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CLIMACCS: A Computer Model of Forest Stand Development for Western Oregon and Washington

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Abstract


A simulation model for the development of timber stands in the Pacific Northwest is described. The model grows individual trees of 21 species in a 0.20-hectare (0.08-acre) forest gap. The model provides a means of assimilating existing information, indicates where knowledge is deficient, suggests where the forest system is most sensitive, and provides a first testing ground for hypotheses. Model verification simulations are included for up to 500 years on various sites. Fire, wind, or clearcutting can occur at intervals and intensities specified by users. The model was developed by modifying an existing forest succession simulator of eastern deciduous forests. Birth, growth, and death of individual trees are functions of existing light and temperature conditions, competition and species characteristics. Modifications of the existing simulator include tree height growth being related to temperature and moisture conditions, the foliage biomass to diameter relationship being more realistic, and five mortality classes and shade tolerance classes being defined.

Keywords: Succession, models, simulation, community dynamics (plant).
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CLIMACS (Computer Linked Integrative Model for Assessing Community Structure) is a simulation model of forest succession for western Oregon and Washington. The model tracks characteristics of individual trees growing in a forest opening of 0.20 hectare (0.08 acre). The FORTRAN IV code of CLIMACS is based on FORET (Shugart and West 1977), a succession model for eastern Tennessee, which in turn was modified from JABOWA (Botkin and others 1972), a simulator for forests of the northeastern United States. CLIMACS retains the stochastic features of the succession models for the eastern deciduous forests and has a more elaborate diameter increment equation and treatment of mortality. A moisture stress index is incorporated into the function that calculates diameter increment, and height growth is dependent upon site quality for some species. Mortality is related to the size of the tree and the successional status of the species under consideration. Three types of disturbance can occur: fire, wind, or clearcuts.

The model paradigm represents our view of succession as the result of individual tree processes and episodic disturbances. The term "climax" is tenuous because pioneer species are so long-lived that climax forests rarely develop in the Pacific Northwest even though major disturbances are infrequent. Although the simulator should be realistic enough to approximate stand development on particular sites, its main value is in summarizing and testing current hypotheses about tree growth and the factors affecting succession. The model is an exercise that should be useful to managers to examine hypotheses of the long-term effects of human activities on stand development.

A review of forest succession models is presented by Shugart and West (1980). According to their terminology, CLIMACS is a gap model that simulates characteristics of individual trees in a small portion of the forest—either an opening in the canopy or a sample plot. Such models are particularly useful for evaluation of long-term and large-scale changes in the environment and the effects of those changes on forest succession.

The purpose of this paper is to clarify algorithms and subroutines of the model. The basic features of the model are described in Botkin and others (1972) and Shugart and West (1977). Following the standards for model documentation from Swartzman (1979), the assumptions of the model are set forth, the value and source of each parameter is given, the source of the equations and potential problems of the curve forms are indicated, and the logic of the FORTRAN program is presented. This paper describes the structure of the main program and discusses the four major subroutines: BIRTH, GROW, KILL, and DISTRB. Results for several forest sites are presented.

The model code is stored on computer tape at the Forest Science Data Bank, Department of Forest Science, Oregon State University, Corvallis, Oregon.
Table 1—State variables

<table>
<thead>
<tr>
<th>Name</th>
<th>Definition</th>
<th>Units</th>
<th>Subroutines</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(KYR, i)</td>
<td>Aboveground biomass for species i</td>
<td>t/ha</td>
<td>MAIN, OUTPUT, PLTREE</td>
</tr>
<tr>
<td>A(KYR, NSPEC+1)</td>
<td>Total number of trees per plot</td>
<td>m²/ha</td>
<td>PLTREE, OUTPUT, MAIN</td>
</tr>
<tr>
<td>A(KYR, NSPEC+2)</td>
<td>Leaf area index for plot</td>
<td>cm²/ha</td>
<td>SPROUT, KILL, GROW, OUTPUT, KILL, OUTPUT, GROW</td>
</tr>
<tr>
<td>YRS</td>
<td>Stand biomass</td>
<td>cm</td>
<td>SPROUT, KILL, GROW, OUTPUT, KILL, OUTPUT, GROW</td>
</tr>
<tr>
<td>DBH(j)</td>
<td>Diameter at breast height of tree j</td>
<td>yrs</td>
<td>SPROUT, GROW</td>
</tr>
<tr>
<td>AGE(k)</td>
<td>Age of tree k</td>
<td>yrs</td>
<td></td>
</tr>
<tr>
<td>NTREES(i)</td>
<td>Number of trees of species i</td>
<td>yrs</td>
<td></td>
</tr>
<tr>
<td>BIOM</td>
<td>Stand biomass = A(KYR, 1)</td>
<td>t/ha</td>
<td>PLTREE</td>
</tr>
<tr>
<td>BAREA</td>
<td>Basal area of stand</td>
<td>m²</td>
<td>PLTREE</td>
</tr>
<tr>
<td>A(KYR, 26)</td>
<td>Total foliage biomass</td>
<td>t/ha</td>
<td>OUTPUT, PLTREE</td>
</tr>
<tr>
<td>FB(i)</td>
<td>Foliage biomass for species i</td>
<td>t/ha</td>
<td>OUTPUT, PLTREE</td>
</tr>
<tr>
<td>D(i, k)</td>
<td>Number of stems of species i in diameter class (k x 10)</td>
<td>t/ha</td>
<td>PLTREE</td>
</tr>
</tbody>
</table>

Numbers that represent the current state or condition of the system.

Structure and Assumptions

The model updates and records on an annual basis characteristics of all individual trees greater than 10 cm diameter at breast height (d.b.h.) on a 0.20-hectare (0.08-acre) plot (table 1). In the model, foliage is distributed vertically but not horizontally (Cartesian coordinates of each tree are not recorded). The driving variables (numbers that are inputs to the model and are not affected by the components of the system) for the model are plant moisture stress (PMS) (-bars) and temperature growth index (TGII) (days). PMS is the predawn negative xylem pressure measured near the end of the growing season (Waring and Cleary 1967). TGII is from a temperature summation formula that weights temperatures by their effects on the production of seedlings of Pseudotsuga menziesii (Mirb.) Franco (Cleary and Waring 1969). In the model, the yearly temperature growth index (TGII) varies from year to year in a normal distribution around the driving variable TGII. The model has six major assumptions:

1. PMS and TGII reflect the main physical driving variables of forest succession.
2. Competition for light is the primary biological factor affecting forest succession.
3. Regeneration of species that can grow under existing light and soil conditions is stochastic within the bounds of the geographic distribution of the species.
4. Diameter increment can be modeled as a multiplicative function of tree size, photosynthetic rate as reflected in foliage biomass, nutrient competition, light availability, shade tolerance, and moisture and temperature stress.
5. Mortality can occur at two levels—an individual tree and a portion of the stand.
6. Individual tree mortality is conditioned by growth rate.

A listing of the entire program is given in Appendix 1.

The model can be applied to four geographic regions west of the Cascade Range: Santiam Pass south to the California border, Santiam Pass north to Mount Rainier, north of Mount Rainier to the Canadian border, and the Olympic Peninsula (fig. 1). Restriction of a model run to a geographic region limits the species in the succession model to those found naturally in the region.
Main Program

The main program manages the entire model by initializing the year and plot replicate counters, setting the data storage array to zero, and calling the major subroutines as outlined in figure 2. A successional sequence can occur on replicate plots and for as many years as specified by the user. The model can start from a bare plot (see subroutine BIRTH), or the user can read in the species and diameter of each tree on the plot (see subroutine INPUT). The names and parameters of the species, driving variables, and length of the model run are read in by a call from the main program to subroutine INPUT. For each year of the simulation the appropriate species for the site are selected (subroutine SELECT), trees can die (subroutine KILL), regeneration occurs (subroutine BIRTH), and the diameter of

Figure 1.—The model is applicable to four geographic regions in Oregon and Washington.
Figure 2.—General scheme of model.
Table 2—Subroutines

<table>
<thead>
<tr>
<th>Subroutine</th>
<th>Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIRTH(KYR)</td>
<td>Introduces new trees with the diameter randomly distributed between 10 and 15 cm at breast height of the tree. KYR = current year.</td>
</tr>
<tr>
<td>ERR</td>
<td>Indicates error when there are more than 700 trees per plot.</td>
</tr>
<tr>
<td>GGNORD (NSEED1, NSEED2, Z)</td>
<td>Provides a normal distribution, Z, based on the random numbers NSEED1 and NSEED2.</td>
</tr>
<tr>
<td>GROW</td>
<td>Growth of d.b.h. and leaf area.</td>
</tr>
<tr>
<td>INIT</td>
<td>NOGro(I) = 0, I = 1, 700; KSPRT(I) = 1, I = 1, NSPEC.</td>
</tr>
<tr>
<td>INPUT</td>
<td>Reads and writes species specific names and parameters.</td>
</tr>
<tr>
<td>KILL</td>
<td>Eliminates trees as a function of diameter and growth rate.</td>
</tr>
<tr>
<td>OUTPUT</td>
<td>Updates biomass and the leaf area index.</td>
</tr>
<tr>
<td>PLOTIN(IPLOT)</td>
<td>Variables to start simulation in a bare plot (IPLOT = plot number).</td>
</tr>
<tr>
<td>PLTREE</td>
<td>Writes out information on species and years.</td>
</tr>
<tr>
<td>RANDOM(NSEED)</td>
<td>Random number generator (NSEED = seed).</td>
</tr>
<tr>
<td>RANSEE</td>
<td>Reads random number generator seed from input file.</td>
</tr>
<tr>
<td>SELECT</td>
<td>Checks water stress and temperature requirements for species in the four geographic regions.</td>
</tr>
<tr>
<td>SPROUT</td>
<td>Stump sprouting for appropriate species.</td>
</tr>
</tbody>
</table>

Existing trees increases (subroutine GROW). A discussion of each subroutine is given in table 2. For specified years, stand and species characteristics are printed out in tabular form (see Appendix 2).

Definitions of the constants, indices, and parameters are given in tables 3, 4, 5, and 6. The parameter values are appropriate for species in the Pacific Northwest and their sources are indicated in tables 7, 8 and 9.
### Table 3—Constants

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Definition</th>
<th>Units</th>
<th>Subroutines</th>
</tr>
</thead>
<tbody>
<tr>
<td>soilq</td>
<td>100000.0</td>
<td>Maximum biomass for forests in the area</td>
<td>kg/ha</td>
<td>GROW, MAIN</td>
</tr>
<tr>
<td>size</td>
<td>10.0</td>
<td>Mean d.b.h. of new trees</td>
<td>cm</td>
<td>SPROUT, BIRTH</td>
</tr>
<tr>
<td>PI2</td>
<td>6.283</td>
<td></td>
<td></td>
<td>GGNORD, GROW</td>
</tr>
<tr>
<td>phi</td>
<td>1.0</td>
<td>Proportion of annual light attenuation constant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tinc</td>
<td>.1</td>
<td>Minimum growth of d.b.h. per year to trigger mortality</td>
<td>cm</td>
<td>GROW</td>
</tr>
</tbody>
</table>

### Table 4—Indexes

<table>
<thead>
<tr>
<th>Index</th>
<th>Range</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>1 - NSPEC</td>
<td>Species of tree</td>
</tr>
<tr>
<td>j</td>
<td>1 - NTOT</td>
<td>Individual tree</td>
</tr>
<tr>
<td>KYR</td>
<td>1 - NYEAR</td>
<td>Model year</td>
</tr>
<tr>
<td>IPLOT</td>
<td>1 - total number of plots</td>
<td>Plot number</td>
</tr>
<tr>
<td>Name</td>
<td>Definition</td>
<td>Units</td>
</tr>
<tr>
<td>------</td>
<td>------------</td>
<td>-------</td>
</tr>
<tr>
<td>AAA(1,i)</td>
<td>Array of species names</td>
<td></td>
</tr>
<tr>
<td>A1[i]</td>
<td>Intercept for the foliage</td>
<td>kg</td>
</tr>
<tr>
<td>A2[i]</td>
<td>Intercept for stemwood</td>
<td>kg</td>
</tr>
<tr>
<td>AL2</td>
<td>Available light</td>
<td></td>
</tr>
<tr>
<td>AREA</td>
<td>Total leaf area</td>
<td>m²/m²</td>
</tr>
<tr>
<td>ATOT</td>
<td>Total number of trees in plot</td>
<td>t/ha</td>
</tr>
<tr>
<td>B0(i)</td>
<td>Slope for total foliage biomass</td>
<td></td>
</tr>
<tr>
<td>B1(i)</td>
<td>Slope for total stemwood biomass</td>
<td></td>
</tr>
<tr>
<td>B2(i)</td>
<td>Coefficient relating tree volume growth to leaf biomass</td>
<td></td>
</tr>
<tr>
<td>B3[i]</td>
<td>Height parameter</td>
<td></td>
</tr>
<tr>
<td>B4[i]</td>
<td>Exponential relating tree volume growth to leaf biomass</td>
<td></td>
</tr>
<tr>
<td>C[i]</td>
<td>Conversion from leaf area to tree area</td>
<td>m²/kg</td>
</tr>
<tr>
<td>DMAX1</td>
<td>Maximum number of growing days</td>
<td>days</td>
</tr>
<tr>
<td>DMAX2</td>
<td>Maximum diameter at breast height</td>
<td>cm</td>
</tr>
<tr>
<td>DBHMX</td>
<td>Geographic region</td>
<td></td>
</tr>
<tr>
<td>DBHND(i)</td>
<td>Diameter increment shading and competition</td>
<td>cm</td>
</tr>
<tr>
<td>FEB10</td>
<td>Total foliage biomass</td>
<td>kg</td>
</tr>
<tr>
<td>FRI</td>
<td>Fire intensity (DFT[1])</td>
<td>DN</td>
</tr>
<tr>
<td>HTT</td>
<td>Maximum height of species</td>
<td>dn</td>
</tr>
<tr>
<td>IHT</td>
<td>Tree height</td>
<td>dn</td>
</tr>
<tr>
<td>IMST</td>
<td>Decimeter height class for trees in geographic region IGED</td>
<td></td>
</tr>
<tr>
<td>IMGD</td>
<td>Geographic region IGED</td>
<td></td>
</tr>
<tr>
<td>ISL</td>
<td>Indicates species availability in geographic region</td>
<td></td>
</tr>
<tr>
<td>ISEL(i)</td>
<td>Summarizes whether species can occur in a region</td>
<td></td>
</tr>
<tr>
<td>ITC(i)</td>
<td>Indicates shade tolerance</td>
<td></td>
</tr>
<tr>
<td>M chiar(i)</td>
<td>Randomly chosen number of species to plant (0 to 8)</td>
<td></td>
</tr>
<tr>
<td>NDRDE(i)</td>
<td>Species code number</td>
<td></td>
</tr>
<tr>
<td>NTOT</td>
<td>Total number of trees in plot</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>Probability a tree survives a disturbance (wind or fire)</td>
<td></td>
</tr>
<tr>
<td>PR</td>
<td>Probability a tree species survives 1 year of slow growth</td>
<td></td>
</tr>
<tr>
<td>KSPRT</td>
<td>Randomly selected number of trees to sprout</td>
<td>t/ha</td>
</tr>
<tr>
<td>SBI(i)</td>
<td>Total foliage biomass and stem wood biomass (without bark) except for alder</td>
<td>m²/m²</td>
</tr>
<tr>
<td>SLAR</td>
<td>Shading leaf area, leaf above that of size (dn) of tree</td>
<td>m²/m²</td>
</tr>
<tr>
<td>SPNAM(i)</td>
<td>Alphanumeric species names being considered</td>
<td></td>
</tr>
<tr>
<td>SPRT</td>
<td>Minimum d.b.h. for sprouting to occur</td>
<td>cm</td>
</tr>
<tr>
<td>SPTREH</td>
<td>Maximum d.b.h. for sprouting</td>
<td>cm</td>
</tr>
<tr>
<td>SPTNDT</td>
<td>Average number of sprouts on death of main stem</td>
<td></td>
</tr>
<tr>
<td>SUML(i)</td>
<td>Sum of leaf area of trees in size class</td>
<td>m²/m²</td>
</tr>
<tr>
<td>WMIN(i)</td>
<td>Minimum value of water stress index W (i)</td>
<td>bars</td>
</tr>
<tr>
<td>WMIN(i)</td>
<td>Normal distribution</td>
<td></td>
</tr>
</tbody>
</table>

