35),SOIM(35)
ISN 0006           COMMON /KILD/ NOGRO(100),DDBH(500),KDEAD(35),AREA,KD
ISN 0007           COMMON /HDATA/ B2(35),B3(35),PHI,SOILQ,DEGD
ISN 0008           COMMON /CLIMAT/ DMIN(35),DMAX(35)
ISN 0009           NTOT=0
         C         REQUIRES EACH TREE TO ADD A 1.0 MM GROWTH RING EACH YEAR
ISN 0010           AINC=0.1
ISN 0011           DO 1 I=1,INDEX
ISN 0012         1 NTOT=NTOT+NTREES(I)
ISN 0013           IF(NTOT.EQ.0) RETURN
ISN 0015           DO 2 I=1,100
ISN 0016         2 NOGRO(I)=0
ISN 0017           DO 9998 MN=1,1000
ISN 0018      9998 PROF(MN)=0.0
ISN 0019           N2=1
ISN 0020           BAR=0.
ISN 0021           DO 8 LL=1,INDEX
ISN 0022           L=LL
ISN 0023           IF(NTREES(L).EQ.0) GO TO 8
ISN 0025           N3=N2+NTREES(L)-1
ISN 0026           DO 7 KM=N2,N3
ISN 0027           K=KM
ISN 0028           BAR=BAR+.785*(DBH(K)**2)
         C
         C          THE HEIGHT PROFILE IS CALCULATED IN .1 METER UNITS
         C
ISN 0029           IHT=IFIX((B2(L)*DBH(K)-B3(L)*DBH(K)**2)/10.+1.)
         C
         C         DATA FROM SULLINS ET AL  PAGE 41.  SCALED TO 1/24 HA.
         C
ISN 0030           PROF(IHT)=PROF(IHT)+1.9283295E-4*DBH(K)**2.129
ISN 0031         7 CONTINUE
ISN 0032         8 N2=N2+NTREES(L)
ISN 0033           BAR=BAR/10000.
ISN 0034            DO 9997 MN=1,999
ISN 0035           MN1=1000-MN
ISN 0036           PROF(MN1)=PROF(MN1)+PROF(MN1+1)
ISN 0037      9997 CONTINUE
ISN 0038           N=1
ISN 0039           M=1
ISN 0040           DO 10 I=1,INDEX
ISN 0041           IF(NTREES(I).EQ.0) GO TO 10
ISN 0043           NN=N+NTREES(I)-1
ISN 0044           DO 9 KK=N,NN
ISN 0045           J=KK
ISN 0046           HT=B2(I)*DBH(J)-B3(I)*DBH(J)**2
         C          SAME SCALE FACTOR AS ABOVE
ISN 0047           IHT=IFIX(HT/10.+2.)
ISN 0048           SLA=PROF(IHT)
ISN 0049           AL=PHI*EXP(-SLA*.25)
ISN 0050           CC=(137.+0.25*B2(I)**2/B3(I))*(0.5*B2(I)/B3(I))
ISN 0051           DINC=G(I)*DBH(J)*(1.0-(137.0*DBH(J)+B2(I)*DBH(J)**2-B3(I)*DBH(J
          *)**3)/CC)/(274.+3.0*B2(I)*DBH(J)
          * -4.0*B3(I)*DBH(J)**2)*(1.0-BAR/SOILQ)*SOIM(I)*4.0*(DEGD-DMIN(I))*
          *(DMAX(I)-DEGD)/(DMAX(I)-DMIN(I))**2
ISN 0052            IF (ITYPE(I).EQ.3) DINC=2.24*(1.0-EXP(-1.136*(AL-0.08)))*DINC
         C          IF(ITYPE(I).EQ.2) DINC=.5*DINC*(2.24*(1.0-EXP(-1.136*(AL-.08)))+
         C         *(1.0-EXP(-4.64*(AL-.05))))
ISN 0054           IF(ITYPE(I).EQ.1) DINC=(1.0-EXP(-4.64*(AL-.05)))*DINC
ISN 0056           IF(DINC.LT.AINC) DINC=0.0
ISN 0058           IF(DINC.GT.5.0) PRINT 6,J,I,DBH(J),DINC
ISN 0060         6 FORMAT(' DINC IS .GT. 5.0 FOR TREE',I5,' SPECIES',I3,' DBH',F6.
          *1,' DINC',F8.3)
ISN 0061           IF(DINC.NE.0.0) GO TO 91
ISN 0063           NOGRO(M)=J
ISN 0064           M=M+1
ISN 0065        91 DBH(J)=DBH(J)+DINC
ISN 0066         9 CONTINUE
ISN 0067        10 N=N+NTREES(I)
ISN 0068           RETURN
ISN 0069           END
```

