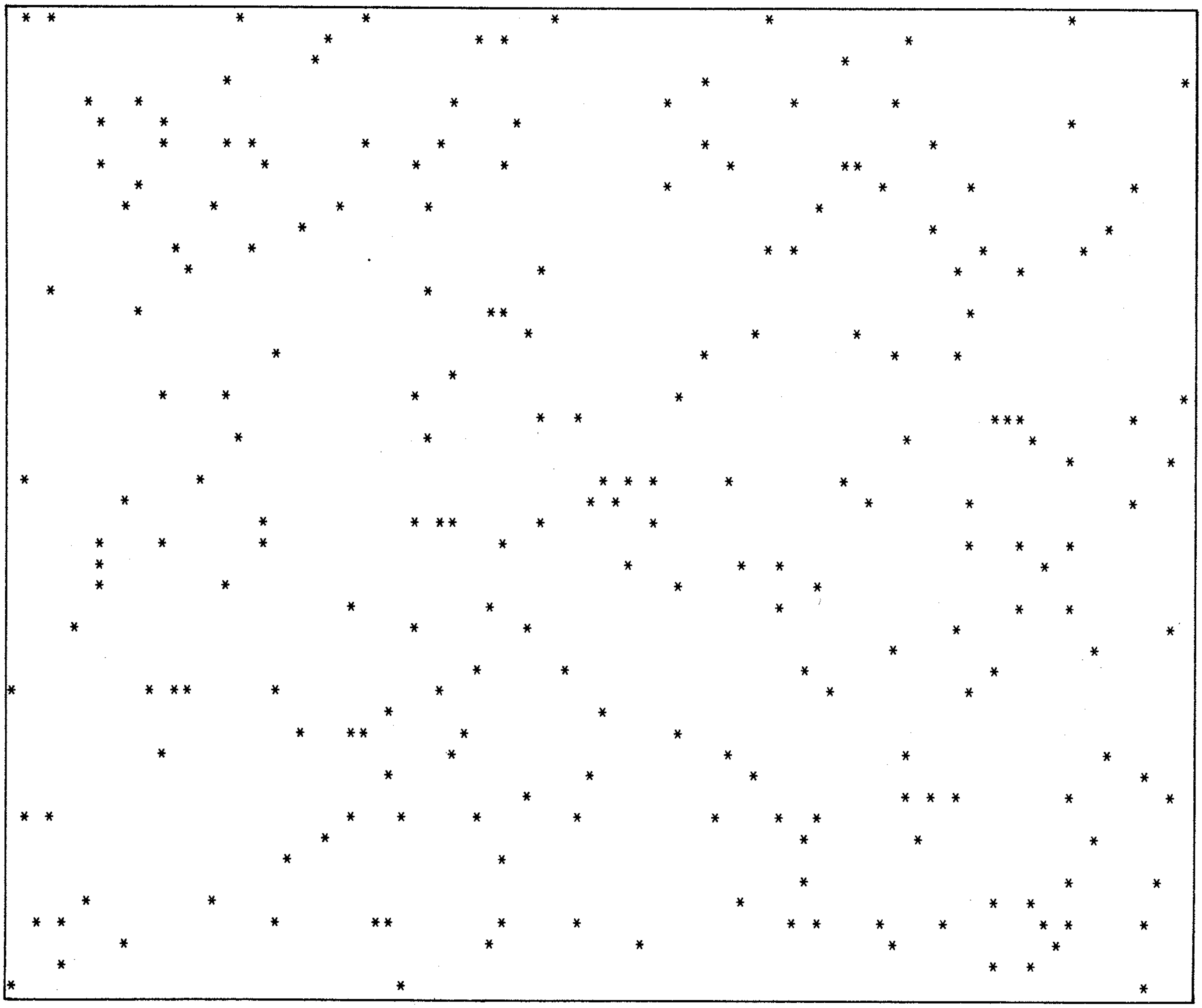
METHODS FOR MODELING INDIVIDUAL TREE GROWTH AND STAND DEVELOPMENT IN SEEDED LOBLOLLY PINE STANDS



FWS—1—79 • SCHOOL OF FORESTRY & WILDLIFE RESOURCES • VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY • 1979

METHODS FOR MODELING INDIVIDUAL TREE GROWTH AND STAND DEVELOPMENT IN SEEDED LOBLOLLY PINE STANDS

by

Richard F. Daniels
Harold E. Burkhart
Gerald D. Spittle
Greg L. Somers

Publication FWS-1-79
School of Forestry and Wildlife Resources
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061 U.S.A.
1979

ABSTRACT

Methods were developed to model growth and development of seeded loblolly pine (*Pinus taeda* L.) stands, using individual trees as the basic growth units. Aggregated spatial patterns and individual tree sizes are generated at age 10. Tree diameters and heights are then incremented annually as a function of their size, site quality, competition from neighbors, and stochastic components representing genetic and microsite variability. Individual tree mortality is determined stochastically through Bernouli trials. Subroutines were developed to simulate the effects of hardwood competition and control, thinning, and fertilization. The overall model was programmed in FORTRAN and initial tests were made with published yields. The initial stand generation components were calibrated using a comprehensive set of data from young seeded stands of loblolly pine, but individual tree growth and mortality components relied on previously published relationships developed for plantations. Results indicated that, in order to accurately model stand structure, the growth and mortality relationships must be calibrated for seeded stands. Data collection procedures, calibration methods, and recommendations for further work are discussed.

ACKNOWLEDGEMENTS

The authors are Research Associate, Professor, Computer Systems Analyst, and Research Assistant, School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. This study was funded partly by a U. S. Department of Agriculture program entitled, "The Expanded Southern Pine Beetle Research and Applications Program" (grant number CSRS 704-15-1); partly by a cooperative study with the U. S. Forest Service, Southeastern Area State and Private Forestry; and partly by the VPI & SU Loblolly Pine Growth and Yield Research Cooperative. The findings, opinions, and recommendations expressed herein are those of the authors and not necessarily those of the U. S. Department of Agriculture.

COVER

The cover design is a computer-generated spatial pattern for a seeded loblolly pine stand.

TABLE OF CONTENTS

INTRODUCTION

Loblolly pine (*Pinus taeda* L.) is one of the most commercially important species in the South, with a natural range extending from Maryland through the southeastern and southern states to east Texas. Although recent emphasis has been on plantation management, there exist millions of acres in natural and direct-seeded loblolly pine stands. Increasing loblolly production to meet future demands will require thorough regeneration of all cutover pine sites (Boyce 1975) and natural and direct-seeding should become increasingly attractive regeneration alternatives.

Most recent studies of loblolly pine growth and yield have considered only plantations and those that have considered seeded stands have worked only with natural stands. However, intensive management has reached the point where the forest manager is faced with a number of regeneration alternatives as well as intermediate cultural treatments. Flexible models capable of providing detailed growth and yield information for the range of available management options have been developed for some species, including planted loblolly pine (Daniels and Burkhart 1975), but are badly needed for seeded loblolly pine.

The objectives of this study were to identify, formulate, and where possible quantify individual tree and stand level relationships in natural and direct-seeded loblolly pine stands for the purpose of constructing a flexible tree and stand growth model. In this paper methods are presented for the development and calibration of an individual-tree-based model of stand development for seeded loblolly pine.

The modeling approach taken is drawn from that of Daniels and Burkhart (1975) in their model for managed loblolly pine plantations. Stand development is modeled as the growth and competitive interaction of individual trees. This offers flexibility since it allows use of both tree- and stand-level information and may be closely tied to biological growth processes. Spatial and competitive relationships can be incorporated directly in such a model. Thus, it lends itself to study of intensive management practices such as thinning and fertilization. Because individual tree locations are known, this type of model is naturally suited to the study of stand development in seeded stands where irregular spatial patterns may affect growth.

RELATED WORK

Growth and Yield/Stand Modeling

Stand Level Models

Yield prediction in natural loblolly pine stands began with classical normal yield tables constructed using graphical techniques from data collected in natural stands of "normal" density (Anon. 1929). Modern quantitative study of growth and yield got its start with MacKinney and Chaiken's (1939) application of multiple regression analysis in constructing a variable density yield equation for loblolly pine. Since that time a number of studies have used multiple regression analysis to construct yield equations for natural and planted southern pine stands (Bennett, et al. 1959, Clutter, 1963, Goebel and Shipman 1964, Burkhart, et al. 1972a, 1972b, and others). Schumacher and Coile (1960) presented a comprehensive study of the growth and yield of natural stands of southern pines which relied on both graphical and regression techniques.

A number of studies have used a diameter distribution analysis procedure for yield prediction in southern pine plantations (Bennett and Clutter 1968, Lenhart and Clutter 1971, Lenhart 1972, Burkhart and Strub 1974, Smalley and Bailey 1974a, 1974b). In this approach a probability density function is used to model the diameter distribution. The number of trees in each diameter class is estimated, total heights are predicted, and volume is calculated by substituting into tree volume equations. Unit area estimates are made by summing over diameter classes of interest. This technique has had very limited application in seeded southern pine stands.

Individual Tree Models

Stand models which use the individual tree as the basic growth unit will be denoted individual tree models. Munro (1974) further segregated this class of models into distance dependent and distance independent categories depending on whether or not individual tree locations are required in the list of tree attributes. Distance independent models may simulate tree growth either individually or by size classes, usually as a function of present size and stand level attributes. No general form has been followed in the construction of individual tree distance independent models so it is difficult to make general statements about their structure. Examples of distance independent models are found in the work of Goulding (1972), Stage (1973), Dale (1975), and Botkin, et al. (1970).

Distance dependent models that have been developed, although varying in detail, have, in general, shared a common structure. Initial tree and stand attributes are input or generated and each tree is assigned a coordinate location. The growth of each tree is simulated as a function of its size, the site quality, and a measure of competition from neighbors. The competition index varies from model to model (see e.g., Bella 1971, Gerrard 1969, Keister 1971, Moore, et al. 1973, Daniels 1976, Alemdag 1978) but in general is a function of the tree's size in relation to the size of and distance to competitors (hence, the need for individual tree locations). Mortality may be controlled either probabilistically or deterministically as a function of competition and/or other individual tree attributes.

Individual tree distance dependant models provide very detailed records of stand structure and development and are well suited for inclusion of routines to simulate cultural treatments. Since Newnham and Smith's (1964) original model for Douglas-fir and lodgepole pine a number of advancements have been made which have allowed evaluation of the effects of various management regimes. By varying initial spatial patterns of trees in a stand, the effects of different regeneration alternatives may be evaluated. The ability to generate regular, random, and aggregated patterns was included in Bella's (1970) aspen model, Hatch's (1971) red pine model, and others. Arney (1974) modeled growth along the entire bole of the tree which allowed examination of tree taper and volume relationships. A flexible model capable of simulating development of uneven-aged mixed-species stands was introduced by Ek and Monserud (1974). Thinnings have been studied using distance-dependant models since it is generally felt that response follows directly from the competition relationships included. Response to fertilizer has also been studied (Ek and Monserud 1974, Heygi 1974).

Daniels and Burkhart (1975) developed a model for loblolly pine plantations which includes routines to simulate the effects of site preparation levels, thinning regimes, and fertilizer applications. To date their work represents the only published application of individual tree distance dependent modeling techniques to southern pine species; the model is finding utility in both research and practical industrial applications.

Spatial Patterns

Interest in quantitative descriptions of forest spatial patterns has increased with the development of distance dependant stand models, especially when considering the irregular patterns found in seeded stands. Quadrat and distance sampling methods have both been used to quantify departures from random spatial arrangements (see Pielou 1969). Both methods have numerous variations, but almost all published studies involve comparisons of observed spatial characteristics (e.g., plot stem counts in quadrat sampling and distances from random points to nearest plants in distance sampling) with those expected in random populations of the same density, providing both an index and a test for the degree of nonrandomness.

Quadrat sampling is generally easy to apply in the field and can be quite reliable, but estimates of nonrandomness may vary with plot size (Pielou 1969). Distance sampling has been suggested to avoid dependence on plot size, but usually requires an independent density estimate for inferences on spatial patterns. Distances from random points to nearest plants (point-to-plant) and distances from random plants to nearest plants (nearest neighbor) have both been used to quantify spatial patterns. Point-to-plant distances are often preferred since it is difficult to choose plants at random in nonrandom stands (Pielou 1969). After comparing several techniques Payandeh (1970) recommended point-to-plant distance sampling and Pielou's index of nonrandomness for quantifying spatial patterns in natural and computer-generated forest populations.

A number of theoretical frequency distributions have been used in spatial studies. The number of individuals per unit area has been described by the Poisson distribution in random populations and by the negative binomial distribution, the Neyman type A distribution and others in clumped populations (Pielou 1969, Southwood 1966). Ker (1954) demonstrated the utility of the negative binomial distribution in examining spatial patterns in young naturally seeded pine stands. The negative binomial distribution has properties that make it desirable for clumped pattern description. For example, it may be derived as the distribution resulting from any of a number of causal mechanisms which produce clumping (Pielou 1969, Southwood 1966) and its two parameters may be directly interpreted as an overall density parameter and a heterogeneity parameter (loosely, a "clumping factor"). The distribution tends to the Poisson distribution as the heterogeneity parameter tends to infinity. A direct correspondence exists between the discrete quadrat sampling distributions discussed above and continuous distributions of point-to-plant distances. Eberhardt (1967) and others have derived distance distributions for populations in which quadrat sampling would yield Poisson and negative binomial distributions of plot densities.