1Calculated parameters.
Table 6—Internal parameters

<table>
<thead>
<tr>
<th>Name</th>
<th>Definition</th>
<th>Subroutine</th>
</tr>
</thead>
<tbody>
<tr>
<td>KSPRT(j)</td>
<td>= -1 if sprouting occurs</td>
<td>KILL, SPROUT, INIT</td>
</tr>
<tr>
<td></td>
<td>= 1 if no sprouts</td>
<td></td>
</tr>
<tr>
<td>KLAST</td>
<td>= KTIMES, current iteration</td>
<td>MAIN</td>
</tr>
<tr>
<td>KYR</td>
<td>Current year (0 KYR NYEAR)</td>
<td>MAIN</td>
</tr>
<tr>
<td>NCT</td>
<td>Keeps track of number of years</td>
<td>MAIN</td>
</tr>
<tr>
<td>NCT</td>
<td>in the main program</td>
<td></td>
</tr>
<tr>
<td>KYRI</td>
<td>KYR = 1</td>
<td>MAIN, OUTPUT,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BIRTH</td>
</tr>
<tr>
<td>NG</td>
<td>Number of trees not growing</td>
<td>KILL, GROW</td>
</tr>
<tr>
<td>N1</td>
<td>NSPEC + 1</td>
<td>OUTPUT</td>
</tr>
<tr>
<td>N2</td>
<td>NSPEC + 2</td>
<td>OUTPUT, NSPC</td>
</tr>
<tr>
<td>NSPC</td>
<td>Species to sprout iteration</td>
<td>SPROUT</td>
</tr>
<tr>
<td>NUM</td>
<td>Species number (i = NUM = NSPEC)</td>
<td>INPUT</td>
</tr>
<tr>
<td>NSP</td>
<td>Randomly selected species to plant</td>
<td>BIRTH</td>
</tr>
<tr>
<td>NEW</td>
<td>Possible species to sprout</td>
<td>KILL, SPROUT</td>
</tr>
<tr>
<td>NEWTR</td>
<td>Species of possible new trees</td>
<td>KILL, GROW</td>
</tr>
<tr>
<td>NOGRO(i)</td>
<td>Equals 0 if tree is not growing</td>
<td>INIT, KILL, GROW</td>
</tr>
<tr>
<td>RANDOM</td>
<td>Random number</td>
<td></td>
</tr>
<tr>
<td>RAT</td>
<td>Random number which is fixed for year</td>
<td>BIRTH</td>
</tr>
<tr>
<td>ZNYR</td>
<td>KLAST</td>
<td>MAIN</td>
</tr>
</tbody>
</table>

1Those that keep track of processes in the FORTRAN program itself.

Table 7—Parameter values for CLIMACS

<table>
<thead>
<tr>
<th>Species</th>
<th>SPRTMN</th>
<th>SPRTMN</th>
<th>KTIME</th>
<th>A1</th>
<th>A2</th>
<th>BB</th>
<th>BC</th>
<th>C</th>
<th>MIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abies amabilis</td>
<td>0</td>
<td>0</td>
<td>9999</td>
<td>-3.5057</td>
<td>-4.5490</td>
<td>2.5744</td>
<td>2.1926</td>
<td>15.2000</td>
<td>18</td>
</tr>
<tr>
<td>Abies grandis</td>
<td>0</td>
<td>0</td>
<td>9999</td>
<td>-3.7389</td>
<td>-3.4660</td>
<td>2.6825</td>
<td>1.9278</td>
<td>13.1000</td>
<td>18</td>
</tr>
<tr>
<td>Abies lasiocarpa</td>
<td>0</td>
<td>0</td>
<td>9999</td>
<td>-3.7389</td>
<td>-3.4660</td>
<td>2.6825</td>
<td>1.9278</td>
<td>13.1000</td>
<td>18</td>
</tr>
<tr>
<td>Abies procera</td>
<td>0</td>
<td>0</td>
<td>9999</td>
<td>-3.7158</td>
<td>-4.8730</td>
<td>2.7992</td>
<td>2.1683</td>
<td>13.2000</td>
<td>18</td>
</tr>
<tr>
<td>Acer macrophyllum</td>
<td>10</td>
<td>50</td>
<td>9999</td>
<td>-3.4930</td>
<td>-3.7650</td>
<td>2.7230</td>
<td>1.6170</td>
<td>26.1000</td>
<td>18</td>
</tr>
<tr>
<td>Alnus rubra</td>
<td>10</td>
<td>75</td>
<td>9999</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>28.2000</td>
<td>8</td>
</tr>
<tr>
<td>Arbutus menziesi</td>
<td>10</td>
<td>120</td>
<td>9999</td>
<td>-3.7080</td>
<td>-3.1230</td>
<td>2.6580</td>
<td>1.6930</td>
<td>12.6000</td>
<td>30</td>
</tr>
<tr>
<td>Castanopsis chrysophylla</td>
<td>10</td>
<td>90</td>
<td>9999</td>
<td>-2.0927</td>
<td>-2.6170</td>
<td>2.1863</td>
<td>1.7824</td>
<td>17.7000</td>
<td>28</td>
</tr>
<tr>
<td>Chamaecyparis nootkatensis</td>
<td>0</td>
<td>0</td>
<td>9999</td>
<td>-2.0927</td>
<td>-2.6170</td>
<td>2.1863</td>
<td>1.7824</td>
<td>17.7000</td>
<td>27</td>
</tr>
<tr>
<td>Libocedrus decurrens</td>
<td>0</td>
<td>0</td>
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<td>17.4000</td>
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1SPRTMN = SPRTMN except for Alnus rubra which does not sprout from large trees.
2Waring and others (1979).
3Waring and others (1976), Waring (1969), and Waring, personal communication.
Table 8—Parameter values for moisture index

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<td>B2</td>
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<td>0.21</td>
<td>76.05</td>
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<td>0.78</td>
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Table 9—Parameter values for shade tolerance equation

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¹Values from Fowles (1965).
²Values from Franklin and Oren (1973), Fowles (1965), and Parro (1973).
³Adjusted form values given in Reed and Clark (1971) so that a given DHI increment is reasonable.
Subroutine BIRTH

The subroutine BIRTH is based on the FORET model of Shugart and West (1977) (figure 3 presents a flow chart for the routine). Species available for regeneration are selected depending on the existing water stress, temperature range, and geographic region of the plot.

Figure 3.—Flow chart for subroutine BIRTH.
Regeneration depends on the projected leaf area of any existing trees. During the first year any available species can regenerate. Thereafter if the projected leaf area is greater than 3 m²/m² (square meter of leaf area per square meter of ground), *Pinus contorta* Dougl. ex Loud., *P. ponderosa* Dougl. ex Laws., and *Quercus garryana* Dougl. ex Hook. cannot regenerate. If the projected leaf area is greater than 6 m²/m², then *Abies procera* Rehd., *Alnus rubra* Bong., *Arbutus menziesii* Pursh, *Castanopsis chrysophylla* (Dougl.) A. DC., *Picea engelmannii* Parry ex Engelm., and *Pseudotsuga menziesii* cannot appear in the plot. For a projected leaf area exceeding 8 m²/m² *Abies grandis* (Dougl. ex D. Don) Lindl., *A. lasiocarpa* (Hook.) Nutt., *Acer macrophyllum* Pursh, *Picea sitchensis* (Bong.) Carr., *Pinus lambertiana* Dougl., and *P. monticola* Dougl. ex D. Don cannot appear. If the projected leaf area exceeds 10 m²/m², *Libocedrus decurrens* Torr., *Chamaecyparis nootkatensis* (D. Don) Spach, *Thuja plicata* Donn ex D. Don, and *Tsuga mertensiana* (Bong.) Carr. cannot regenerate. At leaf areas exceeding 10 m²/m² only the most shade tolerant species, *Abies amabilis* Dougl. ex Forbes and *Tsuga heterophylla* (Raf.) Sarg., can regenerate. The trees appear in the plot when they are between 10 and 15 cm d.b.h. This limit on size is necessary because numbers of smaller seedlings become so large that computer time is prohibitive, and the abundance of very small seedlings may not reflect the composition of an understory that could replace large-canopy trees.

The projected leaf area (XLAI) (in m²/m²) is based on foliage biomass (FB10) of all trees on the plot. The equations for the foliage biomass of trees less than 50 cm (19.7 in) in diameter are from Binkely (1983) for *Ainus rubra* and from Gholz and others (1979) for all other species. Because the data range of Gholz' equations is exceeded for large trees (DBH > 50) (fig. 4), the equations for the foliage bio-

![Graph of foliage biomass vs diameter](image)

**Figure 4.**—Foliage biomass as related to diameter using the equations of Gholz and others (1979). A warning is given by Gholz and others (1979) that "maximum and minimum values from the data set...do not necessarily mean that the equation provides reasonable numbers at these extremes." Because of problems in exceeding the data ranges, the foliage biomass-d.b.h. relationship was modified using figure 5, as described in the text.
mass of large trees are calculated indirectly. The sapwood-diameter equation for *Pseudotsuga menziesii* has been obtained by regression analysis.\(^1\) Foliage biomass can then be calculated from the foliage biomass-sapwood area ratio (Grier and Waring 1974) (fig. 5). To estimate the foliage biomass for large trees of other species, a multiplier is calculated from the ratio of the foliage biomass at 50 cm diameter of the species being considered to that of *P. menziesii* at 50 cm diameter. The multiplier is used to adjust the foliage biomass equations from Gholz and others (1979) for trees larger than 50 cm.

\(^1\) Personal communication, R. H. Waring, School of Forestry, Oregon State University, Corvallis, Oregon.

![Figure 5.—Foliage biomass as related to diameter for *Pseudotsuga menziesii*.](image)
The equations are as follows:

\[
FBIO = \begin{cases} 
\exp[A_2(i) + BC(i) \ln DBH(k)] & DBH(k) \leq 50, \ i \neq 6 \\
3.2 + 1.89 \ln (DBH(k)) & DBH(k) \leq 50, \ i = 6 \\
[256 \times \ln (DBH(k)) - 639] \cdot 2.5 \cdot DRANGE(i)/C(16) & DBH(k) > 50 
\end{cases}
\]

where:

\[
i = 1,...,NSPEC \ (NSPEC = \text{total number of species}) \\
\quad (i = 6 = Alnus rubra), \\
i = 1,...,NTOT \ (NTOT = \text{total number of trees}), \\
A_2(i) = \text{parameters from Gholz and others (1979) (see table 7)}, \\
BC(i) = \text{diameter at breast height of tree } k \ (\text{cm}), \\
DBH(k) = \text{the ratio of the foliage biomass of species } i \text{ to that of } P. \text{ menziesii at } 50 \ \text{cm}, \text{ and} \\
DRANGE(i) = \text{conversion from kg to } m^2 \text{ for } P. \text{ menziesii.}
\]

To calculate the leaf area for each tree the foliage biomass is multiplied by the factor \(C(i)\) to convert from kg to \(m^2\) and is divided by 2.0 for deciduous trees and 2.5 for conifers to convert total leaf area to projected leaf area.\(^2\) The projected leaf areas are then summed for all trees and divided by the plot size (2000 \(m^2\)) to obtain a value for square meter of leaf area per square meter of ground surface:

\[
XLAI = \frac{\sum_{k=1}^{NTOT} C(i) FBIO/P(i)}{2000}
\]

where: \(P(i) = \begin{cases} 
2.0 \text{ if } i \text{ is a deciduous tree and} \\
2.5 \text{ if } i \text{ is a coniferous tree.}
\end{cases}\)

The projected leaf area of the plot is tested against the maximum leaf area at which available species can regenerate. If the projected leaf area is less than the species maximum, a random number of saplings (from 1 to 8) enters the plot. Each introduced sapling has a randomly selected diameter of 10 to 15 cm (3.9 to 5.9 in).

Sprouting may occur depending on tree size (subroutine SPROUT). Species that reproduce vegetatively in this manner are Acer macrophyllum, Alnus rubra, Castanopsis chrysophylla, Quercus garryana, and Arbutus menziesii.

BIRTH continues until the projected leaf area exceeds 1.0 \(m^2/m^2\) resulting in full stocking the first year of the model run.

\(^2\) Leaf area conversions from personal communication, R. H. Waring, School of Forestry, Oregon State University, Corvallis, Oregon, based on Grier and Waring (1974).
Subroutine GROW

Subroutine GROW calculates diameter increment for each tree (fig. 6). The annual diameter increment function is similar to that used by Botkin and others (1972), Shugart and West (1977), and Mielke and others (1978). CLIMACS is unique in that it incorporates a specific function for the effect of soil moisture upon growth. Diameter growth takes into account the following conditions:

1. Growth per year is dependent upon existing foliage biomass
2. Growth decreases as tree size increases
3. Temperature affects photosynthetic rate
4. Available moisture affects growth
5. Competition influences growth
6. Shading and shade tolerance affect growth.

Optimum Growth Per Year

The growth subroutine calculates the maximum growth of a species and modifies that optimal growth by size and site considerations. There is strong evidence that diameter growth is related to existing foliage biomass (Grier and Logan 1977). CLIMACS uses a nonlinear relationship between leaf biomass and growth: to calculate optimal diameter increment \( B_1(i) FBIO^{B_2(i)} \). The parameters for this relationship are adjusted from those of Reed and Clark (1979) to give reasonable diameter increments for trees 50 cm (19.7 in) in diameter.

Decreases in Growth Rate Related to Size

As a tree increases in size, an increasing portion of its photosynthetic output is used in respiration and not in producing additional tissue. The phenomenon of decreasing growth in large trees is represented by the following calculation from Botkin and others (1972):

\[
1 - \frac{DBH(j) HT(i)}{DBHMX(i) HMAX(i)};
\]

for species \( i \) and tree \( j \).

As a tree becomes very large, growth approaches zero. Maximum diameter and height were chosen for each species to represent large but not the largest trees of a species to avoid record-sized stands.