```
      SUBROUTINE BIRTH(IX,NTREES,DBH)
      LOGICAL SWITCH(5),S(35,5)
      DIMENSION KTIME(35)
      COMMON /FDATA/ FARDAM(500),ALIMIT(35),BLIMIT(35),IMYR
      COMMON /RUNNR/ NYR,INYR,KPNT,KAGE,KTIMES,KLAST
      COMMON /LOGBLK/ SWITCH,KTIME,S
      COMMON /IRUN/ INDEX
      DIMENSION NTREES(35),ANEW(700),DBH(700),NAGE(700)
      DIMENSION NEW(35)
      COMMON /TRAGE/ IGES(700),IDGE(500)
      COMMON /HDATA/ B2(35),B3(35),PHI,SOILQ,DEGD
C     SMALLEST TREE IS 1.27 CM OR .5 INCHES
      SIZE=1.27
      CALL RANDOM(IX,R)
      CALL RANDOM(IX,RAT)
       MMMM=3.*R+1.
      DO 777 MMMMM=1,MMMM
  210 WEIGHT=0.0
      NU=1
      DO 230 LL=1,INDEX
      L=LL
      IF(NTREES(L).EQ.0) GO TO 230
      NNU=NU+NTREES(L)-1
      DO 220 MM=NU,NNU
      M=MM
       BIOM=1.9283295E-4*DBH(M)**2.129
  220 WEIGHT=WEIGHT+BIOM
C        EQUATIONS FOR LEAF MASS FROM SOLLIN'S
  230 NU=NU+NTREES(L)
      KEND=NU-1
      NIX=0
      DO 44 JKL=1,5
   44 SWITCH(JKL)=.TRUE.
C     SWITCH 1 SETS LOWER LIMIT FOR PLANTS NEEDING LITTER
      IF(WEIGHT.GE..1) SWITCH(1)=.FALSE.
C     SWITCH 2 SETS UPPER LIMIT FOR TREES NEEDING MINERAL SOIL
      IF(WEIGHT.LE..2.AND.IMYR.LE.100) SWITCH(2)=.FALSE.
C     SWITCH 3 ELIMINATES DROUGHT SENSITIVE SPECIES
      IF(DEGD.LE.8700.0) SWITCH(3)=.FALSE.
      CALL RANDOM(IX,R)
C      SWITCH 5 REDUCES SEEDING RATE OF DESIRABLE MAST
      IF(R.GE..5) SWITCH(5)=.FALSE.
      CALL RANDOM(IX,R)
C     SWITCH 4 ELIMINATES DEER EATEN SPECIES
      IF(RAT.GT..5) SWITCH(4)=.FALSE.
      DO 205 LL=1,INDEX
      L=LL
      DO 444 JKL=1,5
  444 IF(S(LL,JKL).AND.SWITCH(JKL)) GO TO 205
C     THIS SECTION RESTRICTS THE PLANTING OF CERTAIN TREE SPECIES
C      THAT TYPICALLY ARE ASSOCIATED WITH OLD FIELD SUCCESSION.
C      KTIME(I) IS THE LAST YEAR SINCE A CLEARING THAT THE ITH
C      SPECIES CAN BE EXPECTED TO SEED IN.  SINCE THE LIMITING FACTOR
C      IS POSTULATED TO BE A SEED SOURCE PROBLEM, WE ALLOW SEEDING IN
C       IF THERE IS A PARENT TREE ON THE PLOT.
      IF ((IMYR.GT.KTIME(LL)).AND.(NTREES(LL).LE.0)) GO TO 205
      NIX=NIX+1
      NEW(NIX)=L
  205 CONTINUE
      IF (NIX .EQ.0) GO TO 74
      DO 2 J=1,KEND
      NAGE(J)=IGES(J)
      ANEW(J)=DBH(J)
    2 CONTINUE
      CALL RANDOM(IX,R)
C    VALUE OF 5.0 ASSUMES AN AVERAGE OF 1284 SEEDLINGS/HA.
      M=8.0*R
      CALL RANDOM(IX,R)
      NIX=NIX*R+1.0
      N=NEW(NIX)
      KSUM=0
      DO 51 I=1,N
   51 KSUM=KSUM+NTREES(I)
      DO 70 J=1,M
      KSUM=KSUM+1
      NTREES(N)=NTREES(N)+1
      NAGE(KSUM)=0
      CALL RANDOM(IX,R)
      ANEW(KSUM)=SIZE+0.3*(1.0-R)**3
      KEND=KEND+1
      K1=KSUM+1
      DO 60 II=K1,KEND
      I=II
      ANEW(I)=DBH(I-1)
      NAGE(I)=IGES(I-1)
   60 CONTINUE
      IF(KEND .LT.701) GO TO 61
      PRINT 98
      STOP
   61 CONTINUE
   98 FORMAT (' <<<<<<<<<<<LOOK OUT THE NTREES VECTOR GOT TOO BIG>>>
     *>>>',13I4/' <<<<<<<<<<<<TRY COMPATIBLE SPECIES AND CLIMATE>>>>>>')
```