Daniels (1978) used point-to-plant distance methods and Pielou's (1959, 1969) index of nonrandomness to quantify spatial patterns in 40 5-to-12-year-old loblolly pine stands of seed origin. His work indicated that aggregated, or clumped, patterns were prevalent in all seeding methods studied, including natural (old field), seed tree, broadcast, and aerial methods. Further, nonrandomness index values were not found to be related to seeding method or stand attributes such as age, site index, or stand density.

Distance frequencies were further described by Daniels (1978) using distribution methods. By using squared distance as the variate he derived a form of the Pearson type XI distribution from the aggregated distribution proposed by Eberhardt (1967). The Pearson type XI distribution fit observed values well and was proposed as a general spatial model for seeded stands. Because of its relationship to the negative binomial distribution, its parameters were also interpreted in terms of stand density and heterogeneity. A direct relationship was shown between the heterogeneity parameter and Pielou's index of nonrandomness.

A number of computerized algorithms have been developed to generate spatial arrangements of points. Regular patterns are simple to generate by placing points on a grid. Random patterns may be produced by generating coordinates from a uniform distribution. Aggregated patterns have been generated by concentrating points around clump centers and by establishing density gradients for the placement of points (Newnham 1968, Newnham and Maloley 1970). Wensel (1975) used a method involving a probability matrix which was altered to increase or decrease the probability of future points being located within a certain distance of the point just located.

Although realistic aggregated patterns resulted from the above algorithms, none are related to field measures of spatial pattern mentioned earlier. This prompted Daniels and Spittle (1977) and Stauffer (1978), independently, to develop methods of generating spatial patterns with known spatial parameters (e.g., Pielou's index) by using distributions of point-to-plant distances. This work will be discussed later.

METHODS

The basic modeling philosophy and framework used by Daniels and Burkhart (1975) for loblolly pine plantations was adopted in constructing model components for seeded loblolly pine stands. In this approach, stand development is divided into two stages. The first stage involves the generation of an initial stand of trees at the onset of competition. The second deals with the annual growth and development of that stand by simulating the growth, mortality, and competitive interaction of individual trees. Added to this structure are routines to simulate intensive management practices such as thinning and fertilization.

This section provides detailed descriptions for model components in the initial stand generation and stand development stages and for the management routines. Special emphasis has been placed on identifying and quantifying components unique to seeded stands.

Initial Stand Generation

The initial stand generation stage involves the complete specification of the stand spatial pattern and size distributions including the assignment of individual tree coordinate locations, dbh, height, and crown length. Realistic specification of early stand structure is crucial to subsequent simulation of stand dynamics. The aggregated spatial patterns found in seeded stands are much more complex to model than the simple rectangular patterns of plantations. Size distributions are also more varied. Daniels and Burkhart (1975) employed a prediction of the age at which intraspecific competition begins to determine the age to generate tree sizes and to begin annual growth computations. This approach was questioned for seeded stands due to the higher degree of variability in size and spatial relationships and even in age itself for some seeding types. These considerations prompted intensive investigations into methods for realistically generating size and spatial relationships in young seeded stands.

Spatial Patterns

A spatial pattern generator for seeded stands must be capable of generating patterns with varying degrees of aggregation at different levels of stand density. An algorithm was desired which would produce patterns of known aggregation, as measured by an index such as Pielou's. Such an algorithm, which works by essentially inverting the sampling procedures used in point-to-plant distance sampling, was developed.

The Pearson type XI distribution was suggested by Daniels (1978) as a general model for describing squared point-to-plant distances in seeded stands. This distribution, used here as the basis for generating spatial patterns, may be written with cumulative density function (c.d.f.)

$$F_W(w) = 1 - (1 + \frac{c}{k} w)^{-k}, \; w>0$$

where,

w = squared point-to-plant distance

k = heterogeneity parameter

c = density parameter (number of trees per circle of radius = 1 (foot))

Daniels (1978) further noted that the heterogeneity parameter, k, of the Pearson type XI distribution may be estimated by the simple function of Pielou's index of nonrandomness

$$\tilde{k} = \frac{\alpha}{\alpha-1}$$

where,

$\tilde{k}$ = estimated value of k

α = Pielou's index of nonrandomness

Thus, input to a spatial pattern generator based on this distribution requires only knowledge of the stand density, c, and the nonrandomness value, α, desired. Such a generator would be applicable to all types of seeded stands including seed tree, natural, aerial, and broadcast seeding.

By inverting the distribution function via the probability integral transformation, values of a Pearson type XI distributed random variable can be generated stochastically. Specifically, squared distances from random points to nearest trees are generated from the following equation:

$$w = \frac{k}{c}[(1-u)^{-1/k}-1]$$

where,

k = heterogeneity parameter

c = density parameter

u = a random number from the uniform (0,1) distribution

The distance from a random point to the nearest tree, $r = \sqrt{w}$, defines a circle of radius r, centered at the random point, within which no trees are located, but with one tree located on the perimeter. A set of such distances then describes a set of circular open areas. Circles of open area with radius r_i are generated and then allocated to random points distributed throughout a given area. Actual coordinates of the trees are determined by fixing their positions on the circumference of the generated circles, i.e., by fixing the angles Θ_i (Figure 1).

In programming this algorithm, steps had to be taken to ensure that no tree be positioned within the open area associated with another tree. This required detailed accounting and mapping of available space on the plot to check, as trees were positioned sequentially, that 1) no new tree location was fixed within the open area of a tree previously positioned, and 2) open areas of new trees contained no previously positioned trees.

Experience with the algorithm indicated that it provided a flexible tool for generating aggregated patterns over a wide range of conditions. However, because of the constant checking for the two conditions mentioned above, computer time and storage demands were judged too high for practical inclusion in a forest stand growth model.

Independently, Stauffer (1978) developed a set of algorithms for aggregating points to fit Pielou's index which was also based on inverting distance sampling methods. He reported biases in his approach; generated aggregation was considerably less than that specified by the input value of Pielou's index. His observed bias is explained by the use of inappropriate squared-distance distributions (e.g., the exponential distribution) and the relaxation of condition 2) above (i.e., no check was made on new tree open areas).

A "hybrid" spatial pattern generator was then developed which used the Pearson type XI distribution to generate squared distances, but in which condition 2) was relaxed. The result provided a generator capable of producing aggregated stands in seconds (rather than minutes) with considerably less aggregation bias than reported by Stauffer (1978). This modified Stauffer algorithm was thus adopted for generating seeded stand spatial patterns.

Size Distributions

After generating the initial stand spatial pattern and assigning tree coordinates, tree sizes are assigned. A two parameter Weibull

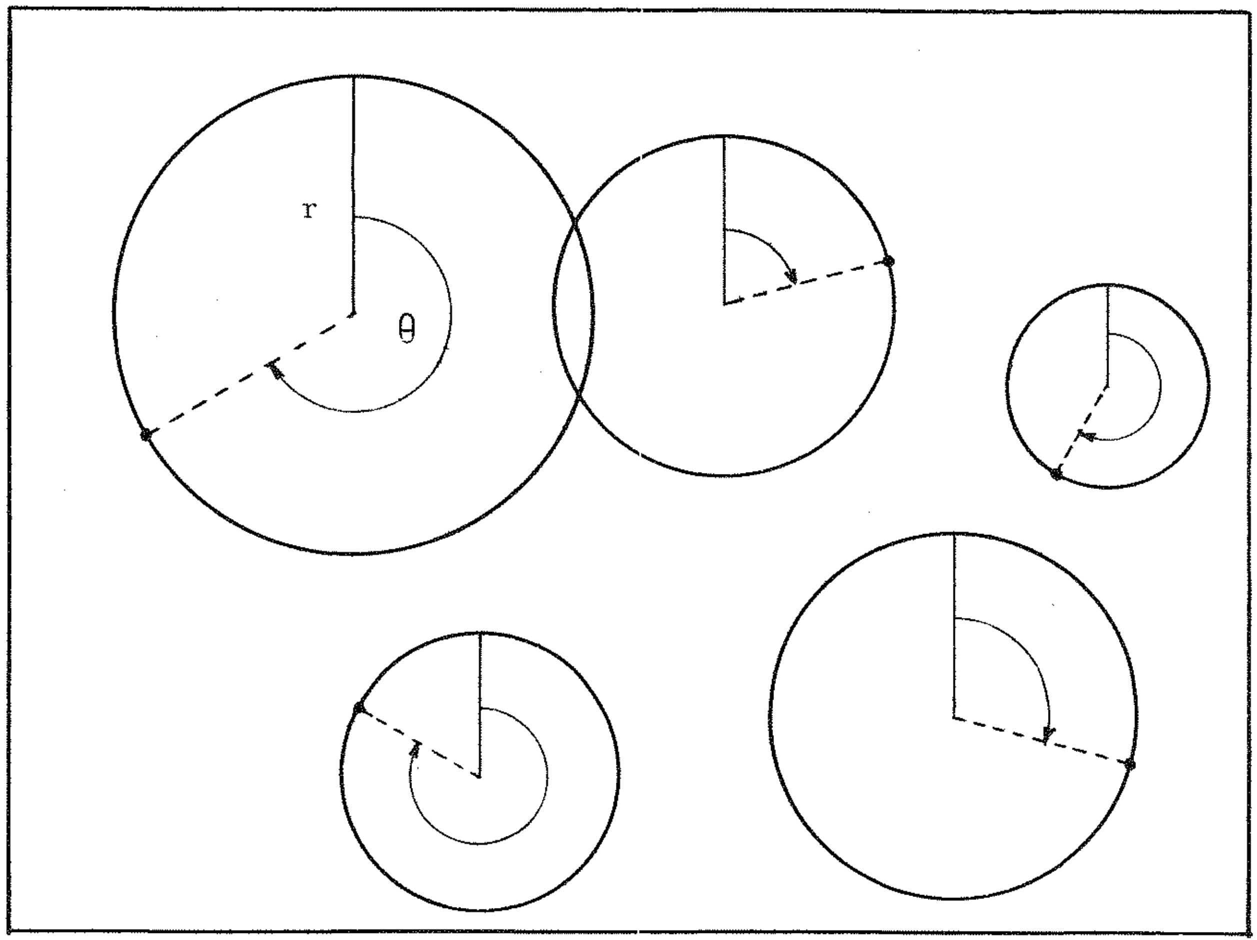


Figure 1. Determining tree positions by fixing distances (r) and angles (θ) from random points.

function was chosen to model the diameter distribution of the initial stand. This function can be written with cumulative distribution function (c.d.f.)

$$F_y(y) = 1 - e^{-ay^b} \quad o<y<\infty$$

Specifically, diameter at breast height is generated from the function

$$D = [-\frac{1}{a}\ln(1-u)]^{1/b}$$

where,

D = d.b.h.

u = a random number from the uniform (0,1) distribution

a,b = Weibull parameters

Estimators for parameters a and b are

$$\hat{b} = \frac{\ln(N)}{\ln DAVE - \ln DMIN}$$

$$\hat{a} = [\frac{\Gamma(1 + 1/b)}{DAVE}]^b$$

where,

DMIN = minimum d.b.h.

DAVE = average d.b.h.

N = number of trees measured for DAVE, DMIN

In conjunction with Daniels' (1978) work, data were collected on size distributions in young seeded stands. Forty 5- to 12-year-old seeded loblolly pine stands were selected from industrial and state ownerships over a wide range of stand conditions in Eastern Virginia and North Carolina (Table 1), to obtain approximately equal numbers in each of the following regeneration categories: 1) seed tree/shelterwood, 2) natural old field, 3) aerial seeded, and 4) broadcast seeded. In each stand, 10 trees were selected for detailed measurements, including d.b.h. total height, crown length, and age. In addition, d.b.h. was determined for all trees in each of three temporary .05-.10 acre plots.

Table 1. Summary of conditions in 40 seeded loblolly pine stands used to derive size relationships for initial stand generation.

Variable	Mean	Range
Age (years)	9	5 - 12
Density (stems/acre)	2067	400 - 6350
Height (feet)[a/]	14.9	7.1 - 30.2
D.B.H. (inches)	1.4	0.1 - 19.1[b/]

[a/] Average height of dominants and codominants.

[b/] Overstory tree.

Prediction equations were developed to determine DMIN and DAVE in terms of total basal area per acre (BAT) and average height of dominants and codominants (HD) (Table 2). Total height (H) is assigned for each tree using a prediction equation based on d.b.h. (D), HD, surviving number of loblolly pine trees per acre (TS), and age (A) (Table 2). Crown length is determined as total height minus clear bole length (CBL) where CBL is predicted as a function of H, D, TS, and A (Table 2). Coefficients for the equations in Table 2 were solved for using the data summarized in Table 1.

Because of the difficulties involved with determining an age when intraspecific competition begins, a fixed age 10 was chosen for generating the initial stand. It was thought that competition already has begun to affect growth at age 10 in typical seeded stands. To reflect this influence initial diameters are assigned as a function of competition at age 10. For each tree in the stand, d.b.h. is temporarily set equal to DAVE and the competition index is evaluated to provide an index of tree growing space. Actual diameters are then generated, sorted largest to smallest, and assigned to tree locations so that the largest d.b.h. is associated with the smallest competition value, etc. Correlations between tree sizes and spatial measures in young seeded stands were shown by Daniels (1978) to be negligible, but these methods should ensure logical spatial-size relationships.

