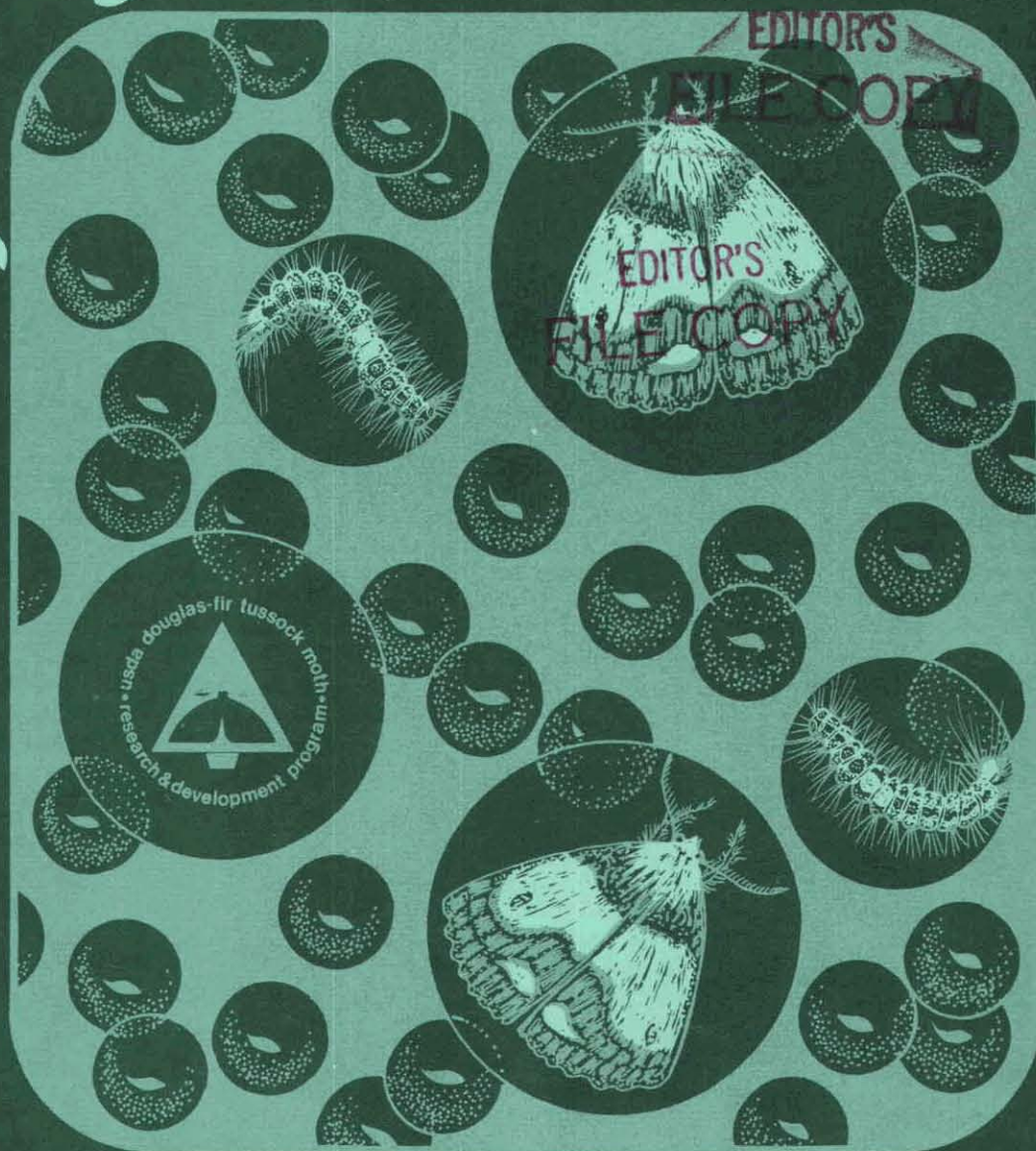


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# Douglas-Fir Tussock Moth

Documentation of the

Outbreak-Population Model



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## Reference Abstract

Documentation of three model versions: the Douglas-fir tussock moth population-branch model on (1) daily temporal resolution, (2) instar temporal resolution, and (3) the Douglas-fir tussock moth stand-outbreak model; the hierarchical framework and the conceptual paradigm used are described. The coupling of the model with a normal-stand model is discussed. The modeling convention and algorithm used are also discussed.

KEYWORDS: Population dynamics, defoliation damage, outbreak prediction, models, Douglas-fir tussock moth, *Orgyia pseudotsugata*.

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## INTRODUCTION

This paper documents the mathematical form and computational framework of the Douglas-fir tussock moth (DFTM) stand-outbreak model. The model is constructed to simulate outbreaks of Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough)), a defoliator of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), and the true firs (*Abies* spp.) in western North America. The details of the model's background, its historical development, and the basis for formulation of its present structure and functional forms will be covered in another paper, as will documentation of model behavior.

The conceptual structure of the DFTM model provides a perspective on the relation of the various models developed. Three versions of the DFTM outbreak-population model were developed. Version 1.2, presented here, is at daily resolution and differs little from the original version (V1.1) conceived in 1974. The second version presented (V2.2) was originally developed (V2.1) to reduce computing costs and necessitated only minor alterations. These two versions follow the insect on a model branch through 1 year. This branch model became the operational unit of the stand-outbreak model (V3.1). Details of the coupling relation between the normal-stand model and the DFTM stand-outbreak model follow the overview of the general model structure.

A summary of the FLEX processing algorithm and notational convention precedes detailed documentation of the models. Adjustments to the current algorithm were necessitated by the DFTM stand-outbreak model structure, and these are detailed next. The computational framework in which the models are embedded is discussed in these two sections.

A short discussion, preceding the details of each model version, gives the relations among the three model versions and how they derive from each other. The detailed FLEXFORMS, summarizing model structure and parameterization, follow.<sup>1/</sup> Next are the specifics of file manipulation used in the third model version. This includes a more detailed discussion of the computational order discussed in general in another section.

Last is a description of the stand-postoutbreak model. This is the filtering mechanism that assigns mortality and growth impacts to the stand of trees. These result from defoliation of the model branch as transformed by the whole-tree-defoliation equation.

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<sup>1/</sup> A FLEXFORM is a form developed for presenting the details of a component module of a model described in the FLEX paradigm.

# THE GENERAL MODEL STRUCTURE

A hierarchical structure is conceptualized for the general model: each level is a dynamic unit of the level above (figures 1 and 2).

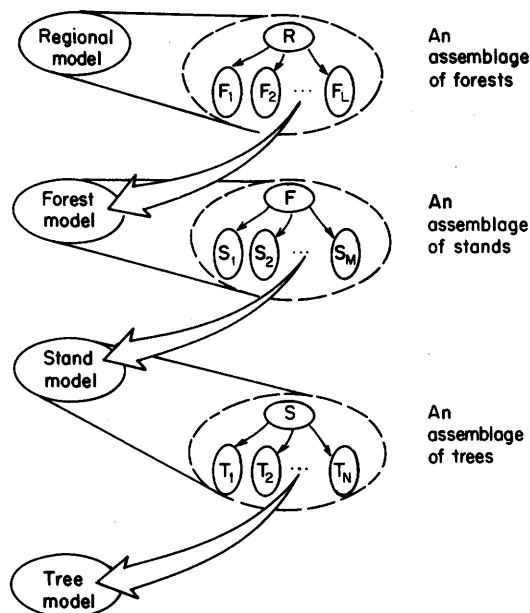


Figure 1.--How various models assemble into the hierarchical model. A region (R) consists of a number (L) of forests (F), a forest consists of a number (M) of stands (S), and each stand consists of a number (N) of trees (T).

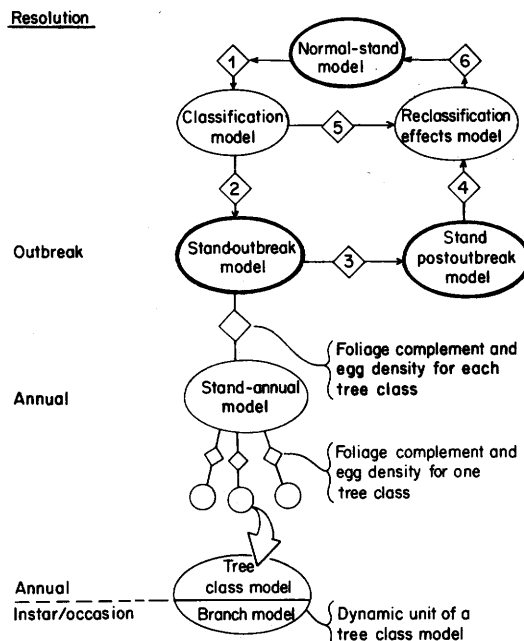


Figure 2.--Hierarchical organization of the DFTM stand-outbreak model relative to the normal-stand model.

- A. Regional model: The socioeconomic context of the forest.  
Resolution: 1 century; not implemented.
- B. Forest model: An explicit assemblage of ecotype-stand units.  
Resolution: 1 rotation; not implemented.
- C. Stand model:
  - (a) Normal-stand model: An assemblage of trees of varying size and species, in a specific ecological and management regime.  
Resolution: 1 decade; not implemented.
  - (b) Stand-outbreak model: An assemblage of tree classes prescribed by the effective resolution of knowledge of stand conditions and insect population levels. The conceptual structure of an outbreak is patterned after the observed sequence of population "phases" of Wickman et al. (1973). The successive years of an outbreak are parameterized according to phase-specific mortality vectors and other population properties.  
Resolution: Duration of outbreak, 4 years.

(c) Stand-postoutbreak model: Translates the effects of defoliation into mortality, top-kill, and reduction of growth for each tree class and covers delayed mortality and remedial management practices.

Resolution: Duration of postoutbreak period, 6 years.

(d) Stand-annual model: The potential of integration over tree classes at the end of each year effectively imposes a stand-annual structure on the assemblage of tree classes. Redistribution of eggs over the tree classes in the stand is determined in this model.

Resolution: 1 year.

D. Tree model:

(a) Normal-tree model: The rules of normal growth and survival of a tree, of specific species, size, and age and of specific ecological and stand regimes.

Resolution: 1 year; not implemented.

(b) Tree-class model: A class of trees is represented by a typical tree. Defoliation of the typical tree over a season is derived from the branch model.

Resolution: 1 year.

(c) Tree-outbreak model: Normal growth increments and survival are modified by the degree of defoliation as determined from the branch model. The tree-outbreak model is simply a branch model, coupled or linked over seasons, with outputs translated at the end of the outbreak into the effects of defoliation on tree mortality, top-kill, and growth. This model does not explicitly appear, being subsumed by the stand-outbreak model. Effects of defoliation are relegated to the stand-postoutbreak model.

Resolution: Duration of outbreak and postoutbreak periods.<sup>2/</sup>

E. Branch model: Contains the rules of growth and survival of tussock moth, branch defoliation, and the production of new foliage and loss of old foliage by the branch; specific for ratio of eggs to foliage, for nominal ratio of new to old foliage, and for species of tree and year (phase) of outbreak. Standardization of the total biomass of foliage on the model branch (100 grams for Douglas-fir and 144 grams for grand fir (*Abies grandis* (Dougl.) Lindl.)) allows specification of only two variables, percent new foliage and eggs (per total grams of foliage).

The mechanisms of the branch model are conceptualized at a daily resolution, with runs spanning one season. Initial conditions for a season run are identifiable from the terminating condition of a season run which provides the capacity to couple several seasons (years) together. In the daily resolution branch model, days are occasions.

---

<sup>2/</sup> The postoutbreak period has been set at 6 years so that the outbreak and postoutbreak periods will sum to the resolution of the normal-stand model.

For efficiency in computing, the daily resolution model was collapsed into an instar resolution model. This changes little and reduces the number of occasions in a season.

We can now identify several levels of temporal resolution: outbreak (containing several phase-specific years), year (containing several occasions), and occasion.

## IDENTIFICATION OF COUPLING VARIABLES

In this outline of the couplings between the different models, Arabic numerals correspond to those in the numbered diamonds in figure 2.

1. Outputs of the normal-stand model and inputs to the classification model: Those state variables and parameters of the normal-stand model needed to assign trees of the stand to the classes of the stand-outbreak model.
2. Outputs of the classification model and inputs to the stand-outbreak model:
  - i. The number of tree classes in the stand;
  - ii. For each tree class, represented by a "typical tree":
    - a. The number of trees in the class;
    - b. The foliage composition of the model branch: Biomass of foliage and percent new foliage;
    - c. Egg density;
    - d. Species;
    - e. The weighting factor to account for relative contribution of a tree in the class to stand foliage biomass and insect population density;
  - iii. Ecological or site-specific model parameters.
3. Outputs of the stand-outbreak model and inputs to the stand-postoutbreak model for each class of trees in the stand:
  - i. Defoliation of the model branch after each season during the outbreak;
  - ii. Tree defoliation at the end of the outbreak.
4. Outputs of the stand-postoutbreak model and inputs to the reclassification-effects model, for each tree class:
  - i. Direct mortality; proportion of trees that die as a direct result of defoliation;
  - ii. Secondary mortality; proportion of trees that suffer secondary mortality in the postoutbreak period, identified as:
    - a. Bark beetle mortality;
    - b. Other mortality caused by the outbreak;
    - c. Noncausal mortality;
  - iii. Top-kill; proportion of trees in each top-kill subclass. Each subclass is defined in terms of height reduction. An additional output, the proportion of the nominal diameter-growth increment actually achieved is also given;

- iv. No top-kill; proportion of trees that suffer neither top-kill nor mortality; and for these trees, the damage expressed as:
    - a. Proportion of the nominal height-growth increment actually achieved;
    - b. Proportion of the nominal diameter-growth increment actually achieved;
  - v. Factors for delayed reduction of growth beyond the postoutbreak period.
5. Outputs of the classification model and inputs to the reclassification-effects model: The record of which trees were assigned to the various classes.
  6. Outputs of the reclassification-effects model and inputs to the normal-stand model: The allocation of mortality factors to the trees of the stand and the updating of growth increments to cover the outbreak period.

## ABSTRACT OF THE FLEX CONVENTION AND ALGORITHM

The conceptual basis of FLEX is the identification of several kinds of variables and functions in the context of a general algorithm for dynamic behavior. Identify:

- $\underline{x}$ , the vector of state variables;
- $\underline{y}$ , the vector of output variables (functions of state variables);
- $\underline{z}$ , the vector of input variables;
- $\underline{b}$ ,  $\underline{r}$ , two vectors of constants (model parameters).

The update algorithm is a simple difference equation

$$\underline{x}(k+1) = \underline{x}(k) + \underline{\Delta}(k)$$

with  $\underline{\Delta}(k)$  constructed as a sum of internal variables that are identified as  $f$  function values. These functions account for fluxes (flows) between state variables. Flux from  $x_i$  to  $x_j$  is  $f_{ij}$ ;

$$f_{ij} = f_{ij}(k, \underline{z}, \underline{x}, \underline{g}, \underline{s}, \underline{b}, \underline{r});$$

where  $\underline{g}$  and  $\underline{s}$  are vectors of functions;  $f_{ii}$  is a source or sink for  $x_i$  depending on the sign of  $f_{ii}$ . The  $\underline{g}$  functions are intermediate functions--internal variables that are used extensively,

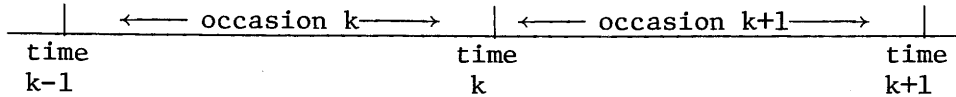
$$g_i = g_i(k, \underline{z}, \underline{x}, \underline{b}, \underline{r}).$$

The  $\underline{s}$  functions, or special functions, are included for further modeling and programing flexibility; these are implemented as FORTRAN<sup>3/</sup> subroutines and are therefore much more general. Details of how this process is implemented are given in the FLEX users' manual (White and Overton 1977).

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<sup>3/</sup> FORMula TRANslating system--a language used to express computer programs by arithmetic or logical formula.

The model processor outputs the initial conditions read at time 0, and from this point forward uses the values of the variables at time  $k$  to compute the values of the state variables at time  $k+1$ . The processor uses the values for time  $k$  to compute the outputs for time  $k+1$ . This accounts for actions taking place during occasion  $k+1$ .



In a terminal (or FLEX) module the algorithm may be summarized as follows:

- (1) Receive (or calculate) inputs and store the values of  $\underline{z}$  using the  $z$  functions.
- (2) Calculate and store the values of the  $g$  functions.
- (3) Calculate and store the values of the  $f$  functions.
- (4) Construct the update vector,  $\underline{\Delta}$ .
- (5) Update the state variables.
- (6) Calculate and store (generate outputs) and values of  $\underline{y}$  using the  $y$  functions.

A time step  $k$  may be subdivided into  $q$  subintervals indexed by  $k' = 0, 1, \dots, q - 1$ . Then define:

$$\begin{aligned} \underline{x}(k) &= \underline{x}(k, 0), \\ \underline{x}(k, k' + 1) &= \underline{x}(k, k') + \underline{\Delta}(k, k'), \\ \underline{x}(k + 1) &= \underline{x}(k, q); \end{aligned}$$

$k'$  is added to the  $g$  and  $f$  function arguments. This capability implies an additional step, 5a, in the above sequence:

- (5a) Increment  $k'$  and compare to  $q$  where  $q$  is the resolution ratio. If less than  $q$ , return to step 2, otherwise proceed to step 6.

Processing of a ghost (REFLEX) module, one that has control over submodules, requires a modified procedure; steps 3, 4, and 5 are replaced by step 3a:

- (3a) Call and process subsystems (submodules), which in turn update the values of the state variables in ghost. Then continue with step 5a.

The current FLEX algorithm assumes that a division of one time-step into  $q$  subintervals within a terminal (FLEX) module is being done to implement a solution to a set of differential equations, and accordingly only  $1/q$  of the update ( $\Delta$ ) value is added to each variable. In module  $S_1$  of version 3, this capacity is used differently; an event structure is **assumed** and a full update on each variable is desired. Because  $q = 10$  (representing the 10 occasions in a season), each  $f$  function is multiplied by 10 to nullify the automatic multiplication by  $1/q$  (White and Overton 1977, p. 21 and 32).

The symbol,  $x^*$ , represents **implicit** state variables, carried for computational convenience internal to the FORTRAN code of a function (e.g., a  $g$  function). These are available to no other functions and will not appear in the list of explicit state variables.

## VECTOR PROCESSING IN FLEX2

The current version of the DFTM stand-outbreak model makes use of some of the conceptual structure of the FLEX paradigm that is not explicitly a part of the current algorithm used by the model processor as detailed in the FLEX users manual. The following explanation will clarify a newly adopted notational convention, its conceptual meaning in the paradigm, its place in the algorithm, and its implementation using the current version of the processor.

In the FLEX paradigm,  $\underline{x}$ , the vector of state variables, may contain elements that are themselves vectors--usually when a class II system is being considered, a system in which each subsystem has the same structure and function, as in a population of individuals that have the same rules of behavior. Thus,  $\underline{x}_i$  may be an element of  $\underline{x}$ . For example,  $\underline{x}_i$  might represent the biomasses of each of the individuals in a population, with an element of  $\underline{x}_i$  the biomass of a particular individual. The notational convention is established that  $\underline{x}$  is the vector of state variables;  $\underline{x}_i$  is a vector element of  $\underline{x}$ ; and  $x_{ij}$  is a scalar element of  $\underline{x}_i$ .

Only the homogeneous case is allowed, so that each member subsystem of the class II system has the same state variable structure. A  $g$  function that operates on  $\underline{x}_i$  is a vector valued function.  $\underline{g}$  is the vector of intermediate functions with  $g_i$  an element of this vector.  $\hat{g}_i$  is a scalar value of  $g_i$  where the caret notation is used to signify an actual value of the function. When  $g_i$  operates on the vector  $\underline{x}$ , it may produce a vector  $\hat{g}_i$ . The values generated by operation of  $\underline{g}$  on  $\underline{x}$  form a matrix,  $\hat{g}_{ij}$ , corresponding to the  $i$ th element of  $\underline{g}$  and the  $j$ th member of the population. Then the notation  $\hat{g}_{.j}$  denotes the column vector of values for all  $g$  functions for the  $j$ th population member, and the notation  $\hat{g}_i$  represents the row vector of values of the  $i$ th  $g$  function for all population members. A similar notation is extended to the function vectors  $\underline{z}$  and  $\underline{y}$ ;  $\underline{b}$  and  $\underline{r}$  parameter vectors may also have vector elements.