```
ISN 0089          DO 65 I=1,KEND
ISN 0090          IGES(I)=NAGE(I)
ISN 0091       65 DBH(I)=ANEW(I)
ISN 0092       70 CONTINUE
ISN 0093          N=0
ISN 0094       74 CONTINUE
ISN 0095           CALL SPROUT(IX,NTREES,DBH)
ISN 0096          IF(WEIGHT.LT.0.2) GO TO 210
ISN 0098          DO 100 I=1,KEND
ISN 0099          IGES(I)=IGES(I)+1
ISN 0100      100 CONTINUE
ISN 0101      777 CONTINUE
ISN 0102          RETURN
ISN 0103          END
```

```
ISN 0002          SUBROUTINE DATA
ISN 0003          COMMON /TITLE/ AAA(35,6)
ISN 0004          LOGICAL SWITCH(5),S(35,5)
ISN 0005          DIMENSION KTIME(35)
ISN 0006          COMMON /LOGBLK/ SWITCH,KTIME,S
ISN 0007          COMMON /SDATA/ KSPRT(35),STEND(35),SPTMIN(35),SPTMAX(35)
ISN 0008          COMMON /IRUN/ INDEX
ISN 0009          COMMON /TDATA/ G(35),C(35),ITYPE(35),AGEMX(35),SOIM(35)
ISN 0010          COMMON /RUNNR/ NYR,INYR,KPNT,KAGE,KTIMES,KLAST
ISN 0011          COMMON /HDATA/ B2(35),B3(35),PHI,SOILQ,DEGD
ISN 0012          COMMON /CLIMAT/ DMIN(35),DMAX(35)
ISN 0013          INDEX=33
ISN 0014          IX=76123
ISN 0015          KTIMES=1
ISN 0016          KLAST=3
ISN 0017          NYR=500
ISN 0018          KPNT=50
ISN 0019          KAGE=-1
ISN 0020          PHI=1.0
ISN 0021          SOILQ=3.83
ISN 0022          DEGD=8700.
            C      VALUE FOR SOILQ FROM MAX VALUE CITED BY DICK WILLIAMS, GP FORESTER
ISN 0023          DO 23 J=1,INDEX
ISN 0024       23 READ(5,24)(AAA(J,II),II=1,6),DMAX(J),DMIN(J),B3(J),B2(J),ITYPE(J),
                 AAGEMX(J),C(J),G(J),STEND(J),SPTMIN(J),SPTMAX(J),
                 B(S(J,JI),JI=1,5),KTIME(J),SOIM(J)
ISN 0025       24 FORMAT(6A4,F6.0,F5.0,F4.3,F5.2,I1,F4.0,F2.0,F5.1,F2.0,F4.1,F4.0,
                 A5L1,I4,F3.1)
ISN 0026       30 RETURN
ISN 0027          END
```

```
      SUBROUTINE RANDOM(IX,R)
      R=FLTRN(IX)
      RETURN
      END
```

```
      SUBROUTINE GAUSS(IX,S,AM,DEGD)
      Z=0.0
      DO 5 I=1,12
    5 Z=Z+FLTRN(DUM)
      Z=Z-6.
      DEGD=AM+S*Z
      RETURN
      END
```

```
      SUBROUTINE INIT(DBH,NTREES,DBHK,NTREEK,JJ)
      COMMON /IRUN/ INDEX
      DIMENSION DBH(1),NTREES(1),DBHK(1),NTREEK(1)
      COMMON /SDATA/ KSPRT(35),STEND(35),SPTMIN(35),SPTMAX(35)
      COMMON /KILD/ NOGRO(100),DDBH(500),KDEAD(35),AREA,KD
      COMMON /TRAGE/ IGES(700),IDGE(500)
      DO 10 J=1,500
      DDBH(J)=0.0
      IDGE(J)=0
   10 CONTINUE
      DO 11 J=1,100
   11 NOGRO(J)=0
      DO 13 J=1,INDEX
   13 KSPRT(J)=1
      IF (JJ .GT.1) GO TO 1
      DO 2 J=1,INDEX
    2 NTREEK(J)=NTREES(J)
      DO 3 K=1,100
    3 DBHK(K)=DBH(K)
      RETURN
    1 CONTINUE
      DO 4 J=1,INDEX
    4 NTREES(J)=NTREEK(J)
      DO 5 K=1,100
    5 DBH(K)=DBHK(K)
      RETURN
      END
```

```
      SUBROUTINE PLOTIN(IPLOT,DBH,NTREES)
      COMMON /TRAGE/ IGES(700),IDGE(500)
      COMMON /KILD/ NOGRO(100),DDBH(500),KDEAD(35),AREA,KD
      DIMENSION DBH(700),NTREES(35)
      DO 1 J=1,35
      KDEAD(J)=0
      DBH(J)=0.0
      IGES(J)=0
    1 NTREES(J)=0
      DO 2 J=36,700
      IGES(J)=0
    2 DBH(J)=0.0
      IPLOT=IPLOT+1
      PRINT 13,IPLOT
   13 FORMAT (/,'  PLOT NUMBER   ',I4)
      RETURN
      END
```