No attempt was made in the initial stage to project stand conditions to age 10 from some earlier point in time. Input to this stage requires stand information at age 10. Somers, et al.[1/], derived survivorship curves based on one minus the cumulative density function of the two-parameter Weibull distribution:

$$F(x) = e^{-(x/b)^{c}}$$

where,

$F(x)$ = percent survival

x = age

c = 2.9561

$b = \mathrm{EXP}\,[4.9023 - 0.2030 \, \mathrm{Log}\, N_a]$

N_a = initial number of trees at age 3

Then $F(x)$ times N_a gives the number surviving at any age x.

1/ Somers, G. L., R. G. Oderwald, W. R. Harms, O. G. Langdon. Predicting mortality with a Weibull distribution. Manuscript submitted to Forest Science.

Table 2. Equations used in generating initial stand in a growth model for seeded loblolly pine.

Equation[a]			R^2	$S_{y \cdot x}$
DAVE[b]	=	-1.54190 + 1.14324 ln(HD) + 0.0038993 BAT	0.78	0.117
DAVE[c]	=	0.47040 + 0.069485 HD - 0.00000083 A·TS + 5.45478 HD/TS	0.84	0.078
DMIN	=	-0.067446 + 0.029395 HD - 0.00000112 A·TS + 6.23266	0.75	0.028
ln(H)	=	1.44287 + 0.32192 ln(HD) + 0.52118 ln(D) + 0.0026328 BAT + 0.07299/D - 1.08825/A	0.93	0.023
ln(CBL)	=	-1.43430 + 1.48535 ln(H) - 0.47173 ln(D) + 0.00092034 BAT - 0.10991/D - 3.34385/A	0.96	0.043
ln(TS)	=	5.31958 + 0.83535 ln(BAT) + 1.04073 ln(PPINE) -1.60866 ln(DAVE)	0.85	0.092

a/ Where DMIN = minimum d.b.h. (inches), DAVE = average d.b.h. (inches), H = total height (feet), CBL = clear bole length (feet), TS = number of loblolly pine trees surviving per acre, BAT = total basal area per acre (ft^2/acre), HD = average height of dominants and codominants (feet), D = d.b.h. (inches), A = age (years), PPINE = proportion of BAT in pine (pine BA/BAT).

b/ Used for existing stands only.

c/ Used in initial stand generation.

The above coefficients were estimated using the data of Harms and Langdon (1976). Briefly, their study consisted of 20, 0.1-acre plots located in the Lower Coastal Plain of South Carolina, all with site index of 105 feet (base age 50). The twenty plots were thinned at age 3 to 5 densities: 1, 2, 4, 8, and 16 thousand trees per acre, with four plots at each density level. Potential users who feel these data are applicable to their stands may wish to use the function above to project stand density at age 3 to that at age 10.

The capacity for simulating existing stands of ages older than 10 years was included. This requires that basal area per acre at the existing age be provided. Basal area is projected back to age 10 using the basal area growth equation of Sullivan and Clutter (1972), average d.b.h. is estimated (Table 2), the number of trees per acre is determined (Table 2), and a stand at age 10 is generated.

Stand Growth and Development

Competition Index

A number of competition indices were evaluated and compared for planted loblolly pine by Daniels (1976). The modified Hegyi index suggested there and used by Daniels and Burkhart (1975) was adopted for seeded loblolly pine stands. It is calculated

$$CI_i = \sum_{j=1}^{n} (D_j/D_i)/DIST_{ij}$$

where,

D = d.b.h.

DIST = distance between subject tree i and competitor j

CI_i = Competition Index of the tree i

n = the number of neighbors included in a 10 BAF angle gauge sweep with vertex at the subject tree

Competitive stress on border trees is calculated through a translation of plot borders so that border trees compete with border trees on the opposite side of the plot. This technique was suggested by Monserud and Ek (1974) to control plot edge bias.

Growth Relationships

After generation of the juvenile stand, competition is evaluated and trees are grown individually on an annual basis. In general, growth in height and diameter is assumed to follow some theoretical growth potential. An adjustment or reduction factor is applied to this potential increment based on a tree's competitive status and vigor, and a random component is then added representing microsite and/or genetic variability.

The potential height increment for each tree is considered to be the change in average height of the dominant and codominant trees, obtained as the first difference with respect to age of the following expression, transformed from the site index equation presented by Schumacher and Coile (1960):

$$HD = SI\ 10^{-6.528(1/A - 1/50)}$$

where,

HD = average height of dominant stand (feet)

SI = site index base 50 (feet)

A = stand age (years)

A tree may grow more or less than this potential, depending on its individual attributes.

Experience in loblolly pine plantations (Daniels and Burkhart 1975) suggested the inclusion of competition index and crown ratio in the height growth adjustment factor with the form

$$(b_1 + b_2 CR^{b_3} e^{-b_4 CI - b_5 CR})$$

where,

CR = crown ratio

CI = competition index

b_i = constants to be estimated from data

The maximum d.b.h. attainable for an individual tree of given height and age was considered to be equal to that when open-grown. An equation describing this relationship was developed from open-grown tree data (Daniels and Burkhart 1975) and is shown below:

$$D_0 = -2.422297 + 0.286583\ H + 0.209472\ A$$

where,

D_0 = open-grown tree d.b.h. (inches)

H = total tree height (feet)

A = age from seed (years)

The first difference of this equation with respect to age was thought to represent a maximum potential diameter increment:

$$PDIN = 0.286583\ HIN + 0.209472$$

where,

PDIN = potential diameter increment (inches)

HIN = observed height increment (feet)

This potential diameter increment is reduced by a reduction factor of the form

$$(b_1 + b_2\ CL^{b_3} e^{-b_4 CI})$$

where,

CI = competition index

CL = crown length (feet)

The inclusion of measures of photosynthetic potential in the above models plays a key role in determining thinning response. Others have included only competitive effects in such adjustment factors. However, when a tree is released by removing neighboring trees its response will depend not only on the reduction in competition for resources, but the potential it has for using those resources. Both crown length and crown ratio reflect this potential.

Crown length is incremented each year as the difference between height increment and change in clear bole length. Clear bole length is predicted annually as a function of height, d.b.h., age, and basal area per acre (Table 2).

Mortality

The probability that a tree remains alive in a given year was assumed to be a function of its competitive stress and individual vigor as measured by photosynthetic potential. The probability of survival equation took the form

$$PLIVE = b_1 CR^{b_2} e^{-b_3 CI^{b_4}}$$

where,

PLIVE = probability that a tree remains alive

Survival probability is calculated for each tree and used in Bernouli trials to stochastically determine annual mortality. The calculated PLIVE is compared to a uniform random variate between zero and one. If PLIVE is less than this generated threshold, the tree is considered to have died.

Management Routines

Hardwood Control

Daniels and Burkhart (1975) simulated the effects of competing vegetation and site preparation by including a competition adjustment factor. This factor modified all stand density and competition relationships by, essentially, increasing the number of competing stems. Additional competition was described in terms of "loblolly-equivalent" stems and decreased linearly to a specified age of release.

A similar approach was taken for seeded stands. Three parameters are specified, HDWD, IRLSE, and ARLSE, which determine the proportion of additional competing (loblolly equivalent) stems, the type of release, and the age of release, respectively. If HDWD is set equal to one the number of additional competing stems (in loblolly equivalents) is equal to the number of loblolly stems at age 10. The parameter ARLSE determines the age at which the stand will be released to a pure loblolly stand and IRLSE determines whether the release will be a gradual linear release or a sudden release. The competition adjustment factor (CAF) is calculated annually from these parameters to obtain the multiplier for competitive relationships.

Fertilization

The methods used by Daniels and Burkhart (1975) to simulate fertilization were adopted. Fertilizer application was viewed as an adjustment of site quality as measured by site index. A site adjustment factor (SAF) was included which modifies site index for the duration of the fertilizer response. The value of SAF is calculated from three parameters, RESP, LMR, and LR, which specify, respectively, the maximum response in site index, the length of time in years to attain maximum response, and the total length of the response. SAF increases linearly from the time of application until RESP is attained LMR years later, and then decreases linearly until LR.

Thinning

A thinning routine was constructed which allows thinning from below, by corridors, or in combination. Thinning from below removes trees one at a time, from smallest to largest, until the thinning limit, TLIM is met. The thinning limit may be specified either in terms of residual stand basal area per acre or an upper diameter limit. In either case, a lower diameter limit, DLOW, may be specified below which trees will not be removed. Corridor thinning involves removing a swath of trees. Swaths may be removed in either the x or y direction, or both. Swath widths are controlled by the parameters XCORW and YCORW and swath spacing is controlled by XCORS and YCORS. When used in combination, the corridor thinnings are performed first and the residual stand is then thinned from below to TLIM.

INITIAL TESTS

A preliminary model, Seed-PTAEDA, based on Daniels and Burkhart's (1975) plantation model was programmed in FORTRAN IV to include the seeded stand components discussed earlier. The initial stand generation stage was constructed and calibrated using seeded-stand data collected by Daniels (1978) (Table 1). Mapped-stand growth data necessary for calibrating the stand growth and development stage were not available for seeded stands. The individual tree diameter and height growth adjustment factors and the survival probability equation presented by Daniels and Burkhart (1975) for loblolly pine plantations were used for these initial tests of Seed-PTAEDA. The volume equations used to obtain stand yield estimates are from the natural stand work of Burkhart et al. (1972a). Input variable definitions, flow charts, and a complete program listing are included in the Appendices.

The natural stand plot data of Burkhart et al. (1972a) were available for comparisons with simulated yields generated by Seed-PTAEDA. These data consist of stand summary information from 121 temporary plots measured in natural loblolly pine stands located in Virginia and North Carolina (Table 3).

Seed-PTAEDA was used to estimate stand characteristics for each of the 121 observed plots by using the existing stand option mentioned earlier. That is, basal area per acre was projected back in time from the observed age to age 10, when an initial stand is generated. Observed site index was used at age 10. The hardwood control parameter was estimated from observed ratios of basal area in pine to that in hardwood. Growth to the observed age was then simulated.

Early simulations indicated that simulated height and diameter growth were far exceeding observed patterns resulting in large over predictions in total cubic-foot yield and basal area. Moderate over predictions in the number of trees per acre accentuated this bias. Further analysis indicated that bias decreased with decreasing stand age and for young stands close to age 10 bias was negligible. It was concluded that the plantation-derived growth and survival relationships were not well suited for simulating the development of seeded stands. The initial stand generation stage of the model seemed to be working well.

It was thought that perhaps the relative growth patterns of individual trees, once scaled to known average growth curves, could be modeled using the plantation relationships, even if absolute growth predictions were biased. An equation to estimate average height as a function of average dominant height (from the site index curve) was developed from the natural stand data of Burkhart et al. (1972a) and took the form

Table 3. Summary of stand conditions in 121 natural loblolly pine stands used for testing initial version of seeded stand simulator.

Variable	Mean	Range
Age	29	13 - 77
Density (stems/acre)	476	80 - 1220
Height (feet)[a/]	61.0	39.5 - 90.0
Total basal area (ft^2/acre)	143.4	35.5 - 269.2

[a/] Average height of dominants and codominants.

$$HAVE = a + b\ HD$$

where,

HAVE = average height of all trees

HD = average height of dominant and codominant trees

This relationship was used to scale predicted tree heights, after each growth period, so that average height conformed to that expected. Only relative growth allocations for individual trees were then obtained from the plantation equations.

Results from this refinement of the original model were more logical. Height growth was reduced to observed levels and diameter growth, determined from height growth, was also reduced. Over all 121 plots average predicted cubic-foot volume was only 4% greater than the observed average. Basal area per acre was under predicted by 6% on the average.

However, while stand aggregate measures such as total volume and basal area appeared to agree with observed values, predicted stand structure did not agree with that observed. The average predicted number of trees per acre was 27% greater than that observed, whereas average diameter was 12% less than that observed. This indicated that problems still existed in using the plantation-derived survival relationships.

It was again thought that the plantation equations provided accurate relative ratings of survival probabilities. By scaling the predicted survival probabilities downward, numbers of trees were reduced and diameter growth was increased due to decreased competition. Total stand cubic-foot yield and basal area were not greatly affected.

Data were not available to develop a prediction equation for scaling survival probabilities; the above trial was based solely on trial and error simulations. Without quantifying the scaling factor for survival relationships the model, as presented, is somewhat incomplete. Further tests were considered to be of limited usefulness without first calibrating the model.

CALIBRATION PROCEDURES

Deficiencies in preliminary tests of Seed-PTAEDA indicated the need for detailed calibration of growth and survival relationships after the generation of the initial stand. Calibration will require further data collection specific to growth and survival of individual trees in seeded stands. Data requirements and model fitting techniques for calibration will be discussed.

Complete calibration of Seed-PTAEDA will require refitting three equations: 1) the individual tree height growth adjustment factor, 2) the diameter growth adjustment factor, and 3) the survival probability equation. All three expressions involve competition index and either crown ratio or corwn length.