Introduction of the ability to cycle through a single subsystem a specified number of times, with each cycle processing in turn a member of a population of identically structured subsystems, required modification in the FLEX algorithm. Instead of incrementing  $k'$  automatically after each pass through the subsystem, counter  $k''$  is incremented after each pass and then checked against  $p$ . The population number,  $p$ , is set before a simulation run. If the subsystem has not been processed  $p$  times, then the  $g$  functions are called and the subsystem is processed again. The values  $\hat{g}_{.j}$  are calculated, the updated values of  $\underline{x}_{.j}$  are obtained, and  $k''$  and  $j$  are incremented. After cycling  $p$  times, the vector elements of  $\underline{g}$  and  $\underline{x}$  have been updated;  $k'$  is then incremented and the next pass through the  $g$  functions will fix  $\hat{g}_{.1}$  before the first call to the subsystem for that time step.

Although complex, this procedure is straightforward. The matrix of state variables,  $\tilde{X}$ , is updated by column vectors and the values  $\hat{G}$  are calculated by column vectors. It implies, however, that internal storage locations for the values  $\hat{g}_{ij}$ ,  $x_{ij}$ , etc., are within the processor. These locations do not exist in the current processor version. Vector values must be stored on external files that are accessed, manipulated, and updated by the various functions and subroutines that use them.

The following procedure is used to implement this algorithm feature on the current processor version. At  $k' = 0$ , the  $g$  functions are called as usual. In a ghost module, each  $g_i$  may operate in a different mode. A  $g_i$  may calculate  $\hat{g}_i$  at this time and store it on an external file. A  $g_i$  may calculate only a scalar value and have it available in the standard way for use by other  $g_i$ 's. Or a  $g_i$  may be used to process external files, initialize the state variable and input variable matrices, and store them on external files for subsystem access. Each time the subsystem is processed, the functions within the subsystem reads ghost's  $\hat{g}_{.j}$  from the file. The  $g$  functions in the subsystem generate only that subsystem's column vector  $\hat{g}_{.j}$ , and these values are stored in the processor and are accessed in the standard way. The subsystem's updated values of  $x_{.j}$  are stored on a different external file, not in the ghost module. On completion of subsystem processing, the functions in the ghost module may then access those files as necessary.

The above procedure introduces a new level of complexity in FLEX programming. Much of this complexity could be avoided by introducing a new level in the hierarchy, but this entails difficulties as well as increasing processing time and cost. The approach used here is relatively inexpensive and easily implemented.

## CORRESPONDENCE OF THE THREE MODEL VERSIONS

The model for interaction of the tussock moth larvae and host foliage was originally conceptualized and developed in terms of daily resolution mechanisms. Table 1 defines the daily resolution occasion structure of version 1.2. This model was restructured into the instar resolution of table 2 for version 2.2. Only one change in the conceptual structure is necessitated by this change in resolution. The model growth and feeding of the tussock moth is altered in the fourth instar to accommodate the convolution of larval growth with population survival over an instar. This is accomplished by assuming that the growth rate is constant throughout this instar, at the average of the two growth rates used during this instar in version 1.2. This changes the accumulating larval biomass, but only slightly and only during the fourth instar.

The organization of the models by subsystem and function identification is shown in table 3. The subsystems are those of the branch model at both daily and instar resolution. The  $g$  functions, although representing the same processes, do change form from version 1.2 to version 2.2. The details of the functional forms are given in the FLEXFORMS that follow.

The functions of version 2.2 are directly transferred into the branch model of module  $S_1$  of version 3.1 (see figure 3). The only changes necessary are:

- (i) some "normal tree" parameters are being brought in as  $z$  inputs rather than being internal  $b$  parameters;
- (ii) the time index is changed from  $k$  to  $k'$ ;
- (iii) the overwintering activities of occasion 10 of table 2 take place in the ghost module  $S_0$  of version 3.1. The details of these changes are presented in the version 3.1 FLEXFORMS.

Table 1 --Douglas-fir tussock moth population-branch model, daily resolution form, Version 1.2. Occasion/time structure: note that occasion  $t$  is the interval before time  $k$ ;  $k = t-1$  during occasion  $t$

| <u>Occasion</u> | <u>Description</u>                                                                      |
|-----------------|-----------------------------------------------------------------------------------------|
| Initiation      | Bud burst and shoot elongation complete.                                                |
| 1               | Egg hatch and establishment of first instars.                                           |
| 2               | First day of feeding, growth, and mortality.                                            |
| .               |                                                                                         |
| .               |                                                                                         |
| 10              | Ninth day of feeding, growth, and mortality.                                            |
| 11              | Last day larvae are in the first instar: feeding, growth, and mortality.                |
| .               |                                                                                         |
| .               |                                                                                         |
| 21              | Last day larvae are in the second instar: feeding, growth, and mortality.               |
| .               |                                                                                         |
| .               |                                                                                         |
| 31              | etc.                                                                                    |
| .               |                                                                                         |
| .               |                                                                                         |
| 41              | etc.                                                                                    |
| .               |                                                                                         |
| .               |                                                                                         |
| 51              | Last day larvae are in the fifth instar: feeding, growth, mortality, and male pupation. |
| .               |                                                                                         |
| .               |                                                                                         |
| 61              | Last day of sixth instar: feeding, growth, mortality, and female pupation.              |
| 62              | Pupal mortality and adult female emergence.                                             |
| 63              | Eggs laid, aging of new foliage, and new foliage potential set.                         |
|                 | Redistribution of insects over the stand. <sup>1/</sup>                                 |
| 64              | Overwinter mortality of foliage.                                                        |
|                 | Overwinter mortality of eggs. <sup>2/</sup>                                             |

<sup>1/</sup> This is not operative in a single-tree run, only in the stand-outbreak model.

<sup>2/</sup> Overwinter mortality accounts for all the mortality factors to which the egg masses are subjected between the time they are laid in the fall and hatch in the spring. In the current version, it also implicitly accounts for the mortality between hatching and establishment of first instars.

Table 2 --Douglas-fir tussock moth population-branch model instar resolution form, Version 2.2 and 3.1 (module S<sub>1</sub>)

| Occasion/time structure |                                                                                                         |
|-------------------------|---------------------------------------------------------------------------------------------------------|
| <u>Occasion</u>         | <u>Description</u>                                                                                      |
| Initiation              | Bud burst and shoot elongation complete.                                                                |
| 1                       | Egg hatch, establishment on foliage.                                                                    |
| 2                       | First instars: feeding, growth, and mortality.                                                          |
| 3                       | Second instars: feeding, growth, and mortality.                                                         |
| 4                       | Third instars: feeding, growth, and mortality.                                                          |
| 5                       | Fourth instars: feeding, growth, and mortality.                                                         |
| 6                       | Fifth instars: feeding, growth, and mortality. Male pupation occurs after fifth-instar feeding.         |
| 7                       | Sixth instars (female): feeding, growth, mortality, and female pupation.                                |
| 8                       | Pupal mortality and adult female emergence.                                                             |
| 9                       | Eggs laid, aging of foliage, and new foliage potential set.                                             |
| 10                      | Redistribution of eggs. <sup>1/</sup> Overwinter mortality of foliage and overwinter mortality of eggs. |

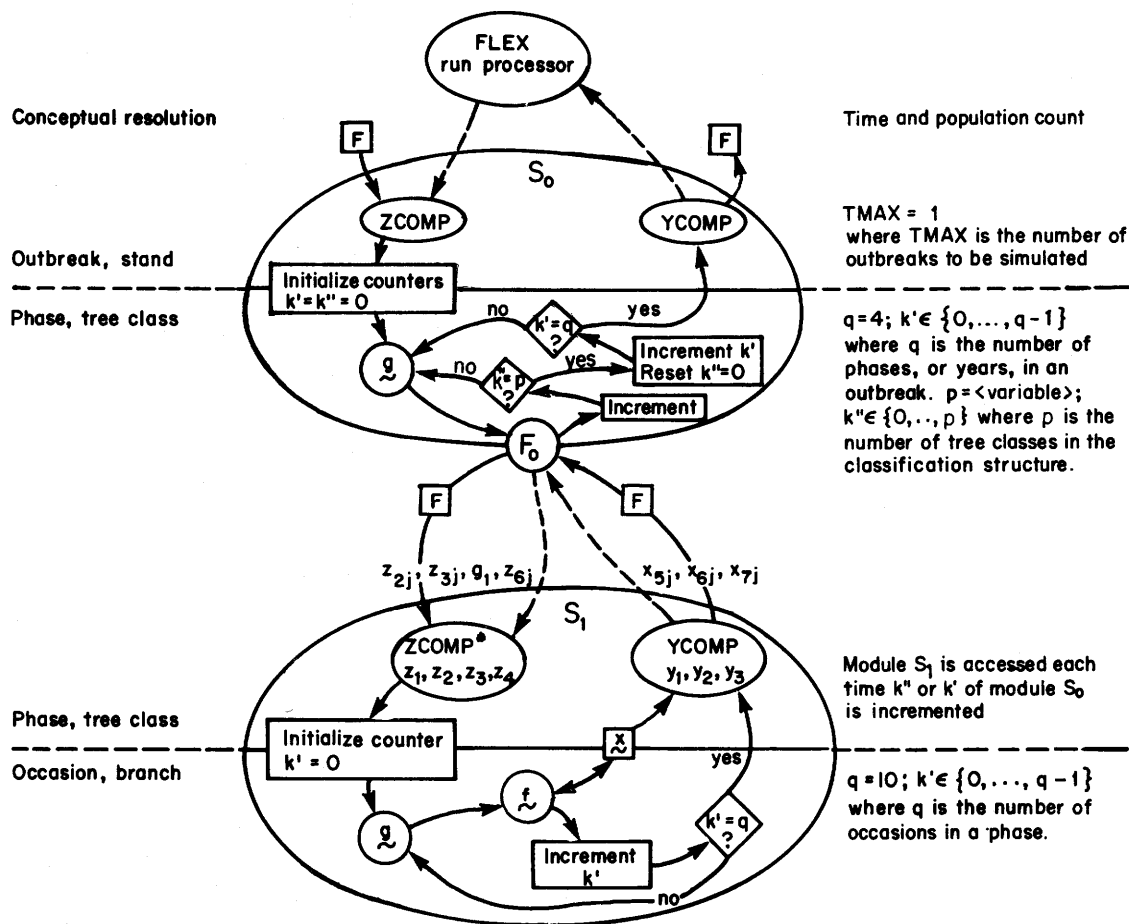
<sup>1/</sup> In Version 3.1, the events of occasion 10 take place in module S<sub>0</sub>.

Table 3 --G function assignment by subsystems for the three model versions

Subsystems (S<sub>j</sub>):

1. Foliage dynamics
2. Population dynamics
3. Growth and feeding

| <u>Subsystems</u>                                  | <u>G Functions</u> | <u>Identity</u>                                                           |
|----------------------------------------------------|--------------------|---------------------------------------------------------------------------|
| Versions 1.2 & 2.2 and<br>Version 3.1 Lower Module |                    |                                                                           |
| S <sub>1</sub> :                                   | { 1, 4             | New foliage destruction and production.                                   |
|                                                    | { 2, 5             | Old foliage destruction and (for V1 and V2) mortality.                    |
|                                                    | { 3                | Aging of new foliage into old.                                            |
| S <sub>2</sub> :                                   | { 6, 7, 8          | Determination of daily larval mortality.                                  |
|                                                    | { 9                | Index of days spent feeding on old foliage.                               |
|                                                    | { 10               | Fecundity or special occasion mortality.                                  |
|                                                    | { 11               | Total mortality (or egg production).                                      |
| S <sub>3</sub> :                                   | { 12               | Nominal larval growth rate.                                               |
|                                                    | { 13               | Achieved larval growth.                                                   |
|                                                    | { 14               | Fecundity stress index.                                                   |
|                                                    | { 15, 16, 17, 18   | Food demand and function for allocation of demand to new and old foliage. |
|                                                    | { 19               | Index of day on which foliage was depleted by feeding.                    |
| Version 3.1 Upper Module                           |                    |                                                                           |
|                                                    | 1                  | Phase or year of the outbreak.                                            |
|                                                    | 2                  | Redistribution of insects over the stand.                                 |
|                                                    | 3                  | Old foliage mortality.                                                    |
|                                                    | 4                  | Overwinter mortality of eggs.                                             |



\* ZCOMP sets the values in  $S_1$  of  $b_1, \dots, b_6, b_{34}, b_{35}, b_{36}$ , and  $r_1, \dots, r_{12}$  according to the value of  $z_3$ , and  $r_{13}, \dots, r_{18}$  according to the value of  $z_4$ . Also, the values of  $x_{5j}, x_{6j}$ , and  $x_{7j}$  of  $S_0$  become the initial conditions for  $x_1, x_2$ , and  $x_3$  of  $S_1$ , respectively, and  $x_4$  of  $S_1$  is initialized to zero.

**[F]** external file

Figure 3.--Stand-outbreak model, Version 3.1: Module stacking and sequencing. Note: The ovals marked ZCOMP and YCOMP represent the FLEX input and output variable processor subroutines, respectively, for each module. This figure follows the convention of figures 5 and 6 in White and Overton (1977). The F's in boxes are external data files used in data storage and module coupling. For details, see page 46. Couplings between  $S_0$  and  $S_1$  are given in terms of variables of  $S_0$ .

# FLEXFORMS: V1.2; V2.2; V3.1 MODULE S<sub>0</sub>; V3.1, MODULE S<sub>1</sub>

FLEXFORM: V1.2  
Page 1 of 12

TITLE: DFTM Population-Branch Model,  
Version 1.2

DATE: March 8, 1974

INVESTIGATORS: Overton, White, Hunt,

March 15, 1977 (revised)

Colbert

TEMPORAL RESOLUTION: day, occasion; duration of run, one season.

SPATIAL RESOLUTION: the hypothetical model branch.

QUANTITIES MODELED: Biomass (dry weight) of foliage and larva,  
numbers of insects.

Note: Conceptually this model can be treated as one occasion in an annual resolution model, with the annual quantities:

1. Annual variables
  - (i) actual foliage complement
    - a) new foliage biomass
    - b) old foliage biomass
  - (ii) viable egg density
2. "Phase-specific" parameters
  - (i) egg-mass size
  - (ii) disease, parasite/predator mortality rates
  - (iii) overwinter egg and larval establishment mortality rates
3. Parameters that originate as "branch-outbreak" variables or parameters
  - (i) nominal foliage complements
  - (ii) Phase I initial viable egg density
  - (iii) host specific mortality rates
  - (iv) (host species)

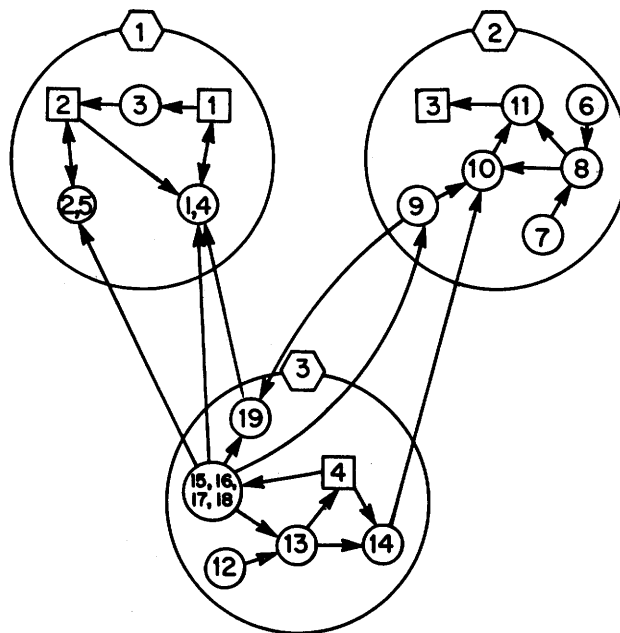
SUBSYSTEMS:

1. Foliage dynamics
2. Population dynamics
3. Growth and feeding

Symbol Key:

- ◊ Subsystem designation.
- System, subsystem, process or function. Numbers in small circles are g function indices.
- State variables.

DIAGRAM:



## VARIABLES AND FUNCTIONS

### 1. X List

| <u>Variable</u> | <u>Description</u>                                                                                                                                                                                                                                                                                                                              | <u>Units</u> |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
| x <sub>1</sub>  | New foliage biomass ( $0 \leq k \leq 62$ ) and new foliage potential for the next year ( $k = 63, 64$ ).                                                                                                                                                                                                                                        | g            |
| x <sub>2</sub>  | Old foliage biomass.                                                                                                                                                                                                                                                                                                                            | g            |
| x <sub>3</sub>  | Viable eggs ( $k = 0$ ).<br>Established first instars ( $k = 1$ ).<br>Feeding larvae, male and female ( $1 < k \leq 50$ ).<br>Feeding female larvae ( $51 \leq k \leq 60$ ).<br>Female pupae ( $k = 61$ ).<br>Adult females emerged ( $k = 62$ ).<br>Viable eggs produced ( $k = 63$ ).<br>Viable eggs after overwinter mortality ( $k = 64$ ). | number       |
| x <sub>4</sub>  | Individual larval biomass.                                                                                                                                                                                                                                                                                                                      | mg           |
| x <sub>5</sub>  | Individual larval biomass at $k = 36$ .                                                                                                                                                                                                                                                                                                         | mg           |

### 2. Z Functions

No inputs other than initial conditions are needed in this single-year version of the model. Phase-specific "inputs" are incorporated as parameters.

### 3. G Functions

| <u>Functional Form and Description</u>                                                                                                                                           | <u>Units</u> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
| $g_1 = \begin{cases} \frac{b_{37}}{100} \cdot b_{38} \left[ \frac{x_1 + x_2 + b_{38}}{2b_{38}} - g_{19}b_{32} \right] & \text{for } k = 62 \\ 0 & \text{otherwise.} \end{cases}$ | g            |

This function accounts for the capacity to produce new foliage (g-dryweight) after the completion of feeding by the DFTM ( $k = 62$ ) and before the overwinter needle drop. If feeding results in total defoliation, then new foliage is reduced in proportion to the number of days of total defoliation ( $g_{19}$ ).

| Functional Form and Description | Units |
|---------------------------------|-------|
|---------------------------------|-------|

$$g_2 = \begin{cases} \max \left[ 0, x_2 - b_{38} \left( 1 - \frac{b_{37}}{100} \right) \right] & \text{for } k = 63, \\ 0 & \text{otherwise.} \end{cases} \quad g$$

Needle drop or litter production (g-dryweight) from the branch. This process is required to keep the branch in equilibrium under normal conditions.

$$g_3 = \begin{cases} x_1 & \text{for } k = 62, \quad \text{Aging of new foliage to old foliage.} \\ 0 & \text{otherwise.} \end{cases} \quad g$$

$$g_4 = \begin{cases} \min(g_{16}, x_1) & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases} \quad g$$

Destruction of new foliage (g-dryweight) for each day of feeding ( $1 \leq k \leq 60$ ).

$$g_5 = \begin{cases} \min(g_{18} - g_4, x_2) & \text{for } 1 \leq k \leq 60 \text{ and } g_4 < g_{16}, \\ 0 & \text{otherwise.} \end{cases} \quad g$$

Destruction of old foliage (g-dryweight) for each day of feeding ( $1 \leq k \leq 60$ ) for which demand for food can not be fully satisfied by feeding on new foliage.

$$g_6 = \begin{cases} (1 - r_{s_1})(1 - r_{s_1 + 6})(1 - b_{s_1}) & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases} \quad d^{-1}$$

The survivorship per day ( $d^{-1}$ ) associated with disease mortality ( $r_{s_1}$ ), predator and parasite mortality ( $r_{s_1 + 6}$ ), and background mortality ( $b_{s_1}$ ). Each is instar specific (see special function  $s_1$ ).

---

| Functional Form and Description | Units |
|---------------------------------|-------|
|---------------------------------|-------|

---

|                                                                                                             |          |
|-------------------------------------------------------------------------------------------------------------|----------|
| $g_7 = \begin{cases} 1 - r_{s_1} + 12 & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases}$ | $d^{-1}$ |
|-------------------------------------------------------------------------------------------------------------|----------|

The daily survivorship associated with stress from feeding on old foliage; instar specific.