```
ISN 0002          SUBROUTINE KILL(DBH,NTREES,IX)
ISN 0003          DIMENSION DBH(700),NTREES(35)
ISN 0004          COMMON /FDATA/ FARDAM(500),ALIMIT(35),BLIMIT(35),IMYR
ISN 0005          COMMON /IRUN/ INDEX
ISN 0006          COMMON /SDATA/ KSPRT(35),STEND(35),SPTMIN(35),SPTMAX(35)
ISN 0007          COMMON /TDATA/ G(35),C(35),ITYPE(35),AGEMX(35),SOIM(35)
ISN 0008          COMMON /KILD/ NOGRO(100),DDBH(500),KDEAD(35),AREA,KD
ISN 0009          COMMON /TRAGE/ IGES(700),IDGE(500)
ISN 0010          COMMON /RUNNR/ NYR,INYR,KPNT,KAGE,KTIMES,KLAST
ISN 0011          ID = 1
ISN 0012          IDF=0
ISN 0013          N = 0
ISN 0014          NB=0
ISN 0015          DO 100 J=1,INDEX
ISN 0016          NB=NB+KDEAD(J)
ISN 0017          IF(NTREES(J).EQ.0) GO TO 100
ISN 0019          NA = N + 1
ISN 0020          NN = NTREES(J) + N
ISN 0021          DO 80 II=NA,NN
ISN 0022          I=II
ISN 0023          CALL RANDOM(IX,R1)
ISN 0024          IF (FARDAM(IDF).EQ.I) GO TO 42
ISN 0026          IF(R1.LE.(4.605/AGEMX(J))) GO TO 50
ISN 0028          GO TO 44
ISN 0029       42 IDF=IDF+1
ISN 0030          IF (R1.LE..275) GO TO 50
ISN 0032       44 IF(NOGRO(ID).EQ.I) GO TO 40
ISN 0034          GO TO 80
ISN 0035       40 ID=ID + 1
ISN 0036          CALL RANDOM(IX,R2)
ISN 0037          IF(R2.GT.0.368) GO TO 80
ISN 0039       50 IF(KAGE.LT.0) GO TO 70
ISN 0041          KDEAD(J)=KDEAD(J)+1
ISN 0042          NB=NB+1
ISN 0043          NUP=KD-NB
ISN 0044          IF(NUP.EQ.0) GO TO 56
ISN 0046          DO 55 KK=1,NUP
ISN 0047          K=KK
ISN 0048          IJ=KD-K+1
ISN 0049          IF(IJ .GT.500) GO TO 99
ISN 0051          DDBH(IJ)=DDBH(IJ-1)
ISN 0052          IDGE(IJ)=IDGE(IJ-1)
ISN 0053       55 CONTINUE
ISN 0054       56 DDBH(NB)=DBH(I)
ISN 0055          IDGE(NB)=IGES(I)
ISN 0056          KD=KD+1
ISN 0057          GO TO 70
ISN 0058       99 PRINT 98
ISN 0059       98 FORMAT(' DEAD TREES VECTOR FILLED, RERUN WITH SMALLER PERIOD BE
                 *TWEEN PRINTOUTS (KPNT)')
ISN 0060          KAGE=-1
ISN 0061       70 NTREES(J)=NTREES(J)-1
            C      THIS IS THE SWITCH TO STUMP SPROUT TREES.
ISN 0062          IF(DBH(I).GT.SPTMIN(J).AND.DBH(I).LT.SPTMAX(J)) KSPRT(J)=-1
ISN 0064          DBH(I)= -1.0
ISN 0065       80 CONTINUE
ISN 0066          N = NN
ISN 0067      100 CONTINUE
ISN 0068          DO 200 II=1,700
ISN 0069          I=II
ISN 0070          IF(DBH(I).EQ.0.0) RETURN
ISN 0072          IF(DBH(I) .GT. 0.0) GO TO 200
ISN 0074      110 DO 120 KK = I,699
ISN 0075          K=KK
ISN 0076          DBH(K) = DBH(K+1)
ISN 0077          IGES(K)=IGES(K+1)
ISN 0078      120 CONTINUE
ISN 0079          DBH(700) = 0.0
ISN 0080          IF(DBH(I).LT.0.0) GO TO 110
ISN 0082      200 CONTINUE
ISN 0083          RETURN
ISN 0084          END
```