To fit these expressions requires a set of data from remeasured, stem mapped plots. Site index and age must be known. Individual tree measurements must include d.b.h., height, crown length, and a code indicating whether a tree is alive or dead, for at least 2 measurement years. Remeasurements should be close together in time, say one to three years, to avoid insensitivity due to averaging growth over a long period. If possible, the exact year of tree mortality should be known. Plots must be mapped to allow calculation of the competition index, and should be sufficiently large (say greater than .25 acre) to permit a buffer of trees around the interior trees for which the competition index will be calculated.

With these data one may derive the necessary variables for fitting the three equations. The model forms for the equations, as described earlier, should perform well with coefficients specific to seeded stands. The models may be fitted using any non-linear regression routine. However, the availability of new data may offer the potential user an opportunity to investigate new functional relationships, as well. Other competition indices may also be investigated for their applicability to seeded stands, once new data are available. Such modifications from the original model forms may require additional variables to be measured.

CONCLUSIONS AND RECOMMENDATIONS

Methods have been described for constructing a detailed, flexible model of tree growth and stand development for seeded loblolly pine. The initial stand generation stage was developed and fitted specifically for seeded stands over a wide range of conditions. Preliminary results indicated that this stage of the model described young stand structure quite well. However, subsequent stand development in seeded stands was not well described when plantation-derived growth and survival relationships were used. This is not surprising since stand conditions in the data used for fitting the plantation relationships must be considered a very small subset of conditions found in seeded stands--not just in terms of spatial pattern, but also in age, stand density, site quality, and competition.

Initial attempts to improve predictive ability of the model were moderately successful, but also somewhat inadequate. Methods were used to scale the individual plantation predictions to fit average values for seeded stands. Although this technique was useful in improving predictions, and may be of further interest to some potential users as a means of calibrating the model, it suffers two main drawbacks. First, it serves to fit the model to one specific data set--in this case the test data set. Continued refinement of this type may provide a model that fits the test data set extremely well, but does not ensure flexibility elsewhere. Second, by scaling to stand averages, the model loses its appeal as an individual-tree-based growth model. In effect, after scaling factors were introduced, the model became a series of stand average prediction equations, with the individual tree growth components serving only to allocate stand variability. The computer time and expense incurred by these calculations could not be justified in this context.

As interest grows in seeded stands of loblolly, and as new data become available, it is hoped that complete calibration of the model described here will follow. The development of flexible models, which can provide information for intensive management decisions, is important. The methods described here should help in developing these models for seeded loblolly pine stands.

LITERATURE CITED

Alemdag, I. S. 1978. Evaluation of some competition indexes for the prediction of diameter increment in planted white spruce. Can. Dep. Environ., Forest Management Institute, Information Report FMR-X-108, 39 pp.

Anon. 1929. Volume, yield, and stand tables for second growth southern pines. USDA Forest Service. USDA Misc. Publ. 50. 202 pp.

Arney, J. D. 1974. An individual tree model for stand simulation in Douglas-fir. In, Growth Models for Tree and Stand Simulation (J. Fries, Ed.). Royal College of Forestry. Stockholm, Sweden. pp. 38-46.

Bella, I. E. 1970. Simulation of growth, yield and management of aspen. Unpublished Ph.d. Thesis. Univ. of British Columbia. 190 pp.

Bella, I. E. 1971. A new competition model for individual trees. Forest Sci. 17:364-372.

Bennett, F. A. and J. L. Clutter. 1968. Multiple-product yield estimates for unthinned slash pine plantations--pulpwood, sawtimber, gum. USDA Forest Service Res. Pap. SE-35. 21 pp.

Bennett, F. A., C. E. McGee and J. L. Clutter. 1959. Yield of old-field slash pine plantations. USDA Forest Service Station Paper 107. 19 pp.

Botkin, D. B., J. F. Janak, and J. R. Wallis. 1970. The rationale, limitations and assumptions of a northeast forest simulator. IBM Res. Rep. RC 3188. IBM Thomas J. Watson Research Center. Yorktown Heights, N.Y. 38 pp.

Boyce, S. G. 1975. How to double the harvest of loblolly pine and slash pine timber. J. Forestry. 73:761-766.

Burkhart, H. E. and M. R. Strub. 1974. A model for simulation of planted loblolly pine stands. In, Growth Models for Tree and Stand Simulation (J. Fries, Ed.). Royal College of Forestry. Stockholm, Sweden. pp. 128-135.

Burkhart, H. E., R. C. Parker and R. G. Oderwald. 1972a. Yields for natural stands of loblolly pine. Div. of Forestry and Wildlife Resources, Va. Polytech. Inst. and State Univ. FWS-2-72. 63 pp.

Burkhart, H. E., R. C. Parker, M. R. Strub and R. G. Oderwald. 1972b. Yields of old-field loblolly pine plantations. Div. of Forestry and Wildlife Resources. Va. Polytech. Inst. and State Univ. FWS-3-72. 51 pp.

Clutter, J. L. 1963. Compatible growth and yield models for loblolly pine. Forest Sci. 9:354-371.

Dale, M. E. 1975. Individual tree growth and simulation of stand development of an 80-year-old white oak stand. In, Forest Modeling and Inventory (A. R. Ek, J. W. Balsiger and L. C. Promnitz. Eds.). Dept. of For. Univ. of Wis. pp. 49-63.

Daniels, R. F. 1976. Simple competition indices and their correlation with annual loblolly pine tree growth. Forest Sci. 22:454-456.

Daniels. R. F. 1978. Spatial patterns and distance distributions in young seeded loblolly pine stands. Forest Sci. 24:260-266.

Daniels, R. F. and H. E. Burkhart. 1975. Simulation of individual tree growth and stand development in managed loblolly pine plantations. Div. of Forestry and Wildlife Resources. Va. Polytech. Inst. and State Univ. FWS-5-75. 69 pp.

Daniels, R. F. and G. D. Spittle. 1977. Reproducing spatial and size distributions for tree and stand simulation. Unpublished Report to U.S. Forest Service. 10 pp.

Eberhardt, L. L. 1967. Some developments in distance sampling. Biometrics 23:207-216.

Ek, A. R. and R. A. Monserud. 1974. FOREST: A computer model for simulating the growth and reproduction of mixed species forest stands. University of Wisconsin School o f Natural Resources Res. Rep. R2635. 13 pp.

Gerrard, D. J. 1969. Competition quotient: A new measure of the competition affecting individual forest trees. Mich. State Univ. Agric. Exp. Sta. Res. Bull. No. 20. 32 pp.

Goebel, N. B. and R. D. Shipman. 1964. Volume yields of loblolly pine plantations for a variety of sites in the South Carolina Piedmont. Clemson Univ. Forest Res. Series No. 13. 23 pp. (Revised 1966, Revised 1969).

Goulding, C. J. 1972. Simulation techniques for a stochastic model of the growth of Douglas-fir. Ph.D. Thesis, Univ. B.C. Vancouver. 234 pp. Nat. Lib. of Canada. Ottawa, Canada. (Diss. Abstr. 33:5599-B).

Harms, W. R. and O. G. Langdon. 1976. Development of loblolly pine in dense stands. Forest Sci. 22:331-337.

Hatch, C. R. 1971. Simulation of an even-aged red pine stand on northern Minnesota. Unpublished Ph.D. Thesis. Univ. Minn. 120 pp.

Hegyi, F. 1974. A simulation model for managing jack-pine stands. In, Growth Models for Tree and Stand Simulation (J. Fries, Ed.). Royal College of Forestry. Stockholm, Sweden. pp. 74-90.

Keister, T. D. 1971. A measure of the intraspecific competition experienced by an individual tree in a planted stand. La. State Univ. Sta. Bull. 447. 109 pp.

Ker, J. W. 1954. Distribution series arising in quadrat sampling of reproduction. J. Forestry. 54:834-841.

Lenhart, J. D. 1972. Cubic volume yields for unthinned old-field loblolly pine plantations in the Interior West Gulf Coastal Plain. Stephen F. Austin State Univ. Texas Forestry Paper 14. 46 pp.

Lenhart, J. D. and J, L. Clutter. 1971. Cubic-foot yield tables for old-field loblolly pine plantations in the Georgia Piedmont. Ga. Forest Res. Council. Report 22. Series 3. 12 pp.

MacKinney, A. L. and L. E. Chaiken. 1939. Volume, yield, and growth of loblolly pine in the Mid-Atlantic Coastal Region. USDA Forest Service Technical Note No. 33. 30 pp.

Moore, J. A., C. A. Budelsky, and R. C. Schlesinger. 1973. A new index representing individual tree competitive status. Can. J. For. Res. 3:495-500.

Monserud, R. A. and A. R. Ek. 1974. Plot edge bias in forest stand growth simulation models. Can. J. For. Res. 4:419-423.

Munro, D. D. 1974. Forest growth models--a prognosis. In, Growth Models for Tree and Stand Simulation (J. Fries, Ed.). Royal College of Forestry. Stockholm, Sweden. pp. 7-21.

Newnham, R. M. 1968. The generation of artificial populations of points (spatial patterns) on a plane. Forest Management Inst. Ottawa, Ont. Canada. Information Rep. FMR-10. 28 p.

Newnham, R. M. and J. H. G. Smith. 1964. Development and testing of stand models for Douglas-fir and lodgepole pine. Forestry Chron. 40:492-502.

Newnham, R. M. and G. T. Maloley. 1970. The generation of hypothetical forest stands for use in simulation studies. Forest Management Inst. Ottawa, Ont. Canada. Information Rep. RMS-X-26. 41 pp.

Payandeh, B. 1970. Comparisons of methods for assessing spatial distribution of trees. Forest Sci. 16:312-317.

Pielou, E. C. 1959. The use of point-to-plant distances in the study of the pattern of plant populations. J. Ecol. 47:607-613.

Pielou, E. C. 1969. An Introduction to Mathematical Ecology. John Wiley and Sons, Inc. New York. 286 pp.

Schumacher, F. X. and T. X. Coile. 1960. Growth and yield of natural stands of the southern pines. T. S. Coile, Inc. 115 pp.

Smalley, G. W. and R. L. Bailey. 1974a. Yield tables and stand structure for loblolly pine plantations in Tennessee, Alabama, and Georgia highlands. USDA Forest Service Res. Pap. SO-96. 81 pp.

Smalley, G. W. and R. L. Bailey. 1974b. Yield tables and stand structure fir shortleaf pine plantations in Tennessee, Alabama, and Georgia highlands. USDA Forest Service Res. Pap. SO-97. 57 pp.

Southwood, T. R. E. 1966. Ecological Methods. Methuen and Co., Ltd. London. 391 pp.

Stage, A. R. 1973. Prognosis model for stand development. USDA Forest Service Res. Pap. INT-137. 32 pp.

Stauffer, H. B. 1978. Aggregating points to fit Pielou's index of non-randomness. Can. J. For. Res. 8:355-363.

Sullivan, A. D. and J. L. Clutter. 1972. A simultaneous growth and yield model for loblolly pine. Forest Sci. 18:76-86.

Wensel, L. C. 1975. Computer generation of points on a plane. Hilgardia. 43:131-142.

APPENDICES

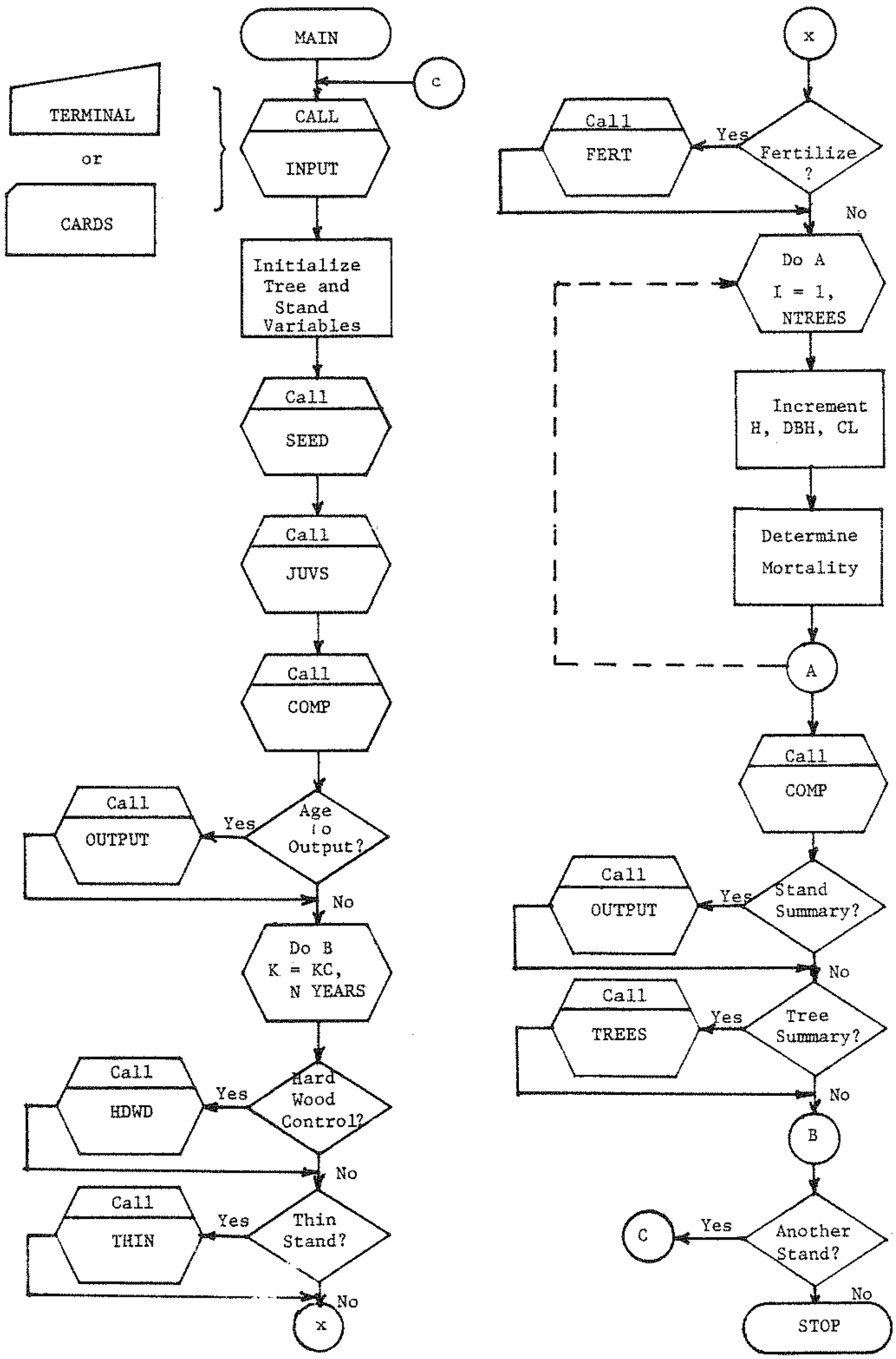
Appendix I. Input variable definitions for simulation model Seed-PTAEDA.