---

|                                                                                                                   |          |
|-------------------------------------------------------------------------------------------------------------------|----------|
| $g_8 = \begin{cases} g_6 g_7^{1-g_{15}} - 1 & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases}$ | $d^{-1}$ |
|-------------------------------------------------------------------------------------------------------------------|----------|

Negative total daily mortality rate. [Assume  $0^0 \equiv 1.$ ]

---

|                                                                                                                   |     |
|-------------------------------------------------------------------------------------------------------------------|-----|
| $g_9 = \begin{cases} 0 & \text{for } k = 0 \text{ or } k = 63, \\ x_1^* + g_{17} & \text{otherwise.} \end{cases}$ | $d$ |
|-------------------------------------------------------------------------------------------------------------------|-----|

(implicitly,  $x_1^*(k+1) = x_1^*(k) + g_{17}(k)$ )

Total number of days (d) spent feeding on old foliage during which demands are fully satisfied.

---

|                                                                                                                                                                                                                                                                   |        |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|
| $g_{10} = \begin{cases} -b_{39} & \text{for } k = 0, \\ -b_{34}(1 + g_8) & \text{for } k = 50, \\ -b_{26} & \text{for } k = 61, \\ b_{27} g_{14}(1 - b_{33} g_9) - 1 & \text{for } k = 62, \\ -b_{35} & \text{for } k = 63, \\ 0 & \text{otherwise.} \end{cases}$ | number |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|

This function accounts for changes in number of larvae from establishment mortality ( $k = 0$ ), male pupation ( $k = 50$ ), female pupal mortality ( $k = 61$ ), viable eggs produced by the remaining females ( $k = 62$ ), and overwinter mortality ( $k = 63$ ). Fecundity is reduced in proportion to the number of days spent feeding on old foliage ( $g_9$ ) and the final weight of the female larva ( $g_{14}$ ).

---

| Functional Form and Description                                                                                                                                                                                                                                  |                                                                                                                           | Units    |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|----------|
| $g_{11} = (g_8 + g_{10})x_3$                                                                                                                                                                                                                                     | Larval mortality, male pupation,<br>pupal mortality, egg production.                                                      | number   |
| $g_{12} = \begin{cases} b_{22} & \text{for } 1 \leq k \leq 35, \\ b_{23} & \text{for } 36 \leq k \leq 60, \\ 0 & \text{for } x_3 \leq 0 \text{ or} \\ & x_1 + x_2 \leq 0 \text{ or} \\ & k = 0 \text{ or } k \geq 61. \end{cases}$                               | The nominal instantaneous<br>larval growth rate. Lar-<br>vae grow at the nominal<br>rate as long as food is<br>available. | $d^{-1}$ |
| $g_{13} = \begin{cases} b_{25} & \text{for } k = 0, \\ x_4(e^{\phi g_{12}} - 1) & \text{for } 1 \leq k \leq 60, \\ 0 & \text{for } k \geq 61. \end{cases}$                                                                                                       |                                                                                                                           | mg       |
| Here                                                                                                                                                                                                                                                             |                                                                                                                           |          |
| $\phi = \begin{cases} \frac{g_4 + g_5}{g_{15}g_{16} + g_{17}g_{18}} & \text{for } (g_{15} + g_{17}) \neq 0, \\ \frac{g_4 + g_5}{g_{18}} & \text{for } (g_{15} + g_{17}) = 0. \end{cases}$                                                                        |                                                                                                                           |          |
| Achieved larval growth increment. The proportion $\phi$ is the ratio of actual foliage destruction to total foliage demand; if less than one, then the larvae did not feed for the full day and hence the growth is reduced according to the proportion $\phi$ . |                                                                                                                           |          |
| $g_{14} = \max \left[ \frac{2x_4}{b_{24}} - 1, 0 \right]$                                                                                                                                                                                                        | Fecundity stress index,<br>which is measured relative<br>to the nominal final biomass( $b_{24}$ ).                        | none     |
| $g_{15} = \begin{cases} 1 & \text{if } g_{16} < x_1 \\ & \text{and } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases}$                                                                                                                                     | The indicator of a day spent<br>feeding exclusively on new<br>foliage.                                                    | d        |

---

| Functional Form and Description | Units |
|---------------------------------|-------|
|---------------------------------|-------|

---

$$g_{16} = \begin{cases} b_{s_1+6} \left[ \frac{10^{-3}}{b_{21}} (b_{19} + \frac{b_{20}}{g_{12}}) (e^{g_{12}} - 1) \right] x_3 x_4 & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases} \quad g$$

New foliage demand for the day's feeding and growth.

---


$$g_{17} = \begin{cases} 1 & \text{if } g_{15} = 0, \\ 1 \leq k \leq 60, \text{ and } (x_1 + x_2) > g_{18}, \\ 0 & \text{otherwise.} \end{cases} \quad d$$

The indicator of a day spent feeding on old foliage with demand completely satisfied.

---


$$g_{18} = \begin{cases} b_{s_1+12} \left[ \frac{10^{-3}}{b_{21}} (b_{19} + \frac{b_{20}}{g_{12}}) (e^{g_{12}} - 1) \right] x_3 x_4 & \text{for } 1 \leq k \leq 60, \\ 0 & \text{otherwise.} \end{cases} \quad g$$

Old foliage demand for the day's feeding and growth.

---


$$g_{19} = \begin{cases} 60 - [x_2^* + g_9] & \text{for } k = 62, \\ 0 & \text{otherwise.} \end{cases} \quad d$$

(implicitly,  $x_2^*(k+1) = x_2^*(k) + g_{15}(k)$ )

Total number of days during the larval period for which food demands were not fully satisfied.

---

| Functional Form and Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Units    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| $g_{20}^{4/} = \begin{cases} 0 & \text{for } k = 0, x_3 \leq 0, x_1 + x_2 \leq 0, \text{ or } k \geq 61, [1] \\ b_{22} & \text{for } k = 1 \text{ or } [x_4 \geq (1 - b_{31})g_{21} \text{ and } 2 \leq k \leq 35], [2] \\ \frac{\ln(x_4/b_{25})}{k-1} & \text{for } x_4 < (1 - b_{31})g_{21} \text{ and } 2 \leq k \leq 35, [3] \\ b_{23} & \text{for } k = 36 \text{ or } [x_4 \geq (1 - b_{31})g_{21} \text{ and } 37 \leq k \leq 60], [4] \\ \frac{\ln(x_4/x_5)}{k-36} & \text{for } x_4 < (1 - b_{31})g_{21} \text{ and } 37 \leq k \leq 60. [5] \end{cases}$ | $d^{-1}$ |

The modified growth rate of an individual larva. [3] and [5] are growth rates for trajectories below the normal; [2] and [4] for normal trajectories.

$$g_{21}^{4/} = \begin{cases} b_{25}e^{b_{22}k} & \text{for } 0 \leq k \leq 35, \\ b_{25}e^{35b_{22} + (k - 35)b_{23}} & \text{for } 36 \leq k \leq 60, \\ b_{25}e^{35b_{22} + 25b_{23}} & \text{otherwise.} \end{cases} \quad \text{mg}$$

Nominal larval growth trajectory.

$$g_{22}^{4/} = \begin{cases} x_4 & \text{if } k = 36, \\ 0 & \text{otherwise.} \end{cases} \quad \begin{array}{l} \text{Larval biomass after 35} \\ \text{days of feeding, bench-} \\ \text{mark for determining re-} \\ \text{duced growth rate.} \end{array} \quad \text{mg}$$

$$g_{23}^{4/} = \max \left\{ 2 \left[ \frac{x_4 + g_{13}}{g_{21}} \right] - 1, 0 \right\} \quad \begin{array}{l} \text{Fecundity stress index.} \\ \text{none} \end{array}$$

<sup>4/</sup> Note: These four g-functions are not operational, but are given here to exhibit how variable growth rates for the larvae might be implemented if additional food becomes available after foliage is depleted. The functions  $g_{20}$  and  $g_{23}$  would replace the present  $g_{12}$  and  $g_{14}$ , respectively.

#### 4. F Functions

| Functional Form and Description |                                                                                                             | Units  |
|---------------------------------|-------------------------------------------------------------------------------------------------------------|--------|
| $f_{1,1} = g_1 - g_4$           | $\left. \begin{array}{l} \\ \\ \\ \\ \\ \end{array} \right\}$ See state variables X list, for descriptions. | g      |
| $f_{1,2} = g_3$                 |                                                                                                             | g      |
| $f_{2,2} = -g_5 - g_2$          |                                                                                                             | g      |
| $f_{3,3} = g_{11}$              |                                                                                                             | number |
| $f_{4,4} = g_{13}$              |                                                                                                             | mg     |
| $f_{5,5} = g_{22}$              |                                                                                                             | mg     |

#### 5. Y Functions

| Functional Form and Description |                                                         | Units |
|---------------------------------|---------------------------------------------------------|-------|
| $y_i = x_i,$                    | $i = 1, 2, 3, 4$ See X list for descriptions and units. |       |

#### 6. Special Functions

| Functional Form and Description                |                                       | Units |
|------------------------------------------------|---------------------------------------|-------|
| $s_1^{5/} = \left[ \frac{k-1}{10} \right] + 1$ | The current instar of the population. | none  |

### PARAMETERS

#### 7. B Parameters

$b_1, \dots, b_{22}$  identical to  $b_1, \dots, b_{22}$  of Version 2.2. See page 7, 8 of Version 2.2 FLEXFORM.

<sup>5/</sup> Note: For this function,  $[x]$  is the largest integer that does not exceed the magnitude of  $x$ .

| <u>List</u>                   | <u>Value</u>                           | <u>Description</u>                                                             | <u>Units</u>           |
|-------------------------------|----------------------------------------|--------------------------------------------------------------------------------|------------------------|
| b <sub>23</sub>               | 0.0625                                 | Instantaneous growth rate for<br>36 ≤ k ≤ 60.                                  | d <sup>-1</sup>        |
| b <sub>24</sub>               | 52.063                                 | Nominal biomass of female larvae<br>at the end of the sixth instar,<br>k = 61. | mg                     |
| b <sub>25</sub>               | 0.197                                  | Initial nominal biomass of larvae<br>after establishment.                      | mg                     |
| b <sub>26</sub>               | I, .50; II, 0.62;<br>III, .75; IV, .90 | Phase-specific pupal mortality<br>rate.                                        | occasion <sup>-1</sup> |
| b <sub>27</sub>               | I, 200; II, 200;<br>III, 150; IV, 150. | Phase-specific nominal egg-<br>mass size.                                      | number                 |
| b <sub>28</sub>               | (not used)                             |                                                                                |                        |
| b <sub>29</sub>               | (not used)                             |                                                                                |                        |
| b <sub>30</sub>               | (not used)                             |                                                                                |                        |
| b <sub>31</sub>               | 1.0 X 10 <sup>-8</sup>                 | Error tolerance in larval<br>growth trajectory.                                | none                   |
| b <sub>32</sub>               | 0.02                                   | Coefficient of reduction in<br>bud capacity from total branch<br>defoliation.  | d <sup>-1</sup>        |
| b <sub>33</sub>               | 0.01                                   | Coefficient of reduction in<br>fecundity from feeding on old<br>foliage.       | d <sup>-1</sup>        |
| b <sub>34</sub>               | 0.50                                   | Proportion of larvae that are male<br>at the end of the fifth instar.          | none                   |
| b <sub>35</sub>               | I, .50; II, .60;<br>III, .85; IV, .90. | Overwinter mortality.                                                          | occasion <sup>-1</sup> |
| b <sub>36</sub>               | 1, 2, 3 or 4                           | Phase index.                                                                   | none                   |
| b <sub>37</sub> <sup>6/</sup> |                                        | Nominal percent of new foliage.                                                | none                   |
| b <sub>38</sub> <sup>6/</sup> |                                        | Nominal total foliage biomass<br>per model branch.                             | g                      |
| b <sub>39</sub>               | 0.0                                    | Phase-specific larval establish-<br>ment mortality.                            | occasion <sup>-1</sup> |

---

<sup>6/</sup> The values of b<sub>37</sub> and b<sub>38</sub> are chosen according to the properties of the host tree for a particular simulation.

8. R Parameters

| <u>List</u>     | <u>Value</u> |       |           |       |        | <u>Description</u>                                                 | <u>Units</u>    |
|-----------------|--------------|-------|-----------|-------|--------|--------------------------------------------------------------------|-----------------|
|                 | I            | II    | III       | IV    | Instar |                                                                    |                 |
| r <sub>1</sub>  | 0.0          | 0.0   | 0.002     | 0.025 | 1st    | Instar and phase-specific daily disease mortality rate.            | d <sup>-1</sup> |
| r <sub>2</sub>  | 0.0          | 0.0   | 0.003     | 0.028 | 2nd    |                                                                    |                 |
| r <sub>3</sub>  | 0.0          | 0.0   | 0.006     | 0.031 | 3rd    |                                                                    |                 |
| r <sub>4</sub>  | 0.0          | 0.0   | 0.013     | 0.034 | 4th    |                                                                    |                 |
| r <sub>5</sub>  | 0.0          | 0.001 | 0.035     | 0.035 | 5th    |                                                                    |                 |
| r <sub>6</sub>  | 0.0          | 0.001 | 0.028     | 0.035 | 6th    |                                                                    |                 |
| r <sub>7</sub>  | 0.0          | 0.0   | 0.001     | 0.005 | 1st    | Instar- and phase-specific daily predator/parasite mortality rate. | d <sup>-1</sup> |
| r <sub>8</sub>  | 0.0          | 0.0   | 0.002     | 0.006 | 2nd    |                                                                    |                 |
| r <sub>9</sub>  | 0.0          | 0.0   | 0.003     | 0.007 | 3rd    |                                                                    |                 |
| r <sub>10</sub> | 0.0          | 0.0   | 0.010     | 0.021 | 4th    |                                                                    |                 |
| r <sub>11</sub> | 0.0          | 0.001 | 0.016     | 0.033 | 5th    |                                                                    |                 |
| r <sub>12</sub> | 0.0          | 0.001 | 0.042     | 0.056 | 6th    |                                                                    |                 |
| <hr/>           |              |       |           |       |        |                                                                    |                 |
|                 | Douglas-fir  |       | Grand fir |       |        |                                                                    |                 |
| r <sub>13</sub> | 1.0          |       | 1.0       |       | 1st    | Instar- and host-specific daily food stress mortality rate.        | d <sup>-1</sup> |
| r <sub>14</sub> | 0.75         |       | 0.8       |       | 2nd    |                                                                    |                 |
| r <sub>15</sub> | 0.10         |       | 0.5       |       | 3rd    |                                                                    |                 |
| r <sub>16</sub> | 0.0          |       | 0.1       |       | 4th    |                                                                    |                 |
| r <sub>17</sub> | 0.0          |       | 0.0       |       | 5th    |                                                                    |                 |
| r <sub>18</sub> | 0.0          |       | 0.0       |       | 6th    |                                                                    |                 |

9. Initial Conditions<sup>7/</sup>

|       |      |
|-------|------|
| $x_1$ | 50.4 |
| $x_2$ | 93.6 |
| $x_3$ | 3.5  |
| $x_4$ | 0.0  |

---

GENERAL RUN INFORMATION

TSTART = 0

TMAX = 64

q = 1

LP, DUMP<sup>8/</sup>: All y's, all g's

LP, DUMP frequency: 1

RUN LOG: This version of the model was developed for documentation purposes and was run only to verify model output against V3.1.

Source code file: DAILY

FLEX3 overlay<sup>9/</sup>: \*DAILY

---

---

<sup>7/</sup> The full range of admissible initial conditions is available from the authors upon request.

<sup>8/</sup> LP stands for "line printer". DUMP stands for "dump file", a file used for compact storage of the details of a simulation for later review or reconstruction.

<sup>9/</sup> "Overlay" as used here is the machine-executable code, and is called an "absolute element" on some other computers.

FLEXFORM: V2.2  
Page 1 of 11

TITLE: DFTM Population-Branch Model  
Version 2.2

INVESTIGATORS: Overton, Colbert, White

DATE: December 1, 1975

March 15, 1977 (revised)

TEMPORAL RESOLUTION: instar, occasion; duration of run is one season

SPATIAL RESOLUTION: the hypothetical model branch

QUANTITIES MODELED: biomass (dry weight) of foliage and larvae;  
number of insects

SUBSYSTEMS: 1. Foliage dynamics  
2. Population dynamics  
3. Growth and feeding

DIAGRAM:

(See the diagram on page 2 of Version 1.2 FLEXFORM.)

---

#### VARIABLES AND FUNCTIONS

##### 1. X List

| <u>List</u> | <u>Description</u>                                                                                                                                                                                                                                                                                                           | <u>Units</u> |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
| $x_1$       | New foliage biomass                                                                                                                                                                                                                                                                                                          | g            |
| $x_2$       | Old foliage biomass                                                                                                                                                                                                                                                                                                          | g            |
| $x_3$       | Viable eggs, $k = 0$ .<br>Established first instars ( $k = 1$ ).<br>Feeding larvae, male and female ( $k = 2, 3, 4, 5$ ).<br>Feeding female larvae ( $k = 6$ ).<br>Female pupae ( $k = 7$ ).<br>Adult female moths ( $k = 8$ ).<br>Viable eggs produced ( $k = 9$ ).<br>Viable eggs after overwinter mortality ( $k = 10$ ). | number       |
| $x_4$       | Individual larval biomass                                                                                                                                                                                                                                                                                                    | mg           |

---

## 2. Z Functions

No inputs, other than initial conditions, are in this single-year version of the model. Phase-specific "inputs" are incorporated as parameters.

## 3. G Functions

| Functional Form and Description <sup>10/</sup> | Units |
|------------------------------------------------|-------|
|------------------------------------------------|-------|

|                                                                                                                                                                           |   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|
| $g_1 = \begin{cases} \frac{b_{31}b_{32}}{100} \left[ \frac{x_1 + x_2 + b_{32}}{2b_{32}} - g_{19}b_{27} \right] & \text{for } k = 8, \\ 0 & \text{otherwise.} \end{cases}$ | g |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|

New foliage capacity.

|                                                                                                                                                                                |   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|
| $g_2 = \begin{cases} \max \left[ 0, x_2 - b_{32} \left( 1 - \frac{b_{31}}{100} \right) \right] & \text{for } k = 9, \text{ Needle drop.} \\ 0 & \text{otherwise.} \end{cases}$ | g |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|

|                                                                                     |                                                                             |
|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| $g_3 = \begin{cases} x_1 & \text{for } k = 8, \\ 0 & \text{otherwise.} \end{cases}$ | <p style="margin: 0;">Aging of new foliage.</p> <p style="margin: 0;">g</p> |
|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|

|                                                                                                             |                                                                                   |
|-------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| $g_4 = \begin{cases} \min(g_{16}, x_1) & \text{for } 1 \leq k \leq 6, \\ 0 & \text{otherwise.} \end{cases}$ | <p style="margin: 0;">Destruction of new foliage.</p> <p style="margin: 0;">g</p> |
|-------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|

|                                                                                                             |                                                                                   |
|-------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| $g_5 = \begin{cases} \min(g_{18}, x_2) & \text{for } 1 \leq k \leq 6, \\ 0 & \text{otherwise.} \end{cases}$ | <p style="margin: 0;">Destruction of old foliage.</p> <p style="margin: 0;">g</p> |
|-------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|

<sup>10/</sup> For more complete descriptions see Version 1.2 FLEXFORM.

| Functional Form and Description | Units |
|---------------------------------|-------|
|---------------------------------|-------|

$$g_6 = \begin{cases} (1 - r_k)(1 - r_{k+6})(1 - b_k) & \text{for } 1 \leq k \leq 6, \\ 0 & \text{otherwise.} \end{cases} \quad d^{-1}$$

Daily survivorship after disease, predator/parasite, and background mortality.

$$g_7 = \begin{cases} 1 - r_{k+12} & \text{for } 1 \leq k \leq 6, \\ 0 & \text{otherwise.} \end{cases} \quad d^{-1}$$

Daily survivorship after food stress.

$$g_8 = \begin{cases} 10^{g_6} 10^{g_7} - 1 & \text{for } 1 \leq k \leq 6, \\ 0 & \text{otherwise.} \end{cases} \quad \text{none}$$

Negative total mortality rate for an instar. [Assume  $0^0 \equiv 1$ .]

$$g_9 = \begin{cases} 0 & \text{for } k = 0 \text{ or } 9, \\ x_1^* + g_{17} & \text{otherwise.} \end{cases} \quad d$$

(Implicitly,  $x_1^*(k+1) = x_1^*(k) + g_{17}(k)$ )

Total number of days spent feeding on old foliage during which demand is fully satisfied.