```
ISN 0002          SUBROUTINE FIRE (DBH,NTREES)
ISN 0003          DIMENSION DBH(700),NTREES(35)
ISN 0004          COMMON /FDATA/ FARDAM(500),ALIMIT(35),BLIMIT(35),IMYR
ISN 0005          COMMON /SDATA/ KSPRT(35),STEND(35),SPTMIN(35),SPTMAX(35)
ISN 0006          COMMON /IRUN/ INDEX
ISN 0007          LOGICAL LOGS
         C        R=0.
ISN 0008          LOGS=.FALSE.
ISN 0009          IF (R.GE..828) GO TO 20
ISN 0011          PRINT 12
ISN 0012       12 FORMAT (5X,  'LIGHT FIRE'/)
ISN 0013          DO 15 J=1,INDEX
ISN 0014          ALIMIT(J)=0.
ISN 0015          BLIMIT(J)=12.7
ISN 0016       15 CONTINUE
ISN 0017          CALL CUT (DBH,NTREES,LOGS)
ISN 0018          RETURN
ISN 0019       20 IF (R.GE..966) GO TO 30
ISN 0021          PRINT 21
ISN 0022       21 FORMAT (5X,'  MEDIUM FIRE'/)
ISN 0023          DO 25 J=1,INDEX
ISN 0024          ALIMIT(J)=0.
ISN 0025          GO TO (22,22,23,23,22,22,23,22,23,22,22,24,22,23,22,24,22,23,22,23
                 A,22,24,24,22,23,23,23,23,24,24,23,23,23),J
ISN 0026       22 BLIMIT(J)=500.
ISN 0027          GO TO 25
ISN 0028       23 BLIMIT(J)=25.4
ISN 0029          GO TO 25
ISN 0030       24 BLIMIT(J)=17.8
ISN 0031       25 CONTINUE
ISN 0032          CALL CUT (DBH,NTREES,LOGS)
ISN 0033          N=0
ISN 0034          IJ=0
ISN 0035          DO 42 J=1,INDEX
ISN 0036          NA=N+1
ISN 0037          NN=N+NTREES(J)
ISN 0038          GO TO (35,35,40,40,35,35,40,35,40,35,35,35,35,40,35,35,35,40,35,40
                 A,35,35,35,35,40,40,40,40,35,35,40,40,40),J
ISN 0039       40 DO 35 JJ=NA,NN
ISN 0040          IJ=IJ+1
ISN 0041          FARDAM(IJ)=JJ
ISN 0042       35 CONTINUE
ISN 0043          N=NN
ISN 0044       42 CONTINUE
ISN 0045          IMYR=0
ISN 0046          RETURN
ISN 0047       30 DO 36 J=1,INDEX
ISN 0048          IF (NTREES(J).EQ.0) GO TO 36
ISN 0050          KSPRT(J)=-1
ISN 0051          NTREES(J)=0
ISN 0052       36 CONTINUE
ISN 0053          DO 37 J=1,700
ISN 0054          DBH(J)=0.
ISN 0055       37 CONTINUE
ISN 0056          PRINT 38
ISN 0057       38 FORMAT (5X,'SEVERE FIRE--ALL TREES WERE BURNED'/)
ISN 0058          RETURN
ISN 0059          END
```

Appendix A-4

Sample Output of Program FORAR

SAMPLE OUTPUT OF PROGRAM FORAR

```
 PLOT NUMBER       1

YEAR SPEC.   NUM.          NAME                    BIOMASS
  0
        YEAR      0 NO TREES LIVING

YEAR SPEC.   NUM.          NAME                    BIOMASS
 50
         5      3    CARYA LACINIOSA            0.674E 00

              DBH      1.270    1.364    1.271

         6      3    CARYA OVATA                0.251E 02

              DBH      9.260    1.472    1.209

        11      2    CORNUS FLORIDA             0.506E 02

              DBH      9.385    9.378

        12      5    DIOSPYROS VIRGINIANA       0.182E 03

              DBH     10.426   10.307   11.507   11.528
                      10.728

        13      6    FAGUS GRANDIFOLIA          0.144E 01

              DBH      1.383    1.270    1.276    1.288
                       1.362    1.451

        14      7    FRAXINUS AMERICANA         0.497E 03

              DBH     14.376   14.365   16.780   14.526
                      16.222   15.875    0.138

        15      3    ILEX OPACA                 0.303E-02

              DBH      0.118    0.172    0.106

        18     11    LIQUIDAMBAR STYRACIFLUA    0.450E 03

              DBH     12.194   13.847   12.539   13.211
                      12.277   12.960   13.946   13.633
                       1.388    1.270    1.427

        19      1    MORUS RUBRA                0.963E 01

              DBH      6.265

        23     13    PINUS TAEDA                0.692E 04

              DBH     30.651   31.511   39.092   29.708
                      35.729   38.035   37.236   34.367
                      31.520   33.687   29.159   29.154
                      32.083

        24      8    PRUNUS SEROTINA            0.752E 03

              DBH     17.908   17.181   17.240   16.655
                      16.766   17.733   16.634    0.168

        25      3    QUERCUS ALBA               0.708E 00

              DBH      1.430    1.270    1.270

        26     17    QUERCUS FALCATA            0.531E 03

              DBH     11.952   11.824   12.001   12.693
                      12.748   12.252   11.821   12.005
                      12.555   12.221   11.820    4.430
                       5.289    1.451    1.277    1.321
                       1.273

        27      1    QUERCUS MARILANDICA        0.226E 01

              DBH      3.418

        28      7    QUERCUS SHUMARDII          0.170E 03

              DBH     10.143   11.432   10.429   10.143
                      10.708    1.371    1.458

        31      8    SASSAFRAS ALBIDUM          0.224E 02

              DBH      8.677    1.503    1.301    0.113
                       0.192    1.437    1.389    1.399
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        32      19     ULMUS ALATA                 0.628E 03