Variable Name	Definition
TITLE	A descriptive title up to 80 characters long
NYEARS	Length of simulation in years
SITE	Site index (base age 50)
IX	Random number seed, any odd integer
ALPHA	Pielou's index of nonrandomness
TS	Loblolly pine trees surviving per acre at age 10
AGE	Age of existing stands
BA	Total basal area per acre for existing stands
HDWD	Additional proportion of (loblolly equivalent) competing stems per acre to simulate hardwood competition
IRLSE	Type of release from hardwood competition 1 = gradual release until ARLSE 2 = sudden release at ARLSE
ARLSE	Age at which site will be released from additional competing hardwoods
KIN	Age at next decision period or age of next input
ITHIN	Thinning type: 1 = corridor thinning 2 = low thinning 3 = combination of 1 and 2

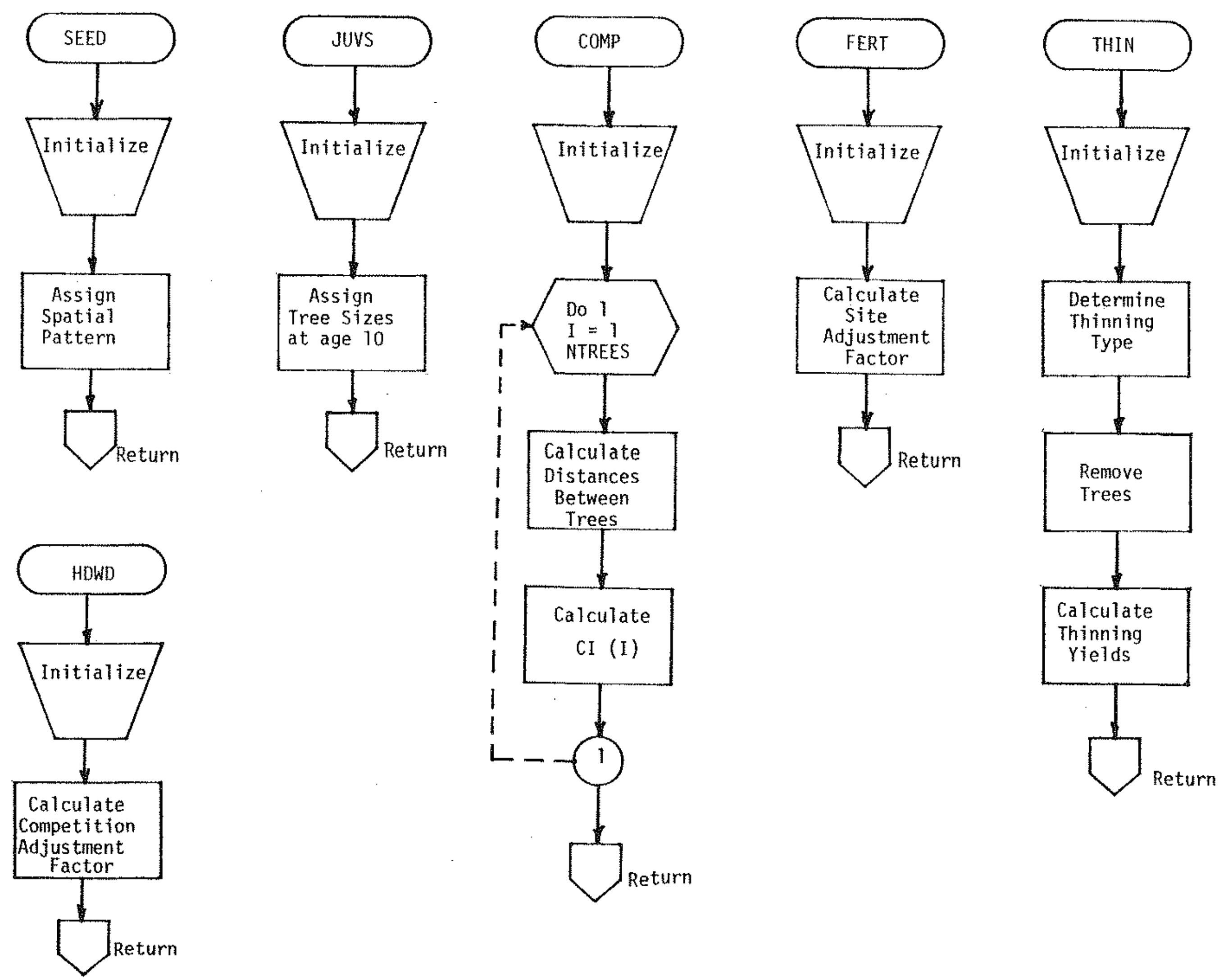
Appendix I. Input variable definitions for simulation model Seed-PTAEDA (continued).

Variable Name	Definition
KTHIN	Age of growing season immediately after thinning
XCORW	Swath width in x direction
YCORW	Swath width in y direction
XCORS	Swath spacing in x direction
YCORS	Swath spacing in y direction
ILOW	Low thinning type 1 = diameter limit 2 = residual basal area limit
DLOW	Lower diameter limit below which trees will not be removed (low thinning option only)
TLIM	Thinning limit: If ILOW = 1, upper diameter limit above which trees will not be removed ILOW = 2, residual basal to be left after thinning
KFERT	Age of growing season immediately after treatment
RESP	Maximum site index increase (feet) due to fertilization
LMR	Length of time (years) to attain RESP after initially fertilizing
LR	Total length of fertilization response
QAGAIN	To simulate another stand QAGAIN = YES

Appendix II. Flowchart of tree and stand growth simulation program Seed-PTAEDA.



Appendix II. Flowchart of tree and stand growth simulation program Seed-PTAEDA (continued).



Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA.

```
C*********************************************************************
C
C                        SEED-PTAEDA
C
C          SEED-PTAEDA IS A SIMULATION MODEL OF TREE AND STAND GROWTH
C     IN MANAGED, SEEDED LOBLOLLY PINE (PINUS TAEDA L.) STANDS.
C
C     DEVOLPED BY RICHARD F. DANIELS, VPI&SU, 1978.
C
C*********************************************************************
      DIMENSION VOL(3),S(2)
      COMMON /BLOK1/X(100),Y(100),LMORT(100),KMORT(100),D(100),
     1 H(100),CL(100),CI(100),MID(100),LEDGE(9),ACRES
      COMMON /BLOK3/YCUFT(75,3),YCUFTM(75,3),BA(75),KJ,K,NLIVE,
     1 NTHIN,HD,NOLD
      COMMON /BLOK4/TITLE(20),NYEARS,SITE,QEXIST,EXAGE,EXBA,
     1 TS,TS10,KCUT,KIN,KTREE,QJUV,QAGAIN
      COMMON /BLOK5/HRDWD,CAF,ARLSE,QHDWD,IRLSE
      COMMON /BLOK6/KFERT,LMR,LR,RESP,SAF,QFERT
      COMMON /BLOK7/KTHIN,ITHIN,ILOW,DLOW,TLIM,XCOR,YCOR,XCORS,YCORS
      COMMON /BLOK8/PLOTX,PLOTY,ALPHA
      REAL YES/'YES'/,NO/'NO'/
      COMMON /BLOKD/N
      DATA S/0.77093,0.07729/
C
C     INPUT INITIAL SIMULATION CRITERIA
C
    1 CALL INPUTS(IX,NC,NCARDS)
C
C     INITIALIZE TREE AND STAND VARIABLES
C
      DO 50 K=1,75
      BA(K)=0.
      DO 50 L=1,3
      YCUFT(K,L)=0.
   50 YCUFTM(K,L)=0.
      DO 60 I=1,N
      D(I)=0.
      H(I)=0.
      CL(I)=0.
      CI(I)=0.
      KMORT(I)=NYEARS
   60 LMORT(I)=1
      KTHIN=0
      KOUT=0
      KTREE=0
      QFERT=NO
      NOLD=N
C
C     GENERATE INITIAL STAND
C
      CALL SEED(IX)
      CALL JUVS(IX)
      CALL COMP
      IF(QJUV.EQ.NO) GO TO 65
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
      CALL OUTPUT
      KIN=KJ+1
C
C     COMMENCE ANNUAL TREE GROWTH
C
   65 KC=KJ+1
      A=KC
      DO 200 K=KC,NYEARS
      A=K
C
C     INPUT MANAGEMENT CRITERIA
C
      IF(QHDWD.EQ.YES) CALL HDWD(A)
      IF(KIN  .EQ.K) CALL INPUT2
      IF(KTHIN.EQ.K) CALL THIN(A)
      IF(QFERT.EQ.YES) CALL FERT(A)
      SI=SITE
      POTH=SI*10.**(-6.528*(1./A-.02))
      PHIN=POTH-HD
      DO 100 I=1,N
      IF(LMORT(I)-1) 100,10,90
   10 CR=CL(I)/H(I)
C
C     DETERMINE TREE MORTALITY
C
      PLIVE=1.086*CR**.0702826*EXP(-.0281694*(CI(I)*CAF)
     1      **1.177809)
      P=U(IX)
      IF(P.LT.PLIVE) GO TO 80
      NLIVE=NLIVE-1
      LMORT(I)=2
      KMORT(I)=K
      GO TO 90
C
C     COMPUTE H AND D INCREMENT ON ALL TREES
C
   80 HRED=.54631+CR**1.66254*EXP(4.82722-1.15083*CI(I)
     1      *CAF-6.66226*CR)
      R=STNORM(IX)
      HIN=PHIN*HRED
      HINMAX=1.00206*PHIN+.13462026
      IF(HIN.GT.HINMAX) HIN=HINMAX
      PDIN=.28658336*HIN +.2094718
      HIN=HIN+R*S(1)
      IF(HIN.LT.0.) HIN = 0.
      DRED=.086524+.020178*CL(I)**1.179986*EXP(-1.320610
     1      *CI(I)*CAF)
      DIN=PDIN*DRED+R*S(2)
      IF(DIN.LT.0.) DIN=0.
C
C     CALCULATE PRODUCTS
C
      D(I)=D(I)+DIN
      H(I)=H(I)+HIN
   90 L=LMORT(I)
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
      DSQ=D(I)*D(I)
      IF(L.EQ.1) BA(K)=BA(K)+DSQ
      YCUFT(K,L)=YCUFT(K,L)+DSQ*H(I)*.00253+.27611
      YCUFTM(K,L)=YCUFTM(K,L)+DSQ*H(I)*.00205-.8421
  100 CONTINUE
      BA(K)=BA(K)*.005454/ACRES
      DO 150 L=1,3
      YCUFT(K,L)=YCUFT(K,L)/ACRES
      YCUFTM(K,L)=YCUFTM(K,L)/ACRES
  150 CONTINUE
C
C     DETERMINE CROWN LENGTH
C
      T=NLIVE/ACRES
      DO 101 I=1,N
      CI(I)=0.
      IF(LMORT(I).NE.1) GO TO 101
      CBL=H(I)**1.48535*D(I)**(-0.47173)*EXP(-1.4343+.92034E-3*BA(K)
     1     *CAF-0.10991/D(I)-3.34385/A)
      IF(H(I)-CBL-CL(I).GT.HIN) CBL=H(I)-CL(I)-HIN
      CL(I)=H(I)-CBL
      IF(CL(I).LT.0) CL(I)=0.
  101 CONTINUE
      HD=POTH
      CALL COMP
C
C     OUTPUT STAND SUMMARY
C
      IF(KOUT.EQ.K) CALL OUTPUT
  200 CONTINUE
C
C     HOUSE KEEPING
C
      CALL INPUT3
      N=NOLD
      IF(QAGAIN.EQ.YES) GO TO 1
      STOP
      END
C
C***********************************************************************
C
      SUBROUTINE INPUTS(IX,NC,NCARDS)
C
C          SUBROUTINE INPUT IS DIVIDED INTO 3 MAIN SUB-SECTIONS
C     DESIGNED TO PROMPT THE USER FOR AND READ INITIAL SIMULATION
C     CRITERIA, MANAGEMENT CRITERIA, AND PROGRAM CONTINUATION
C     CRITERIA.  THIS SUBROUTINE IS THE ONLY ONE WHICH NEED
C     BE CHANGED FOR BATCH MODE OPERATION.
C
C***********************************************************************
      COMMON /BLOK4/TITLE(20),NYEARS,SITE,QEXIST,EXAGE,EXBA,
     1 TS,TS10,KOUT,KIN,KTREE,QJUV,QAGAIN
      COMMON /BLOK5/HDWD,CAF,ARLSE,QHDWD,IRLSE
      COMMON /BLOK6/KFERT,LMR,LR,RESP,SAF,QFERT
      COMMON /BLOK7/KTHIN,ITHIN,ILOW,DLOW,TLIM,XCCR,YCCR,XCORS,YCORS
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
      COMMON /BLOK8/PLOTY,PLOTX,ALPHA
      REAL YES/'YES'/,NO/'NO'/
C
C     READ INITIAL SIMULATION CRITERIA
C
      WRITE(6,6001)
 6001 FORMAT(//13X,10('-'),5X,'SEED-PTAEDA',5X,10('-')//
     1 ' SIMULATION OF TREE AND STAND GROWTH IN',
     2 ' SEEDED LOBLOLLY PINE STANDS '//
     3 ' ENTER: TITLE')
      READ(9,5001) (TITLE(L),L=1,20)
 5001 FORMAT(20A4)
      WRITE(6,6002)
 6002 FORMAT(' ENTER: NYEARS,SITE,IX')
      READ(9,*) NYEARS,SITE,IX
   10 WRITE(6,6003)
 6003 FORMAT(' EXISTING STAND ?  ENTER: YES OR NO')
      READ(9,5002)QEXIST
 5002 FORMAT(A3)
      IF(QEXIST.EQ.NO)  GO TO 20
      IF(QEXIST.NE.YES) GO TO 10
      GO TO 25
   20 WRITE(6,6005)
 6005 FORMAT(' ENTER SPATIAL PARAMETERS: ALPHA,TS')
      READ(9,*) ALPHA,TS
      TS10=TS
      GO TO 30
   25 WRITE(6,60051)
60051 FORMAT(' ENTER SPATIAL PARAMETERS: ALPHA,BA,AGE')
      READ(9,*)ALPHA,EXBA,EXAGE
   30 HDWD=0.
      WRITE(6,6006)
 6006 FORMAT(' HARDWOOD CONTROL ? ')
      READ(9,5002) QHDWD
      IF(QHDWD.EQ.NO)  GO TO 35
      IF(QHDWD.NE.YES) GO TO 30
      WRITE(6,6007)
 6007 FORMAT(' ENTER HARDWOOD CONTROL PARAMETERS: HDWD,IRLSE,ARLSE')
      READ(9,*)  HDWD,IRLSE,ARLSE
   35 CAF=HDWD+1
      SAF=1.
      WRITE(6,6008)
 6008 FORMAT(' JUVENILE STAND OUTPUT?')
      READ (9,5002) QJUV
      IF(QJUV.EQ.YES) GO TO 38
      WRITE(6,6009)
 6009 FORMAT(' ENTER: AGE AT NEXT DECISION PERIOD')
      READ(9,*) KIN
   38 RETURN
C
C     READ MANAGEMENT CRITERIA
C
      ENTRY INPUT2
      IF(KIN.EQ.NYEARS) GO TO 39
      WRITE(6,6010) KIN
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
 6010 FORMAT(//,' INPUT BEFORE ',I2,' TH GROWING SEASON')
   39 KTHIN=0
      IF(KIN.EQ.NYEARS.OR.KIN.LT.10) GO TO 60
   40 WRITE(6,6011)
 6011 FORMAT(' THIN STAND?')
      READ(9,5002) QTHIN
      IF(QTHIN.EQ.NO) GO TO 60
      IF(QTHIN.NE.YES)GO TO 40
      WRITE(6,6012)
 6012 FORMAT(' ENTER THINNING TYPE, AGE: ITHIN,KTHIN')
      READ(9,*) ITHIN,KTHIN
      GO TO (50,55,50), ITHIN
   50 WRITE(6,6013)
 6013 FORMAT(' ENTER CORRIDOR THINNING PARAMETERS: XCORW,YCORW,',
     1       'XCORS,YCORS')
      READ(9,*) XCOR,YCOR,XCORS,YCORS
      IF(ITHIN.EQ.1) GO TO 60
   55 WRITE(6,6014)
 6014 FORMAT(' ENTER LOW THIN PARAMETERS: ILOW,DLOW,TLIM')
      READ(9,*) ILOW,DLOW,TLIM
   60 IF(KIN.EQ.NYEARS.OR.KIN.LT.15.OR.QFERT.EQ.YES) GO TO 70
      QFERT=NO
      WRITE(6,6015)
 6015 FORMAT(' FERTILIZE STAND?')
      READ(9,5002) QFERT
      IF(QFERT.EQ.NO) GO TO 70
      IF(QFERT.NE.YES)GO TO 60
      WRITE(6,6016)
 6016 FORMAT(' ENTER FERT PARAMETERS: RESP,LR,LMR,KFERT')
      READ(9,*) RESP,LR,LMR,KFERT
   70 KOUT=0
      IF(KIN.EQ.NYEARS) GO TO 75
      WRITE(6,6017)
 6017 FORMAT(' STAND SUMMARY?')
      READ(9,5002) QSTAND
      IF(QSTAND.EQ.NO) GO TO 80
      IF(QSTAND.NE.YES)GO TO 70
   75 KOUT=KIN
   80 CONTINUE
   90 IF(KIN.EQ.NYEARS) GO TO 95
      WRITE (6,6019)
 6019 FORMAT(' ENTER: AGE AT NEXT DECISION PERIOD')
      READ(9,*) KIN
   95 RETURN
C
C     TRY AGAIN?
C
      ENTRY INPUT3
      WRITE(6,6020)
 6020 FORMAT('0ANOTHER STAND ?')
      READ(9,5002) QAGAIN
      RETURN
      END
C
C***********************************************************************
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
C
      SUBROUTINE SEED(IX)
C
C          SUBROUTINE SEED CONTROLS ASSIGNMENT OF
C     INITIAL SPATIAL PATTERNS.
C
C     ROUTINE DEVELOPED BY HOWARD B. STAUFFER
C     MODIFIED BY RICHARD F. DANIELS AND GERALD D. SPITTLE
C
C************************************************************************
      COMMON /BLOK1/X(100),Y(100),LMORT(100),KMORT(100),D(100),
     1 H(100),CL(100),CI(100),MID(100),LEDGE(9),ACRES
      COMMON /BLOK4/TITLE(20),NYEARS,SITE,QEXIST,EXAGE,EXBA,
     1 TS,TS10,KOUT,KIN,KTREE,QJUV,QAGAIN
      COMMON /BLOK5/HDWD,CAF,ARLSE,QHDWD,IRLSE
      COMMON /BLOK8/PLOTY,PLOTX,ALPHA1
      COMMON /BLOKD/N
      REAL YES/'YES'/,NO/'NO'/
       DIMENSION XX(100),YY(100),RAD1(100),IDEG(360)
       DISTSQ(A,B,C,D)=(A-C)*(A-C)+(B-D)*(B-D)
       PI=3.14159
C
C     EXISTING STANDS
C
      KJ=10
      A=KJ
      SI=SITE
      IF(QEXIST.NE.YES) GO TO 10
      HD=SI*10.**(-6.528*(1./A-.02))
      ARAT=EXAGE/A
      BAT=EXBA**ARAT*EXP(-(3.4344*(ARAT-1)+.026748*(ARAT-1)*SI))
      DAVE=-1.5419017+1.1432425*ALOG(HD)+.0038993*BAT
      TS=EXP(5.319584)*BAT**.8353507*DAVE**(-1.608657)/CAF**1.0407345
      TS10=TS
C
C     GENERATE SPATIAL PATTERN
C
   10 FN=N
      ACRES=FN/TS
      PLOTX=SQRT(ACRES*43560)
      PLOTY=PLOTX
       DO 1030 I=1,N
       RNX=U(IX)
       XX(I)=PLOTX*RNX
       RNY=U(IX)
       YY(I)=PLOTY*RNY
       C=FN*PI/(PLOTX*PLOTY)
       FK=ALPHA1/(ALPHA1-1)
 1021  RND=U(IX)
       IF(RND.LE.0.005) GO TO 1021
 1030  RAD1(I)=SQRT((FK/C)*(RND**(-1./FK)-1.))
       DO 1190 I=1,N
 1176  CONTINUE
       DO 1040 K=1,360
 1040   IDEG(K)=K
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
      DO 1130 J=1,N
      IF(J.EQ.1) GO TO 1130
      IF(SQRT(DISTSQ(XX(I),YY(I),XX(J),YY(J))).GT.(RAD1(I)+RAD1(J)))
     1 GO TO 1130
      CFAC=XX(I)**2+YY(I)**2-XX(J)**2-YY(J)**2
      XFAC=2.*XX(J)-2.*XX(I)
      YFAC=2.*YY(J)-2.*YY(I)
      IF(XFAC.EQ.0.) GO TO 1050
      IF(YFAC.EQ.0.) GO TO 1060
      YFAC=-YFAC/XFAC
      CFAC=-CFAC/XFAC
      YSQ=YFAC**2+1
      YVAL=(CFAC-XX(I))*2.*YFAC-2.*YY(I)
      CVAL=(CFAC-XX(I))**2+YY(I)**2-RAD1(I)**2
      BSQ=YVAL**2
      FOURAC=4.*YSQ*CVAL
      Z=ABS(BSQ-FOURAC)
      YROOT1=(-YVAL+SQRT(Z))/(2.*YSQ)
      YROOT2=(-YVAL-SQRT(Z))/(2.*YSQ)
      XROOT1=YFAC*YROOT1+CFAC
      XROOT2=YFAC*YROOT2+CFAC
      GO TO 1070
 1050 IF(YFAC.EQ.0.) GO TO 1130
      YROOT1=-CFAC/YFAC
      YROOT2=YROOT1
      XSQ=1.
      XVAL=-2.*XX(I)
      CVAL=XX(I)**2-RAD1(I)**2+(YY(I)-YROOT1)**2
      BSQ=XVAL**2
      FOURAC=4.*XSQ*CVAL
      Z=ABS(BSQ-FOURAC)
      XROOT1=(-XVAL+SQRT(Z))/(2.*XSQ)