Special Occasion Processes:

$$g_{10} = \begin{cases} -b_{36} & \text{for } k = 0, \text{ Establishment mortality.} \\ -b_{30}(1 + g_8) & \text{for } k = 5, \text{ Male pupation.} \\ -b_{34} & \text{for } k = 7, \text{ Female pupal mortality.} \\ b_{35}g_{14}(1 - b_{28}g_9) - 1 & \text{for } k = 8, \text{ Viable eggs produced.} \\ -b_{37} & \text{for } k = 9, \text{ Overwinter mortality.} \\ 0 & \text{otherwise.} \end{cases} \quad \text{none}$$

| Functional Form and Description                                                                                                                                                                                                                                                                                           | Units    |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| $g_{11} = (g_8 + g_{10})x_3$ <p>Larval mortality, male pupation, pupal mortality, egg production, and overwinter mortality.</p>                                                                                                                                                                                           | number   |
| $g_{12} = \begin{cases} 0 & \text{for } x_3 \leq 0, \\ (x_1 + x_2) \leq 0, \text{ or } k > 6, \text{ Instantaneous} \\ b_{22} & \text{for } 1 \leq k < 4, \quad \text{daily growth} \\ b_{23} & \text{for } k = 4, \quad \text{rate.} \\ b_{24} & \text{for } 4 < k \leq 6. \end{cases}$                                  | $d^{-1}$ |
| $g_{13} = \begin{cases} b_{25} & \text{for } k = 0, \\ x_4(e^{[10\phi g_{12}]} - 1) & \text{for } 1 \leq k \leq 6, \\ 0 & \text{for } k > 6, \end{cases}$                                                                                                                                                                 | mg       |
| <p>where</p> $\phi = \left[ \frac{g_4 + g_5}{g_4 + g_{18}} \right]$                                                                                                                                                                                                                                                       |          |
| <p>Achieved larval growth increment for an instar. The proportion <math>\phi</math> is the ratio of actual needle destruction to total needle demand; if less than one, the larvae did not feed all 10 days, and the number of days spent growing is reduced according to the proportion <math>\phi</math>.</p>           |          |
| $g_{14} = \max \left[ \frac{2x_4}{b_{26}} - 1, 0 \right]$ <p>Fecundity stress index.</p>                                                                                                                                                                                                                                  | none     |
| $g_{15} = \begin{cases} \alpha & \text{where } \alpha \in \{0, 1, \dots, 10\} \text{ is} \\ & \text{the largest integer such that} \\ & \text{UV1}(k, x, b, \alpha) < x_1, \\ 0 & \text{for } k = 0 \text{ or } k > 6 \text{ or if no } \alpha \text{ exists that} \\ & \text{satisfies the above inequity.} \end{cases}$ | d        |
| <p>Time spent feeding exclusively on new foliage.</p>                                                                                                                                                                                                                                                                     |          |

| Functional Form and Description | Units |
|---------------------------------|-------|
|---------------------------------|-------|

$$g_{16} = \begin{cases} UV1(k, \underline{x}, \underline{b}, \min[g_{15} + 1, 10]) & \text{for } x_1 > 0 \text{ and } 1 \leq k \leq 6, \\ 0 & \text{otherwise.} \end{cases} \quad g$$

Total new foliage demand.

$$g_{17} = \begin{cases} \eta & \text{where } \eta \in \{0, 1, \dots, 10 - g_{15}\} \\ & \text{is the smallest integer such that} \\ & [UV2(k, \underline{x}, \underline{b}, g_{15}, \eta + 1) - \\ & (x_1 - UV1(k, \underline{x}, \underline{b}, g_{15}))] > x_2 \text{ and} \\ 10 - g_{15} & \text{otherwise for } 1 \leq k \leq 6, \\ 0 & \text{for } k = 0 \text{ or } k > 6. \end{cases} \quad d$$

The number of days spent feeding on old foliage for which demand is fully satisfied.

$$g_{18} = \begin{cases} \max[UV2(k, \underline{x}, \underline{b}, g_{15}, 10 - g_{15}) - \\ (x_1 - UV1(k, \underline{x}, \underline{b}, g_{15}))], & \text{for } 1 \leq k \leq 6, \\ 0 & \text{for } k = 0 \text{ or } k > 6. \end{cases} \quad g$$

Total old foliage demand for remainder of the instar.

$$g_{19} = \begin{cases} 0 & \text{for } k = 0 \text{ or } 9, \\ x_2^* & \text{for } k = 7 \text{ or } 8, \\ x_2^* + 10 - [g_{15} + g_{17}] & \text{otherwise.} \end{cases} \quad g$$

(Implicitly,  $x_2^*(k + 1) = x_2^*(k) + 10 - [g_{15}(k) + g_{17}(k)]$ ).

Total number of days during which demand for food is not fully satisfied.

#### 4. F Functions

| Functional Form and Description                                                                                                                           | Units                                              |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|
| $\left. \begin{aligned} f_{1,1} &= g_1 - g_4 \\ f_{1,2} &= g_3 \\ f_{2,2} &= -g_5 - g_2 \\ f_{3,3} &= g_{11} \\ f_{4,4} &= g_{13} \end{aligned} \right\}$ | <p>g</p> <p>g</p> <p>g</p> <p>number</p> <p>mg</p> |
| See state variables, X list,<br>for descriptions.                                                                                                         |                                                    |

#### 5. Y Functions

$$y_i = x_i, \quad i = 1, 2, 3, 4 \text{ See X list for description and units.}$$

#### 6. Special Functions

| Functional Form and Description                                                                                                                                                                                                                                                                                                                                                                                                                                              | Units |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| $UV_1(k, \underline{x}, \underline{b}, \alpha) = U(\underline{x}, \underline{b}, k) \cdot V_1(\underline{b}, \alpha, k),$ <p>where</p> $U(\underline{x}, \underline{b}, k) = \frac{10^{-3}}{b_{21}} \left[ b_{19} + \frac{b_{20}}{g_{12}} \right] (e^{g_{12}} - 1)x_3x_4,$ $V_1(\underline{b}, \alpha, k) = b_{6+k} \frac{1 - \left[ g_6 e^{g_{12}} \right]^\alpha}{1 - g_6 e^{g_{12}}},$ <p>and</p> <p><math>UV_1 = 0</math> for <math>k \notin \{1, \dots, 6\}</math>.</p> | g     |

Total new foliage demand for an instar. U is the food demand for metabolism and growth,  $V_1$  is the product of the destruction/consumption ratio and the convolution of daily larval growth and daily larval survivorship during feeding on new foliage. See  $g_{14}$  and  $g_{15}$ .

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Functional Form and Description Units

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$$UV2(k, \underline{x}, \underline{b}, \alpha, \eta) = U(\underline{x}, \underline{b}, k) \cdot V_2(\underline{b}, \alpha, \eta, k). \quad g$$

where U is given in UV1 above

and

$$V_2(\underline{b}, \alpha, \eta, k) = b_{12+k} g_6^{\alpha} e^{\alpha g_{12}} \left[ \frac{1 - \left[ g_6 g_7^e \right]^{\eta}}{1 - \left[ g_6 g_7^e \right]} \right]$$

$$UV2 = 0 \text{ for } k \notin \{1, \dots, 6\}$$

Total old foliage demand for an instar. U is the food demand for metabolism and growth,  $V_2$  is the product of the destruction/consumption ratio with the convolution of the daily larval growth and daily larval survivorship during feeding on old foliage.

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PARAMETERS

7. B Parameters

| <u>List</u> | <u>Value</u> |        | <u>Description</u>                                                        | <u>Units</u> |
|-------------|--------------|--------|---------------------------------------------------------------------------|--------------|
|             |              | Instar |                                                                           |              |
| $b_1$       | 0.02         | 1st    | Instar-specific background daily mortality rate.                          | $d^{-1}$     |
| $b_2$       | 0.02         | 2nd    |                                                                           |              |
| $b_3$       | 0.02         | 3rd    |                                                                           |              |
| $b_4$       | 0.02         | 4th    |                                                                           |              |
| $b_5$       | 0.02         | 5th    |                                                                           |              |
| $b_6$       | 0.02         | 6th    |                                                                           |              |
| $b_7$       | 5.4          | 1st    | Instar-specific destruction/consumption ratio for feeding on new foliage. | none         |
| $b_8$       | 6.25         | 2nd    |                                                                           |              |
| $b_9$       | 6.25         | 3rd    |                                                                           |              |
| $b_{10}$    | 2.71         | 4th    |                                                                           |              |
| $b_{11}$    | 2.27         | 5th    |                                                                           |              |
| $b_{12}$    | 2.0          | 6th    |                                                                           |              |
| $b_{13}$    | 5.4          | 1st    | Instar-specific destruction/consumption ratio for feeding on old foliage. | none         |
| $b_{14}$    | 6.25         | 2nd    |                                                                           |              |
| $b_{15}$    | 6.25         | 3rd    |                                                                           |              |
| $b_{16}$    | 3.69         | 4th    |                                                                           |              |
| $b_{17}$    | 3.29         | 5th    |                                                                           |              |
| $b_{18}$    | 3.0          | 6th    |                                                                           |              |

| List                           | Value                                       | Description                                                             | Units                  |
|--------------------------------|---------------------------------------------|-------------------------------------------------------------------------|------------------------|
| b <sub>19</sub>                | 1.19                                        | Assimilated food, growth coefficient.                                   | none                   |
| b <sub>20</sub>                | 0.081                                       | Assimilated food, respiration coefficient.                              | d <sup>-1</sup>        |
| b <sub>21</sub>                | 0.10                                        | Assimilation efficiency.                                                | none                   |
| b <sub>22</sub>                | 0.1147                                      | Instantaneous growth rate for first three instars.                      | d <sup>-1</sup>        |
| b <sub>23</sub>                | 0.0886                                      | Instantaneous growth rate for fourth instar.                            | d <sup>-1</sup>        |
| b <sub>24</sub>                | 0.0625                                      | Instantaneous growth rate for fifth and sixth instars.                  | d <sup>-1</sup>        |
| b <sub>25</sub>                | 0.197                                       | Initial biomass of larvae at hatch.                                     | mg                     |
| b <sub>26</sub>                | 52.063                                      | Nominal biomass of female larvae at the end of the sixth instar.        | mg                     |
| b <sub>27</sub>                | 0.02                                        | Coefficient of reduction in bud capacity from total branch defoliation. | d <sup>-1</sup>        |
| b <sub>28</sub>                | 0.01                                        | Coefficient of reduction in fecundity from feeding on old foliage.      | d <sup>-1</sup>        |
| b <sub>29</sub>                | 1,2,3,4                                     | Phase index.                                                            | none                   |
| b <sub>30</sub>                | 0.50                                        | Proportion of larvae that are male at the end of the fifth instar.      | none                   |
| b <sub>31</sub> <sup>11/</sup> |                                             | Nominal percent new foliage.                                            | none                   |
| b <sub>32</sub> <sup>11/</sup> |                                             | Nominal total foliage biomass.                                          | g                      |
| b <sub>33</sub>                | (not used)                                  |                                                                         |                        |
| b <sub>34</sub>                | I:0.50;<br>II:0.62;<br>III:0.75;<br>IV:0.80 | Phase-specific pupal mortality rate.                                    | occasion <sup>-1</sup> |
| b <sub>35</sub>                | I,II:200;<br>III,IV:150.                    | Phase-specific maximum egg-mass size.                                   | number                 |
| b <sub>36</sub>                | I,II,III,<br>IV:0.0                         | Phase-specific establishment mortality rate.                            | occasion <sup>-1</sup> |
| b <sub>37</sub>                | I:0.50;<br>II:0.60;<br>III:0.85;<br>IV:0.90 | Phase-specific overwinter mortality rate.                               | occasion <sup>-1</sup> |

<sup>11/</sup> Note: b<sub>31</sub> and b<sub>32</sub> have values that depend on the host tree being simulated and are chosen, accordingly, prior to a specific simulation.

# 8. R Parameters

| <u>List</u>                | <u>Value</u> |       |       |       |        | <u>Description</u>                                                | <u>Units</u>    |
|----------------------------|--------------|-------|-------|-------|--------|-------------------------------------------------------------------|-----------------|
|                            | - Phase -    |       |       |       | Instar |                                                                   |                 |
|                            | I            | II    | III   | IV    |        |                                                                   |                 |
| r <sub>1</sub>             | 0.0          | 0.0   | 0.002 | 0.025 | 1st    | Instar- and phase-specific daily disease mortality rate           | d <sup>-1</sup> |
| r <sub>2</sub>             | 0.0          | 0.0   | 0.003 | 0.028 | 2nd    |                                                                   |                 |
| r <sub>3</sub>             | 0.0          | 0.0   | 0.006 | 0.031 | 3rd    |                                                                   |                 |
| r <sub>4</sub>             | 0.0          | 0.0   | 0.013 | 0.034 | 4th    |                                                                   |                 |
| r <sub>5</sub>             | 0.0          | 0.001 | 0.035 | 0.035 | 5th    |                                                                   |                 |
| r <sub>6</sub>             | 0.0          | 0.001 | 0.028 | 0.035 | 6th    |                                                                   |                 |
| r <sub>7</sub>             | 0.0          | 0.0   | 0.001 | 0.005 | 1st    | Instar- and phase-specific daily predator/parasite mortality rate | d <sup>-1</sup> |
| r <sub>8</sub>             | 0.0          | 0.0   | 0.002 | 0.006 | 2nd    |                                                                   |                 |
| r <sub>9</sub>             | 0.0          | 0.0   | 0.003 | 0.007 | 3rd    |                                                                   |                 |
| r <sub>10</sub>            | 0.0          | 0.0   | 0.010 | 0.021 | 4th    |                                                                   |                 |
| r <sub>11</sub>            | 0.0          | 0.001 | 0.016 | 0.033 | 5th    |                                                                   |                 |
| r <sub>12</sub>            | 0.0          | 0.001 | 0.042 | 0.056 | 6th    |                                                                   |                 |
| Douglas-fir      grand fir |              |       |       |       |        |                                                                   |                 |
| r <sub>13</sub>            | 1.0          |       | 1.0   |       | 1st    | Instar- and host-specific daily food-stress mortality rate.       | d <sup>-1</sup> |
| r <sub>14</sub>            | 0.75         |       | 0.8   |       | 2nd    |                                                                   |                 |
| r <sub>15</sub>            | 0.10         |       | 0.5   |       | 3rd    |                                                                   |                 |
| r <sub>16</sub>            | 0.0          |       | 0.1   |       | 4th    |                                                                   |                 |
| r <sub>17</sub>            | 0.0          |       | 0.0   |       | 5th    |                                                                   |                 |
| r <sub>18</sub>            | 0.0          |       | 0.0   |       | 6th    |                                                                   |                 |

9. Initial Conditions<sup>12/</sup>

|       |      |
|-------|------|
| $x_1$ | 50.4 |
| $x_2$ | 93.6 |
| $x_3$ | 75.0 |
| $x_4$ | 0.0  |

---

GENERAL RUN INFORMATION

TSTART = 0

TMAX = 10

q = 1

LP, DUMP: All y's; all g's

LP, DUMP frequency: 1

RUN LOG: This version of the model was developed for the purpose of documentation and was run only to verify this model form against V3.1. See appendix B for verification output.

Source code file: INSTAR

FLEX3 overlay: \*INSTAR

---

<sup>12/</sup> These initial conditions, along with the phase II b and r parameters for grand fir, were used to develop the appendix B verification output.

FLEXFORM: V3.1  
MODULE: S<sub>0</sub>  
Page 1 of 7

TITLE: DFTM Stand-Outbreak Model Version 3.1  
Outbreak/Stand Module.

INVESTIGATORS: Overton, Colbert, White

DATE: September 17, 1976

March 15, 1977 (revised)

TEMPORAL RESOLUTION: Outbreak/phase.

SPATIAL RESOLUTION: Stand (by tree class).

QUANTITIES MODELED: Biomass (dry weight) of foliage and larvae, number of insects per model branch, for each tree class.

DIAGRAM: See figure 3.

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#### VARIABLES AND FUNCTIONS

##### 1. X List

| <u>List</u>    |       | <u>Description</u>                                                                      | <u>Units</u> |
|----------------|-------|-----------------------------------------------------------------------------------------|--------------|
|                | Phase |                                                                                         |              |
| x <sub>1</sub> | I     | Weighted mean number of eggs<br>per model branch over the tree<br>classes of the stand. | number       |
| x <sub>2</sub> | II    |                                                                                         |              |
| x <sub>3</sub> | III   |                                                                                         |              |
| x <sub>4</sub> | IV    |                                                                                         |              |

The vector variables below contain an element for each tree class:

|                |                                                             |        |
|----------------|-------------------------------------------------------------|--------|
| x <sub>5</sub> | Actual new foliage potential (on entry to S <sub>1</sub> ). | g      |
|                | Actual new foliage biomass (on exit from S <sub>1</sub> ).  |        |
| x <sub>6</sub> | Actual total foliage biomass (on entry to S <sub>1</sub> ). | g      |
|                | Actual old foliage biomass (on exit from S <sub>1</sub> ).  |        |
| x <sub>7</sub> | Number of viable eggs.                                      | number |

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2. Z Functions<sup>13/</sup>

| <u>List</u>    |                                                                                                                                                                                                                                                                                                                            | <u>Units</u> |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
| z <sub>1</sub> | The number of tree classes in the stand for the current model run. This number is entered by the user <b>during</b> a model run. This value is stored in b57 for use in computing the final weighted mean number of eggs. This is also the value of p in the input command file and must be set <b>before</b> a model run. | number       |

The vector variables below contain an element for each tree class:

|                |                                                |        |
|----------------|------------------------------------------------|--------|
| z <sub>2</sub> | Nominal percent new foliage.                   | none   |
| z <sub>3</sub> | Nominal total foliage biomass.                 | g      |
| z <sub>4</sub> | Number of trees.                               | number |
| z <sub>5</sub> | Weighting factor.                              | none   |
| z <sub>6</sub> | Host species (1 = Douglas-fir, 2 = grand fir). | none   |

3. G Functions

| <u>Functional Form and Description</u>                                                                                               | <u>Units</u>           |
|--------------------------------------------------------------------------------------------------------------------------------------|------------------------|
| $g_1 = k' + 1$                                                                                                                       | Phase index.<br>number |
| $g_{2j} \stackrel{14/}{=} \begin{cases} x_{7j} + b_{62}(x_{k'} - x_{7j}) & \text{for } k' > 0, \\ 0 & \text{otherwise.} \end{cases}$ | none                   |

Redistribution of viable eggs over the stand. (Implemented by a call to special function REDIST.)

<sup>13/</sup> Note: the z values are entered by the user in specifying a stand-outbreak model run.

<sup>14/</sup> Functions g<sub>2</sub>, g<sub>3</sub>, and g<sub>4</sub> process all tree classes on the first pass through the g functions each phase.

| Functional Form and Description                                                                                                | Units |
|--------------------------------------------------------------------------------------------------------------------------------|-------|
| $g_{3j}^{14/} = \begin{cases} \min[x_{6j}, z_{3j}(1 - z_{2j}/100)] & \text{for } k' > 0, \\ 0 & \text{otherwise.} \end{cases}$ | g     |

Old foliage survivorship.

|                                                                                                                  |        |
|------------------------------------------------------------------------------------------------------------------|--------|
| $g_{4j}^{14/} = \begin{cases} (1 - b_{56+g_1})g_{2j} & \text{for } k' > 0, \\ 0 & \text{otherwise.} \end{cases}$ | number |
|------------------------------------------------------------------------------------------------------------------|--------|

Overwinter survival of eggs.

#### 4. Y Functions

YCOMP calls REDIST for computation of the mean fall egg density over the stand after phase IV. No y functions, per se, are included in this module. Instead, YCOMP accesses certain special functions to produce specially formatted output tables. These are documented elsewhere (see: Logical Unit Manipulation by User-Specified Functions).