                DBH     14.744   13.260   12.779   13.492
                        12.770   12.772   15.100   14.663
                        14.269   12.770    0.100    1.289
                         1.287    1.409    0.126    1.270
                         1.528    1.298    1.270

        33       8     ULMUS AMERICANA             0.560E 02

                DBH      6.175    6.507    6.619    6.079
                         5.771    5.768    0.102    1.570

               125    0.124E 03 METRIC TON/HA. LEAF AREA =     7.171

YEAR SPEC.      NUM.            NAME                     BIOMASS
 100

        1C       3     CELTIS LAEVIGATA            0.773E 00

                DBH      1.271    1.368    1.487

        18       2     LIQUIDAMBAR STYRACIFLUA     0.460E 00

                DBH      1.271    1.359

        21       8     OSTRYA VIRGINIANA           0.191E 01

                DBH      1.316    1.272    1.287    1.392
                         1.519    1.281    1.299    1.305

        23       6     PINUS TAEDA                 0.117E 05

                DBH     63.029   70.297   57.756   46.638
                        53.833   50.296

        26       5     QUERCUS FALCATA             0.575E 03

                DBH     18.933   19.034   20.430   19.059
                         1.304

        27       2     QUERCUS MARILANDICA         0.553E 00

                DBH      1.517    1.316

        32       1     ULMUS ALATA                 0.211E 00

                DBH      1.270

                27    0.148E 03 METRIC TON/HA. LEAF AREA =     6.904

YEAR SPEC.      NUM.            NAME                     BIOMASS
 150

         2       1     CARPINUS CAROLINIANA        0.323E 00

                DBH      1.516

         6       1     CARYA LACINIOSA             0.231E 00

                DBH      1.317

        18       1     LIQUIDAMBAR STYRACIFLUA     0.214E 00

                DBH      1.276

        21       3     OSTRYA VIRGINIANA           0.768E 00

                DBH      1.399    1.288    1.435

        23       3     PINUS TAEDA                 0.130E 05

                DBH    102.195   58.679   71.723

        25       6     QUERCUS ALBA                0.152E 01

                DBH      1.275    1.409    1.308    1.436
                         1.492    1.270

        26      11     QUERCUS FALCATA             0.391E 03

                DBH     29.130    3.746    4.503    3.188
                         0.116    0.110    1.516    1.323
                         1.291    1.281    1.316

        32       5     ULMUS ALATA                 0.142E 01

                DBH      1.284    1.550    1.479    1.541
                         1.304

        33       2     ULMUS AMERICANA             0.472E 00

                DBH      1.367    1.292

                33    0.161E 03 METRIC TON/HA. LEAF AREA =     6.774
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YEAR SPEC.    NUM.            NAME                     BIOMASS
 200

       2        2    CARPINUS CAROLINIANA      0.534E 00

              DBH      1.502    1.286

       7        2    CARYA TEXANA              0.442E 00

              DBH      1.316    1.270

      10        7    CELTIS LAEVIGATA          0.168E 01

              DBH      1.270    1.327    1.288    1.466
                       1.289    1.439    1.270

      21        1    OSTRYA VIRGINIANA         0.264E 00

              DBH      1.394

      23        2    PINUS TAEDA               0.157E 05

              DBH    125.903   69.541

      26       10    QUERCUS FALCATA           0.739E 03

              DBH     38.387    1.508    1.273    1.270
                       1.270    1.302    1.286    1.272
                       1.516    1.289

      27       11    QUERCUS MARILANDICA       0.274E 01

              DBH      1.325    1.270    1.393    1.276
                       1.542    1.270    1.540    1.285
                       1.271    1.350    1.389

      29        7    QUERCUS STELLATA          0.174E 01

              DBH      1.281    1.454    1.271    1.303
                       1.488    1.314    1.391

      32        4    ULMUS ALATA               0.902E 00

              DBH      1.331    1.270    1.303    1.313

               46   0.197E 03 METRIC TON/HA. LEAF AREA =     7.786

YEAR SPEC.    NUM.            NAME                     BIOMASS
 250

       6        5    CARYA OVATA               0.832E 01

              DBH      3.490    3.159    3.150    3.142
                       1.600

       8        7    CARYA TOMENTOSA           0.260E 01

              DBH      1.503    1.562    1.574    1.658
                       1.598    1.808    1.525

      10        8    CELTIS LAEVIGATA          0.476E 01

              DBH      2.083    1.856    1.865    1.856
                       2.026    1.897    2.172    1.865

      11        4    CORNUS FLORIDA            0.805E 01

              DBH      3.344    3.124    3.418    3.124

      15       13    ILEX OPACA                0.148E 02

              DBH      3.421    3.399    3.563    3.420
                       2.586    2.617    2.482    2.454
                       1.274    1.271    1.283    1.270
                       1.319