      XROOT2=(-XVAL-SQRT(Z))/(2.*XSQ)
      GO TO 1070
 1060  XROOT1=-CFAC/XFAC
      XROOT2=XROOT1
      YSQ=1.
      YVAL=-2.*YY(I)
      CVAL=YY(I)**2-RAD1(I)**2+(XX(I)-XROOT1)**2
      BSQ=YVAL**2
      FOURAC=4.*YSQ*CVAL
      Z=ABS(BSQ-FOURAC)
      YROOT1=(-YVAL+SQRT(Z))/(2.*YSQ)
      YROOT2=(-YVAL-SQRT(Z))/(2.*YSQ)
 1070  THETA1=ATAN2(YROOT1-YY(I),XROOT1-XX(I))
      IF(THETA1.LT.0.) THETA1=THETA1+2.*PI
      THETA2=ATAN2(YROOT2-YY(I),XROOT2-XX(I))
      IF(THETA2.LT.0.) THETA2=THETA2+2.*PI
      THMIN=THETA1
      THMAX=THETA2
      IF(THETA2.LT.THETA1) THMIN=THETA2
      IF(THETA2.LT.THETA1) THMAX=THETA1
      I1=360.*THMIN/(2.*PI)
      I2=360.*THMAX/(2.*PI)
       IF(I1.EQ.I2) GO TO 1130
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
      THMED=THMIN+(THMAX-THMIN)/2.                                      SEE03860
      XXX=XX(I)+RAD1(I)*COS(THMED)                                      SEE03870
      YYY=YY(I)+RAD1(I)*SIN(THMED)                                      SEE03880
      IF(SQRT(DISTSQ(XX(J),YY(J),XXX,YYY)).LE.RAD1(J)) GO TO 1110       SEE03890
      IF(I1.EQ.0) GO TO 1090                                            SEE03900
      DO 1080 K=1,I1                                                    SEE03910
 1080 IDEG(K)=0                                                         SEE03920
 1090 DO 1100 K=I2,360                                                  SEE03930
 1100 IDEG(K)=0                                                         SEE03940
      GO TO 1130                                                        SEE03950
 1110 IF(I1.EQ.0) IDEG(360)=0                                           SEE03960
      IF(I1.EQ.0) I1=I1+1                                               SEE03970
      DO 1120 K=I1,I2                                                   SEE03980
 1120 IDEG(K)=0                                                         SEE03990
 1130 CONTINUE                                                          SEE04000
 1140 DO 1150 K=1,360                                                   SEE04010
      XXX=XX(I)+RAD1(I)*COS(FLOAT(K)*2.*PI/360.)                        SEE04020
      YYY=YY(I)+RAD1(I)*SIN(FLOAT(K)*2.*PI/360.)                        SEE04030
 1150 IF(XXX.LT.0..OR.XXX.GT.PLOTX.OR.YYY.LT.0..OR.YYY.GT.              SEE04040
     1 PLOTY) IDEG(K)=0                                                 SEE04050
      L=0                                                               SEE04060
      DO 1160 K=1,360                                                   SEE04070
      IF(IDEG(K).EQ.0) GO TO 1160                                       SEE04080
      L=L+1                                                             SEE04090
      IDEG(L)=IDEG(K)                                                   SEE04100
 1160 CONTINUE                                                          SEE04110
 1170 M=FLOAT(L)*U(IX)+1                                                SEE04120
      IF(M.EQ.(L+1)) M=L                                                SEE04130
      IF(L.NE.0) GO TO 1174                                             SEE04140
C     XX(I)=PLOTX*U(IX)                                                 SEE04150
C     YY(I)=PLOTY*U(IX)                                                 SEE04160
C     GO TO 1176                                                        SEE04170
      M=1                                                               SEE04180
      IDEG(M)=360.*U(IX)                                                SEE04190
 1174 CONTINUE                                                          SEE04200
      THETA=2.*PI*IDEG(M)/360.                                          SEE04210
      X(I)=XX(I)+RAD1(I)*COS(THETA)                                     SEE04220
      Y(I)=YY(I)+RAD1(I)*SIN(THETA)                                     SEE04230
      IF(L.EQ.0) X(I)=XX(I)                                             SEE04240
      IF(L.EQ.0) Y(I)=YY(I)                                             SEE04250
 1190 CONTINUE                                                          SEE04260
      RETURN                                                            SEE04270
      END                                                               SEE04280
C                                                                       SEE04290
C***********************************************************************SEE04300
C                                                                       SEE04310
      SUBROUTINE JUVS(IX)                                               SEE04320
C                   JUVS                                                SEE04330
C                                                                       SEE04340
C          SUBROUTINE JUVS GENERATES A JUVENILE SEEDED                  SEE04350
C     STAND AT AGE 10 FROM EXISTING STAND INFORMATION.                  SEE04360
C                                                                       SEE04370
C***********************************************************************SEE04380
      DIMENSION S(2)                                                    SEE04390
      COMMON /BLOK1/X(100),Y(100),LMORT(100),KMORT(100),D(100),         SEE04400
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
     1 H(100),CL(100),CI(100),MID(100),LEDGE(9),ACRES
      COMMON /BLOK3/YCUFT(75,3),YCUFTM(75,3),BA(75),KJ,K,NLIVE,
     1 NTHIN,HD,NOLD
      COMMON /BLOK4/TITLE(20),NYEARS,SITE,QEXIST,EXAGE,EXBA,
     1 TS,TS10,KOUT,KIN,KTREE,QJUV,QAGAIN
      COMMON /BLOK5/HDWD,CAF,ARLSE,CHDWD,IRLSE
      COMMON /BLOK8/PLOTX,PLOTY,ALPHA
      REAL YES/'YES'/,NO/'NO'/
      COMMON /BLOKD/N
      DIMENSION DUMMY(100)
      KJ=10
      A=KJ
      SI=SITE
      HD=SI*10**(-6.528*(1./A-.02))
      A=KJ
       DAVE= .470401+.069485*HD-.083E-5*A*(TS*CAF)+5.45478*HD/(TS*CAF)
       DMIN=-.067446+.029395*HD-.112E-5*A*(TS*CAF)+6.23266*HD/(TS*CAF)
      IF(DAVE.LE.0)DAVE=.0001
      IF(DMIN.LE.0)DMIN=.0001
      BHAT=ALOG(TS*.1*CAF)/ALOG(DAVE/DMIN)
      AHAT=(GAMMA(1.+1./BHAT)/DAVE)**BHAT
      ACRES=100./TS
      NLIVE=N
      NMORT=0
      NTHIN=0
  120 DO 1100 I=1,N
      D(I)=DAVE
      CI(I)=0.
      LMORT(I)=1
 1100 DUMMY(I)=(-ALOG(U(IX))/AHAT)**(1./BHAT)
      CALL CCMP
      NTREES=0
  130 IF(NTREES.EQ.N) GO TO 145
      DMAX=0.
      CMIN=9.E9
      DO 1200 J=1,N
      IF(DUMMY(J).LE.DMAX) GO TO 140
      JD=J
      DMAX=DUMMY(J)
  140 IF(CI(J).GE.CMIN) GO TO 1200
      JC=J
      CMIN=CI(J)
 1200 CONTINUE
      D(JC)=DMAX
      CI(JC)=9.E9
      DUMMY(JD)=0.
      NTREES=NTREES+1
      DSQ=D(JC)*D(JC)
      BA(KJ)=BA(KJ)+DSQ
      GO TO 130
  145 BA(KJ)=BA(KJ)*.005454/ACRES
      HAV=0.
      DO 1250 I=1,N
      H(I)=HD**0.32192*D(I)**0.52118*EXP(1.44287+.263276E-2*BA(KJ)*CAF
     1       +0.07299/D(I)-1.08825/A)
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
 1250 HAV=HAV+H(I)
        HAV=HAV/N
        HAVHAT=-1.623476+0.916285*HD
        HRAT=HAVHAT/HAV
       DO 1300 I=1,N
       CI(I)=0.
       H(I)=H(I)*HRAT
       CBL=H(I)**1.48535*D(I)**(-0.47173)*EXP(-1.4343+.92034E-3*BA(KJ)
      1     *CAF-0.10991/D(I)-3.34385/A)
       CL(I)=H(I)-CBL
       IF(CL(I).LT.0)CL(I)=0
       DSQ=D(I)*D(I)
       IF(D(I).GE.4.55) YCUFTM(KJ,1)=YCUFTM(KJ,1)-.8421+.00205*DSQ*H(I)
       YCUFT(KJ,1)=YCUFT(KJ,1)+.27611+.00253*DSQ*H(I)
 1300 CONTINUE
       YCUFTM(KJ,1)=YCUFTM(KJ,1)/ACRES
       YCUFT(KJ,1)=YCUFT(KJ,1)/ACRES
       RETURN
       END
C
C**********************************************************************
C
       SUBROUTINE THIN(A)
C
C           SUBROUTINE THIN REMOVES TREES EITHER BY CORRIDORS OR FROM
C      BELOW.  THINNING FROM BELOW MAY BE ACCOMPLISHED BY REMOVING
C      TREES BELOW A SPECIFIED DBH OR BY THINNING TO A SPECIFIED
C      RESIDUAL BASAL AREA.  CORRIDOR THINNING MAY BE USED IN EITHER
C      THE X OR Y DIRECTION OR BOTH.
C
C**********************************************************************
       COMMON /BLOK1/X(100),Y(100),LMORT(100),KMORT(100),D(100),
      1 H(100),CL(100),CI(100),MID(100),LEDGE(9),ACRES
       COMMON /BLOK3/YCUFT(75,3),YCUFTM(75,3),BA(75),KJ,K,NLIVE,
      1 NTHIN,HD,NOLD
       COMMON /BLOK4/TITLE(20),NYEARS,SITE,QEXIST,EXAGE,EXBA,
      1 TS,TS10,KOUT,KIN,KTREE,QJUV,QAGAIN
       COMMON /BLOK7/KTHIN,ITHIN,ILOW,DLOW,TLIM,XCOR,YCOR,XCORS,YCORS
       COMMON /BLOK8/PLOTX,PLOTY,ALPHA
       COMMON /BLOKD/N
       BATHIN=0.
       GO TO (1,2,1),ITHIN
C
C      CORRIDOR THINNING
C
    1 IF(YCORS.LE.0) YCORS=1
       IF(XCORS.LE.0) XCORS=1
       NCORY=PLOTY/YCORS+.5
       NCORX=PLOTX/XCORS+.5
       XSTART=XCORS/2.-XCOR/2.
       YSTART=YCORS/2.-YCOR/2.
       DO 100 I=1,N
       IF(LMORT(I).NE.1) GO TO 100
       IF(YCOR.LE.0) GO TO 97
       DO 96 J=1,NCORY
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
      FJ=J
      YIN=YSTART*FJ
      YAX=YIN+YCOR
      IF(YAX.GT.PLOTY) YAX=PLOTY
      IF(Y(I).LT.YIN.OR.Y(I).GT.YAX) GO TO 96
      NTHIN=NTHIN+1
      NLIVE=NLIVE-1
      LMORT(I)=3
      KMORT(I)=KTHIN
      BATHIN=BATHIN+D(I)*D(I)
      GO TO 100
   96 CONTINUE
   97 CONTINUE
      IF(XCOR.LE.0) GO TO 99
      DO 98 J=1,NCORX
      FJ=J
      XIN=XSTART*FJ
      XAX=XIN+XCOR
      IF(XAX.GT.PLOTX) XAX=PLOTX
      IF(X(I).LT.XIN.OR.X(I).GT.XAX) GO TO 98
      NTHIN=NTHIN+1
      NLIVE=NLIVE-1
      LMORT(I)=3
      KMORT(I)=KTHIN
      BATHIN=BATHIN+D(I)*D(I)
      GO TO 100
   98 CONTINUE
   99 CONTINUE
  100 CONTINUE
      IF(ITHIN.EQ.1) GO TO 3
C
C     LOW THINNING
C
    2 IF(ILOW.EQ.2) GO TO 22
C
C          DIAMETER LIMIT OPTION
C
      DO 200 I=1,N
      IF(LMORT(I).NE.1) GO TO 200
      IF(D(I).LT.DLOW.OR.D(I).GE.TLIM) GO TO 200
      NTHIN=NTHIN+1
      NLIVE=NLIVE-1
      LMORT(I)=3
      KMORT(I)=KTHIN
  200 CONTINUE
      GO TO 3
C
C          BA LIMIT OPTION
C
   22 BATH=(BA(K-1)-TLIM)*ACRES/.005454
      DO 400 IT=1,N
      IF(BATHIN.GE.BATH) GO TO 3
      DMIN=9.E6
      DO 300 I=1,N
      IF(LMORT(I).NE.1) GO TO 300
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
      IF(D(I).GE.DMIN.OR.D(I).LT.DLOW) GO TO 300
      DMIN=D(I)
      IMIN=I
  300 CONTINUE
      BATHIN =BATHIN+D(IMIN)*D(IMIN)
      NTHIN=NTHIN+1
      NLIVE=NLIVE-1
      LMORT(IMIN)=3
      KMORT(IMIN)=KTHIN
  400 CONTINUE
    3 IF(KTHIN.NE.NYEARS-1) GO TO 4
      K=K-1
      DO 500 I=1,N
      IF(KMORT(I).NE.K+1) GO TO 500
      DSQ=D(I)*D(I)
      BA(K)=BA(K)-DSQ*.005454/ACRES
      YCFT=DSQ*H(I)*.00253 + .27611