#### 5. Special Functions

Subroutine REDIST(k', n, b, x)

This subroutine first computes the mean egg density over the stand as follows:

$$x_{k'} = \frac{1}{T} \sum_{j=1}^N z_{4j} z_{5j} x_{7j}(k'),$$

where

$$T = \sum_{j=1}^N z_{4j} z_{5j}$$

and N is the number of tree classes;  $z_{4j}$  is the number of trees in the jth tree class;  $z_{5j}$  is the weight associated with a tree of the jth tree class;  $x_{7j}$  is the number of viable eggs laid for the jth tree class; and  $x_{k'}$  is the fall mean egg density over the stand in phase k'.

The subroutine then redistributes the eggs over the stand according to  $g_2$ .

PARAMETERS

6. B Parameters

|                 | <u>Value</u> |        |       | <u>Description</u>                                                                                                    | <u>Units</u>    |  |  |
|-----------------|--------------|--------|-------|-----------------------------------------------------------------------------------------------------------------------|-----------------|--|--|
|                 |              | Instar | Phase |                                                                                                                       |                 |  |  |
| b <sub>1</sub>  | 0.0          | 1st    | I     | Instar-specific<br>disease mortality<br>rate.<br>(r <sub>1</sub> , ..., r <sub>6</sub> in<br>Version 2.2)             | d <sup>-1</sup> |  |  |
| b <sub>2</sub>  | 0.0          | 2nd    |       |                                                                                                                       |                 |  |  |
| b <sub>3</sub>  | 0.0          | 3rd    |       |                                                                                                                       |                 |  |  |
| b <sub>4</sub>  | 0.0          | 4th    |       |                                                                                                                       |                 |  |  |
| b <sub>5</sub>  | 0.0          | 5th    |       |                                                                                                                       |                 |  |  |
| b <sub>6</sub>  | 0.0          | 6th    |       |                                                                                                                       |                 |  |  |
| b <sub>7</sub>  | 0.0          | 1st    | II    |                                                                                                                       |                 |  |  |
| b <sub>8</sub>  | 0.0          | 2nd    |       |                                                                                                                       |                 |  |  |
| b <sub>9</sub>  | 0.0          | 3rd    |       |                                                                                                                       |                 |  |  |
| b <sub>10</sub> | 0.0          | 4th    |       |                                                                                                                       |                 |  |  |
| b <sub>11</sub> | 0.001        | 5th    |       |                                                                                                                       |                 |  |  |
| b <sub>12</sub> | 0.001        | 6th    |       |                                                                                                                       |                 |  |  |
| b <sub>13</sub> | 0.002        | 1st    | III   |                                                                                                                       |                 |  |  |
| b <sub>14</sub> | 0.003        | 2nd    |       |                                                                                                                       |                 |  |  |
| b <sub>15</sub> | 0.006        | 3rd    |       |                                                                                                                       |                 |  |  |
| b <sub>16</sub> | 0.013        | 4th    |       |                                                                                                                       |                 |  |  |
| b <sub>17</sub> | 0.035        | 5th    |       |                                                                                                                       |                 |  |  |
| b <sub>18</sub> | 0.028        | 6th    |       |                                                                                                                       |                 |  |  |
| b <sub>19</sub> | 0.025        | 1st    | IV    |                                                                                                                       |                 |  |  |
| b <sub>20</sub> | 0.028        | 2nd    |       |                                                                                                                       |                 |  |  |
| b <sub>21</sub> | 0.031        | 3rd    |       |                                                                                                                       |                 |  |  |
| b <sub>22</sub> | 0.034        | 4th    |       |                                                                                                                       |                 |  |  |
| b <sub>23</sub> | 0.035        | 5th    |       |                                                                                                                       |                 |  |  |
| b <sub>24</sub> | 0.035        | 6th    |       |                                                                                                                       |                 |  |  |
| b <sub>25</sub> | 0.0          | 1st    | I     | Instar-specific<br>predator/parasite<br>mortality rates.<br>(r <sub>7</sub> , ..., r <sub>12</sub> in<br>Version 2.2) | d <sup>-1</sup> |  |  |
| b <sub>26</sub> | 0.0          | 2nd    |       |                                                                                                                       |                 |  |  |
| b <sub>27</sub> | 0.0          | 3rd    |       |                                                                                                                       |                 |  |  |
| b <sub>28</sub> | 0.0          | 4th    |       |                                                                                                                       |                 |  |  |
| b <sub>29</sub> | 0.0          | 5th    |       |                                                                                                                       |                 |  |  |
| b <sub>30</sub> | 0.0          | 6th    |       |                                                                                                                       |                 |  |  |
| b <sub>31</sub> | 0.0          | 1st    | II    |                                                                                                                       |                 |  |  |
| b <sub>32</sub> | 0.0          | 2nd    |       |                                                                                                                       |                 |  |  |
| b <sub>33</sub> | 0.0          | 3rd    |       |                                                                                                                       |                 |  |  |
| b <sub>34</sub> | 0.0          | 4th    |       |                                                                                                                       |                 |  |  |
| b <sub>35</sub> | 0.001        | 5th    |       |                                                                                                                       |                 |  |  |
| b <sub>36</sub> | 0.001        | 6th    |       |                                                                                                                       |                 |  |  |

Instar-specific  
disease mortality  
rate.  
(r<sub>1</sub>, ..., r<sub>6</sub> in  
Version 2.2)

Instar-specific  
predator/parasite  
mortality rates.  
(r<sub>7</sub>, ..., r<sub>12</sub> in  
Version 2.2)

(continued)

|                 | <u>Value</u> |                                          |       | <u>Description</u>                                                     | <u>Units</u>           |
|-----------------|--------------|------------------------------------------|-------|------------------------------------------------------------------------|------------------------|
|                 |              | Instar                                   | Phase |                                                                        |                        |
| b <sub>37</sub> | 0.001        | 1st                                      | III   |                                                                        |                        |
| b <sub>38</sub> | 0.002        | 2nd                                      |       |                                                                        |                        |
| b <sub>39</sub> | 0.003        | 3rd                                      |       |                                                                        |                        |
| b <sub>40</sub> | 0.010        | 4th                                      |       |                                                                        |                        |
| b <sub>41</sub> | 0.016        | 5th                                      |       |                                                                        |                        |
| b <sub>42</sub> | 0.042        | 6th                                      |       |                                                                        |                        |
| b <sub>43</sub> | 0.005        | 1st                                      | IV    |                                                                        |                        |
| b <sub>44</sub> | 0.006        | 2nd                                      |       |                                                                        |                        |
| b <sub>45</sub> | 0.007        | 3rd                                      |       |                                                                        |                        |
| b <sub>46</sub> | 0.021        | 4th                                      |       |                                                                        |                        |
| b <sub>47</sub> | 0.033        | 5th                                      |       |                                                                        |                        |
| b <sub>48</sub> | 0.056        | 6th                                      |       |                                                                        |                        |
| b <sub>49</sub> | 0.50         |                                          | I     | Pupal mortality rate.<br>(b <sub>34</sub> in Version 2.2)              | occasion <sup>-1</sup> |
| b <sub>50</sub> | 0.62         |                                          | II    |                                                                        |                        |
| b <sub>51</sub> | 0.75         |                                          | III   |                                                                        |                        |
| b <sub>52</sub> | 0.80         |                                          | IV    |                                                                        |                        |
| b <sub>53</sub> | 200          |                                          | I     | Maximum egg-mass size<br>eggs/mass (b <sub>35</sub> in<br>Version 2.2) | number                 |
| b <sub>54</sub> | 200          |                                          | II    |                                                                        |                        |
| b <sub>55</sub> | 150          |                                          | III   |                                                                        |                        |
| b <sub>56</sub> | 150          |                                          | IV    |                                                                        |                        |
| b <sub>57</sub> | --           | Number of tree classes (see z functions) |       |                                                                        | number                 |
| Phase           |              |                                          |       |                                                                        |                        |
| b <sub>58</sub> | 0.50         |                                          | I     | Overwinter<br>mortality rate.<br>(b <sub>37</sub> in Version 2.2)      | occasion <sup>-1</sup> |
| b <sub>59</sub> | 0.60         |                                          | II    |                                                                        |                        |
| b <sub>60</sub> | 0.85         |                                          | III   |                                                                        |                        |
| b <sub>61</sub> | 0.90         |                                          | IV    |                                                                        |                        |
| b <sub>62</sub> | 0.0          | Redistribution dispersal factor          |       |                                                                        | none                   |
| b <sub>63</sub> | 0.0          |                                          | I     | Establishment<br>mortality rate.<br>(b <sub>36</sub> in Version 2.2)   | occasion <sup>-1</sup> |
| b <sub>64</sub> | 0.0          |                                          | II    |                                                                        |                        |
| b <sub>65</sub> | 0.0          |                                          | III   |                                                                        |                        |
| b <sub>66</sub> | 0.0          |                                          | IV    |                                                                        |                        |

## 7. R Parameters

|                 | <u>Value</u> |        | <u>Description</u>                                                                                                                                       | <u>Units</u> |
|-----------------|--------------|--------|----------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
|                 |              | Instar |                                                                                                                                                          |              |
| r <sub>1</sub>  | 1.0          | 1st    | Instar-specific daily food stress <sup>15/</sup> mortality rates for Douglas-fir host species. (r <sub>13</sub> , ..., r <sub>18</sub> in Version 2.2)   | none         |
| r <sub>2</sub>  | 0.75         | 2nd    |                                                                                                                                                          |              |
| r <sub>3</sub>  | 0.10         | 3rd    |                                                                                                                                                          |              |
| r <sub>4</sub>  | 0.0          | 4th    |                                                                                                                                                          |              |
| r <sub>5</sub>  | 0.0          | 5th    |                                                                                                                                                          |              |
| r <sub>6</sub>  | 0.0          | 6th    |                                                                                                                                                          |              |
| r <sub>7</sub>  | 1.0          | 1st    | Instar-specific daily food stress <sup>15/</sup> mortality rates for the grand fir host species. (r <sub>13</sub> , ..., r <sub>18</sub> in Version 2.2) | none         |
| r <sub>8</sub>  | 0.8          | 2nd    |                                                                                                                                                          |              |
| r <sub>9</sub>  | 0.5          | 3rd    |                                                                                                                                                          |              |
| r <sub>10</sub> | 0.1          | 4th    |                                                                                                                                                          |              |
| r <sub>11</sub> | 0.0          | 5th    |                                                                                                                                                          |              |
| r <sub>12</sub> | 0.0          | 6th    |                                                                                                                                                          |              |
| r <sub>13</sub> | 0.02         | 1st    | Instar-specific daily background mortality rate. (b <sub>1</sub> , ..., b <sub>6</sub> in Version 2.2)                                                   | none         |
| r <sub>14</sub> | 0.02         | 2nd    |                                                                                                                                                          |              |
| r <sub>15</sub> | 0.02         | 3rd    |                                                                                                                                                          |              |
| r <sub>16</sub> | 0.02         | 4th    |                                                                                                                                                          |              |
| r <sub>17</sub> | 0.02         | 5th    |                                                                                                                                                          |              |
| r <sub>18</sub> | 0.02         | 6th    |                                                                                                                                                          |              |

## 8. Initial Conditions

See appendix C for an example of the specification of initial conditions.

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<sup>15/</sup> Stress from feeding on old foliage during early instars.

FLEXFORM: V3.1  
MODULE: S<sub>0</sub>  
Page 7 of 7

DFTM Stand-Outbreak Model  
March 15, 1977

#### GENERAL RUN INFORMATION

Module Sequence Number = 0  
TMAX = 1      q = 4  
Module type: ghost  
Variables to be monitored: none.  
Variables to be dump filed: none.

#### FILE NAMES

FLEX2 function overlay name: \*V31SO  
Source file name: V31SO

#### COMMENTS

Model behavior will be documented in a separate paper. A record of the model runs made in studying behavior will be included therein. Appendix A contains the source code for Version 3.1 and the command file for initializing a simulation. Appendix C contains the inputs and outputs from a verification simulation.

FLEXFORM: V3.1      TITLE: DFTM Stand-Outbreak Model,  
 MODULE: S<sub>1</sub>      Version 3.1, Tree/Branch Module  
 Page 1 of 5      INVESTIGATORS: Overton, Colbert, White  
                     DATE: September 17, 1976  
                                 March 15, 1977 (revised)  
 TEMPORAL RESOLUTION: Phase/instar, occasion.  
 SPATIAL RESOLUTION: Tree class/hypothetical model branch.  
 QUANTITIES MODELED: Biomass (dry weight) of foliage and larvae, number  
                                 of insects.  
 SUBSYSTEMS: 1. Foliage dynamics  
                     2. Population dynamics  
                     3. Growth and feeding

DIAGRAM:

(See the diagram on page 2 of Version 1.2 FLEXFORM.)

# VARIABLES AND FUNCTIONS

## 1. X List

| <u>List</u>    | <u>Description</u>                                                                                                                                                           | <u>Units</u> |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
| x <sub>1</sub> | New foliage biomass (k' = 0, ..., 8).<br>New foliage potential for next year (k' = 9, 10).                                                                                   | g            |
| x <sub>2</sub> | Old foliage biomass.                                                                                                                                                         | g            |
| x <sub>3</sub> | Viable eggs (k' = 0).<br>Larvae (k' = 1, ..., 5).<br>Female larvae (k' = 6).<br>Female pupae (k' = 7).<br>Adult female moths (k' = 8).<br>Viable eggs produced (k' = 9, 10). | number       |
| x <sub>4</sub> | Individual larval biomass.                                                                                                                                                   | mg           |

## 2. Input Variables

### Z Functions

| <u>Functional Form</u>  | <u>Description</u>             | <u>Units</u> |
|-------------------------|--------------------------------|--------------|
| $z_1 = z_{2j}$ in $S_0$ | Nominal percent new foliage.   | none         |
| $z_2 = z_{3j}$ in $S_0$ | Nominal total foliage biomass. | g            |
| $z_3 = g_1$ in $S_0$    | Phase index.                   | none         |
| $z_4 = z_{6j}$ in $S_0$ | Host species index.            | none         |

### Parameter Assignments

#### B Parameters

$[b_1, \dots, b_6] = [r_{13}, \dots, r_{18}]$  in  $S_0$ ,  
respectively, for  $z_3 = 1, 2, 3, 4$ .

#### Value, Description, and Units

See V3.1 FLEXFORM, Module  $S_0$ , for the values, descriptions, and units of the assigned b and r parameters.

$$b_{34} = \begin{cases} b_{49} \text{ in } S_0 \text{ if } z_3 = 1, \\ b_{50} \text{ in } S_0 \text{ if } z_3 = 2, \\ b_{51} \text{ in } S_0 \text{ if } z_3 = 3, \\ b_{52} \text{ in } S_0 \text{ if } z_3 = 4. \end{cases}$$

$$b_{35} = \begin{cases} b_{53} \text{ in } S_0 \text{ if } z_3 = 1, \\ b_{54} \text{ in } S_0 \text{ if } z_3 = 2, \\ b_{55} \text{ in } S_0 \text{ if } z_3 = 3, \\ b_{56} \text{ in } S_0 \text{ if } z_3 = 4. \end{cases}$$

$$b_{36} = \begin{cases} b_{63} \text{ in } S_0 \text{ if } z_3 = 1, \\ b_{64} \text{ in } S_0 \text{ if } z_3 = 2, \\ b_{65} \text{ in } S_0 \text{ if } z_3 = 3, \\ b_{66} \text{ in } S_0 \text{ if } z_3 = 4. \end{cases}$$

R Parameters

$$[r_1, \dots, r_6] = \begin{cases} [b_1, \dots, b_6] & \text{in } S_0, \text{ respectively, for } z_3 = 1, \\ [b_7, \dots, b_{12}] & \text{in } S_0, \text{ respectively, for } z_3 = 2, \\ [b_{13}, \dots, b_{18}] & \text{in } S_0, \text{ respectively, for } z_3 = 3, \\ [b_{19}, \dots, b_{24}] & \text{in } S_0, \text{ respectively, for } z_3 = 4. \end{cases}$$

$$[r_7, \dots, r_{12}] = \begin{cases} [b_{25}, \dots, b_{30}] & \text{in } S_0, \text{ respectively, for } z_3 = 1, \\ [b_{31}, \dots, b_{36}] & \text{in } S_0, \text{ respectively, for } z_3 = 2, \\ [b_{37}, \dots, b_{42}] & \text{in } S_0, \text{ respectively, for } z_3 = 3, \\ [b_{43}, \dots, b_{48}] & \text{in } S_0, \text{ respectively, for } z_3 = 4. \end{cases}$$

$$[r_{13}, \dots, r_{18}] = \begin{cases} [r_1, \dots, r_6] & \text{in } S_0, \text{ respectively, for } z_4 = 1, \\ [r_7, \dots, r_{12}] & \text{in } S_0, \text{ respectively, for } z_4 = 2. \end{cases}$$


---

3. G Functions

$g_1, \dots, g_{19}$  are the same as in model Version 2.2, except that  $g_2$  and the portion of  $g_{10}$  accounting for occasion 10( $k=9$ ) have been moved to the upper module and the following substitutions have been made:

| Version 2.2 | Version 3.1, S <sub>1</sub> |
|-------------|-----------------------------|
| $b_{31}$    | $z_1$                       |
| $b_{32}$    | $z_2$                       |
| $b_{29}$    | $z_3$                       |

Because processing in this module takes place using the lower level,  $k$  is replaced by  $k'$  in all of the  $g$  functions.

---

4. F Functions<sup>16/</sup>

| <u>Functional Form and Description</u> |                           | <u>Units</u> |
|----------------------------------------|---------------------------|--------------|
| $f_{1,1} = 10(g_1 - g_4)$              |                           | g            |
| $f_{1,2} = 10g_3$                      | See state variables,      | g            |
| $f_{2,2} = -10g_5$                     | X List, for description   | g            |
| $f_{3,3} = 10g_{11}$                   | by corresponding indexes. | number       |
| $f_{4,4} = 10g_{13}$                   |                           | mg           |

5. Y Functions

$y_i = x_i$ ,       $i = 1, 2, 3$       See X list for description and units.

6. Special Functions

The special functions UV1 and UV2 are the same as those used in Version 2.2 except that k in the call string has been replaced by k'.

PARAMETERS

For values and definitions, see Version 2.2 FLEXFORM.

7. B Parameters

| <u>List</u>              | <u>Description</u>                                          |
|--------------------------|-------------------------------------------------------------|
| $b_1, \dots, b_6$        | Carried in S <sub>0</sub> and assigned as a variable input. |
| $b_7, \dots, b_{12}$     | As in Version 2.2 FLEXFORM.                                 |
| $b_{13}, \dots, b_{18}$  |                                                             |
| $b_{19}, \dots, b_{30}$  |                                                             |
| $b_{34}, b_{35}, b_{36}$ |                                                             |

<sup>16/</sup> Because  $q = 10$  for this module, each update is multiplied by 10 to nullify the automatic division by  $q$  (see Abstract of the FLEX Convention for further discussion).

8. R Parameters

$\left. \begin{array}{l} r_1, \dots, r_6 \\ r_7, \dots, r_{12} \\ r_{13}, \dots, r_{18} \end{array} \right\}$  Carried in  $S_0$  and assigned as a variable input.

---

---

9. Initial Conditions

See appendix C for an example of the specification of initial conditions.

---

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GENERAL RUN INFORMATION

Module Sequence Number = 1.

TMAX = 1          q = 10      TARGET

Module type: terminal.

Variables to be monitored: y<sub>1</sub>, y<sub>2</sub>, y<sub>3</sub>. Resolution: 1.

Variables to be dump filed: y<sub>1</sub>, y<sub>2</sub>, y<sub>3</sub>. Resolution: 1.

FILE NAMES

FLEX2 function overlay name: \*V31S1.

Source File name: V31S1.

COMMENTS

Model behavior will be documented in a separate paper. A record of the model runs made in studying behavior will be included therein. Appendix A contains the source code for version 3.1 and the command file for beginning a simulation. Appendix C contains the inputs and outputs from a verification simulation.

## LOGICAL UNIT MANIPULATION BY USER-SPECIFIED FUNCTIONS

The DFTM stand-outbreak model, V3.1, makes extensive utilization of logical units (LUNs) in storing various vector values and in producing specially formatted output tables. Much of the information concerning these LUNs is summarized in table 4 and figure 4. This section details the information stored on some of the LUNs and the user specified functions that produce that information.