---

3. Symbols are defined in table 5 and parameter values given in table 7. Because growth is conditioned by the maximum diameter and height for the species, the maximum values determine the upper limit for tree growth. When using the data for record trees (Fowles 1965, Pardo 1973) the model always grows Site 1 trees. The current values for \( DBHMX(i) \) and \( HMAX(i) \) are for large but not the largest trees of a species (from Franklin and Dyrness 1973).
Set minimum growth limit, set available light constant

Reset suppression flags to 0, INITIALIZE leaf area sum and biomass sum

Calculate total stand, stem and foliage biomass

Calculate height leaf area profile by decimeter intervals

Next tree

Calculate growth moisture index (dry, intermediate, or wet)

Calculate tree height and shading of trees taller

Any trees?

Yes

No

Calculate foliage biomass of this tree

Calculate maximum, open-growth diameter increment F (DBHMX,FBIO,DBH)

Calculate reduced diameter increment for tolerant, intermediate, and intolerant species DNC F (DNC,AL)

Increment less than minimum set?

Yes

No

Increment DBH

Set suppression flag

Last tree?

Yes

No

Return
Table 10—Regression values for height as compared to diameter where
\[ HT = 137 + B_2 \text{DBH} + B_3 \text{DBH}^2 \]

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<th>( B_3 )</th>
<th>( R^2 )</th>
<th>( N )</th>
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<td>22.3 - 200.4</td>
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<td>-0.27</td>
<td>0.97</td>
<td>39</td>
<td>6.8 - 130.0</td>
</tr>
<tr>
<td>Abies procera</td>
<td>Stressed</td>
<td>68.29</td>
<td>-0.19</td>
<td>0.98</td>
<td>24</td>
<td>48.1 - 127.3</td>
</tr>
<tr>
<td>Abies amabilis</td>
<td>Nonstressed</td>
<td>85.60</td>
<td>-0.55</td>
<td>0.98</td>
<td>19</td>
<td>16.7 - 62.0</td>
</tr>
<tr>
<td>Tsuga mertensiana</td>
<td>Nonstressed</td>
<td>55.29</td>
<td>-0.07</td>
<td>0.98</td>
<td>23</td>
<td>32.2 - 84.2</td>
</tr>
<tr>
<td>Thuja plicata</td>
<td>Nonstressed</td>
<td>64.71</td>
<td>-0.23</td>
<td>0.98</td>
<td>38</td>
<td>6.2 - 157.9</td>
</tr>
</tbody>
</table>

*Data is from research stands in the H. J. Andrews Experimental Forest.

1/ Stressed trees are growing in a habitat where PMS < 15 or TGI > 60.

The height-diameter relationship used for some species is based on that used by Botkin and others (1972) and Mielke and others (1978). The parabolic equation follows from a discussion in Ker and Smith (1955). Height (HT) is a function of the diameter at breast height (DBH):

\[ HT(j) = 137 + B_2(i) \text{DBH}(j) - B_3(i) \text{DBH}(j)^2. \]

The constants \( B_2(i) \) and \( B_3(i) \) are chosen so that height is at a maximum and the rate of change of height with respect to diameter is zero \( (\text{dHT}(j)/\text{dDBH}(j) = 0) \) when \( \text{DBH}(j) \) is at a maximum:

\[ B_2(i) = \frac{2(\text{HMAX}(i) - 137)}{\text{DBHMX}(i)}, \quad \text{and} \]
\[ B_3(i) = \frac{\text{HMAX}(i) - 137}{\text{DBHMX}(i)^2}. \]

The rate of change in height decreases as the diameter increases. For Tsuga heterophylla, T. mertensiana, Thuja plicata, Pseudotsuga menziesii, Abies amabilis, and A. procera height was estimated directly from diameter using equations developed by regression analyses of diameter-height data from the H.J. Andrews Experimental Forest (Willamette National Forest, Oregon) (table 10). Sufficient data were not available to treat all species in this manner. Because height growth is related to habitat and Tsuga heterophylla and P. menziesii were sampled in a variety of habitats, regressions for these two species were also performed for temperature- or moisture-stressed stands (TGI > 60 or PMS < 15) and nonstressed stands. In stressed stands the height growth is less—particularly for large trees (fig. 7).
Figure 7.—Tree height as related to diameter for Tsuga heterophylla and Pseudotsuga menziesii for stressed and nonstressed stands from regression analysis.
Temperature

The effect of temperature on the photosynthetic rate is modeled with a parabolic equation that ranges from 0 to 1 (following Botkin and others 1972):

$$\text{TEGD} = \frac{4(TGI - DMIN(i)) (DMAX(i) - TGI)}{(DMAX(i) - DMIN(i))^2}$$

A value of 0 occurs for TGI less than the minimum degree days (DMIN(i)) or greater than the maximum degree days (DMAX(i)). Thus, this function reflects the temperature range in which a species can grow. The values for DMIN(i) and DMAX(i) are from Emmingham and Waring.4

Effects of Moisture

The inclusion of the moisture index (WATDEX) in the equation for diameter increment is necessary due to the major influence of available moisture on the growth of tree species in the Pacific Northwest (Franklin and Waring 1980). In this model the effect of available moisture on growth is represented by a beta function (following Reed and Clark 1979):

$$\text{WATDEX} = \beta(a,b,c,x) = \begin{cases} 
(x-a) (c-x)^v, & \text{for } x \in (a, c) \\
(b-a) (c-b), & \text{otherwise} 
\end{cases}$$

where: 
\(x = \) PMS,
\(c = \) WMIN(i) = the minimum value of water stress for a species (−bars),
\(a = \) the negative x-intercept,
\(b = \) the optimum PMS for growth (−bars), and
\(v = (c-b)/(b-a)\).

See table 11 for a list of the parameter values.

4 Personal communication, W. Emmingham and R. H. Waring, School of Forestry, Oregon State University, Corvallis, Oregon.
Table 11—Parameter values for moisture index

<table>
<thead>
<tr>
<th>Moisture</th>
<th>a</th>
<th>b</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>-10</td>
<td>5</td>
<td>Abies grandis, Arbutus menziesii, Acer macrophyllum, Castanopsis chrysophylla, Libocedrus decurrens, Pinus contorta, P. lambertiana, P. ponderosa, Pseudotsuga menziesii, Quercus garryana</td>
</tr>
<tr>
<td>Intermediate</td>
<td>-8</td>
<td>1</td>
<td>Abies amabilis, A. lasiocarpa, A. procera, Picea engelmannii, Pinus monticola, Thuja plicata, Tsuga heterophylla, T. mertensiana</td>
</tr>
<tr>
<td>Moist</td>
<td>-2</td>
<td>0</td>
<td>Alnus rubra, Chamaecyparis nootkatensis, Picea sitchensis</td>
</tr>
</tbody>
</table>

1 The parameters, a and b, are explained in the text.

According to the model, dry site species have a high value of WATDEX for most values of PMS (see fig. 8). Intermediate site species, such as Tsuga heterophylla, grow only at lower PMS values, and the wet site species, such as Picea sitchensis, have a positive value of WATDEX only at very low values of PMS.

Figure 8.—The effect of plant moisture stress upon diameter increment.
**Competition for Nutrients**

The crude expression for rooting space competition, which reflects competition for nutrients, is from JABOWA (Botkin and others 1972) and is dependent upon the total aboveground biomass (TBIO) and the maximum biomass a stand can support (SOILQ): 1 – TBIO/SOILQ. The total aboveground biomass (TBIO) is the sum of the foliage biomass and stemwood biomass. The equations for stemwood biomass are from Gholz and others (1979):

\[ SBIO = \begin{cases} 
0.02 + 2.09 \text{DBH}(j) - 0.0015 \text{DBH}(j)^2, & i = 6 \text{ (Alnus rubra)} \\
\exp(A_t(i) + BB(i) \ln \text{DBH}(j)), & i \neq 6 
\end{cases} \]

where \( A_t(i) \) and \( BB(i) \) are parameter values from Gholz and others (1972) (table 7). The data range for the Gholz equations for stemwood biomass does not include large trees. To assess the impact of this problem stemwood biomass was plotted against values from yield tables (MacLean and Berger 1976) (fig. 9). Modeled and measured biomass values for Calocedrus decurrens and Pinus ponderosa compare well, but the predicted curve for Pseudotsuga menziesii stemwood biomass is greater than measured biomass at large diameters. As there are no data available, evaluation of this discrepancy is not possible.

The maximum biomass for a site (SOILQ) is obtained from recorded values of natural stands similar to the habitat for which the model is being run. As TBIO approaches SOILQ from below, (1-TBIO/SOILQ) approaches 0, and diameter increment decreases. When TBIO exceeds SOILQ, (1-TBIO/SOILQ) becomes negative; no diameter increase occurs. The value for SOILQ should be chosen carefully because evaluation of the model output suggests that the stand biomass is strongly influenced by this value.

**Shade Tolerance**

Diameter growth is also related to the light a tree receives and its shade tolerance. The regulation of photosynthetic rate by available light is expressed as:

\[ 1 - \exp(-t_1(AL - t_2)) \]

where \( t_1 \) and \( t_2 \) are species specific parameters (see table 12). The available light a tree receives (AL) is based on the total foliage area of all trees in the plot that are taller than the tree being considered (fig. 10 illustrates how available light changes over time). The canopy is broken into tree height intervals by decimeters. The sum of the leaf areas of all trees in height classes greater than the one being considered is calculated and stored as the shading leaf area (SLAR). Available light is then found by using an equation modified from Botkin and others (1972) and Mielke and others (1978):

\[ AL = PHI \times \exp(-0.26 \text{SLAR}) \]

where \( PHI = 1.0 \) is the annual insolation (in appropriate units).
Figure 9.—The relationship of stemwood biomass to diameter for (A) *Calocedrus decurrens*, (B) *Pseudotsuga menziesii*, and (C) *Pinus ponderosa*. The curves are from Gholz and others (1979), and the line crossing the curve indicates the end of the data range. Circles are from volume tables in MacLean and Berger (1976) with solid circles being inside and open circles outside the range of sampled trees.
<table>
<thead>
<tr>
<th>$t_1$</th>
<th>$t_2$</th>
<th>Shade tolerance class based on Minore (1979)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.026</td>
<td>0.30</td>
<td>Quercus garryana, Pinus ponderosa, P. contorta</td>
</tr>
<tr>
<td>9.695</td>
<td>0.025</td>
<td>Acer macrophyllum, Alnus rubra, Castanopsis chrysophylla, Arbutus menziesii, Picea engelmannii, Abies procera</td>
</tr>
<tr>
<td>20.467</td>
<td>0.025</td>
<td>Abies grandis, A. lasiocarpa, Pinus lambertiana, P. monticola, P. sitchensis, Pseudotsuga menziesii,</td>
</tr>
<tr>
<td>32.846</td>
<td>0.025</td>
<td>Libocedrus decurrens, Chamaecyparis nootkatensis, Thuja plicata, T. mertensiana</td>
</tr>
<tr>
<td>40.0</td>
<td>0.025</td>
<td>Abies amabilis, Tsuga heterophylla</td>
</tr>
</tbody>
</table>

1The relative diameter growth is equal to (1-exp (-t, (AL-t_2))) for AL being the available light derived from the projected leaf area (m$^2$/m$^2$).
Figure 10.—The relationship of height to foliage biomass from a simulation model. The size of the arrow representing light is meant to depict the amount of light reaching the canopy at each level.
CLIMACS includes five curves that translate available light into photosynthetic capacity based on shade tolerance (fig. 11). *Pinus ponderosa* is the least tolerant of the Pacific Northwest species and cannot grow under a leaf area greater than 5 m²/m² (Minore 1979; Waring). Hardwoods, intolerant conifers, and tolerant conifers, respectively, represent increasing levels of shade tolerance (Minore 1979). In the model the greatest difference in these categories occurs at a projected leaf area of 8 m²/m².

The diameter increment equation is a multiplicative function of six factors:

\[
D_{INC} = \left( \frac{1 - \text{DBH}(j) \text{ HT}(j)}{\text{DBHMX}(i) \text{ HMAX}(i)} \right) \left( \frac{\text{DBH}(j) \text{ B}_1(i) \text{ F}_1(i)(1 - \text{TBIOSQLQ}) \text{TEGD}}{274 + 3\text{B}_2(i) \text{ DBH}(j)^2 - 4\text{B}_3(i) \text{ DBH}(j)^3} \right) 
\times (\text{WATDEX}) \times [1 - \exp(-a_1(\text{AL-a}_2))] ;
\]

where: \( j = 1, \ldots, \text{NTOT} \) = the tree number and \( i = 1, \ldots, \text{NSPEC} \) = the tree species code.

This assumes that optimum growth is modified by the effects of temperature, moisture availability, competition, and shade tolerance, all acting independently. A multiplicative function is the most common relationship used (Botkin and others 1972, Reed and Clark 1979, Shugart and West 1977) but can tend to underestimate growth if many factors are incorporated (Swartzman and Bentley 1979).

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3 Personal communication, R. H. Waring, School of Forestry, Oregon State University, Corvallis, Oregon.

Figure 11.—The effect of shade tolerance on diameter growth.
Subroutine KILL

Much of the existing literature on mortality predicts death of a tree based on its crown quality or vigor class (Graham 1980, Hamilton and Edwards 1976, Staebler 1953). Because we cannot identify crown features in the current model structure, individual tree mortality is based on diameter, the maximum diameter for the species, and the life history of the species (see fig. 12). A tree is subjected to KILL if

![Flow chart for subroutine KILL](image-url)
Table 13—Equations for slow growth-related mortality

<table>
<thead>
<tr>
<th>Successional status</th>
<th>Conditions</th>
<th>Probability of surviving 1 year</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-lived early seral</td>
<td>DBH &lt; 0.2DBHMX</td>
<td>0.8866 * 0.1029 DBH-1/DBHMX + 0.1029 DBH-1</td>
<td>Pinus ponderosa, Pseudotsuga menziesii</td>
</tr>
<tr>
<td></td>
<td>DBH &gt; 0.2DBHMX</td>
<td>0.9895</td>
<td></td>
</tr>
<tr>
<td>Short-lived early seral</td>
<td></td>
<td>0.628</td>
<td>Acer macrophyllum, Alnus rubra, Arbutus menziesii, Quercus garryana</td>
</tr>
<tr>
<td>Long-lived mid-seral</td>
<td>DBH &lt; 0.1 DBHMX</td>
<td>0.96496 * 0.01294 DBH-1/DBHMX + 0.01294 DBH-1</td>
<td>Thuja plicata, Picea engelmannii, P. Gloria, P. lambertiana, P. monticola</td>
</tr>
<tr>
<td></td>
<td>DBH &gt; 0.1 DBHMX</td>
<td>0.97556 * 0.02339 DBH-1/DBHMX + 0.02339 DBH-1</td>
<td></td>
</tr>
<tr>
<td>Long-lived mid-seral with increasing mortality</td>
<td>DBH &lt; 0.5 DBHMX</td>
<td>0.8866 * 0.1112 DBH-1/DBHMX + 0.1112 DBH-1</td>
<td>Abies grandis, P. engelmannii, P. Sitchensis, P. contorta, P. lambertiana, P. monticola</td>
</tr>
<tr>
<td></td>
<td>DBH &gt; 0.5 DBHMX</td>
<td>1.0538 * 0.1112 DBH-1/DBHMX + 0.1112 DBH-1</td>
<td></td>
</tr>
<tr>
<td>Late seral</td>
<td>DBH &lt; 0.1 DBHMX</td>
<td>0.9956 * 0.9935 DBH-1/DBHMX + 0.9935 DBH-1</td>
<td>Abies amabilis, Tsuga heterophylla, T. mertensiana</td>
</tr>
<tr>
<td></td>
<td>DBH &gt; 0.1 DBHMX</td>
<td>1.0053 * 0.0675 DBH-1/DBHMX + 0.0675 DBH-1</td>
<td></td>
</tr>
</tbody>
</table>

Compiled from McArdle and others (1949) and from unpublished data from a chronosequence of stands in the Cascade Range in Oregon and Washington (Ted Thomas, USFS, Forestry Sciences Laboratory, Corvallis).