      18        7    LIQUIDAMBAR STYRACIFLUA   0.355E 01

              DBH      1.022    1.843    1.812    1.810
                       1.886    1.841    1.805

      21        6    OSTRYA VIRGINIANA         0.532E 01

              DBH      2.615    2.700    2.030    2.090
                       2.034    2.273

      26        2    QUERCUS FALCATA           0.147E 04

              DBH     51.207    4.339
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        27     15    QUERCUS MARILANDICA       0.985E 01

               DBH     2.676   2.363   2.429   2.417
                       2.001   2.299   2.035   2.340
                       1.582   1.534   1.641   1.753
                       1.656   1.534   1.549

        29      1    QUERCUS STELLATA          0.377E 01

               DBH     4.234

        32      6    ULMUS ALATA               0.311E 02

               DBH     5.226   4.915   5.346   4.915
                       4.917   3.335

               74   0.188E 02 METRIC TON/HA. LEAF AREA =     0.954

YEAR SPEC.     NUM.            NAME                    BIOMASS
 300

         2      4    CARPINUS CAROLINIANA      0.103E 01

               DBH     1.569   1.386   1.270   1.270

         5      3    CARYA LACINIOSA           0.692E 00

               DBH     1.376   1.279   1.293

         6     16    CARYA OVATA               0.283E 03

               DBH    16.100  13.134   9.369   9.139
                       9.157   6.338   6.737   6.385
                       6.815   6.083   2.824   2.813
                       2.962   3.227   2.873   2.909

         7      2    CARYA TEXANA              0.493E 00

               DBH     1.431   1.271

         8     10    CARYA TOMENTOSA           0.229E 03

               DBH    15.015  14.841   8.482   8.763
                       7.965   7.749   1.270   1.345
                       1.270   1.352

        10     11    CELTIS LAEVIGATA          0.216E 03

               DBH    11.299  10.962  11.454   8.471
                       8.459   8.625   8.345   6.664
                       4.288   3.522   3.508

        11     14    CORNUS FLORIDA            0.540E 02

               DBH     7.389   7.159   7.297   4.481
                       4.555   1.480   2.127   1.918
                       1.606   1.480   1.902   1.588
                       1.486   1.486

        13      1    FAGUS GRANDIFOLIA         0.218E 00

               DBH     1.288

        15      6    ILEX OPACA                0.260E 03

               DBH    15.932  13.160  12.649  12.019
                       7.631   0.102

        18     11    LIQUIDAMBAR STYRACIFLUA   0.498E 03

               DBH    18.288  18.504  15.747  13.676
                       8.819   8.557   8.461   8.461
                       5.405   5.225   0.101

        21      2    OSTRYA VIRGINIANA         0.275E 00

               DBH     0.101   1.417

        25      5    QUERCUS ALBA              0.838E 02

               DBH    11.629  11.258   2.438   2.455
                       1.477

        26     34    QUERCUS FALCATA           0.482E 04

               DBH    77.409  25.001  15.814  16.623
                      15.784  15.972  15.789  10.441
                       6.992   6.904   6.164   5.724
                       6.056   5.721   5.719   6.029
                       5.413   5.870   3.911   3.587
                       3.723   3.592   2.895   2.862
                       2.862   2.864   2.977   2.862
                       2.874   2.862   3.148   2.896
                       2.921   2.995
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        27      3     QUERCUS MARILANDICA         0.659E 02
              DBH       9.811    8.891    7.628
        29     20     QUERCUS STELLATA            0.799E 03
              DBH      20.563   13.642   13.651   13.999
                       13.784   13.587   13.728   13.638
                       13.641   14.575    7.393    5.898
                        6.067    5.897    6.470    5.896
                        1.276    1.272    1.270    0.173

        32     11     ULMUS ALATA                 0.446E 03
              DBH      22.916   17.756   16.466    4.480
                        4.242    4.289    3.538    3.548
                        1.294    1.665    0.152
        33      1     ULMUS AMERICANA             0.224E 00
              DBH       1.300
              154    0.931E 02 METRIC TON/HA. LEAF AREA =      5.125

YEAR SPEC.    NUM.            NAME                     BIOMASS
 350
         2      2     CARPINUS CAROLINIANA        0.430E 00
              DBH       1.280    1.278
         5      1     CARYA LACINIOSA             0.223E 00
              DBH       1.299
         6     16     CARYA OVATA                 0.792E 03
              DBH      27.565   19.406   15.211   14.672
                       14.207    9.866    9.837   10.460
                        0.136    0.112    1.407    1.329
                        1.303    1.282    1.370    1.270