Table 4. Logical units: assignment list  
Note: All LUNs are equipped as linear access files except LUN 25, which is a random access file.

### Logical Unit

| Number (LUN) | Description                                                                                           | Data Format      |
|--------------|-------------------------------------------------------------------------------------------------------|------------------|
| 1            | Phase I initial conditions                                                                            | (I2, 7F11.5, I3) |
| 2            | Phase I outputs                                                                                       | (3F12.6)         |
| 3            | Phase I redistributed insects                                                                         | (1F12.6)         |
| 4            | Phase II initial conditions                                                                           | (I2, 7F11.5, I3) |
| 5            | Phase II outputs                                                                                      | (3F12.6)         |
| 6            | Phase II redistributed insects                                                                        | (1F12.6)         |
| 7            | Phase III initial conditions                                                                          | (I2, 7F11.5, I3) |
| 8            | Phase III outputs                                                                                     | (3F12.6)         |
| 9            | Phase III redistributed insects                                                                       | (1F12.6)         |
| 10           | Phase IV initial conditions                                                                           | (I2, 7F11.5, I3) |
| 11           | Phase IV outputs                                                                                      | (3F12.6)         |
| 12           | Phase IV redistributed insects                                                                        | (1F12.6)         |
| 13           | Mortality and top-kill for<br>Douglas-fir host species                                                | (1F7.4, 6F6.3)   |
| 14           | Mortality and top-kill for<br>grand fir                                                               | (1F7.4, 6F6.3)   |
| 15           | Table 1: Insect-foliage<br>outbreak summary                                                           | variable BCD     |
| 16           | Table 2: Foliage-stand<br>outbreak summary                                                            | variable BCD     |
| 17           | Table 3: Simulation run model<br>parameterization                                                     | variable BCD     |
| 18           | Screen display format of table 1                                                                      | variable BCD     |
| 19           | Scratch pad for temporary storage<br>of module $S_0$ function $g_3$ output<br>values ( $\hat{g}_3$ .) | (1F12.6)         |
| 20           | Table 4: (optional) detail<br>output of state variables during<br>each phase                          | variable BCD     |
| 21           | State variable values at each<br>occasion for each tree class and<br>phase in a simulation            | (4(2X, F14.7))   |
| 22           | Screen display format of<br>table 2: part I                                                           | variable BCD     |
| 23           | Screen display format of<br>table 2: part II                                                          | variable BCD     |
| 24           | Screen display format of<br>table 2: part II                                                          | variable BCD     |
| 25           | State-variable values: input<br>file for table 4 generation                                           | binary           |

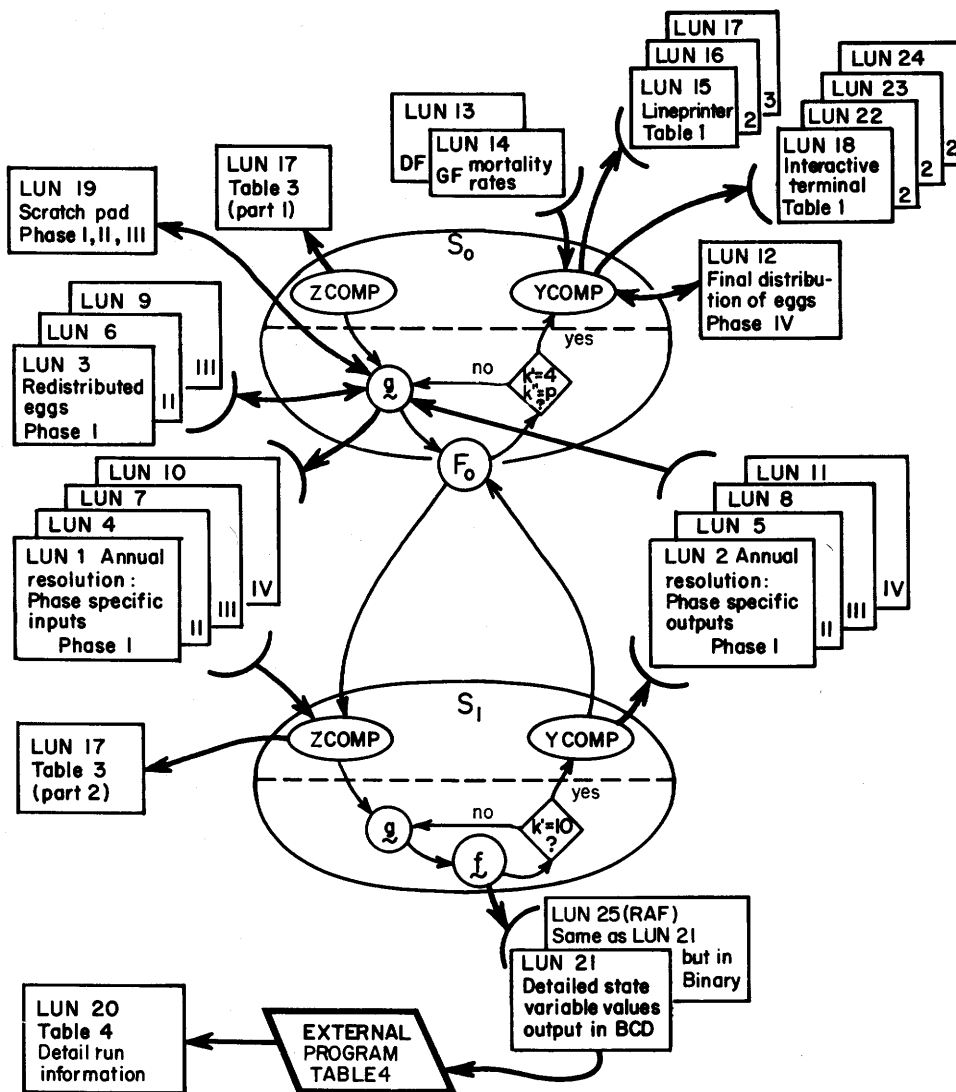


Figure 4.--Stand-outbreak model, Version 3.1:  
LUN assignment and identity.

LUNs 1, 4, 7, and 10 contain phase-specific initial condition information for phases I, II, III, and IV, respectively. The variable identity, by record on the LUN, is:

$$z_{6j}, z_{4j}, z_{5j}, z_{2j}, z_{3j}, x_{5j}, x_{6j}, x_{7j}, j$$

where  $j$  is the tree-class identification index, and all variables are those of module  $S_0$ .

LUNs 2, 5, 8, and 11 contain phase-specific output conditions from phases I, II, III, and IV, respectively. The variable identity is:

$$y_1, y_2, y_3$$

where all variables are those of module  $S_1$ .

LUNs 3, 6, 9, and 12 contain outputs from the insect redistribution process. The variable identity is:

$$g_{2j}$$

from module  $S_0$ .

LUN 19 is used as a "scratch" pad and stores the values  $\hat{g}_3$  of module  $S_0$  for each phase, with each successive phase-specific output vector written over the previous vector.

Information is read from and/or written on the LUNs in the following order as a simulation run proceeds (see fig. 3):

(1) Module  $S_0$ :

Z Functions: ZCOMP<sup>17/</sup> calls special function TABLE31.

Subroutine TABLE31

This subroutine writes most of *table 3*<sup>18/</sup> on LUN 17. The parameters that are local to the lower module  $S_1$  are written from that module.

G Functions: LUN 1 has been constructed before the simulation and contains the initial conditions for phase I. Only  $g_1$  returns a value at this time, the other  $g$  functions produce no (zero) outputs at  $k' = 0$ .

(2) Module  $S_0$  (phase I):

Z Functions: ZCOMP, on the initial entry only, makes a call to the special function TABLE32.

Subroutine TABLE32

This subroutine writes the portion of *table 3* that contains the destruction/consumption ratios and the larval growth rates on LUN 17.

F Functions: Function  $f_{4,4}$  makes a call to special function  $S_2$ .

Subroutine  $S_2(b)$

This subroutine writes the value of each state variable for each occasion ( $k'$ ) on a random access file, LUN 25, in binary and a duplicate output on LUN 21 in BCD. The material on LUN 25 is then available for access by an external program TABLE4 that will produce detailed information on any state variable at any occasion for each tree class during a simulation; this is produced as output *table 4* on LUN 20.

---

<sup>17/</sup> Two special-purpose standard FLEX subroutines, ZCOMP and YCOMP, are associated with each module in a model. ZCOMP is processed first and YCOMP last in each time step. ZCOMP handles all input-variable processing, and YCOMP handles all output-variable processing.

<sup>18/</sup> To distinguish computer output tables from the tables in this paper, the computer output tables will be written in italics, *table*. Subroutines are given in all cap., e.g., TABLE32.

Y Functions: YCOMP<sup>19/</sup> writes the values of  $y_1$ ,  $y_2$ , and  $y_3$  on LUN 2. These are the year-end values of the variables, that is the phase-specific population-branch model outputs.

Module  $S_1$  is processed once for each tree class with no calculation of any  $g$  function values in module  $S_0$  during this processing.

(3) Module  $S_0$ :

G Functions: Function  $g_2$ , through special function REDIST, writes the values  $\hat{g}_2$ . on LUN 3.

Function  $g_3$  writes the values  $\hat{g}_3$ . on LUN 19.

Function  $g_4$ , utilizing the information on LUNs 1, 2, 3, and 19, writes new values on LUN 4, where  $x_5$  is replaced by the tree class specific values of  $y_1$  from LUN 2,  $x_6$  is replaced by  $\hat{g}_3$ . from LUN 19 and  $x_7$  is replaced by the values  $\hat{g}_4$ . produced by this function. LUN 4 now contains the initial conditions for phase II. The replacement done by this function constitutes the updating of variables  $x_5$ ,  $x_6$ , and  $x_7$ ; this is normally an automatic part of the FLEX algorithm, but because of the vector manipulations occurring in this module, the updating must be done by a user-defined function (see Vector Processing in FLEX2).

All other values are simply transferred unchanged from LUN 1 to LUN 4.

(4) Module  $S_1$  (phase II):

F Functions: Function  $f_{4,4}$  makes a call to special function S2.

Y Functions: YCOMP writes the values of  $y_1$ ,  $y_2$ , and  $y_3$  on LUN 5.

Module  $S_1$  is processed once for each tree class with no calculation of  $g$  function values in  $S_0$ .

(5) Module  $S_0$ :

G Functions: Function  $g_2$  writes the values  $\hat{g}_2$ . on LUN 6.

Function  $g_3$  writes the values  $\hat{g}_3$ . on LUN 19.

Parallel to what is done in (3) above, function  $g_4$  writes the values  $\hat{g}_4$ . on LUN 7, as well as transferring other appropriate information from LUNs 4, 5, 6, and 19 to LUN 7. LUN 7 contains phase-III initial conditions.

---

<sup>19/</sup> Refer to footnote 17 on previous page.

(6) Module S<sub>1</sub> (phase III):

F Functions: Function  $f_{4,4}$  makes a call to special function S2.

Y Functions: YCOMP writes the values of  $y_1$ ,  $y_2$ , and  $y_3$  on LUN 8.

Module S<sub>1</sub> is processed once for each tree class with no calculation of g function values in S<sub>0</sub>.

(7) Module S<sub>0</sub>:

G Functions: Function  $g_2$  writes the values  $\hat{g}_2$  on LUN 9.

Function  $g_3$  writes the values  $\hat{g}_3$  on LUN 19.

Function  $g_4$  writes the values  $\hat{g}_4$  on LUN 10, as well as transferring other appropriate information from LUNs 7, 8, 9, and 19 to LUN 10. LUN 10 contains phase-IV initial conditions.

(8) Module S<sub>1</sub> (phase IV):

F Functions: Function  $f_{4,4}$  makes a call to special function S2.

Y Functions: YCOMP writes the values of  $y_1$ ,  $y_2$ , and  $y_3$  on LUN 11.

Module S<sub>1</sub> is processed once for each tree class with no calculation of g function values in S<sub>0</sub>.

(9) Module S<sub>0</sub>:

Y Functions: YCOMP calls REDIST for computation of the mean fall egg density over the stand after phase IV. REDIST then computes the redistributed egg density for each tree class and writes them as  $\bar{x}_7$  on LUN 12.

YCOMP then calls the special function subroutines TABLE33 and TABLE12 to complete *table* 3 and produce the output tables 1 and 2.

Subroutine TABLE33

This subroutine completes *table* 3 on LUN 17 by writing the fall mean egg density per model branch over the stand for each phase.

Subroutine TABLE12

This subroutine produces the annual input-output summary of the model branch for each phase and tree class as *table* 1 on LUN 15. It also determines the postoutbreak probabilities of primary and secondary mortality, probabilities of degrees of top-kill, height- and diameter-growth reduction factors for each tree class, all according to the classification structure provided by Boyd Wickman (1963, 1978a, 1978b).

The mortality and top-kill parameters associated with this classification structure are stored on and input to this subroutine from LUNs 13 and 14. This information is used in producing outbreak impacts as *table 2* on LUN 16.

Additionally, *table 1* is output on LUN 18 in a format suitable for viewing from an interactive terminal screen. This is done for *table 2* as well, but with the requirement of outputting it in three parts on LUNs 22, 23, and 24.

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## STAND-POSTOUTBREAK MODEL

The stand-postoutbreak model is the filter that takes the defoliation history from an outbreak simulation and associates with defoliation for each tree class the expectations of: direct and secondary mortality; degrees of top-kill; and radial- and height-growth impacts.

The development of the mortality and top-kill expectations are based on the history of host tree plots associated with the DFTM outbreak of 1972-1974 in eastern Oregon (Wickman 1978b). The model branch defoliation is translated into crown defoliation via the branch-tree relationship.

For each tree class, branch defoliation is converted into crown defoliation using the logistic equation

$$y = \frac{p_1}{p_2 + p_3 e^{p_1 x}}$$

where for  $x, y \in [0.1]$ :

x: model branch defoliation as a proportion of nominal.

y: proportion of crown totally defoliated.

$p_1 = -22.579678$

$p_2 = -22.996253$

$p_3 = -598,181,961.$

These parameters were obtained by nonlinear least squares curve fit to means of data from the six crown-defoliation classes of Wickman (1978b). Crown defoliation determines one of seven possible effects vectors. The vector is used to partition the trees of the tree class into direct and secondary mortality or a range of top-kill and growth loss. The set of vectors that determine these losses is derived from the input files read from LUNs 13 and 14 given in appendix C. The same algorithm is used

for each host-specific file. The information on these files is structured as follows: the first seven contain direct mortality and top-kill information; the remaining two contain secondary mortality information. Letting  $A(i,j)$  be the  $j$ th entry from the  $i$ th row, one has the following correspondences: For  $i =$

- 1: all parameters correspond to trees (a tree class) with less than 15% of the crown totally defoliated,
- 2: all parameters correspond to trees with between 15% and 35% of the crown totally defoliated,
- 3: parameters for trees with between 35% and 65% of the crown totally defoliated,
- 4: parameters for trees with between 65% and 85% of the crown totally defoliated,
- 5: parameters for trees with between 85% and 95% of the crown totally defoliated,
- 6: parameters for trees with between 95% and 99.5% of the crown totally defoliated,
- 7: parameters for trees with greater than 99.5% of the crown totally defoliated,

and for each of the above values of  $i$ , the following definitions are given of  $A(i,j)$  for  $j =$

- 1: expected proportion of trees for which mortality is directly attributable to defoliation,
- 2: expected proportion of trees with no top-kill damage,
- 3: expected proportion of trees with leader-kill, 1 year's growth only,
- 4: expected proportion of trees with top-kill less than 10%,
- 5: expected proportion of trees with top-kill less than 25%,
- 6: expected proportion of trees with top-kill less than 50%,
- 7: expected proportion of trees with some top-kill,
- 8: expected loss in diameter growth from defoliation.

The last two records in these files contain the information necessary to remove secondary mortality from the arrays described above. They are as follows:  $A(i,j)$  for  $i=$

- 8: expectations of secondary mortality associated with bark beetle attack,
- 9: expectations of secondary mortality from all other causes, e.g., windthrow, winterkill, natural attrition,

and for  $j =$

- 1: expectation for trees without top-kill,
- 2: expectation for trees with leader-kill only,
- 3: expectation for trees with more than leader-kill,  
but less than 10% top-kill,
- 4: expectation for trees with top-kill between 10% and 25%,
- 5: expectation for trees with top-kill between 25% and 50%,
- 6: expectation for trees with top-kill greater than 50%.

Because the top-kill information on the external files is cumulative, differences are taken between successive classes to get the number for each interval. From the resulting classes, secondary mortality is removed after combining the two secondary mortality factors--that caused by bark beetles and that caused by other factors such as windthrow, snow, fire, and other "unknown" causes.

The two forms of secondary mortality are assumed to act independently, hence the two vectors are combined by the rule:

$$(m_{1,j} + m_{2,j} - m_{1,j} m_{2,j}) = v_j.$$

The scalar- or dot-product of this vector with the input vector of residuals of direct mortality is then used to compute secondary mortality for each defoliation class:

$$\sum_{j=2}^6 v_j r_{i,j+1} = s_i, \quad i=1, \dots, 7.$$

Here  $r_{i,j}$  is the vector of residuals ( $i$ th record of LUN 13 or LUN 14), and  $s_i$  is the derived secondary mortality that will be used in *table 2* of simulation output (appendix C).

After secondary mortality has been subtracted from the residuals of direct mortality, the remaining numbers are the expected proportions that are to receive various levels of top-kill, and one class that indicates the proportion receiving only growth reductions.

Growth reductions attributable to defoliation are changes in diameter growth at breast height and height growth. Growth reduction is a function of maximum model branch defoliation. These assumptions result in the following table of possible effect vectors. One vector is chosen by species and defoliation.

An example of defoliation impact summaries is given in *table 2* of the output section of appendix C.