Diameter growth is less than 1 mm (0.04 in) in any year. We classified tree species into five groups based on mortality pattern using data from a chronosequence of stands in the Cascade Range (table 13). Short-lived, early seral species have a constant survival probability of 0.628 for 1 year. For all other successional classes, mortality changes with the tree size (fig. 13). Long-lived, early seral species have increasing survival until 20 percent of the maximum diameter is reached, at which point the probability of dying becomes constant. Late seral species have an increasing probability of survival until 10 percent of the maximum diameter is attained; then the probability of surviving tapers off slowly. For long-lived, mid-seral species the probability of survival slowly increases as size increases. Long-lived, mid-seral species with increasing mortality have a peak of surviving at 50 percent of the maximum diameter; the probability of death increases on either side of this asymptote.
Subroutine DISTRB

The subroutine DISTRB models natural and human disturbances to the ecosystem. Fires are the most common natural disturbances to forests of the Pacific Northwest (Hemstrom 1979), and windthrows can cause localized disturbances. Clearcuttings are simulated on user-specified rotation bases with *Pseudotsuga menziesii* planted after the cut (other species could be planted). Each of these disturbances can be introduced at user-specified intervals and intensities (see subroutine INPUT, Appendix 1).

Because the BIRTH subroutine results in small trees (that is, the seedling stage is skipped), model year 1 is approximately stand year 30 (assuming a 10- to 15-cm (3.9- to 5.9-in) tree is found on a 30-year-old-stand). A disturbance should be thought of as occurring approximately 30 years in the past. Thus a disturbance interval of 100 years results in the disturbance occurring in model years 100, 200, 300, etc., or in stand years 130, 260, 390, etc.

Following an episodic disturbance, the species, the diameter, and the age of all trees killed can be printed out in tabular form and can be saved on a tape for further use (refer to Appendix 1, subroutine INPUT).
Fire

Fire is modeled as an event that causes a high proportion of death for young trees dependent upon the species' tolerance to fire (fig. 14). *Pseudotsuga menziesii, Pinus ponderosa, P. lambertiana, Picea sitchensis, Abies grandis, A. lasiocarpa, A. procera, and Quercus garryana* are the species most resistant to fires (Minore 1979; Franklin$^6$); and *Abies amabilis, Tsuga heterophylla,* and *T. mertensiana* usually don't survive fire.$^7$ The probability of a tree surviving a fire ($Pr$) is related to the intensity of the fire $Fl$ ($0 \leq Fl \leq 1$):

$$Pr = \begin{cases} 
\exp(-0.00255*DBH(j))*FI, & i = 2, 3, 4, 12, 14, 15, 16, 17 \\
\exp(-0.00053*DBH(j))*FI, & i = 5, 6, 7, 8, 9, 10, 11, 13, 18, 21 \\
0 & i = 1, 19, 20 
\end{cases}$$

Fire occurs at user-specified intervals. The present model probably works for severe fires that result in stand replacement but is inappropriate for the more frequent and less intense fires in forests dominated by *Quercus garryana* or *Pinus ponderosa.*

Windthrow

The equations for the probability of death of a tree by a catastrophic wind are based on data from Tar Creek in the Clackamas River drainage (see footnote 6). Individual *Pseudotsuga menziesii, Tsuga heterophylla,* and *Thuja plicata* that died as a result of wind between 1948 and 1958 were recorded. All species have an increasing probability of death from wind as size increases (fig. 15). Although large trees have a large surface area upon which the wind can act, smaller trees are frequently in the path of falling large trees. The equations in the model are dependent on size and are conditioned by species and size:

$$P = \begin{cases} 
(1.6 -\exp(-0.00255*DBH(j)))^*FI, & i = 11, 19, 20 \\
(1.9 -\exp(-0.00053*DBH(j)))^*FI, & i = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16, 17, 18, 21 
\end{cases}$$

Clearcuttings

A clearcutting is modeled as an event that occurs at user-specified rotation times and removes all of the trees. After all trees are removed from a plot, 198 trees per 0.20-ha (0.08-acre) plot of 10- to 15-cm (3.9- to 5.9-in) d.b.h. *Pseudotsuga menziesii* are introduced to mimic the normal planting prescription of 1,000 trees per hectare.

---

$^6$ Personal communication, J. F. Franklin, Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, Corvallis, Oregon.

$^7$ Personal communication, J. K. Agee, National Park Service Cooperative Park Studies unit, College of Forest Resources, University of Washington, Seattle, Washington.
$P = \exp(-0.00053 \, \text{DBH}) \times F_I$

Figure 14.—Probability of death of a tree following a fire for fire-tolerant and fire-intolerant species. *Abies amabilis*, *Tsuga heterophylla*, and *T. mertensiana* do not survive fires in the model. The intensity of the fire can be adjusted by the parameter $F_I$. The most severe fire is depicted ($F_I = 1$).
Figure 15.—Probability of death after a windstorm. Species in each tolerance class are listed in the text. The most severe storm is illustrated (FI = 1).
Biological support of the model is based on three criteria:

1. Scientific rationale of equations and parameter values,
2. Applicability of this model paradigm to at least five forest systems, and
3. Model output compared to data.

CLIMACS has been verified through evaluation of the model equations and parameter values as explained in this text. All relationships and values are based on current knowledge of the tree species of the Pacific Northwest. For large trees, little information exists on the height, stemwood biomass, and foliage biomass relationships to diameter. No studies have documented the change in temperature growth index, plant moisture stress, or leaf area as a stand develops.

The FORTRAN code for CLIMACS is based on models that have been applied to other regions. JABOWA (Botkin and others 1972) simulates forest succession in the northeast United States. Shugart and West (1977) used FORET, the predecessor of CLIMACS, to model the chestnut blight in the Appalachian forest of Tennessee. The FORET model has also been used to project the influence of air pollution on stand development (West and others 1980) and to successfully simulate forest development for a mixed pine-hardwood forest in Arkansas (Mielke and others 1978). Other models derived from the core paradigm have been useful in predicting forest changes in eucalyptus forests of Australia (Shugart and Noble 1981) and in a tropical forest (Doyle and others 1979). Weinstein (1982) examined the diameter increment of a version of FORET and found that the average increment overestimated the diameter changes of trees remeasured after a 13-year interval. This discrepancy was corrected when moisture stress and nutrient limitation were introduced to the model. Both of these factors are in the diameter increment equation in CLIMACS.

Simulations of forests in western Oregon compare well to existing stand structure (Hemstrom and Adams 1982). For xeric and mesic stands nearly 450 years old, CLIMACS projects a stand dominated by Pseudotsuga menziesii of a variety of size classes. Projected leaf area, basal area, and foliage biomass of the simulated stand are similar to those of the natural stand (see discussion in Hemstrom and Adams 1982). Differences between the natural and the simulated stand may be due largely to chance and the lack of disturbances in the model forest.

Other comparisons incorporate natural disturbances in the simulation. Projections of 750 years of stand development on the western Olympic Peninsula of Washington State in the aftermath of fire, windstorm, or clearcutting show the major role Pseudotsuga menziesii plays (Adams and others 1983). When these disturbances occur at various frequencies, each disturbance results in unique patterns of stand development (Dale and others 1984).
Sensitivity Analysis

A sensitivity analysis is a process to evaluate how sensitive model output is to variation in parameter values. By varying parameters singly and in combination (for those known to be correlated), the influence of the parameter values on model behavior can be assessed. A sensitivity analysis has not been performed on CLIMACS because of a lack of time and money, and we urge that such a study be carried out. In the documentation process, we have noted the sensitivity of the model to the value for the maximum biomass for the forest (SOILQ) and to maximum diameter for each species. The parameters affecting the diameter increment growth, in particular, should be examined carefully. Shugart and West (1979) report that FORET, a forerunner of CLIMACS, is particularly sensitive to plot size. Finn (1979) introduced a form factor to account for crown depth and shading of trees in JABOWA (Botkin and others 1972) and found little effect. Crown form may, nevertheless, affect the development of coniferous forests.

Areas for Improvement

As with any model, CLIMACS can be altered and improved to meet the objectives of the study for which it is being used. Three possible improvements to the model are: (1) altering the mortality curves, (2) changing the vertical structure of each tree, and (3) improving the competition function.

Mortality is a largely unexplored component of successional processes. The model can be used to ask questions about differences in mortality among species by altering the mortality curves (fig. 13) and treating the survival equations as hypotheses to be tested by simulations. A problem with such a simulation study is the lack of data for comparison with model output. Data on survival rates of tagged trees will be available for such a study from permanent plots established by the USDA Forest Service.

The vertical structure of each tree could be modified to more accurately depict the form of a species. This would allow analyses of the role of available habitat for birds and mammals as forests change over time. By correlating breeding habitat to vegetation structure, the probability of a breeding habitat existing under certain management regimes and natural successions could be assessed (for example, Smith and others 1979). These modifications would also allow further study of the impact of leaf area on growth.

The function that models competition for nutrients in the GROW subroutine is a crude approximation. The model applicability would improve by deletion of the parameter SOILQ and incorporation of nitrogen and phosphorus cycling. The problem in including nutrient cycling in the model is depicting an accurate representation but not requiring too many driving variables.

Acknowledgments

This research could not have been completed without the scientific advice, interest, and encouragement and unpublished data provided by Jerry Franklin. We appreciate technical assistance and discussions with Jim Agee, Paul Alaback, Bill Emmingham, Bob Harr, Mark Harmon, Tom Hinckley, Mark Klopsch, Joe Means, Ed Small, Gordie Swartzman, and Dick Waring. The research was supported by contract CX-900-0-E014 from Pacific Northwest Region, the National Park Service, U.S. Department of the Interior. This is Publication Number 2391 of the Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831.
Literature Cited


Appendix 1

Listing of Program CLIMACS

(0001) C FOREST
(0002) C
(0003) C 
(0004) C 
(0005) C 
(0006) C
(0007) C CONVERSION PROGRAMMERS: J. HOLT, M. RUST
(0008) C MILNE COMPUTER CENTER, OSU.
(0009) C
(0010) CGS
(0011) CGS All comments labeled "CGS" were done at the Center for Quantitative science at the University of Washington using the PRIME. To run the model on a CDC note these comments and make the appropriate changes.
(0012) CGS
(0013) CGS
(0014) CGS
(0015) CGS PROGRAM CONIFER (INPUT, OUTPUT, TAPE4, TAPE5=INPUT, TAPE6=OUTPUT, TAPE
(0016) CGS 1)
(0017) CGS (FILE DECLARATIONS BELOW)
(0018) CGS
(0019) CGS COMMON /FOREST/ NTREES(50), DBH(700), IAGE(1000), KSPRT(50), NEWTR(50)
(0020) CGS 1, SUMLA(1000), NEW(50), NCODE(700), ISEL(50)
(0021) CGS
(0022) CGS PRIME STORES 4 CHARACTERS PER REAL ( 1 REAL = 2 WORDS )
(0023) CGS
(0024) CGS CDC STORES 10 CHARACTERS PER WORD
(0025) CGS
(0026) CGS COMMON /PARAM/ AAA(B, 100), DMAX(50), DMIN(50), B3(50), B2(50), ITOL(50)
(0027) CGS 1, AGEMX(50), Q(50), SPRIND(50), SPRTMN(50), SPRTMX(50), KTIME(50), A1(50)
(0028) CGS 2, A2(50), BB(50), BC(50), C(50), WMIN(50), IREG(50, 4), DBHMX(50), B1(50),
(0029) CGS 3B4(50), HMAX(50), DRANGE(50)
(0030) CGS COMMON /CONST/ NSPEC, SOILG, PMS, TGI, TGI2, SD, IDEDG
(0031) CGS COMMON /DEAD/ NOQRD(700)
(0032) CGS COMMON /COUNT/ NTOT, NYEAR, IPERT, INT, IN, PMORT, FI
(0033) CGS COMMON /PASSX/ A(501, 25), FB(50)
(0034) CGS COMMON /SEED/ USEED(13)
(0035) CGS INTEGER USEED
(0036) CGS
(0037) CGS DIMENSION I(2), SPNAME(5, 40)
(0038) CGS
(0039) CGS GET SOURCE DEFINITIONS OF K*READ, K*WRIT (TO OPEN FILES)
(0040) CGS
(0041) CGS
(0042) CGS NOLIST /* SYS.COM>KEYS.F
(0043) CGS LIST
(0044) CGS
(0045) CGS
(0046) CGS DATA SPNAME / 200 * '--' /
(0047) CGS
(0048) CGS DATA NCT/0/
(0049) CGS
(0050) CGS INITIALIZE FILES
(0051) CGS
(0052) CGS CALL OPEN( 5, 'SUCDAT', 6, K*READ )
(0053) CGS CALL OPEN( 6, 'OUTPUT', 6, K*WRIT )
(0054) CGS CALL OPEN( 7, 'TAPE4', 5, K*WRIT ) /* UNIT 4 RESERVED ON PRIME
(0055) CGS CALL OPEN( 8, 'TAPE5', 5, K*WRIT )
(0056) CGS CALL OPEN( 9, 'TAPE6', 5, K*WRIT )
(0057) CGS
(0058) CGS
(0059) CGS ..... READ INPUT DATA, PARAMETERS, AND VARIABLES FROM TAPE5.
(0060) CGS

36
CALL INPUT

ASSIGN FIRST TEN CHARACTERS OF SPECIES NAME TO THE ARRAY USED BY THE PLOTTING PROGRAM.

DO 10 I=1,NSPEC
    CALL STRMOV( AAA(I,I), 1, 10, SPNAM(I,I), 11 )
10 CONTINUE

CALL RANSEE

PLOT SIZE IS ONE-FIFTH HECTARE.

SOILQ - THE MAXIMUM BIOMASS RECORDED FOR FORESTS IN THE AREA

THE MAXIMUM LIVE ABOVE-GROUND BIOMASS POSSIBLE IS

1000 TONS/HECTARE

SOILQ = 100000.