      YCFTM=DSQ*H(I)*.00205-.8421
      YCUFT(K,1)=YCUFT(K,1)-YCFT/ACRES
      YCUFT(K,3)=YCUFT(K,3)+YCFT/ACRES
      YCUFTM(K,1)=YCUFTM(K,1)-YCFTM/ACRES
      YCUFTM(K,3)=YCUFTM(K,3)+YCFTM/ACRES
  500 CONTINUE
      CALL OUTPUT
      K=K+1
    4 RETURN
      END
C
C***********************************************************************
C
      SUBROUTINE FERT(A)
C
C          SUBROUTINE FERT SIMULATES THE EFFECTS OF
C     FERTILIZATION ON SITE QUALITY BY CALCULATING A SITE
C     ADJUSTMENT FACTOR (SAF) WHICH ACTS AS A MULTIPLIER OF
C     SITE INDEX.
C
C***********************************************************************
      COMMON /BLOK4/TITLE(20),NYEARS,SITE,QEXIST,EXAGE,EXBA,
     1 TS,TS10,KCUT,KIN,KTREE,QJUV,QAGAIN
      COMMON /BLOK6/KFERT,LMR,LR,RESP,SAF,QFERT
      REAL NO/'NO'/
      IF(A-KFERT.LE.0) GO TO 50
      IF(A-KFERT.GT.LMR) GO TO 20
C
C     AGE LE AGE OF MAX RESPONSE (LMR)
C
      SAF=RESP*(1.-(KFERT+LMR-A)/LMR)
      GO TO 30
   20 IF(A-KFERT.GE.LR) GO TO 40
C
C     AGE GT AGE OF MAX RESPONSE (LMR)
C
      SAF=RESP*(1.+(KFERT+LMR-A)/(LR-LMR))
   30 SAF=(SAF+SITE)/SITE
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
      GO TO 50
   40 SAF=1
      QFERT=NO
   50 RETURN
      END
C
C*****************************************************************
C
      SUBROUTINE HDWD(A)
C
C            SUBROUTINE HDWD SIMULATES THE INCREASED
C     COMPETITION DUE TO HARDWOODS BY CALCULATING A
C     COMPETITION ADJUSTMENT FACTOR (CAF) WHICH IS USED
C     TO MULTIPLY ALL COMPETITIVE COMPONENTS CF SEED-PTAEDA.
C
C*****************************************************************
      COMMON /BLOK5/HRDWD,CAF,ARLSE,QHDWD,IRLSE
      REAL NC/'NO'/
      IF(A.GE.ARLSE) GO TO 10
      IF(IRLSE.EQ.2) GO TO 20
      CAF=HRDWD*(1.-A/ARLSE)+1
      GO TO 20
   10 CAF=1
      QHDWD=NC
   20 RETURN
      END
C
C*****************************************************************
C
      SUBROUTINE OUTPUT
C
C            SUBROUTINE OUTPUT CALCULATES AND DISPLAYS
C     SUMMARY STATISTICS FOR TREE AND STAND CHARACTERISTICS.
C
C*****************************************************************
      REAL MAI(3)
      DIMENSION NDC(25,3),HDC(25,3),PROD(3),YINC(3),PAI(3),
     1 BAR(4),DMIN(4),DMAX(4),SD(4)
      COMMON /BLCK1/X(100),Y(100),LMORT(100),KMORT(100),D(100),
     1 H(100),CL(100),CI(100),MID(100),LEDGE(9),ACRES
      COMMON /BLOK3/YCUFT(75,3),YCUFTM(75,3),BA(75),KJ,K,NLIVE,
     1 NTHIN,HD,NOLD
      COMMON /BLOK4/TITLE(20),NYEARS,SITE,QEXIST,EXAGE,EXBA,
     1 TS,TS10,KOUT,KIN,KTREE,QJUV,QAGAIN
      REAL YES/'YES'/,NO/'NO'/
      COMMON /BLOKD/N
      IF(QJUV.EQ.NO) GO TO 1
      K=KJ
      QJUV=NC
    1 INDEX=1
C
C     CALCULATE STAND SUMMARY STATISTICS
C
      CALL STAT(D ,N,LMORT,BAR(1),DMIN(1),DMAX(1),SD(1),INDEX)
      CALL STAT(H ,N,LMORT,BAR(2),DMIN(2),DMAX(2),SD(2),INDEX)
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
      CALL STAT(CL,N,LMORT,BAR(3),DMIN(3),DMAX(3),SD(3),INDEX)
      CALL STAT(CI,N,LMORT,BAR(4),DMIN(4),DMAX(4),SD(4),INDEX)
      INDEX=2
      CALL STAT(D ,N,LMORT,DUMP1,DMIN2,DMAX2,DUMP2,INDEX)
      MAXDC=DMAX2+.45
      MINDC=DMIN2+.45
      IF(MINDC.LT.1) MINDC=1
C
C     CALCULATE CURRENT, PERIODIC, AND MEAN ANNUAL INCREMENT
C
      DO 100 ID=MINDC,MAXDC
      DO 100 L=1,3
      NDC(ID,L)=0
  100 HDC(ID,L)=0
      DO 150 M=1,3
      YINC(M)=9.E9
  150 PAI(M)=9.E9
      IF(KJ.EQ.K) GO TO 3
      YINC(1)=BA(K)-BA(K-1)
      YINC(2)=YCUFT(K,1)-YCUFT(K-1,1)
      YINC(3)=YCUFTM(K,1)-YCUFTM(K-1,1)
      IF(K-KJ.LT.5) GO TO 3
      PAI(1)=(BA(K)-BA(K-5))/5.
      PAI(2)=(YCUFT(K,1)-YCUFT(K-5,1))/5.
      PAI(3)=(YCUFTM(K,1)-YCUFTM(K-5,1))/5.
    3 MAI(1)=BA(K)/K
      MAI(2)=YCUFT(K,1)/K
      MAI(3)=YCUFTM(K,1)/K
      PROD(1)=BA(K)
      PROD(2)=YCUFT(K,1)
      PROD(3)=YCUFTM(K,1)
      TS=NLIVE/ACRES
      NMORT=N-NLIVE-NTHIN
      TM=NMORT/ACRES
      TT=NTHIN/ACRES
C
C     CALCULATE DISTRIBUTION OF SIZES
C
      DO 200 I=1,N
      L=LMORT(I)
      IF(L.EQ.0) GO TO 200
      ID=D(I)+.45
      IF(ID.LT.1) ID=1
      NDC(ID,L)=NDC(ID,L)+1
      HDC(ID,L)=HDC(ID,L)+H(I)
  200 CONTINUE
      DO 300 L=1,3
      DO 300 ID=MINDC,MAXDC
      IF(NDC(ID,L).LE.0) GO TO 300
      HDC(ID,L)=HDC(ID,L)/NDC(ID,L)
      NDC(ID,L)=NDC(ID,L)/ACRES+.5
  300 CONTINUE
C
C     DISPLAY TREE AND STAND CHARACTERISTICS
C
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
      WRITE(6,6100)(TITLE(M),M=1,20)
 6100 FORMAT(//' ',20A4/)
      WRITE(6,6101) K
 6101 FORMAT('0STAND SUMMARY  - AGE',I3//' DIMENSION      ',
     1 'MEAN   ST.DEV.   MIN      MAX')
      WRITE(6,6102)(BAR(M),SD(M),DMIN(M),DMAX(M), M=1,4)
 6102 FORMAT(' DBH',6X,4(3X,F5.2)/'  HT',5X,4(3X,F5.1)/
     1 '  CL',5X,4(3X,F5.1)/'  CI',6X,4(2X,F6.4)/)
      WRITE(6,6103) ACRES,TS10,TS,HD
 6103 FORMAT('0ACRES SIMULATED            ',F10.5/' TREES PER ACRE',
     1 ' AT AGE 10',F10.0/' TREES SURVIVING PER ACRE',F10.0/
     2 ' HEIGHT OF DOMINANT STAND',F11.1/)
      WRITE(6,6104)(PROD(M),YINC(M),PAI(M),MAI(M),M=1,3)
 6104 FORMAT('0PRODUCT         YIELD    INCREM    PAI      MAI'/
     1 ' BASAL AREA',4X,F6.1,3(2X,F6.2)/' CUBIC FEET',3X,F6.0,
     2 3(2X,F6.1)/' MERCH VOL ',2X,F7.0,3(1X,F7.1)/)
      IF(NTHIN.LE.0) GO TO 57
      WRITE(6,6501) YCUFT(K,3),YCUFTM(K,3)
 6501 FORMAT(' TOTAL CUBIC FEET THINNED ',F6.0/
     1     ' MERCH VOLUME THINNED      ',F6.0/)
   57 CONTINUE
      WRITE(6,6105)
 6105 FORMAT('0D CLASS #LIVE    MEAN H     #MORT    MEAN H',
     1 '     #THIN    MEAN H')
      DO 400 ID=MINDC,MAXDC
  400 WRITE(6,6106) ID,(NDC(ID,L),HDC(ID,L),L=1,3)
 6106 FORMAT(' ',I3,3(4X,I5,3X,F6.2))
      WRITE(6,6107) TS,TM,TT
 6107 FORMAT(' TOT ',3(4X,F5.0,9X)/)
      RETURN
      END
C
C**************************************************************************
C
      SUBROUTINE COMP
C
C          SUBROUTINE COMP CALCULATES A MODIFIED
C     HEGYI COMPETITION INDEX ON ALL LIVE TREES IN
C     A STAND.  COMPETITORS ARE FOUND BY SAMPLING
C     NEIGHBORS BASED ON THEIR SIZE AND DISTANCE AWAY
C     BY ESSENTIALLY TAKING A POINT SAMPLE AT EACH
C     SUBJECT TREE WITH A BAF-10 PRISM.
C
C**************************************************************************
      DIMENSION JDIS(9),DIST(9),IDIS(4)
      COMMON /BLOK1/X(100),Y(100),LMORT(100),KMORT(100),D(100),
     1 H(100),CL(100),CI(100),MID(100),LEDGE(9),ACRES
      COMMON /BLOK8/PLOTX,PLOTY,ALPHA
      COMMON /BLOKD/N
      DATA PLOTR/2.75/,PI/3.14159/,JDIS/1,9,8,7,6,5,4,3,2/
      IDIS(1)=1
      DMAX=0
      DO 100 I=1,N
  100 IF(D(I).GT.DMAX) DMAX=D(I)
      DISMAX=PLOTR*DMAX
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
      DISMAY=PLOTR*DMAX
      DO 200 I=1,N
      MID(I)=2
  200 IF(X(I).GT.DISMAX.AND.X(I).LT.(PLOTX-DISMAX).AND.
     1   Y(I).GT.DISMAY.AND.Y(I).LT.(PLOTY-DISMAY)) MID(I)=1
      NLESS1=N-1
      DO 500 I=1,NLESS1
      IF(LMORT(I).NE.1) GO TO 500
      IPLUS1=I+1
      DO 400 J=IPLUS1,N
      IF(LMORT(J).NE.1) GO TO 400
      INTIOR=MID(I)+MID(J)
      XDIST=X(J)-X(I)
      YDIST=Y(J)-Y(I)
      DIST(1)=SQRT(XDIST*XDIST+YDIST*YDIST)
      IF(INTIOR.LT.3) GO TO 1
      IF(XDIST) 6,5,5
    5 DIST(5)=SQRT((XDIST-PLOTX)*(XDIST-PLOTX)+
     1              (YDIST      )*(YDIST      ))
      IDIS(2)=5
      GO TO 10
    6 DIST(6)=SQRT((XDIST+PLOTX)*(XDIST+PLOTX)+
     1              (YDIST      )*(YDIST      ))
      IDIS(2)=6
   10 IF(YDIST) 3,8,8
    3 DIST(3)=SQRT((XDIST      )*(XDIST      )+
     1              (YDIST+PLOTY)*(YDIST+PLOTY))
      IDIS(3)=3
      ICODE=IDIS(2)+IDIS(3)-7
      GO TO (2,4,11,11,11,7,9),ICODE
    8 DIST(8)=SQRT((XDIST      )*(XDIST      )+
     1              (YDIST-PLOTY)*(YDIST-PLOTY))
      IDIS(3)=8
      ICODE=IDIS(2)+IDIS(3)-7
      GO TO (2,4,11,11,11,7,9),ICODE
    2 DIST(2)=SQRT((XDIST-PLOTX)*(XDIST-PLOTX)+
     1              (YDIST+PLOTY)*(YDIST+PLOTY))
      IDIS(4)=2
      GO TO 1
    4 DIST(4)=SQRT((XDIST+PLOTX)*(XDIST+PLOTX)+
     1              (YDIST+PLOTY)*(YDIST+PLOTY))
      IDIS(4)=4
      GO TO 1
    7 DIST(7)=SQRT((XDIST-PLOTX)*(XDIST-PLOTX)+
     1              (YDIST-PLOTY)*(YDIST-PLOTY))
      IDIS(4)=7
      GO TO 1
    9 DIST(9)=SQRT((XDIST+PLOTX)*(XDIST+PLOTX)+
     1              (YDIST-PLOTY)*(YDIST-PLOTY))
   11 GO TO 1
    1 RJI=D(J)/D(I)
      RIJ=1/RJI
      DO 300 L=1,4
      LC=IDIS(L)
      LCC=JDIS(LC)
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
      LEDGE(LC)=0
      LEDGE(LCC)=0
      IF(DIST(LC).GE.D(J)*PLOTR) GO TO 20
      IF(LEDGE(LC ).EQ.0) CI(I)=CI(I)+RJI/DIST(LC)
   20 IF(DIST(LC).GE.D(I)*PLOTR) GO TO 30
      IF(LEDGE(LCC).EQ.0) CI(J)=CI(J)+RIJ/DIST(LC)
   30 IF(INTIOR.LE.3) GO TO 400
  300 CONTINUE
  400 CONTINUE
  500 CONTINUE
      RETURN
      END
C
C***********************************************************************
C
      SUBROUTINE STAT(X,N,FLAG,XBAR,MIN,MAX,S,INDEX)
C
C          SUBROUTINE STAT CALCULATES THE MEAN, STANDARD
C     DEVIATION AND RANGE OF INPUT VECTOR.
C
C***********************************************************************
      REAL X(N),MIN,MAX
      INTEGER FLAG(N)
      M=0
      SUMX=0.
      SUMXSQ=0.
      MAX=0.
      MIN=1.E10
      DO 100 I=1,N
      IF(FLAG(I).EQ.0) GO TO 100
      IF(FLAG(I).NE.1.AND.INDEX.EQ.1) GO TO 100
      IF(X(I).GT.MAX) MAX=X(I)
      IF(X(I).LT.MIN) MIN=X(I)
      IF(FLAG(I).NE.1) GO TO 100
      M=M+1
      SUMX=SUMX+X(I)
      SUMXSQ=SUMXSQ+X(I)*X(I)
  100 CONTINUE
      VAR=(SUMXSQ-SUMX*SUMX/M)/(M-1)
      S=SQRT(VAR)
      XBAR=SUMX/M
      RETURN
      END
C
C***********************************************************************
C
      FUNCTION U(IX)
C
C     GENERATES A UNIFORM(0,1) RANDOM VARIATE
C
C***********************************************************************
      IX=IX*65539
      U=.5+IX*.2328306E-9
      RETURN
      END
```

Appendix III. Source listing of tree and stand growth simulation program Seed-PTAEDA (continued).

```
C
C***********************************************************************
C
      FUNCTION STNORM(IX)
C
C     GENERATES A STANDARD NORMAL RANDOM VARIATE
C
C***********************************************************************
      STNORM=(-2*ALOG(U(IX)))**.5*COS(6.283*U(IX))
      RETURN
      END
C
C***********************************************************************
C
      BLOCK DATA
C
C***********************************************************************
      COMMON /BLOKD/ N
      INTEGER N/100/
      END
```