*Output expectations of mortality and top-kill by tree defoliation*

Douglas-fir host:

| Percent<br>of crown<br>totally<br>defoliated | Direct<br>mortality | Secondary<br>mortality | Top-kill<br>(total) | Growth<br>impacts<br>only | Leader<br>kill | Expected top-kill    |                       |                       |                       |
|----------------------------------------------|---------------------|------------------------|---------------------|---------------------------|----------------|----------------------|-----------------------|-----------------------|-----------------------|
|                                              |                     |                        |                     |                           |                | 1-10%<br>of<br>crown | 10-25%<br>of<br>crown | 25-50%<br>of<br>crown | 50-90%<br>of<br>crown |
| 0-15                                         | 0                   | .1127                  | .1129               | .7744                     | .0675          | .0454                | 0                     | 0                     | 0                     |
| 16-35                                        | 0                   | .1229                  | .2081               | .6690                     | .1360          | .0696                | 0                     | 0                     | .0026                 |
| 36-65                                        | .0090               | .0927                  | .4032               | .4951                     | .1744          | .2058                | 0                     | .0230                 | 0                     |
| 66-85                                        | .0280               | .1000                  | .4820               | .3900                     | .2376          | .1606                | 0                     | .0838                 | 0                     |
| 86-95                                        | .1730               | .1950                  | .2929               | .3391                     | .1400          | .0607                | 0                     | .0782                 | .0140                 |
| 96-99.5                                      | .4770               | .1070                  | .1864               | .2296                     | .1422          | .0359                | 0                     | 0                     | .0083                 |
| 99.5-100                                     | .9230               | .0158                  | .0274               | .0338                     | .0209          | .0053                | 0                     | 0                     | .0012                 |

Grand fir host:

| Percent<br>of crown<br>totally<br>defoliated | Direct<br>mortality | Secondary<br>mortality | Top-kill<br>(total) | Growth<br>impacts<br>only | Leader<br>kill | Expected top-kill    |                       |                       |                       |
|----------------------------------------------|---------------------|------------------------|---------------------|---------------------------|----------------|----------------------|-----------------------|-----------------------|-----------------------|
|                                              |                     |                        |                     |                           |                | 1-10%<br>of<br>crown | 10-25%<br>of<br>crown | 25-50%<br>of<br>crown | 50-90%<br>of<br>crown |
| 0-15                                         | 0                   | .0451                  | .0544               | .9005                     | .0331          | .0123                | .0039                 | .0029                 | .0022                 |
| 16-35                                        | 0                   | .0422                  | .1261               | .8316                     | .0877          | .0294                | .0068                 | .0019                 | .0004                 |
| 36-65                                        | .0090               | .0455                  | .2674               | .6781                     | .1322          | .0882                | .0317                 | .0113                 | .0039                 |
| 66-85                                        | .0280               | .0592                  | .3817               | .5311                     | .1723          | .1022                | .0424                 | .0480                 | .0168                 |
| 86-95                                        | .1730               | .0957                  | .3387               | .3926                     | .1893          | .0580                | .0217                 | .0157                 | .0541                 |
| 96-99.5                                      | .4770               | .0790                  | .2137               | .2302                     | .0963          | .0401                | .0274                 | 0                     | .0499                 |
| 99.5-100                                     | .9230               | .0116                  | .0315               | .0339                     | .0142          | .0059                | .0040                 | 0                     | .0074                 |

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## APPENDIX A VERSION 3.1 SOURCE CODE

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| DFTM stand-outbreak model    |      |
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| Subroutine TABLE12 flowchart | 74   |



```

00001 -C *** S(0) MODULE V3.1 DFTM MODEL ***
00002 -C
00003 -C
00004 -C SUBROUTINE ZCOMP (K,X,B,R,Z,T0,T,G)
00005 -C DIMENSION X(1),B(1),R(1),Z(1),G(1)
00006 -C WRITE(61,2000)
00007 -C 2000 FORMAT(2 ENTER NUMBER OF TREE CLASSES IN STAND#)
00008 -C Z(1)=FFIN(60)
00009 -C B(57)=Z(1)
00010 -C
00011 -C *** WRITE THE BEGINNING OF TABLE 3 ***
00012 -C
00013 -C CALL TABLE31(B,R)
00014 -C RETURN
00015 -C END
00016 -C
00017 -C
00018 -C
00019 -C
00020 -C
00021 -C FUNCTION G01(K,X,B,R,Z,KP)
00022 -C DIMENSION X(1),B(1),R(1),Z(1)
00023 -C G01=FLOAT(KP+1)
00024 -C RETURN
00025 -C END
00026 -C
00027 -C
00028 -C FUNCTION G02 (K,X,B,R,Z,KP)
00029 -C DIMENSION X(1),B(1),R(1),Z(1)
00030 -C G02=0.
00031 -C IF (KP.EQ.IPHASE) RETURN
00032 -C IF (KP.EQ.0) RETURN
00033 -C INUM=IFIX(B(57))
00034 -C CALL REDIST(KP,INUM,B,X)
00035 -C IPHASE=KP
00036 -C RETURN
00037 -C END
00038 -C
00039 -C
00040 -C FUNCTION G03(K,X,B,R,Z,KP)
00041 -C DIMENSION X(1),B(1),R(1),Z(1)
00042 -C G03=0.
00043 -C IP=KP+1
00044 -C IF (IP.EQ.IPHASE) RETURN
00045 -C IF (KP.EQ.0) RETURN
00046 -C NN=IFIX(Z(1))
00047 -C LUN=(IP-2)*3
00048 -C LUN1=LUN+1
00049 -C LUN2=LUN+2
00050 -C LUN19=19
00051 -C REWIND LUN1
00052 -C REWIND LUN2
00053 -C REWIND LUN19
00054 -C DO 10 J=1,NN
00055 -C READ(LUN1,1000) Z2,73
00056 -C 1000 FORMAT(24X,2F11.5)
00057 -C READ(LUN2,1001) X6
00058 -C 1001 FORMAT(12X,1F12.6)
00059 -C G3=FMIN((1.-Z2/100)*Z3,X6)
00060 -C WRITE(LUN19,1002) G3
00061 -C 1002 FORMAT(1F12.6)
00062 -C 10 CONTINUE
00063 -C IPHASE=IP
00064 -C RETURN
00065 -C END
00066 -C
00067 -C
00068 -C FUNCTION G04(K,X,B,R,Z,KP)
00069 -C DIMENSION X(1),B(1),R(1),Z(1)
00070 -C G04=0.
00071 -C IP=KP+1
00072 -C IF (IP.EQ.IPHASE) RETURN
00073 -C IF (KP.EQ.0) RETURN
00074 -C NN=IFIX(Z(1))
00075 -C LUN=(IP-2)*3
00076 -C LUN1=LUN+1
00077 -C LUN2=LUN+2
00078 -C LUN3=LUN+3
00079 -C LUN4=LUN+4
00080 -C LUN19=19

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00081 - REWIND LUN1
00082 - REWIND LUN2
00083 - REWIND LUN3
00084 - REWIND LUN4
00085 - REWIND LUN19
00086 - DO 120 I=1,NN
00087 - READ (LUN1,2000) IZ6,Z4,Z5,Z2,Z3,J
00088 - 2000 FORMAT (1I2,4F11.5,3X,1I3)
00089 - READ (LUN2,2200) X5
00090 - READ (LUN3,2200) G2
00091 - READ (LUN19,2200) G3
00092 - 2200 FORMAT (1F12.6)
00093 - IPP=IP+56
00094 - X7=(1.-B(IPP))*G2
00095 - X6=G3
00096 - 120 WRITE (LUN4,2300) IZ6,Z4,Z5,Z2,Z3,X5,X6,X7,J
00097 - 2300 FORMAT (1I2,7F11.5,1I3)
00098 - REWIND LUN4
00099 - IPHASE=IP
00100 - RETURN
00101 - END
00102 -C
00103 -C
00104 - SUBROUTINE YCOMP(K,X,B,R,Y,XS,T)
00105 - DIMENSION X(1),B(1),R(1),Y(1),XS(1)
00106 - KP=4
00107 - IB57=IFIX(B(57))
00108 - CALL REDIST(KP,IB57,B,X)
00109 -C
00110 -C *** FINISH TABLE 3, ON LUN 17 ***
00111 -C
00112 - CALL TABLE33(X,B)
00113 -C
00114 -C *** WRITE TABLES 1 AND 2 ***
00115 -C
00116 - CALL TABLE12(B)
00117 - RETURN
00118 - END
00119 -C
00120 -C
00121 - SUBROUTINE REDIST(KP,INUM,B,X)
00122 - DIMENSION B(1),X(1),XYCOMP(4)
00123 -C
00124 -C INITIALIZE LUN VALUES AND REWIND
00125 -C
00126 - LUN1=(KP-1)*3+1
00127 - LUN2=(KP-1)*3+2
00128 - LUN3=(KP-1)*3+3
00129 - REWIND LUN1
00130 - REWIND LUN2
00131 -C
00132 -C *** REDISTRIBUTION OF EGGS ***
00133 -C INITIALIZE LOCAL VARIABLES
00134 -C
00135 -C SUM=TOTSTEM=0.0
00136 -C
00137 -C CALCULATE TOTAL EGGS OVER STAND (SUM)
00138 -C AND TOTAL WEIGHTED SUM OF TREES(TOTSTEM)
00139 -C
00140 - DO 10 J=1,INUM
00141 - READ(LUN1,1001) Z4,Z5
00142 - 1001 FORMAT(2X,2F11.5)
00143 - READ (LUN2,1000) X7
00144 - 1000 FORMAT (24X,F12.6)
00145 - SUM=SUM+X7*Z4*Z5
00146 - TOTSTEM=TOTSTEM+Z4*Z5
00147 - 10 CONTINUE
00148 -C
00149 -C CALCULATE X(KP) WHERE KP IS PREVIOUS PHASE
00150 -C STORE LOCALLY IN XYCOMP(KP) UNTIL PHASE IV
00151 -C TO PREVENT XS=0 FROM ERASING STORED VALUES
00152 -C
00153 - XYCOMP(KP)=SUM/TOTSTEM
00154 - REWIND LUN2
00155 -C
00156 -C CALCULATE VALUES OF G(2,J) FOR SO HERE,
00157 -C INSTEAD OF IN FUNCTION G02 CODE AND WRITE ON LUN 3
00158 -C
00159 - DO 20 J=1,INUM

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```

00160 -      READ (LUN2,1000) X7
00161 -      G2=X7+B(62)*(XYCOMP(KP)-X7)
00162 -      WRITE (LUN3,1010) G2
00163 - 1010  FORMAT(F12.6)
00164 - 20    CONTINUE
00165 -      IF(KP.EQ.4) GO TO 25
00166 -      RETURN
00167 -C
00168 -C      TRANSFER VALUES FROM LOCAL STORAGE TO X ARRAY
00169 -C
00170 - 25 DO 30 I=1,4
00171 -      X(I)=XYCOMP(I)
00172 - 30    CONTINUE
00173 -      RETURN
00174 -      END
EOF CN INPUT UNIT

```

```

00001 -C
00002 -C          FLEX FUNCTIONS FOR V3.1 DFTM MODULE S(1)
00003 -C
00004 -C
00005 -C          SUBROUTINE ZCOMP (K,X,B,R,Z,T0,T,G)
00006 -C          DIMENSION X(1),B(1),R(1),Z(1),G(1)
00007 -C
00008 -C***          READ IN THE Z VECTOR, INITIAL X VECTOR      ***
00009 -C
00010 -C          CALL VARIN (Z(3),G(1))
00011 -C          IP=IFIX (Z(3))
00012 -C          LUN1=(IP-1)*3+1
00013 -C          READ (LUN1,1000) ISPECIES,Z(1),Z(2),X(1),X(2),X(3)
00014 -C          1000  FORMAT (1I2,22X,5F11.5)
00015 -C          Z(4)=FLOAT(ISPECIES)
00016 -C          X(4)=0.0
00017 -C
00018 -C***          SET PHASE-SPECIFIC PARAMETERS B(29) AND B(34--36)
00019 -C
00020 -C          B(29)=Z(3)
00021 -C          CALL VARIN(B(34),B(IP+48))
00022 -C          CALL VARIN (B(35),B(IP+52))
00023 -C          CALL VARIN (B(36),B(IP+62))
00024 -C
00025 -C***          READ IN HOST AND PHASE SPECIFIC MORTALITY VECTORS      ***
00026 -C
00027 -C          DO 6 J=1,6
00028 -C          I1=J+(IP-1)*6
00029 -C          I2=J+(IP+3)*6
00030 -C          I3=J+(ISPECIES-1)*6
00031 -C          CALL VARIN (B(J),R(J+12))
00032 -C          CALL VARIN (R(J),B(I1))
00033 -C          CALL VARIN (R(J+6),R(I2))
00034 -C          6 CALL VARIN (R(J+12),R(I3))
00035 -C          IF (K.NE.0) RETURN
00036 -C
00037 -C***          FINISH TABLE 3 ON LUN 17      ***
00038 -C
00039 -C          CALL TABLE32(B)
00040 -C          RETURN
00041 -C          END
00042 -C
00043 -C
00044 -C
00045 -C
00046 -C
00047 -C          FUNCTION G01 (K,X,B,R,Z,KP)
00048 -C          DIMENSION X(1),B(1),R(1),Z(1)
00049 -C          G01=0.
00050 -C          IF (KP.EQ.8) G01=(Z(2)*Z(1)/100.)*((X(1)+X(2)+Z(2))/
00051 -C          A (2.0*Z(2))-G(19)*B(27))
00052 -C          RETURN
00053 -C          END
00054 -C
00055 -C
00056 -C          FUNCTION G03 (K,X,B,R,Z,KP)
00057 -C          DIMENSION X(1),B(1),R(1),Z(1)
00058 -C          G03=0.0
00059 -C          IF (KP.EQ.8) G03=X(1)
00060 -C          RETURN
00061 -C          END
00062 -C
00063 -C
00064 -C          FUNCTION G04 (K,X,B,R,Z,KP)
00065 -C          DIMENSION X(1),B(1),R(1),Z(1)
00066 -C          G04=0.0
00067 -C          IF (KP.GT.0.AND.KP.LE.6) G04=FMIN(G(16),X(1))
00068 -C          RETURN
00069 -C          END
00070 -C
00071 -C
00072 -C          FUNCTION G05 (K,X,B,R,Z,KP)
00073 -C          DIMENSION X(1),B(1),R(1),Z(1)
00074 -C          G05=0.0
00075 -C          IF (KP.GE.1.AND.KP.LE.6) G05=FMIN(G(18),X(2))
00076 -C          RETURN
00077 -C          END
00078 -C
00079 -C

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```

00080 - FUNCTION G06 (K,X,B,R,Z,KP)
00081 - DIMENSION X(1),B(1),R(1),Z(1)
00082 - G06=0.
00083 - IF (KP.GT.0.AND.KP.LE.6) G06=(1.-R(KP))*(1.-R(KP+6))*(1.-R(KP))
00084 - RETURN
00085 - END
00086 -C
00087 -C
00088 - FUNCTION G07 (K,X,B,R,Z,KP)
00089 - DIMENSION X(1),B(1),R(1),Z(1)
00090 - G07=0.
00091 - IF (KP.GT.0.AND.KP.LE.6) G07=1.-R(KP+12)
00092 - RETURN
00093 - END
00094 -C
00095 -C
00096 - FUNCTION G08 (K,X,B,R,Z,KP)
00097 - DIMENSION X(1),B(1),R(1),Z(1)
00098 - G08=0.
00099 - IF (KP.EQ.0.OR.KP.GT.6) RETURN
00100 - G08=G(6)**10.-1.
00101 - IF (G(15).NE.10..AND.G(7).NE.0.) G08=(G(6)**10.)*(G(7)**(10.
00102 - C-G(15)))-1.
00103 - IF (G(7).EQ.0..AND.G(15).NE.10.) G08=-1.
00104 - RETURN
00105 - END
00106 -C
00107 -C
00108 - FUNCTION G09 (K,X,B,R,Z,KP)
00109 - DIMENSION X(1),B(1),R(1),Z(1)
00110 - IF (KP.EQ.0.OR.KP.EQ.9) GTOT=0.
00111 - GTOT=GTOT+G(17)
00112 - G09=GTOT
00113 - RETURN
00114 - END
00115 -C
00116 -C
00117 - FUNCTION G10 (K,X,B,R,Z,KP)
00118 - DIMENSION X(1),B(1),R(1),Z(1)
00119 - G10=0.
00120 - IF (KP.EQ.0) G10=-B(36)
00121 - IF (KP.EQ.5) G10=-(1.+G(8))*B(30)
00122 - IF (KP.EQ.7) G10=-B(34)
00123 - IF (KP.EQ.8) G10=(B(35)*G(14)*(1.0-B(28)*G(9))-1.0)
00124 - RETURN
00125 - END
00126 -C
00127 -C
00128 - FUNCTION G11 (K,X,B,R,Z,KP)
00129 - DIMENSION X(1),B(1),R(1),Z(1)
00130 - G11=(G(8)+G(10))*X(3)
00131 - RETURN
00132 - END
00133 -C
00134 -C
00135 - FUNCTION G12 (K,X,B,R,Z,KP)
00136 - DIMENSION X(1),B(1),R(1),Z(1)
00137 - G12=0.
00138 - IF (X(3).LE.0..OR.X(1)+X(2).LE.0.) GO TO 10
00139 - IF (KP.GE.1.AND.KP.LT.4) G12=B(22)
00140 - IF (KP.EQ.4) G12=B(23)
00141 - IF (KP.GT.4.AND.KP.LE.6) G12=B(24)
00142 - 10 RETURN
00143 - END
00144 -C
00145 -C
00146 -C
00147 - FUNCTION G13 (K,X,B,R,Z,KP)
00148 - DIMENSION X(1),B(1),R(1),Z(1)
00149 - G13=0.
00150 - IF (KP.EQ.0) G13=B(25)
00151 - PHI=(G(4)+G(5))/G(4)+G(18))
00152 - IF (KP.GT.0.AND.KP.LE.6) G13=X(4)*(EXP(10.*G(12)*PHI)-1.)
00153 - RETURN
00154 - END
00155 -C
00156 -C
00157 - FUNCTION G14 (K,X,B,R,Z,KP)
00158 - DIMENSION X(1),B(1),R(1),Z(1)
00159 - G14=FMAX(2.*X(4)/B(26)-1.,0.)
00160 - RETURN
00161 - END