TGI - TEMPERATURE GROWTH INDEX

NSPEC - NUMBER OF SPECIES FOR SIMULATION

30 CONTINUE

CALL PLOTIN (IPLAN)

WRITE (6,40) IPLAN,NYEAR

40 FORMAT (/,'PLOT NUMBER ',I4,' TOTAL LENGTH OF RUN IS ',+ '15.6H YEARS/////////

Kyr = 0

CALL OUTPUT (Kyr,IPLOT)

DO 70 JJ=1,KTIMES

CALL INIT

DO 60 I=1,NYEAR

Kyr = I

NCT = NCT+1

IF(NCT.EQ.2) GO TO 42

CALL GGNORD(12,13,Z)

GO TO 44

Z(I) = Z(2)

NCT = 0

44 TGI=TGII+SD*Z(I)

TGI = TGI

CALL SELECT

CALL KILL (Kyr)

IF(IPERT.NE.0.AND.MOD(Kyr,INT).EQ.0) CALL DISTRB(Kyr)

IF(IPERT.NE.0.AND. Kyr.EQ.1) CALL DISTRB(Kyr)

CALL BIRTH (Kyr)

CALL OUTPUT (Kyr,IPLOT)
CALL PLTREE (Kyr, IPLOT)

CONTINUE

IF (IPLOT.NE.KLAST) GO TO 30

ZNYR = KLAST

DO 110 IV1=1, NYR1

TIMEX = IV1-1

WRITE (7,80) TIMEX

80 FORMAT (2E10.3)

DO 100 IV2=1, N3

A(IV1,IV2) = A(IV1,IV2)/ZNYR

WRITE (7,80) A(IV1,IV2)

CONTINUE

CONTINUE

WRITE INFORMATION NEEDED FOR THE PLOT TO FILE TAPE8.

TAPES MAY BE EXAMINED OR THE PLOT PROGRAM APLLOT MAY

BE RUN.

WRITE (6,120) NYEAR, NSPEC

WRITE (6,150) ((SPNAM(I,J), I=1,5), J=1, NSPEC)

NNY = NYEAR+1

DO 140 I=1, NNY

WRITE (6,130) (A(I,J), J=1, NSPEC)

CONTINUE

CALL EXIT

END
SUBROUTINE ADREG(KYR)

COMMON /FOREST/ NTREES(50), DBH(700), IAGE(1000), KSPRT(50), NEWTR(50)
1, SUMLA(1000), NEW(50), NCODE(700), ISEL(50)

CGS
COMMON /PARAM/ AAA(100, 3), DMAX(50), DMIN(50), B3(50), B2(50), ITOL(50)
COMMON /PARAM/ AAA(8, 100), DMAX(50), DMIN(50), B3(50), B2(50), ITOL(50)
1, AGEMX(50), G(50), SPRTND(50), SPRTMN(50), SPRTMX(50), KTIME(50), A1(50)
2, A2(50), BB(50), BC(50), C(50), WMIN(50), IREG(50, 4), DBHMX(50), B1(50),
3B4(50), HMAX(50), DRANOE(50)
COMMON /CONST/ NSPEC, SOILG, PMS, TQ1, TQ11, SD, IOEQG
COMMON /RAN/ YFL
COMMON /DEAD/ NOORD(700)
COMMON /COUNT/ NTOT, NYEAR
COMMON /SEED/ USEED(13)

INTEGER USEED

REAL LA

ADVANCE REGENERATION SUBROUTINE (ADREG) DIFFERS FROM GROW IN THAT

ONLY SHADE TOLERANT CONIFERS ARE ABLE TO GROW. THIS ROUTINE IS

CALLED AFTER WINDTHROWS

EACH TREE IS REQUIRED TO ADD A 1.0 MM GROWTH RING EACH YEAR

OTHERWISE THAT TREE IS SUBJECTED TO A POTENTIAL FOR SLOW-

GROWTH RELATED MORTALITY (SUBROUTINE KILL)

IF (NTOT.EQ.0) RETURN

TINC = .1

PHI = 1.

CALCULATE TOTAL NUMBER OF TREES

SUM LEAF AREA OF ALL TREES THAT ARE OF APPROXIMATELY

THE SAME HEIGHT

DO 10 I=1,700

10 NOQRO(I) = 0

DO 20 I=1,1000

20 SUMLA(I) = 0.

SBIO = 0.

IF (NTOT .GT. 700) CALL ERR

DO 50 K=1,NTOT

50 I = NCODE(K)

CALCULATE STAND BIOMASS, FOLIAGE BIOMASS IN KG, LEAF AREA

INDEX

LA IS THE LEAF AREA (SG. M) FOR PSME FROM SAPWOOD AREA

LA=(256.*ALOQ(DBH(K))-639.)*2.5

IF (I, NE. 6) GO TO 30

HT=137.+B2(6)*DBH(K)-B3(6)*DBH(K)**2

SBIO=SBIO+.02+.09*DBH(K)**2*(HT/100.)/100.-.0015*(DBH(K)**2*

HT/100.)**2

FBIO=3.2+1.89*ALOQ(DBH(K))

GO TO 31

SBIO = SBIO+EXP(A1(I)+BB(I)*ALOQ(DBH(K)))

FBIO=EXP(A2(I)+BC(I)*ALOQ(DBH(K)))

IF(DBH(K).GE.50.)FBIO=LA*(1/C(16))*.DRANGE(1)
(0060) 35  SBIO = SBIO*FBIO
(0061) C
(0062) C  HEIGHT PROFILE IS CALCULATED IN .1 METER UNITS
(0063) C
(0064)  40  HINT = (137+B2(I)*DBH(K)-B3(I)*DBH(K)**2)/10.AT10.
(0065)  IF (HINT.GT.1000) QD TO 150
(0066)  HINT=HINT
(0067)  IF(I.EQ.5. OR I.EQ.6. OR I.EQ.7. OR I.EQ.17. OR I.EQ.21)QD TO 45
(0068)  SUMLA(IHT) = SUMLA(IHT)+C(I)*FBIO/5000.
(0069)  QD TO 50
(0070)  45  SUMLA(IHT)=SUMLA(IHT) + C(I)*FBIO/4000.
(0071)  50 CONTINUE
(0072)  DO 60 J=1,999
(0073)  J1 = 1000-J
(0074)  SUMLA(J1) = SUMLA(J1)+SUMLA(J1+1)
(0075)  60 CONTINUE
(0076)  C
(0077)  C  CALCULATE AMOUNT OF GROWTH FOR EACH TREE
(0078)  C
(0079)  NO = 1
(0080)  DO 140 J=1,NDT
(0081)  I = NCODE(J)
(0082)  IF (ITOL(I).NE. 5) QD TO 140
(0083)  C
(0084)  C  CALCULATE MOISTURE - GROWTH INDEX.
(0085)  C
(0086)  100  QD TO (80,90,80,90,90,90,90,90,90,80,80,80,90,90,80,80,80
(0087)  1 ,80,90)
(0088)  C
(0089)  70  V = WMIN(I)/2.
(0090)    WATDEX = (PMS+2.)*(WMIN(I)-PMS)**V/(2.*WMIN(I)**V)
(0091)    QD TO 100
(0092)  C
(0093)  80  V = (WMIN(I)-1.)/9.
(0094)    WATDEX = (PMS+8.)*(WMIN(I)-PMS)**V/(9.*WMIN(I)-1.)**V
(0095)    QD TO 100
(0096)  C
(0097)  90  V = (WMIN(I)-5.)/15.
(0098)    WATDEX = (PMS+10.)*(WMIN(I)-PMS)**V/(15.*(WMIN(I)-5.)**V)
(0099)  100  HT = 137+B2(I)*DBH(J)-B3(I)*DBH(J)**2
(0100)  102 CONTINUE
(0101)  C
(0102)  104 CONTINUE
(0103)  SLAR = SUMLA(IHT)
(0104)  AL = PHI*EXP(-SLAR*.26)
(0105)  LA=(256. *ALOG(DBH(J))-.639.)*.2.5
(0106)  FBIO=EXP(A2(I)+BC(I)*ALOG(DBH(J))
(0107)  IF(I.EQ.6)FBIO=3.20+1.89*ALOG(DBH(J))
(0108)  IF(DBH(J).GE.50.)FBIO=LA*(1./C(16))**DRANGE(I)
(0109)  120  A = (1.-DBH(J)*HT)/(DBHM(I)+HMAX(I)))
(0110)  B= DBH(J)*B1(I)*FBIO**B4(I)
(0111)  CC = (274+3.*B2(I)*DBH(J)**2-4.*B3(I)*DBH(J)**3)
(0112)  D= (1.-SBIO/BOILG)*4
(0113)  TEOG = (TQI-DMIN(I))*(DMAX(I)-TQI)/(DMAX(I)-DMIN(I))**2
(0114)  DNC = (A + B/CC) * D * TEOG * WATDEX
(0115)  DINC = (1.-EXP(-32.846*(AL-0.025)))*DNC
(0116)  IF (DBH(J).LT. DBHM(I)) QD TO 121
(0117)  DINC = 0.0
(0118)  121 CONTINUE
C 0119) ..... CHECK INCREMENT LESS THAN 1.0 MM REQUIRED GROWTH
C 0120) ..... WRITE OUT DIAMETER INCREMENT FOR PSME
C 0121) IF (I .NE. 16) GO TO 125
C 0122) IF (DBH(J) .LE. 86. OR. DBH(J) .GT. 165.) GO TO 125
C 0123) WRITE (9,122) DINC,KYR
C 0124) 122 FORMAT (1X,F9.4,5X,I5)
C 0125) CONTINUE
C 0126) IF (DINC .GE. TINC) GO TO 130
C 0127) IF (DINC.LT.0.) DINC = 0.
C 0128) NOORDER(NO) = J
C 0129) NO = NO+1
C 0130) 130 DBH(J) = DBH(J)+DINC
C 0131) CONTINUE
C 0132) RETURN
C 0133) WRITE (6,160)
C 0134) 160 FORMAT (19H1 IHT EXCEEDED 1000)
C 0135) STOP
C 0136) END
SUBROUTINE BIRTH (Kyr)

COMMON /FOREST/ Ntrees(50), DBH(700), TAGE(1000), KSPRT(50), NEWT(50)

1. SUMLA(1000), NEW(50), NCODE(700), ISEL(50)

COMMON /PARAM/ AAA(8, 100), DMAX(50), DHMIN(50), B3(50), B2(50), ITOL(50)

1. AGEMX(50), G(50), SPRTND(50), SPRTMN(50), SPRTMX(50), KTIME(50), A1(50)

2. A2(50), BB(50), BC(50), C(50), WMIN(50), IREG(50, 4), DBHMX(50), B1(50),

DB4(50), HMAX(50), DRANGE(50)

COMMON /CONST/ NSPEC, SOILG, PMS, TQI, TQII, SD, IGEQG

COMMON /RAN/ YFL

COMMON /DEAD/ NDCRD(700)

COMMON /COUNT/ NTOT, NYEAR, IPERT, INT, IN, PMORT

COMMON /SEED/ USEED(13)

INTEGER USEED

REAL LA

C

SAPLINGS ENTER THE PLOT AT AVERAGE SIZE OF 10.0 CM DBH

IF (Kyr <= 20) GO TO 3

IF (NTOT GT 200. AND. MOD(Kyr, 10) .EQ. 0) GO TO 120

CONTINUE

3 SIZE = 10.0

SELECT A SPECIES FROM 1 TO 3 TIMES

ADD UP NUMBER OF ABAM AND TSHE OF SIZE 10 TO 20 CM SO THAT

A RESTRICTION CAN BE PUT ON THE NUMBER OF BIRTHS.

NABAM = 0

NTSHE = 0

DO 9 K = 1, NTOT

KK = NCODE(K)

IF (KK NE 1) GO TO 5

IF (DBH(K) .GE. 20. OR. DBH(K) .LT. 10.) GO TO 5

NABAM = NABAM + 1

CONTINUE

5 CONTINUE

IF (KK NE 19) GO TO 8

IF (DBH(K) .GE. 20. OR. DBH(K) .LT. 10.) GO TO 8

NTSHE = NTSHE + 1

CONTINUE

8 CONTINUE

9 CONTINUE

NPLANT = 3 * RANF(6) + 1.

DO 100 JK = 1, NPLANT

FBIO = 0.

100 CONTINUE

CALCULATE BIOMASS (LEAF MABS) FOR EACH SPECIES

IF (NTOT .EQ. 0) GO TO 40

DO 30 K = 1, NTOT

KK = NCODE(K)

LA = (256.0 + ALQO (DBH(K))) / 639.

IF (KK .EQ. 5. OR. KK .EQ. 7. OR. KK .EQ. 17. OR. KK .EQ. 21) GO TO 25

FBIO = EXP (A2(KK) + BC(KK) * ALQO (DBH(K))) * C(KK) / 2.5 + FBIO

IF (DBH(K) .GE. 50.) FBIO = FBIO + LA * DRANGE(KK) / 2.5

GO TO 30

FBIO = FBIO + EXP (A2(KK) + BC(KK) * ALQO (DBH(K))) * C(KK) / 2.0

IF (DBH(K) .GE. 50.) FBIO = FBIO + LA * DRANGE(KK) / 2.0

CONTINUE

FBIO = 0.

DO 70 J=1, NSPEC

IF (J.EQ.1 .AND. NABAM.GT. 200) GO TO 70
IF (J.EQ.19 .AND. NTSHE.GT. 100) GO TO 70
IF (ISEL(J).NE.1) GO TO 70
IF (XLAI.LT.3.) GO TO 60
GO TO (50, 50, 50, 50, 70, 50, 50, 50, 70, 50, 50, 50, 70, 50, 50, 70, 50, 50, 70)
IF (J.EQ.19 .AND. NTSHE.GT. 100) GO TO 70
GO TO (54, 54, 54, 54, 70, 54, 54, 54, 70, 54, 54, 54, 70, 54, 54, 54, 70, 54, 70, 70, 54, 54, 54, 70, 54, 54, 54, 70, 54, 54, 54, 70, 54, 54, 54, 70)
IF (ISEL(J).NE.1) GO TO 70
IF (XLAI.LT.8.) GO TO 60
GO TO (58, 70, 70, 58, 70, 58, 70, 70, 58, 70, 70, 58, 70, 70, 58, 70, 70, 58)
DO 80 J=1, NSPEC
NEWTR(NW) = J
NW = NW+1
CONTINUE
JOIN
C
CHECK TO SEE IF THERE ARE ANY NEW TREES
JOIN
C
CALCULATE AGE AND DIAMETER FOR NEW TREES
JOIN
C
DETERMINE THE NUMBER OF SEEDLINGS TO PLANT 0 TO 8
JOIN
C
MPLANT = RANF(9)*8.
JOIN
C
SELECT SEEDLINGS (PARTICULAR SPECIES)
JOIN
C
NW = NW+RANF(10)+1.0
NSP = NEWTR(NW)
JOIN
C
PLANT RANDOM NUMBER OF SEEDLINGS
JOIN
DO 90 J=1, MPLANT
NTOT = NTOT+1
IF (NTOT.GT.700) CALL ERR
IAOE(NTOT) = 0
NCODE(NTOT) = NSP
JOIN
CALCULATE DBH FOR SEEDLINGS
JOIN
DBH(NTOT) = SIZE*(1.0-RANF(11))**3
NTREES(NSP) = NTREES(NSP)+1
CONTINUE
JOIN
BIRTH CONTINUED UNTIL LAI .GE. 1.
JOIN
JOIN
IF (XLAI.LT.1.) GO TO 10
CONTINUE
JOIN
INCREMENT AGES
JOIN
DO 110 I=1, NTOT
IAOE(I) = IAOE(I)+1
CONTINUE
JOIN
RETURN
JOIN
END
SUBROUTINE DISTRBI(KYR)