         7      3     CARYA TEXANA                0.675E 00
              DBH       1.284    1.306    1.320
         8      7     CARYA TOMENTOSA             0.349E 03
              DBH      28.040    1.464    1.452    1.347
                        1.366    1.270    1.493
        10      3     CELTIS LAEVIGATA            0.399E 03
              DBH      19.806   20.004   16.148
        11      3     CORNUS FLORIDA              0.788E 00
              DBH       1.288    1.349    1.521
        16      1     ILEX OPACA                  0.342E 00
              DBH       1.553
        18     11     LIQUIDAMBAR STYRACIFLUA     0.192E 04
              DBH      37.444   38.465   29.044   16.818
                        1.425    0.127    1.271    1.276
                        1.412    1.557    1.488
        21      2     OSTRYA VIRGINIANA           0.515E 00
              DBH       1.475    1.273
        26     18     QUERCUS FALCATA             0.386E 04
              DBH      31.984   33.457   31.863   32.422
                       31.914   24.189   19.686   19.530
                       18.363   18.182   17.503   18.110
                       16.980   14.216   13.026   12.966
                       12.952   12.952
        27      2     QUERCUS MARILANDICA         0.450E 00
              DBH       1.332    1.274
        29      5     QUERCUS STELLATA            0.147E 04
              DBH      36.984   25.371   24.921   24.983
                        0.100
        32      1     ULMUS ALATA                 0.565E 03
              DBH      34.347
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          33     6    ULMUS AMERICANA           0.144E 01

                DBH     1.276   1.274   1.270   1.309
                        1.310   1.562

                81    0.112E 03 METRIC TON/HA. LEAF AREA =    6.327

YEAR SPEC.    NUM.            NAME                  BIOMASS
 400

           5     3    CARYA LACINIOSA           0.641E 00

                DBH     1.270   1.281   1.276

           6     2    CARYA OVATA               0.263E 03

                DBH    24.955   1.271

           7     4    CARYA TEXANA              0.113E 01

                DBH     1.408   1.491   1.271   1.553

           8     4    CARYA TOMENTOSA           0.902E 00

                DBH     1.270   1.270   1.326   1.350

          10     5    CELTIS LAEVIGATA          0.239E 03

                DBH    23.952   1.283   1.280   1.285
                        1.532

          13     1    FAGUS GRANDIFOLIA         0.216E 00

                DBH     1.282

          26    12    QUERCUS FALCATA           0.823E 04

                DBH    48.937  47.770  50.093  48.447
                       37.638  30.663  30.143  29.821
                       27.980  24.674  23.138  22.998

          27     5    QUERCUS MARILANDICA       0.132E 01

                DBH     1.271   1.392   1.510   1.473
                        1.296

          29     7    QUERCUS STELLATA          0.732E 03

                DBH    38.240   0.101   1.306   1.386
                        1.314   1.273   1.477

          32     1    ULMUS ALATA               0.218E 00

                DBH     1.287

                44    0.114E 03 METRIC TON/HA. LEAF AREA =    5.819

YEAR SPEC.    NUM.            NAME                  BIOMASS
 450

           2     3    CARPINUS CAROLINIANA      0.764E 00

                DBH     1.422   1.271   1.418

           6     1    CARYA OVATA               0.635E 03

                DBH    36.062

           7     1    CARYA TEXANA              0.215E 00

                DBH     1.278

           8     4    CARYA TOMENTOSA           0.911E 00

                DBH     1.275   1.285   1.382   1.294

          10     1    CELTIS LAEVIGATA          0.500E 03

                DBH    32.643

          15     2    ILEX OPACA                0.466E 00

                DBH     1.325   1.319

          25     6    QUERCUS ALBA              0.156E 01

                DBH     1.461   1.418   1.271   1.564
                        1.280   1.270
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        26     11    QUERCUS FALCATA            0.799E 04

               DBH    64.076  69.005  44.239  41.929
                      33.531   2.805   1.480   1.321
                       1.473   1.458   1.273

        27      3    QUERCUS MARILANDICA        0.754E 00

               DBH     1.475   1.270   1.338

        32      3    ULMUS ALATA                0.793E 00

               DBH     1.384   1.305   1.486

               35   C.110E 03 METRIC TON/HA. LEAF AREA =    5.177

YEAR SPEC.    NUM.          NAME                     BIOMASS
 500

         2      1    CARPINUS CAROLINIANA       0.227E 00

               DBH     1.309

         6      1    CARYA OVATA                0.121E C4

               DBH    47.232

         7      3    CARYA TEXANA               0.848E 00

               DBH     1.271   1.161   1.331

        10      2    CELTIS LAEVIGATA           C.877E 03

               DBH    41.266   1.278

        13      3    FAGUS GRANDIFOLIA          0.780E 00

               DBH     1.540   1.271   1.323

        15      8    ILEX OPACA                 0.189E 01

               DBH     1.272   1.565   1.275   1.360
                       1.285   1.270   1.306   1.282

        21      4    OSTRYA VIRGINIANA          0.990E 00

               DBH     1.511   1.274   1.349   1.272

        26      3    QUERCUS FALCATA            0.119E 05

               DBH    81.316  88.389  68.141

        32      7    ULMUS ALATA                0.188E 01

               DBH     1.288   1.429   1.335   1.519
                       1.374   1.559   1.293

               32   0.167E 03 METRIC TON/HA. LEAF AREA =    7.284
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