COMMON /FOREST/ NTREES(50), DBH(700), IAGE(1000), KSPRT(50),
1 NEWTR(50), SUMA(1000), NEW(50), NCODE(700), ISEL(50)

COMMON /PARAM/ AAB(5,100), DMAX(50), DMIN(50), B3(50), B2(50), ITOL(50)
1 AGEMX(50), G(50), SPRTND(50), SPRTMN(50), SPRTMX(50), KTIME(50), A1(50)
2, A2(50), BB(50), BC(50), C(50), WMIN(50), IREG(50,4), DBMX(50), B1(50),
3B4(50), HMAX(50), DRANGE(50)

COMMON /CONST/ NSPEC, SD1G, PMS, TQ1, TQ1I, SD, IGEOO

COMMON /COUNT/ NTDT, NYEAR, IPERT, INT, IN, PMORT, FI

INTEGER USEED

IF (IPERT.EQ.0) RETURN
IF (IPERT.EQ.1) WRITE(6,16) INT
IF (IPERT.EQ.2) WRITE(6,17) INT
IF (IPERT.EQ.3) WRITE(6,18) INT

FORMAT (1H0,11H FIRE EVERY, 15.6H YEARS)

FORMAT (1H0,17H WINDSTORMS EVERY, 15.6H YEARS)

FORMAT (1H0,17H CLEARCUTS ON, 15.9H ROTATION)

IF(IPERT .NE. 1) GO TO 65

C

C

DD 60 K=1, NTGT

I=NCODE(K)

P=0.0

IF (I.NE.17 OR I.NE.12 OR I.NE.14 OR I.NE.16 OR I.NE.8) GO TO 30

C

C

FIRE TOLERANT SPECIES HAVE THE FOLLOWING PROBABILITY

OF DYING IN A FIRE

C

C

P=(EXP(-.00255*DBH(K)))*FI

GO TO 40

C

C

GO TO 40

C

C

WRITE (9,45) NCODE(K), DBH(K), KYR

CONTINUE

GO TO 50

C

C

CONTINUE

GO TO 98

C

C

CONTINUE

GO TO 79

C

C

GO TO 79

C

C

DO 80 K =1, NTGT

I=NCODE(K)

IF (I.EQ.16 OR I.EQ.13 OR I.EQ.12)

GO TO 70

C

C

GO TO 74

C

C

P = (15 - .001 * DBH(K))

C

C

GO TO 79

C

C

GO TO 79
C 70 IF (DBH(K) .GT. 100.) GO TO 72
(0061) C 72 P = .13 - .001 * DBH(K)
(0062) C 74 IF (DBH(K) .GT. 100.) GO TO 78
(0063) C 78 P = .30 - .02 * DBH(K)
(0064) C 79 IF (DBH(K) .GT. 100.) GO TO 80
(0065) C 80 CONTINUE
(0066) C 89 CONTINUE
(0067) C 90 CONTINUE
(0068) C 98 IF (IPERT .NE. 3) GO TO 110
(0069) C 100 NTOT-K1
(0070) C 104 DBH(K)=1
(0071) C 105 CONTINUE
(0072) C 148 K1=0
(0073) C 150 K1=1
(0074) C 154 DBH(K1)=DBH(K)
(0075) C 158 IAQ(K1)=IAQ(K)
(0076) C 162 NCODE(K1)=NCODE(K)
(0077) CATASTROPHIC WIND
(0078) DO 96 K=1,NTOT
(0079) C 96 CONTINUE
(0080) I = NCODE(K)
(0081) IF (I.EQ.11 .OR. I.EQ.19 .OR. I.EQ.20) GO TO 92
(0082) WRITE(6,91) DBH(K),K
(0083) FORMAT ( F10.3,I5 )
(0084) P=(1-(EXP(-.00255*DBH(K)))+.6)*FI
(0085) GO TO 94
(0086) P=(1-(EXP(-.00053*DBH(K)))+.9)*FI
(0087) IF(RANF(3) .GT. P) GO TO 96
(0088) 1 KSPRT(I)=1
(0089) IF(PMORT .NE. 9) GO TO 95
(0090) WRITE (9,45) NCODE(K),DBH(K),Kyr
(0091) CONTINUE
(0092) DBH(K)=1
(0093) CONTINUE
(0094) IF (IPERT .NE. 3) GO TO 110
(0095) C 96 CONTINUE
(0096) C 98 CLEARCUTS
(0097) C 100 NTOT-K1
(0098) DO 100 K=1,NTOT
(0099) NCODE(K)=NCODE(K)-1
(0100) IF (PMORT .NE. 9) GO TO 99
(0101) WRITE (9,45) NCODE(K),DBH(K),Kyr
(0102) CONTINUE
(0103) DBH(K)=1
(0104) CONTINUE
(0105) 100 CONTINUE
(0106) 110 CONTINUE
(0107) 148 K1=0
(0108) DO 150 K=1,NTOT
(0109) IF(DBH(K) .LT. O.) GO TO 150
(0110) K1=K1+1
(0111) DBH(K1)=DBH(K)
(0112) IAQ(K1)=IAQ(K)
(0113) NCODE(K1)=NCODE(K)
(0114) 150 CONTINUE
(0115) 160 CONTINUE
(0116) NTOT=K1
(0117) IF (IPERT .NE. 3) GO TO 180
(0118) C AFTER CLEARCUT PLANT PSEUDOTSUGA MENZIESII (OTHER SPECIES COULD BE
PLANTED BY MAKING CHANGES IN THE "170" LOOP

DO 170 J = 1, 50
   NTOT = NTOT + 1
   IA0E(NTOT) = 0
   NC0DE(NTOT) = 16
   DBH(NTOT) = 10. + 5. *(1.0-RANF(11))**3
   NTREES(16) = NTREES(16) + 1
170 CONTINUE

INCORRECT YEAR COUNT BY 30 TO MAKE UP LOSS SINCE THESE TREES
WERE INTRODUCED AT 10 CM DBH AFTER THE CLEARCUT.

KVR = KVR + 30

CAUSE ADVANCE REGENERATION BY CALLING SUBROUTINE ADREG AFTER WIND

IF (IPERT .NE. 2) GO TO 200

180 DO 190 IT = 1, 3
190 CONTINUE

200 CONTINUE

SINCE TREES ARE INTRODUCED AT 10 CM DBH, LET MODEL GROW TREES
FOR 30 YEARS TO MAKE UP LAG IN GROWTH.

IF (IPERT .NE. 1 .OR. IPERT .NE. 2) GO TO 220

DO 210 I = 1, 30
210 KVR = KVR + 1
220 CONTINUE

RETURN

SUBROUTINE ERR
WRITE (6, 10)
10 FORMAT (37H1 THE NUMBER OF TREES HAS EXCEEDED 800)
STOP
END

SUBROUTINE QGQRD (NSEED1, NSEED2, Z)
DIMENSION Z(1)
DATA PI2/0.62831853E01/
K = 0
A1 = RANF(NSEED1)
A2 = RANF(NSEED2)
K = K + 1
Z(K) = SQRT(-2E01*ALOG(A1))*SIN(PI2*A2)
K = K + 1
Z(K) = SQRT(-0.2E01*ALOG(A1))*COS(PI2*A2)
RETURN
END
SUBROUTINE GROW(KYR)
COMMON /FOREST/ NNTREES(50), DBH(700), IAQE(1000), KBSPRT(50), NEWTR(50)
COMMON /LONG/ SMLA(1000), NEW(50), NCODE(50), ISEL(50)
COMMON /PARA/ AAA(100,3), DMAX(50), DMIN(50), B3(50), B2(50), ITOL(50)
COMMON /PARA/ AAA(8,100), DMAX(50), DMIN(50), B3(50), B2(50), ITOL(50)
COMMON /AAEMX(50), Q(50), SPRTND(50), SPRTMN(50), SPRTMX(50), KTIME(50), AI(50)
COMMON /AAEMX(50), Q(50), SPRTND(50), SPRTMN(50), SPRTMX(50), KTIME(50), AI(50)
COMMON /AAEMX/ 2, A2(50), BB(50), B(50), C(50), WMIN(50), IREQ(50,4), DBHM(50), B1(50),
COMMON /AAEMX/ 3B4(50), HMAX(50), DRANGE(50)
COMMON /CONST/ NSPEC, SOILQ, PMS, TQ1, TQ2, SD, IQEDG
COMMON /RAN/ YFL
COMMON /DEAD/ NDORD(700)
COMMON /COUNT/ NTOT, NYEAR
COMMON /SEED/ USEED(13)
INTEGER USEED
REAL LA
C
C EACH TREE IS REQUIRED TO ADD A 1.0 MM GROWTH RING EACH YEAR
C OTHERWISE THAT TREE IS SUBJECT TO A POTENTIAL FOR SLOW-
C GROWTH RELATED MORTALITY (SUBROUTINE KILL)
C
IF (NTOT.EQ.0) RETURN
TINC = .1
PHI = 1.
C
C CALCULATE TOTAL NUMBER OF TREES
C
C
C SUM LEAF AREA OF ALL TREES THAT ARE OF APPROXIMATELY
C THE SAME HEIGHT
C
DO 10 I=1,700
10 NDROG(I) = 0
DO 20 I=1,1000
20 SMLA(I) = 0.
SBIO = 0.
IF (NTOT .GT. 700) CALL ERR
DO 30 K=1,NTOT
I = NCODE(K)
C
C CALCULATE STAND BIOMASS, FOLIAGE BIOMASS IN KG, LEAF AREA
C INDEX
C
C LA IS THE LEAF AREA (SQ. M) FOR PSME FROM SAPWOOD AREA
C LA=(256.*ALOG(DBH(K))-639.)*2.5
IF (I.NE.6) GO TO 30
HT=137. +B2(6)*DBH(K)-B3(6)*DBH(K)**2
SBIO=SBIO+.02+.2.09*DBH(K)**2/(HT/100.)/100.-.0015*(DBH(K)**2-
1 HT/100.)*
FBIO=3.2+.89*ALOG(DBH(K))
GO TO 31
30 SBIO = SBIO+EXP(A2(I)+B(1)*ALOG(DBH(K))
FBIO=EXP(A2(I)+B(1)*ALOG(DBH(K))
31 IF(DBH(K).GE.50.)FBIO=LA*(1/C(16))*DRANGE(I)
35 SBIO = SBIO+FBIO
C
C HEIGHT PROFILE IS CALCULATED IN .1 METER UNITS
C
HIHT = (137+B2(I)*DBH(K)-B3(I)*DBH(K)**2)/10.+1.
(0060) IF (HIHT GT 1000) GO TO 150
(0061) 
(0062) IHT=IHT
(0063) IF (I. EQ. 5. OR I. EQ. 6. OR I. EQ. 7. OR I. EQ. 17. OR I. EQ. 21) GO TO 45
(0064) 
(0065) SUMLA(IHT) = SUMLA(IHT) + C(I) * F50/5000.
(0066) 
(0067) GO TO 50
(0068) 
(0069) 45 SUMLA(IHT) = SUMLA(IHT) + C(I) * F50/4000.
(0070) 50 CONTINUE
(0071) DD 60 J=1,999
(0072) J1 = 1000-J
(0073) SUMLA(J1) = SUMLA(J1) + SUMLA(J1+1)
(0074) 
(0075) C ..... CALCULATE AMOUNT OF GROWTH FOR EACH TREE
(0076) 
(0077) C ..... CALCULATE MOISTURE - GROWTH INDEX.
(0078) 
(0079) C ..... 
(0080) GO TO (80,90,80,90,70,90,90,70,90,90,70,90,80,90,80,90,70,90,80,80,1)
(0081) 
(0082) C ..... MOIST SITE SPECIES
(0083) 
(0084) WRITE (6,72) I, WMIN(I), V
(0085) 
(0086) FORMAT (6H I = , I3,6H WMIN = , F6.2, 6H V = , F6.2)
(0087) 
(0088) WRITE (6,73) WATDEX
(0089) 
(0090) C ..... INTERMEDIATE SITE SPECIES
(0091) 
(0092) WATDEX = (PSM+8.)*(WMIN(I)-PMS)**V/(9.* (WMIN(I)-1.)**V)
(0093) 
(0094) C ..... DRY SITE SPECIES
(0095) 
(0096) WATDEX = (PSM+10.)*(WMIN(I)-PMS)**V/(15.* (WMIN(I)-5.)**V)
(0097) 
(0098) 100 HT = 137+B2(I)*DBH(J)-B3(I)*DBH(J)**2
(0099) 
(0100) 102 CONTINUE
(0101) 
(0102) IHT = HT/10.+2.
(0103) 
(0104) 104 CONTINUE
(0105) 
(0106) SLAR = SUMLA(IHT)
(0107) 
(0108) AL = PHI*EXP(-SLAR*.26)
(0109) 
(0110) LA=(256.*ALOG(DBH(J))-639.)*2.5
(0111) 
(0112) FBIO=EXP(A2(I)+BC(I)*ALOG(DBH(J)))
(0113) 
(0114) IF (I. EQ. 6.) FBIO=3.20+1. B9=ALOG(DBH(J))
(0115) 
(0116) IF (DBH(J).EQ.50.) FBIO=LA*(1./C(16))*DRANGE(I)
(0117) 
(0118) A = (1.-DBH(J)*HT)/(DBHMX(I)*HMAX(I))
(0119) 
(0120) B= DBH(J)*B1(I)*FBIO**B4(I)
(0121) 
(0122) CC = (274.3*B2(I)*DBH(J)**2-4.*B3(I)*DBH(J)**3)
(0123) 
(0124) D = (1.-SBI/SOIL%)**4
(0125) 
(0126) TEGD = (TGI-DMIN(I))*(DMAX(I)-TGI)/(DMAX(I)-DMIN(I))**2
(0127) 
(0128) DNC = (A * B / CC) * D * TEGD * WATDEX
(0129) 
(0130) C ..... CHECK FOR PS CURVE TYPE - PONDEROSA PINE
(0131) 
(0132) IF (ITOL(I).EQ.1) DNC = (1.0-EXP(-20.467*(AL-0.025)))*DNC
(0133) 
(0134) C .....
IF (ITOL(I).EQ.1 .AND. AL.LT.0.3) DINC=0.

C CHECK FOR PS CURVE TYPE - HARDWOODS

IF (ITOL(I).EQ.2) DINC = (1.0-EXP(-9.695*(AL-0.025)))*DNC

C CHECK FOR PS CURVE TYPE - TOLERANT CONIFERS

IF (ITOL(I).EQ.4) DINC = (1.-EXP(-32.846*(AL-0.025)))*DNC

IF (DBH(J).LT.DBHMX(I)) GO TO 121

DINC = 0.0

121 CONTINUE

C CHECK INCREMENT LESS THAN 1.0 MM REQUIRED GROWTH

C WRITE OUT DIAMETER INCREMENT FOR PSME

IF (I.NE.16) GO TO 125

IF (DBH(J).LE.86 .OR. DBH(J).GT.165.) GO TO 125

IF (PMLRT.NE.2) GO TO 125

WRITE (9,122) DINC,KYR

122 FORMAT (1X,F9.4,5X,15)

125 CONTINUE

IF (DINC.GE.TINC) GO TO 130

IF (DINC.LT.0. ) DINC = 0.

NOGRD(NO) = J

NG = NG+1

130 DBH(J) = DBH(J)+DINC

140 CONTINUE

RETURN

150 WRITE (6,160)

160 FORMAT (19H1 IHT EXCEEDED 1000)

STOP

END

SUBROUTINE INIT

COMMON /FOREST/ NTREES(50),DBH(700),IAGE(1000),KSPRT(50),NEWTR(50)

COMMON /DEAD/ N0GR0(700)

DO 10 I=1,NSPEC

NOGRD(I) = 0

KSPRT(I) = 1

10 CONTINUE

DO 20 I=NSPE1,1,700

NOGRD(I) = 0

20 CONTINUE

CQS RND IS THE RANDOM NUMBER GENERATOR ON THE PRIME

CALL R=RND(1)

RETURN

END

49
(0001) SUBROUTINE INPUT
(0002) COMMON /PARAM/ AAA(B. 100), DMAX(50), DMIN(50), B3(50), B2(50), ITOL(50)
(0003) 1, AGEX(50), Q(50), SPTRD(50), SPRTMN(50), SPRTMX(50), KTIME(50), A1(50)
(0004) 2, A2(50), B3(50), BC(50), C(50), WMIN(50), IREQ(50, 4), DBHMX(50), B1(50),
(0005) 3B4(50), HMAX(50), DRANGE(50)
(0006) COMMON /CONST/ NSPEC, SOILQ, PMS, TQJ, TQII, SD, IGEQ
(0007) COMMON /COUNT/ NTOT, NYEAR, IPERT, INT, IN, PMORT, FI
(0008) DIMENSION NSELCT(50)
(0009) READ (5, 10) NSPECT, (NSELCT(I), I=1, NSPECT)
(0010) 10 FORMAT (4012)
(0011) READ (5, 20) TQII, SD, PMS, IGEQ, NYEAR, IPERT, INT, PMORT, IN
(0012) 20 FORMAT (F5. 1, 2F3. 0, I1, 5I4)
(0013) C
(0014) C NYEAR=LENGTH OF THE MODEL RUN IN YEARS
(0015) C IPERT=DISTURBANCE TYPE
(0016) 0 NONE
(0017) 1 FIRE
(0018) 2 WINDTHROW
(0019) 3 CLEARCUT
(0020) C INT=INTERVAL OF DISTURBANCE IN YEARS
(0021) C PMORT - IF EQUAL TO
(0022) 2 = PRINT OUT DIAMETER INCREMENT OF DOUGLAS FIR ON YEARLY BASIS
(0023) 7 = PRINT OUT STAND STRUCTURE AT YEAR 700 FOR INPUT INTO NEXT
(0024) RUN OF THE MODEL
(0025) 9 = PRINT OUT MORTALITY INFORMATION: SPECIES, DBH AND YEAR DIED
(0026) FOR INPUT INTO DECAY MODEL - SEE GRAHAM. R. 1982. PH. D. THESIS
(0027) AT OREGON STATE UNIVERSITY. P. 112.
(0028) C
(0029) C IN=READ IN STAND STRUCTURE IF NOT 0
(0030) = NUMBER OF TREES TO BE READ IN (THE DATA IS AT THE END OF THE
(0031) FILE SUCDAT)
(0032) C
(0033) C
(0034) C
(0035) 25 FORMAT (F5. 2)
(0036) C FI= FIRE OR WIND INTENSITY (0<FI<1)
(0037) C
(0038) C
(0039) DO 40 J=1, NSPECT
(0040) READ (5, 30) AAA(I, J), I=1, 5), DMAX(J), DMIN(J), B3(J), B2(J), ITOL(J
(0041) 1 AGEX(J), SPTRD(J), SPRTMN(J), SPRTMX(J), KTIME(J), NUM(A1(J), A2
(0042) 2 (J), B5(J), BC(J), C(J), WMIN(J), IREQ(J, I), I=1, 4), DBHMX(J), B1(J),
(0043) 3 HMAX(J), B4(J), DRANGE(J)
(0044) 30 FORMAT (5A4, 6X, F4.0, 1X, 2F4. 0, F5. 0, I1, F4.0, 7X, F2.0, 2F4. 0, I4, 3X, 12/
(0045) 1F7. 4, F6. 3, F7. 4, F6. 4, 1X, F4. 1, F3. 0, 411/F4. 0, F5. 0, F5. 0, F3. 1, F6. 3)
(0046) 40 CONTINUE
(0047) C
(0048) C FOR "NONSTRESSED" SITES USE HEIGHT PARAMETERS DERIVED FROM
(0049) C REGRESSION ANALYSIS.
(0050) C
(0051) C
(0052) IF(TQII . GT. 60. 0 . AND. PMS . LT. 15.) GO TO 45
(0053) B2(19)=72. 34
(0054) B3(16)=0. 22
(0055) B2(19)=75. 97
(0056) B3(19)=0. 27
(0057) 45 CONTINUE
(0058) WRITE (6, 50)
(0059) 50 FORMAT (1H1, 1H , 6X, 7HSPECIES, 11X, 11HHEIGHT PAR A,
DO 70 I=1,NSPEC
    WRITE (6,60) I, (AAA(J,I), J=1,5), DMAX(I), DMIN(I), B3(I), B2(I),
    1 ITOL(I), AQEMX(I), SPRTND(I)
60 FORMAT (1H, 12, 1X, 5A4, 2X, F4.0, 3X, F4.0, 1X, F5.2, 1X, F6.2, 3X, 12, 3X,
    1F5.0, 4X, F3.0)
70 CONTINUE
DO 80 I=1, NSPEC
    WRITE (6,80) I, (AAA(J,I), J=1,5), DMAX(I), DMIN(I), B3(I), B2(I),
    1 ITOL(I), AQEMX(I), SPRTND(I)
80 FORMAT (1H, 6X, 7HSPRTMN, 2X, 6HSPRTMX, 2X, 5HKTIME, 16X, 2HA1, 7X, 2HA2, 7X, 2HBB, 7X, 2HBC, 7X, 1HC, 6X, 4HWMIN/)
100 CONTINUE
DO 100 I=1,NSPEC
    WRITE (6,90) I, (AAA(J,I), J=1,5), SPRTMN(I), SPRTMX(I), KTIME(I), A1
    1 (I), A2(I), BB(I), BC(I), C(I), WMIN(I)
90 FORMAT (1H, 12, 1X, 5A4, 2X, F4.0, 4X, F4.0, 2X, 16, 6(2X, F7.4))
100 CONTINUE
DO 110 I=1, NSPEC
    WRITE (6,110) I, (AAA(J,I), J=1,5), DMAX(I), DMIN(I), SPRTND(I)
110 FORMAT (1H1, 1H, 6X, 7HSPRTMN, 16X, 4HIRE0, 6X, 5HDBHMX, 6X, 2HB1, 6X,
    14HMAX, 8X, 2HB4, 8X, 6HDRANGE, 1/28X, 1H1, 2X, 1H2, 2X, 1H3, 2X, 1H4/)  
130 CONTINUE
DO 130 I=1, NSPEC
    WRITE (6,120) I, (AAA(J,I), J=1,5), (IREQ(I,J), J=1,4), DBHMX(I), B1
    1 (I), HMAX(I), B4(I), DRANGE(I)
120 FORMAT (1H, 12, 1X, 5A4, 2X, 4I3, 3X, F5.0, 3(2X, F8.1), 2X, F8.3)
130 CONTINUE
RETURN
END
SUBROUTINE KILL (Kyr)

COMMON /FOREST/ NTREES(50), DBH(700), IAGE(1000), KSPRT(50), NEWTR(50)

1. SUMLA(1000), NEW(50), NCOD(700), IBER(50)

COMMON /PARAM/ AAA(5, 100), DMAX(50), DMN(50), B3(50), B2(50), ITOL(50)

1. AGEMX(50), B(50), SPRTND(50), SPRTMN(50), KTIME(50), A1(50)

2. A2(50), BB(50), BC(50), C(50), WMIN(50), IREQ(50, 4), DBHMX(50), B1(50)

3B4(50), HMAX(50), DRANGE(50)

COMMON /CONST/ NSPEC, SOILG, PM, TOI, TOII, SD, IGE00

COMMON /DEAD/ NOORO(700)

COMMON /COUNT/ NTOT, NYEAR, IPMRT, INT, INPMT

COMMON /SEED/ USEED(13)

INTEGER USEED

IF (NTOT.EQ.0) RETURN

NG = 1

10 CONTINUE

C 1... SUPPRESSION MORTALITY

IS DEPENDENT UPON SPECIES AND SIZE OF TREE

C

IF (PMORT .NE. 9. AND. Kyr .NE. 1) GO TO 15

WRITE (9, 12)

12 FORMAT (3X, '3H -1, 10X, 39H DATA FOR DEAD TREES = SPECIES DBH YEAR')

CONTINUE

20 DO 130 K = 1, NTOT

130 I = NCOD(K)

C 1... CHECK FOR SUPPRESSION

IF (NOORO(NG).NE.K) GO TO 130

NG = NG + 1

C 1... SELECT MORTALITY TYPES

131 QD (100, 80, 80, 50, 50, 50, 50, 60, 60, 80, 80, 80, 30, 80, 30, 50, 60).

C 1 100, 100, 50, 50, 50

30 IF (DBH(K) GT 0.2 * DBHMX(I)) QD TO 40

C 1... LONG-LIVED EARLY SERAL SPECIES.

P = 0.8664 + 0.1294/DBHMX(I) + (DBH(K) - 1) / DBHMX(I)

IF (RANF(2).LT.P) GO TO 130

QD TO 120

40 IF (RANF(2).LT.0.995) QD TO 130

QD TO 120

C 1... SHORT-LIVED EARLY SERAL SPECIES.

50 IF (RANF(2).LT.0.628) QD TO 130

QD TO 120

C 1... LONG-LIVED MID SERAL SPECIES.

60 IF (DBH(K).GT.0.1 * DBHMX(I)) QD TO 70

P = 0.96496 + 0.01294/(DBHMX(I)) + (DBH(K) - 1.0) / DBHMX(I)

IF (RANF(2).LT.P) QD TO 130

QD TO 120

70 P = 0.97556 + 0.02339 * DBH(K)/DBHMX(I)

IF (RANF(2).LT.P) QD TO 130

QD TO 120

C 1... LONG-LIVED MID SERAL SPECIES. INCREASING MORTALITY.

80 IF (DBH(K).GT.0.5*DBHMX(I)) QD TO 90

P = 0.8664 + 0.0112/(DBHMX(I)) + (DBH(K) - 1.0) / DBHMX(I)

IF (RANF(2).LT.P) QD TO 130

QD TO 120

QD TO 120

C 1... LATE SERAL SPECIES.

90 P = 1.0338 - 0.1112 * DBH(K)/DBHMX(I)

IF (RANF(2).LT.P) QD TO 130

QD TO 120

C
(0060) 100 IF (DBH(K).GT.0.1*DBHMX(I)) GO TO 110
(0061) P = 0.9956+0.00335/(0.1-1./DBHMX(I))*(DBH(K)-1.)/DBHMX(I)
(0062) IF (RANF(2).LT.P) GO TO 130
(0063) GO TO 120
(0064) 110 P = 1.0053-0.0635*DBH(K)/DBHMX(I)
(0065) IF (RANF(2).LT.P) GO TO 130
(0066) 120 CONTINUE
(0067) NTREES(I) = NTREES(I)-1
(0068) C
(0069) C  . . . . . . . . . . . . CHECK TO SEE IF DEAD TREE CAN STUMP SPROUT. SET KSPRT = -1
(0070) C  . . . . . . . . . . . . IF TREE CAN SPROUT
(0071) C  . . . . . . . . . . . . IF (DBH(K).GT.SPRTMN(I).AND.DBH(K).LT.SPRTMX(I)) KSPRT(I) = -1
(0072) IF (PMORT .NE. 9) GO TO 126
(0073) 125 FORMAT (3X,13.F6,2,14)
(0074) WRITE (9,125) NCODE(K),DBH(K),KYR
(0075) 126 CONTINUE
(0076) 127 DBH(K) = -1.0
(0077) 130 CONTINUE
(0078) C
(0079) C  . . . . . . . . . . . . REWRITE DIAMETERS AND AGES TO ELIMINATE DEAD TREES
(0080) C
(0081) C
(0082) 140 K = 0
(0083) DO 150 I=1,NTOT
(0084) IF (DBH(I).LT.0.) GO TO 150
(0085) K = K+1
(0086) DBH(K) = DBH(I)
(0087) IAGE(K) = IAGE(I)
(0088) NCODE(K) = NCODE(I)
(0089) 150 CONTINUE
(0090) NTOT = K
(0091) 160 CONTINUE
(0092) RETURN
(0093) END
SUBROUTINE OUTPUT (KYR, IPILOT)

COMMON /FOREST/ NTREES(50), DBH(700), IAOE(1000), KSPRT(50), NEWTR(50)

DIMENSION BAR(50)

REAL LA

KYR1 = KYR+1

AREA = 0.0

TBAR = 0.0

TDBAR = 0.0

DD 10 I=1, NSPEC

FB(I) = 0.

A(KYR1, I) = 0.

BAR(I) = 0.

A(KYR1, 22) = 0.

A(KYR1, 23) = 0.

A(KYR1, 24) = 0.

A(KYR1, 25) = 0.

IF (NTOT EQ. 0) GO TO 50

DO 40 J=1, NSPEC

I = NCODE(J)

IF (I .NE. 6) GO TO 20

HT1=137. +B2(6)*DBH(J)-B3(6)*DBH(J)**2

BAR(I) = BAR(I)+0.02+2.09*(HT/100.)*DBH(J)-0.0015*(HT/100.)*

1 DBH(J)**2

FB1=0.32+1.89*ALOG(DBH(J))

QO TO 30

20 BAR(I) = BAR(I)+EXP(A1(I)+BB(I)*ALOG(DBH(J)))

LA= (256. *ALOG(DBH(J)))-639.)*2.5

FB10=EXP(A2(I)+BC(I)*ALOG(DBH(J)))

IF (DBH(J), GE. 50.) FB10=LA*(1/C(16))*DRANGE(I)

30 BAR(I) = BAR(I)+FB10

A(KYR1, 25) = A(KYR1, 25)+FB10*.005

FB1=FB1+FB10*.005

QO TO (32, 32, 32, 32, 34, 34, 32, 32, 32, 32, 32, 32, 32, 32, 32, 34,

1 32, 32, 32, 32, 32, 34).

AREA=AREA + FB10*C(I)/2.5

QO TO 40

AREA=AREA + FB10*C(I)/2.0

40 CONTINUE

50 CONTINUE

DD 60 I=1, NSPEC

60 TBAR = TBAR+BAR(I)

TBAR = TBAR*0.005

DO 70 IV1=1, NSPEC

A(KYR1, IV1) = A(KYR1, IV1)+BAR(IV1)*0.005

70 CONTINUE

ATOT = NTOT

N1 = NSPEC+1

N2 = N1+1

N3 = N2+1

A(KYR1, N1) = A(KYR1, N1)+TBAR

C TYR(KYR1) = TBAR
SUBROUTINE PLOTIN (IPL0T)

COMMON /FOREST/ NTREES(50), DBH(700), IAGE(1000), KSPRT(50), NEWTR(50)
COMMON /SUMLA(1000), NEW(50), NCODE(700), ISEL(50)
COMMON /CONST/ NSPEC, SOILQ, PMS, TQI, TQII, SD, IGEOG
COMMON /COUNT/ NTOT, NYEAR, IPERT, INT, IN, PMORT

C ........ INITIALIZE VARIABLES TO START SIMULATION ON BARE PLOT
C ........ NTREES CONTAINS NUMBER OF TREES FOR EACH SPECIES
C ........ DBH CONTAINS DIAMETER AT BREAST HEIGHT FOR EACH TREE
C ........ KSPRT IS USED TO FLAG THE TREES THAT CAN SPROUT
C ........ AREA CONTAINS THE LOCATION OF EACH TREE
C ........ NOGRO IS USED TO FLAG THE TREES THAT DON'T GROW
C ........ IAGE CONTAINS THE AGE FOR EACH TREE

IPL0T = IPL0T + 1
NTOT = IN
DO 10 I = 1, NSPEC
   IAGE(I) = 0
   NTREES(I) = 0
10 CONTINUE
NSPE1 = NSPEC + 1
DO 20 I = NSPE1, 700
   IAGE(I) = 0
20 CONTINUE
IF (IN .NE. 0) GO TO 80
READ IN TREE SIZES AND SPECIES
READ DATA AT END OF DATA FILE SUCDAT
IF (IN .EQ. 0) GO TO 80
READ IN THE NUMBER OF TREES OF EACH SPECIES
READ (5, 25) (NTREES(I), I = 1, NSPEC)
FORMAT (2113)
READ (5, 30) (NCODE(K), DBH(K), K = 1, IN)
FORMAT (7(13, 1X, F6.2, 7X))
CONTINUE
WRITE (6, 60) NTOT
FORMAT (8H NTOT = , I5)
WRITE (6, 70) (NCODE(K), DBH(K), K = 1, IN)
FORMAT (1X, 7(15, F6.2))
CONTINUE
RETURN
END
SUBROUTINE PLTREE (Kyr, Iplot)

COMMON /PARAM/ A(KYR, 100)

COMMON /FOREST/ NTREES(50), DBH(700), IA, GE(1000), KSPRT(50), NEWTR(50)

COMMON /COUNT/ NTOT, NYEAR, IPERT, INT, IN, PMORT

COMMON /PASS/ A(501, 25), FB(50)

COMMON /CONST/ NSPEC, SOILG, PMS, TQI, TQII, SD, IGEQG

COMMON /FOREST/ NTREES(50), DBH(700), IA, GE(1000), KSPRT(50), NEWTR(50)

COMMON /COUNT/ NTOT, NYEAR, IPERT, INT, IN, PMORT

COMMON /PASS/ A(501, 25), FB(50)

COMMON /CONST/ NSPEC, SOILG, PMS, TQI, TQII, SD, IGEQG

DIMENSION D(25, 20)

DATA PI/0. 314159265E01/

Kyr1 = Kyr + 1

DO 5 K = 1, NTOT

5 CONTINUE

BAREA = (BAREA + 5.) / 10000.

PRINT OUT TABLE FOR LAST YEAR

IF (NYEAR.EQ. Kyr) GO TO 9

WRITE ONTO TAPE5 STAND INFORMATION TO BE USED IN APLLOT:

YEAR, STAND BIOMASS, LEAF AREA, STAND BASAL AREA, &

BIOMASS FOR ABIES AMABILIS, PSEUDOTSUCA MENZIESII & TSUGA

METEOPHYLLA

RECORDED FOR EVERY OTHER YEAR ONTO TAPE5

IF (MOD(Kyr, 2). NE. 0) GO TO 100

WRITE (8, B) Kyr, A(Kyr1, 22), A(Kyr1, 24), BAREA,

1 A(Kyr, 1), A(Kyr, 16), A(Kyr, 19)

FORMAT (7(E10. 3,2X))

ONLY WRITE OUT TABLE EVERY 50 YEARS

OR FOR FIRST 5 YEARS

IF (Kyr.LE. 5) GO TO 9

IF (MOD(Kyr, 50). NE. 0) GO TO 100

WRITE (6, 10) Kyr, Iplot, TQI, PMS

10 FORMAT (1H1, 4HYEAR, 16, 2X, 11HPLLOT NUMBER, 16, 4X, 6HTQI = , F6. 1, 4X,

16HPMS = , F6. 1, 4X, 18HGEOGRAPHIC REGION;

16DBH = , F6. 1, 4X, 18HGEOGRAPHIC REGION;

GO TO (12, 14, 16, 18), IGEQG

WRITE (6, 13)

12 FORMAT (1H+, T86, 22H SOUTH OF SANTIAM PASS)

13 FORMAT (1H+, T86, 22H SOUTH OF SANTIAM PASS)

14 WRITE (6, 15)

15 FORMAT (1H+, T86, 28H SANTIAM PASS TO MT. RAINIER)

16 WRITE (6, 17)

17 FORMAT (1H+, T86, 22H MT. RAINIER TO CANADA)

18 WRITE (6, 19)

19 FORMAT (1H+, T86, 18H OLYMPIC PENINSULA)

129H (W/O BARK) TONS PER HECTARE=F10. 5.

22 FORMAT (1H+, 45H TOTAL FOLIAGE BIOMASS PLUS STEM WOOD BIOMASS

312H AREA INDEX=F10. 5)

2/2X, 38H TOTAL NUMBER OF TREES PER 1/5 H PLOT=F6. 1, 6X, 4HLEAF

WRITE (6, 10) BAREA, A(Kyr1, 25)

27 FORMAT (1H0, 18H THE BASAL AREA IS, F10. 2, 14H SQ. M/HECTARE, 6X, 18H
145H TOTAL FOLIAGE BIOMASS (INCLUDES PETIOLES) IS, F8.3//

C

CALCULATE THE NUMBER OF TREES IN EACH DIAMETER CLASS (FOR EVERY 10 CM). FIRST INITIALIZE D(I,J) TO ZERO.

DO 31 I=1, NSPEC
   DO 31 J=1, 20
      D(I,J)=0.0
   31 CONTINUE

KTOT=A(KYR,23)
DO 46 K=1, NTOT
   I=NCODE(K)
   DC=DBH(K)/10.
   IF (DC .GT. 20.) WRITE (6,35) DC
   35 FORMAT (5H DC-, F8.2)
   IDC=IFIX(DC)
   IF(IDC .GE. 16) IDC=16
   D(I,IDC)=D(I,IDC) +1.
   46 CONTINUE
WRITE (6,47)
47 FORMAT (1H0, 6X, 7HSPECIES, 13X, 7H NUMBER, 2X, 6H ABOVE, 1X, +8H FOLIAGE,
       120X, 26H NUMBER PER DIAMETER CLASS, 24X, 9H OF TREES, 1X,
       27H GROUND, 2X,
       38H BIOMASS, 1X, 40H 10 20 30 40 50 60 70 80 90 100
       48H 110 120
       51H 130 140 150 160+/34X, 8H BIOMASS
       61X, 35H -20 -30 -40 -50 -60 -70 -80 -90 -100
       72H-110-120-130-140-150-160 )
DO 49 I=1, NSPEC
   WRITE (6,48) I, (AAA(J,I), J=1, 5), NTREES(I), A(KYR,I), FB(I),
   1(D(I,J), J=1,16)
   48 FORMAT (1H , I2, 1X, 5A4 , 2X, I6, 2X,F6.2, 2X,F6.2, 4X,16(F4.0))
   49 CONTINUE
WRITE (6,50)
50 FORMAT ( ///)
WRITE (6,65)
65 FORMAT (1H0, 41HSPECIES CODES, DIAMETERS, AND AGES FOLLOW)
WRITE (6,70) (NCODE(K), DBH(K), IAGE(K), K=1, NTOT)
70 FORMAT (1H0, 7(I3,1X,F6.2,1X,I4,2H--)/(1H0,7(I3,1X,F6.2,1X,I4,2H--)
          1))
100 CONTINUE
101
FOR PMORT=7, PRINT OUT STAND STRUCTURE AT TIME 700 FOR INPUT TO NEXT RUN OF CLIMACS
IF (PMORT .NE. 7) GO TO 120
IF (KYR .NE. 700) GO TO 120
WRITE (9, 110) (NCODE(K), DBH(K), K=1, NTOT)
110 FORMAT (7(I3,1X,F6.2,7X))
120 CONTINUE
111
RETURN
112
END
FUNCTION RANDOM (NSEED)
COMMON /SEED/ USEED(13)
INTEGER USEED
ISEED = USEED(NSEED)*100.
DUM = RND(ISEED)
RANDOM = RND(0)
RETURN
END

SUBROUTINE RANSEE
COMMON /SEED/ USEED(13)
INTEGER USEED
DUM = RND(1)
DO 10 I = 1, 13
10 USEED(I) = RND(0)
RETURN
END

REAL*4 FUNCTION RANF( IDUM )
C UNIFORM RANDOM NUMBER GENERATOR
RANF = RND(0)
RETURN
END

SUBROUTINE SELECT
COMMON /FOREST/ NTREES(50), DBH(700), IAGE(1000), KSPRT(50), NEWTR(50)
1, SUMLA(1000), NEW(50), NC0DE(700), ISEL(50)
COMMON /PARAM/ A0EMX(50), A0MNX(50), DMIN(50), B3(50), B2(50), ITOL(50)
1, A0EMXH(50), Q(50), SPRTND(50), SPRTMN(50), SPRTMX(50), KTIME(50), A1(50)
2, A2(50), BB(50), BC(50), C(50), WMIN(50), IREG(50, 4), DBHMX(50), B1(50),
DB4(50), HMAX(50), DRANGE(50)
COMMON /CONST/ NSPEC, SOILG, PMS, TQI, TQII, SD, IQEOO
DO 10 I=1, NSPEC
ISEL(I) = 0
C CHECK MAXIMUM WATER STRESS.
10 IF (WMIN(I).LT.PMS) GO TO 10
C CHECK TEMPERATURE REQUIREMENTS.
10 IF (TQI.LT.DMIN(I).OR.TQI.GT.DMAX(I)) GO TO 10
C CHECK SPECIES DISTRIBUTIONS.
C REGION 1 = SOUTH OF SANTIAM PASS.
C REGION 2 = SANTIAM PASS TO MT. RAINIER NP
C REGION 3 = MT. RAINIER NP TO CANADIAN BOARDER.
C REGION 4 = OLYMPIC NP.
10 IF (IREG(I,IQEOO).NE.1) GO TO 10
ISEL(I) = 1
10 CONTINUE
RETURN
END
SUBROUTINE SPROUT

COMMON /FOREST/ NTREES(50), DBH(700), IAGE(1000), KSPRT(50), NEWTR(50)
1, SUMLA(1000), NEW(50), NCODE(700), ISEL(50)
COMMON /PARAM/ AAA(8,100), DMAX(50), DMIN(50), B3(50), B2(50), ITOL(50)
1, AGEMX(50), G(50), SPROTN(50), SPROTM(50), KTIME(50), A1(50)
COMMON /DEAD/ NOOR0(700)
COMMON /COUNT/ NTOT, NYEAR, IPERT, INT, IN, PMORT
COMMON /SEED/ USEED(13)
COMMON /DEAD/ NOOR0(700)
COMMON /SEED/ USEED(13)
INTEOER USEED
SMALLEST AVERAGE STUMP SPROUT IS .1 CM
SIZE = .1
SUM TOTAL NUMBER OF TREES

DETERMINE WHICH SPECIES CAN SPROUT

NW = 0
DO 10 I=1,NSPEC
  IF (SPRTND(I).LE.0.) GO TO 10
  IF (KSPRT(I).GE.0.) GO TO 10
  NW = NW+1
  NEW(NW) = I
10 CONTINUE

CHECK FOR SPROUTS

IF (NW.EQ.0.) GO TO 30

CHOOSE RANDOM NUMBER OF SPROUTS

NW = NW*RANF(3)+1.0

SELECT SPECIES TO SPROUT

NSPC = NEW(NW)

SPRTND IS THE TENDENCY FOR THE ITH SPECIES TO STUMP OR ROOT SPROUT. THE VALUE OF SPRTND IS THE AVERAGE NUMBER OF SPROUTS THAT MIGHT OCCUR WITH A TREE DEATH

RANDOMLY SELECT NUMBER OF TREES TO SPROUT

NSPRT = RANF(4)*SPRTND(NSPC)+1
DO 20 I=1,NSPRT
NTREES(NSPC) = NTREES(NSPC)+1
NTOT = NTOT+1
20 IF (NTOT.GT.700) CALL ERR
IAGE(NTOT) = 0
NCODE(NTOT) = NSPC
DBH(NTOT) = SIZE+.1*(1.0-RANF(5))**3
STORE DIAMETERS AND AGES FOR NEW SPROUTS

SUM TOTAL NUMBER OF TREES DETERMINE WHICH SPECIES CAN SPROUT NW = 0 NW = NW+1 I = 1, NSPEC I = 1, NSPRT
Appendix 2

Tabular Output of Program CLIMACCS

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of trees</th>
<th>Above-ground biomass</th>
<th>Foliage biomass</th>
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<tr>
<td>Abies amabilis</td>
<td>243</td>
<td>27.16</td>
<td>3.13</td>
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<tr>
<td>Abies grandis</td>
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<td>Abies lasiocarpa</td>
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<td>Abies procera</td>
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<td>Acer macrophyllum</td>
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<td>Alnus rubra</td>
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<td>Arbutus menziesii</td>
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<td>Castanopsis chrysophylla</td>
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<td>Chamaecyparis nootkatensis</td>
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<td>Libocedrus decurrens</td>
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<td>Picea engelmannii</td>
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<td>Pinus contorta</td>
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<td>Pinus lambertiana</td>
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<td>Pseudotsuga menziesii</td>
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<td>Quercus garryana</td>
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<td>Tsuga heterophylla</td>
<td>293</td>
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<td>Tsuga mertensiana</td>
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Number per diameter class

| Diameter Class | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160+
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Year: 450  Plot Number: 1  TG1 = 76.0  PMS = 13.0  Geographic region: Olympic Peninsula  
Total foliage biomass plus stemwood biomass (without bark) tons per hectare = 499.7795  
Total number of trees per 1/2-ha plot = 359.0  Leaf area index = 6.94256  
Basal area is 61.25 m²/ha  Total foliage biomass (includes petioles) is 9.454
A simulation model for the development of timber stands in the Pacific Northwest is described. The model grows individual trees of 21 species in a 0.20-hectare (0.08-acre) forest gap. The model provides a means of assimilating existing information, indicates where knowledge is deficient, suggests where the forest system is most sensitive, and provides a first testing ground for hypotheses. Model verification simulations are included for up to 500 years on various sites. Fire, wind, or clearcutting can occur at intervals and intensities specified by users. The model was developed by modifying an existing forest succession simulator of eastern deciduous forests. Birth, growth, and death of individual trees are functions of existing light and temperature conditions, competition and species characteristics. Modifications of the existing simulator include tree height growth being related to temperature and moisture conditions, the foliage biomass to diameter relationship being more realistic, and five mortality classes and shade tolerance classes being defined.

Keywords: Succession, models, simulation, community dynamics (plant).
The Forest Service of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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