```

```

00162 -C
00163 -C
00164 - FUNCTION G15 (K,X,B,R,Z,KP)
00165 - DIMENSION X(1),B(1),R(1),Z(1)
00166 - IF(KP.EQ.0.OR.KP.GT.6) GO TO 15
00167 - DO 10 I=0,10
00168 - ALPHA=FLOAT(10-I)
00169 - G15=ALPHA
00170 - IF(UV1(KP,X,B,ALPHA).LT.X(1)) RETURN
00171 - 10 CONTINUE
00172 - RETURN
00173 - 15 G15=0.
00174 - RETURN
00175 - END
00176 -C
00177 -C
00178 - FUNCTION G16 (K,X,B,R,Z,KP)
00179 - DIMENSION X(1),B(1),R(1),Z(1)
00180 - G16=0.
00181 - IF(KP.EQ.0.OR.KP.GT.6) RETURN
00182 - ALPHA=FMIN(G(15)+1.,10.)
00183 - IF(X(1).GT.0.0) G16=UV1(KP,X,B,ALPHA)
00184 - RETURN
00185 - END
00186 -C
00187 -C
00188 - FUNCTION G17 (K,X,B,R,Z,KP)
00189 - DIMENSION X(1),B(1),R(1),Z(1)
00190 - IF(KP.EQ.0.OR.KP.GT.6) GO TO 20
00191 - G17=10.-G(15)
00192 - ALPHA=G(15)
00193 - N=IFIX(10.-G(15))
00194 - DO 10 I=0,N
00195 - ETA=FLOAT(I)
00196 - ETAPLUS=ETA+1.
00197 - IF((UV2(KP,X,B,ALPHA,ETAPLUS)-(X(1)-UV1(KP,X,B,ALPHA)))
00198 - C.GT.X(2)) GO TO 15
00199 - 10 CONTINUE
00200 - RETURN
00201 - 15 G17=ETA
00202 - RETURN
00203 - 20 G17=0.
00204 - RETURN
00205 - END
00206 -C
00207 -C
00208 - FUNCTION G18 (K,X,B,R,Z,KP)
00209 - DIMENSION X(1),B(1),R(1),Z(1)
00210 - G18=0.
00211 - IF (KP.EQ.0.OR.KP.GT.6) RETURN
00212 - ALPHA=G(15)
00213 - ETA=10.-ALPHA
00214 - G18=UV2(KP,X,B,ALPHA,ETA)-(X(1)-UV1(KP,X,B,ALPHA))
00215 - IF (G18.LT.0.) G18=0.
00216 - RETURN
00217 - END
00218 -C
00219 -C
00220 - FUNCTION G19 (K,X,B,R,Z,KP)
00221 - DIMENSION X(1),B(1),R(1),Z(1)
00222 - IF(KP.EQ.0.OR.KP.EQ.9) GTOT=0.
00223 - IF(KP.GT.0.AND.KP.LE.6) GTOT=GTOT+(10.-{G(15)+G(17)})
00224 - G19=GTOT
00225 - RETURN
00226 - END
00227 -C
00228 -C
00229 - FUNCTION F0101(K,X,B,R,Z,KP)
00230 - DIMENSION X(1),B(1),R(1),Z(1)
00231 - F0101=10.0*(G(1)-G(4))
00232 - RETURN
00233 - END
00234 -C
00235 -C
00236 - FUNCTION F0102(K,X,B,R,Z,KP)
00237 - DIMENSION X(1),B(1),R(1),Z(1)
00238 - F0102=10.0*G(3)
00239 - RETURN
00240 - END
00241 -C
00242 -C

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00243  FUNCTION F0202(K,X,B,R,Z,KP)
00244  DIMENSION X(1),B(1),R(1),Z(1)
00245  F0202=10.0*(-G(5))
00246  RETURN
00247  END
00248  -C
00249  -C
00250  FUNCTION F0303(K,X,B,R,Z,KP)
00251  DIMENSION X(1),B(1),R(1),Z(1)
00252  F0303=10.0*G(11)
00253  RETURN
00254  END
00255  -C
00256  -C
00257  FUNCTION F0404 (K,X,B,R,Z,KP)
00258  DIMENSION X(1),B(1),R(1),Z(1)
00259  F0404=G(13)*10.0
00260  CALL S2(X,KP,F0404)
00261  RETURN
00262  END
00263  -C
00264  -C
00265  -C
00266  -C
00267  SUBROUTINE YCOMP (K,X,B,R,Y,XS,I)
00268  DIMENSION X(1),B(1),R(1),Y(1)
00269  DO 10 I=1,3
00270  Y(I)=X(I)
00271  IF (K.EQ. 0) RETURN
00272  IF (K.EQ. 0) RETURN
00273  IP=IFIX(B(29))
00274  LUN2=(IP-1)*3+2
00275  WRITE (LUN2,1000) Y(1),Y(2),Y(3)
00276  FORMAT (3F12.6)
00277  RETURN
00278  END
00279  -C
00280  -C
00281  FUNCTION UV1 (KP,X,B,ALPHA)
00282  DIMENSION X(1),B(1)
00283  UV1=0.
00284  IF (KP.EQ.0.OR.KP.GT.6) RETURN
00285  U=X(3)*X(4)
00286  I=KP+6
00287  UV1=U*(B(19)+B(20)/G(12))*(EXP(G(12))-1.)*0.001/B(21)*B(I)*
00288  C(1.-(G(6)*EXP(G(12)))*ALPHA)/(1.-G(6)*EXP(G(12)))
00289  RETURN
00290  END
00291  -C
00292  -C
00293  FUNCTION UV2 (KP,X,B,ALPHA,ETA)
00294  DIMENSION X(1),B(1)
00295  UV2=0.
00296  IF (KP.EQ.0.OR.KP.GT.6) RETURN
00297  U=X(3)*X(4)
00298  I=KP+12
00299  IF (G(7).EQ.0..AND.ETA.EQ.0.) RETURN
00300  UV2=U*(B(19)+B(20)/G(12))*(EXP(G(12))-1.)*0.001/B(21)*B(I)*
00301  CG(6)**ALPHA*EXP(ALPHA*G(12))*(1.-(G(6)*G(7)*EXP(G(12)))*ETA)/
00302  C(1.-G(6)*G(7)*EXP(G(12)))
00303  RETURN
00304  END
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00001 SUBROUTINE TABLE31(R,R)
00002 DIMENSION B(1),R(1)
00003
00004 BEGIN TABLE 3 ON LUN 17
00005 OBTAIN TIME AND DATE
00006
00007 TIME=0.
00008 DATE=0.
00009 EM=0.
00010 CALL XREQ (32R,0,0,EM,TIME)
00011 CALL XREQ (32R,0,0,EM,DATE)
00012
00013 WRITE HEADING ON LUN 17
00014
00015 WRITE (17,1000) TIME,DATE
00016
00017 1000 FORMAT(17,/,#-#,#-#-#,9X,*,TABLE 3: PARAMETERS FOR AN#
00018 C,*,OUTBREAK:*,
00019 C,*,MORTALITY,*,FOLIAGE DESTRUCTION, AND OTHER.*,
00020 C,14X,2(2X,A8)/#0#,19X,
00021 C,*,HOST TREE, STAND, PHASE, OR INSTAR SPECIFIC,*/#-#,9X,
00022 C,*,DESCRIPTION#,9X,*,PHASE#,5X,*,SPECIES#,21X,*,INSTAR#,26X,
00023 C,*,PUPAE#,5X,*,OVERWINTER#,6X,*,EGG MASS#,*,52X,*,1#,6X,*,2#,
00024 C,6X,*,3#,6X,*,4#,6X,*,5#,6X,*,6#,9X,*,MORTALITY MORTALITY#,
00025 C,9X,*,SIZE#/#,*,
00026 C135(#-#)/#0,*, DAILY MORTALITY RATE#/#,*,24(#-#))
00027
00028 WRITE BACKGROUND DAILY MORTALITY RATES
00029
00030 WRITE (17,1010) (R(J),J=13,18)
00031 FORMAT(10#,9X,*,BACKGROUND#,8X,*,I,II,III,IV DF,GF#,5X,
00032 C6(1X,F5.3,1X))
00033
00034 WRITE DAILY DISEASE MORTALITY RATES
00035 PHASES I, II, III, IV
00036
00037 WRITE(17,1020) (R(J),J=1,6)
00038 FORMAT(10#,9X,*,DISEASE#,15X,*,I#,7X,*,DF,GF#,5X,6(1X,F5.3,1X))
00039
00040 WRITE (17,1030) (B(J),J=7,12)
00041 FORMAT(17,*,30X,*,II#,7X,*,DF,GF#,5X,6(1X,F5.3,1X))
00042
00043 WRITE(17,1040) (B(J),J=13,18)
00044 FORMAT(17,*,30X,*,III#,6X,*,DF,GF#,5X,6(1X,F5.3,1X))
00045
00046 WRITE (17,1045) (R(J),J=19,24)
00047 FORMAT (17,*,30X,*,IV#,7X,*,DF,GF#,5X,6(1X,F5.3,1X))
00048
00049 WRITE DAILY PARASITE/PREDATOR MORTALITY RATES
00050 PHASES I, II, III, IV
00051
00052 WRITE (17,1050) (B(J),J=25,30)
00053 FORMAT(10#,9X,*,PARASITE/PREDATOR#,5X,*,I#,7X,*,DF,GF#,5X,
00054 C6(1X,F5.3,1X))
00055
00056 WRITE(17,1060) (B(J),J=31,36)
00057 FORMAT(17,*,30X,*,II#,7X,*,DF,GF#,5X,6(1X,F5.3,1X))
00058
00059 WRITE (17,1070) (B(J),J=37,42)
00060 FORMAT(17,*,30X,*,III#,6X,*,DF,GF#,5X,6(1X,F5.3,1X))
00061
00062 WRITE (17,1075) (B(J),J=43,48)
00063 FORMAT (17,*,30X,*,IV#,7X,*,DF,GF#,5X,6(1X,F5.3,1X))
00064
00065 WRITE HOST-SPECIFIC DAILY STRESS MORTALITY RATES
00066 PHASES I, II, III, IV
00067
00068 WRITE(17,1080) (R(J),J=1,6)
00069 FORMAT(10#,9X,*,STRESS#,12X,*,I,II,III,IV#,2X,*,DF#,7X,6(1X,F5.3,1X))
00070
00071 WRITE (17,1090) (R(J),J=7,12)
00072 FORMAT(17,*,27X,*,I,II,III,IV#,2X,*,GF#,7X,6(1X,F5.3,1X))
00073
00074 WRITE SUR-HEADING
00075
00076 WRITE (17,1095)
00077 FORMAT(17,*,24(#-#)/#0 OCCASION MORTALITY RATE#/#,*,24(#-#))
00078
00079 WRITE PUPATION MORTALITY RATES
00080 PHASES I, II, III, IV
00081
00082 WRITE(17,1100) 9(49)
00083 FORMAT(10#,10X,*,PUPAE#,16X,*,I#,7X,*,DF,GF#,55X,F5.3)
00084
00085 WRITE (17,1110) R(50)
00086 FORMAT(17,*,30X,*,II#,7X,*,DF,GF#,55X,F5.3)
00087
00088 WRITE(17,1120) B(51)
00089

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00080 - 1120 FORMAT( #,30X,#III#,6X,#DF,GF#,55X,F5.3)
00081 - WRITE (17,1125) R(52)
00082 -1125 FORMAT ( #,30X,#IV#,7X,#DF,GF#,55X,1F5.3)
00083 -C
00084 -C WRITE OVERWINTER EGG MORTALITY RATES
00085 -C AFTER PHASES I, II, III, IV
00086 -C
00087 -C WRITE (17,1130) R(58)
00088 - 1130 FORMAT(#0#,9X,#OVERWINTER#,9X,#I - II#,5X,#DF,GF#,67X,F5.3)
00089 -C WRITE (17,1140) R(59)
00090 - 1140 FORMAT( #,27X,#II - III#,4X,#DF,GF#,67X,F5.3)
00091 -C WRITE (17,1150) R(60)
00092 - 1150 FORMAT( #,27X,#III - IV DF,GF#,67X,F5.3)
00093 -C WRITE (17,1155) R(61)
00094 -1155 FORMAT ( #,27X,#IV- #,5X,#DF,GF#,67X,1F5.3)
00095 -C
00096 -C WRITE NOMINAL EGG MASS SIZE
00097 -C PHASES I, II, III, IV
00098 -C
00099 -C WRITE (17,1160) R(53)
00100 - 1160 FORMAT( #,24( #-# )/#0 NOMINAL EGG MASS SIZE#,EX,
00101 -C #I#,7X,#DF,GF#,82X,F5.1)
00102 -C WRITE (17,1170) R(54)
00103 - 1170 FORMAT( #,30X,#II#,7X,#DF,GF#,82X,F5.1)
00104 -C WRITE (17,1180) R(55)
00105 - 1180 FORMAT( #,30X,#III#,6X,#DF,GF#,82X,F5.1)
00106 -C WRITE (17,1190) R(56)
00107 -1190 FORMAT (31X,#IV#,7X,#DF,GF#,82X,1F5.1)
00108 -C RETURN
00109 -C END
EOD CN INPUT UNIT
00001 - SUBROUTINE TABLE33(X,B)
00002 -C DIMENSION X(1),B(1)
00003 -C
00004 -C COMPLETE TABLE 3 BY WRITING THE PHASE-SPECIFIC MEAN
00005 -C EGG DENSITIES FOR PHASES I, II, III, IV, AND THE
00006 -C AND THE OUTBREAK REDISTRIBUTION COEFFICIENT
00007 -C
00008 -C WRITE (17,3000) (X(I),I=1,4)
00009 - 3000 FORMAT(#0#,135( #-# )/#- PHASE SPECIFIC#,
00010 -C # MEAN EGG DENSITIES: I=#,F7.3,# II=#,F7.3,
00011 -C # III=#,F7.3,# IV=#,1F7.3)
00012 -C WRITE (17,2999) B(62)
00013 - 2999 FORMAT (#0,REDISTRIBUTION COEFFICIENT FOR THE#,
00014 -C # OUTBREAK: #,F7.3)
00015 -C RETURN
00016 -C END
EOD CN INPUT UNIT
00001 - SUBROUTINE TABLE12(B)
00002 -C
00003 -C THIS ROUTINE WRITES THE TWO SPECIALLY FORMATTED OUTBREAK
00004 -C SUMMARIES REFERRED TO AS TABLES 1 AND 2.
00005 -C TABLE 1 GIVES THE INPUT/OUTPUT VARIABLE VALUES, BY PHASE,
00006 -C OVER THE COURSE OF THE OUTBREAK. TABLE 2 CONDENSES THIS
00007 -C INFORMATION FURTHER AND GIVES THE MORTALITY AND TOP KILL
00008 -C EXPECTATIONS WHICH COMPRISE THE STAND POST-OUTBREAK MODEL.
00009 -C
00010 -C DIMENSION B(1)
00011 -C DIMENSION ISPECIES(6),IC(15,3),A(15,26),C(15,5),AMORT(14,9)
00012 -C DIMENSION WT(15)
00013 -C DIMENSION IPHASE(4),BB(2,12)
00014 -C DATA ((IPHASE(I),I=1,4)=#I #, #II #, #III #, #IV #)
00015 -C DATA ((ISPECIES(I),I=1,6)=#DOUG#, #LAS-#, #FIR #, # GRA#,
00016 -C #ND F#, #IR #)
00017 -C
00018 -C OBTAIN TIME AND DATE
00019 -C
00020 -C TIME=0.
00021 -C DATE=0.
00022 -C EM=0.
00023 -C CALL XREQ(33B,0,0,EM,TIME)
00024 -C CALL XREQ(32B,0,0,EM,DATE)
00025 -C
00026 -C OBTAIN THE TOP-KILL (AMORT) AND SECONDARY
00027 -C MORTALITY (BB) DISTRIBUTIONS FOR THE MODEL
00028 -C AMORT VALUES ARE READ IN AS FOLLOWS:
00029 -C FROM LUN 13 (DOUGLAS FIR MORTALITY INFO.):
00030 -C AMORT(I,J) I,J=1,...,7 CONTAIN FIRST 7 RECORDS

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00031 -C      RR(I,J) J=1,...,6, I=1,2 CONTAIN LAST 2 RECORDS
00032 -C      FROM LUN 14 (GRAND FIR MORTALITY INFO.):
00033 -C      AMORT(I,J) J=1,...,7, I=8,...,14 CCNTAIN FIRST 7 RECORDS
00034 -C      BB(I,J) J=7,...,12, I=1,2 CONTAIN LAST 2 RECORDS
00035 -C
00036 -C      I VARIES WITH PERCENT OF CROWN DEFOLIATED:
00037 -C      1 OR 8::0-15%; 2 OR 9::16-35%; 3 OR 10::36-65%;
00038 -C      4 OR 11::66-85%; 5 OR 12::86-95%; 6 OR 13::96-99.5%;
00039 -C      7 OR 14::99.5-100%
00040 -C      VALUES READ IN FOR AMORT:
00041 -C      AMORT(I,1)=EXPECTATION OF DIRECT MORTALITY
00042 -C      FOLLOWING ARE CONDITIONAL EXPECTATIONS, GIVEN
00043 -C      SURVIVAL OF DIRECT MORTALITY
00044 -C      AMORT(I,2)=NO TOP KILL DAMAGE
00045 -C      AMORT(I,3)=LEADER KILL
00046 -C      AMORT(I,4)=1-10% TOP KILL
00047 -C      AMORT(I,5)=1-25% TOP KILL
00048 -C      AMORT(I,6)=1-50% TOP KILL
00049 -C      AMORT(I,7)=1-99% TOP KILL
00050 -C
00051 -C      VALUES OF AMORT AS RECALCULATED FOR OUTPUT
00052 -C
00053 -C      AMORT(I,1)=EXPECTATION OF DIRECT MORTALITY FROM DFTM
00054 -C      AMORT(I,2)=EXPECTATION OF SECONDARY MORT., ALL CAUSES
00055 -C      AMORT(I,3)=EXPECTATION OF TOP KILL, ALL DEGREES
00056 -C      AMORT(I,4)=EXPECTATION OF GROWTH REDUCTION ONLY
00057 -C      AMORT(I,5)=EXPECTATION OF LEADER KILL ONLY
00058 -C      AMORT(I,6)=EXPECTATION OF 1-10% TOP KILL
00059 -C      AMORT(I,7)=EXPECTATION OF 11-25% TOP KILL
00060 -C      AMORT(I,8)=EXPECTATION OF 26-50% TOP KILL
00061 -C      AMORT(I,9)=EXPECTATION OF 51-99% TOP KILL
00062 -C
00063 -C      FOR RR ARRAY I=1 SIGNIFIES SECONDARY MORTALITY
00064 -C      DUE TO BARK BEETLE
00065 -C      I=2 SIGNIFIES SECONDARY MORTALITY DUE TO OTHER CAUSES
00066 -C      BB(I,J=1 OR 7)=EXPECT. OF SECOND. MORT., GIVEN
00067 -C      NO TOP KILL DAMAGE
00068 -C      BB(I,J=2 OR 8)=EXPECT. OF SECOND. MORT., GIVEN
00069 -C      LEADER KILL
00070 -C      BB(I,J=3 OR 9)=EXPECT. SECOND. MORT. GIVEN 0-10% TOP KILL
00071 -C      BB(I,J=4 OR 10)=EXPECT. SECOND. MORT. GIVEN 11-25% TOP KILL
00072 -C      BB(I,J=5 OR 11)=EXPECT. SECOND. MORT. GIVEN 26-50% TOP KILL
00073 -C      BB(I,J=6 OR 12)=EXPECT. SECOND. MORT. GIVEN 51-99% TOP KILL
00074 -C      BR ARRAY IS NOT OUTPUT BUT USED TO RECALCULATE THE
00075 -C      AMORT OUTPUT MATRIX
00076 -C
00077 -C
00078 -C
00079 -C      REWIND 13
00080 -C      REWIND 14
00081 -C      READ(13,7000)((AMORT(I,J),J=1,7),I=1,7)
00082 -C      READ(13,7001)((BB(I,J),J=1,6),I=1,2)
00083 -C      READ(14,7000)((AMORT(I,J),J=1,7),I=8,14)
00084 -C      READ(14,7001)((BB(I,J),J=7,12),I=1,2)
00085 -C      7000 FORMAT(1F7.4,6F6.3)
00086 -C      7001 FORMAT(1F7.4,5F6.3)
00087 -C
00088 -C      COMPUTE THE TOTAL SECONDARY MORTALITY FROM
00089 -C      ITS TWO COMPONENTS
00090 -C
00091 -C      DO 770 J=1,12
00092 -C      770 BB(1,J)=BB(1,J)+BB(2,J)-(BB(1,J)*BB(2,J))
00093 -C
00094 -C      SET UP POST-OUTBREAK EXPECTATIONS FROM INPUT DATA
00095 -C
00096 -C      DO 100 I=1,14
00097 -C
00098 -C      TRANSFORM CUMULATIVE TOP-KILL EXPECTATIONS TO
00099 -C      EXPECTATIONS BY TOP-KILL CLASS
00100 -C
00101 -C      DO 90 J=1,3
00102 -C      JJ=8-J
00103 -C      JJ1=JJ-1
00104 -C      90 AMORT(I,JJ)=AMORT(I,JJ)-AMORT(I,JJ1)
00105 -C
00106 -C      REDUCE TOP-KILL EXPECTATIONS BY DIRECT MORTALITY
00107 -C
00108 -C      DO 91 J=2,7
00109 -C      91 AMORT(I,J)=AMORT(I,J)*(1-AMORT(I,1))
00110 -C      IB=13
00111 -C      IF(I.LT.8) IB=7

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00112 -C
00113 -C      REDUCE TOP-KILL EXPECTATIONS BY SECONDARY MORTALITY
00114 -C
00115 -C      DO 92 J=1,6
00116 -C      JJ=10-J
00117 -C      JJ2=JJ-2
00118 -C      JB=18-J
00119 -C 92      AMORT(I,JJ)=(1.-RB(1,JB))*AMORT(I,JJ2)
00120 -C      SUM=0.
00121 -C
00122 -C      CALCULATE PROPORTION OF TREES WHICH SURVIVE
00123 -C      AND SUFFER SOME GROWTH REDUCTION
00124 -C
00125 -C      DO 93 J=5,9
00126 -C 93      SUM=SUM+AMORT(I,J)
00127 -C      AMORT(I,3)=SUM
00128 -C      AMORT(I,2)=1.-AMORT(I,1)-AMORT(I,3)-AMORT(I,4)
00129 -C 100      CONTINUE
00130 -C
00131 -C      REWIND INPUT LUNS
00132 -C
00133 -C      DO 777 I=1,12
00134 -C 777      REWIND I
00135 -C
00136 -C      SET PARAMETERS FOR CROWN DEFOLIATION EQUATION
00137 -C
00138 -C      P1=-22.579678
00139 -C      P2=-22.996253
00140 -C      P3=-598181961.0
00141 -C
00142 -C      INITIALIZE OUTPUT FORMAT CONTROL INDICES
00143 -C      J: PAGE NUMBER
00144 -C      I: LINE NUMBER ON PAGE
00145 -C      INDEX: TOTAL LINES PRINTED
00146 -C      INDEXLIM: TOTAL NUMBER OF TREE CLASSES
00147 -C      IFLAG: FULL PAGE FLAG, 15 LINES
00148 -C      JMPFLAG: 1 INDICATES LINE NEEDS NEW PAGE
00149 -C      BECAUSE OF NEW SPECIES OR FOLIAGE COMPLEMENT
00150 -C
00151 -C      INDEXLIM=8(57)
00152 -C      J=0
00153 -C      INDEX=0
00154 -C      JMPFLAG=0
00155 -C
00156 -C      NEW PAGE: RESET LINE COUNTERS
00157 -C
00158 -C 1      I=0
00159 -C      IFLAG=0
00160 -C
00161 -C      BEGIN NEW LINE: INCREMENT LINE COUNTERS
00162 -C
00163 -C 2      I=I+1
00164 -C      INDEX=INDEX+1
00165 -C
00166 -C      READ IN THE RESULTS OF THE FOUR YEAR OUTBREAK SIMULATION
00167 -C      RUN. THE FOLLOWING CROSS-REFERENCE GUIDE IDENTIFIES
00168 -C      LOCAL VARIABLES.
00169 -C
00170 -C      LOCAL      DESCRIPTION      FLEX      PHASE
00171 -C      -----
00172 -C      IC(I,1)    HCST SPECIES      Z(6) IN S0      ALL
00173 -C      IC(I,2)    TREE CLASS NO.    J, COUNTER FOR P  ALL
00174 -C      IC(I,3)    LINE INDICATOR FOR AMORT TABLE
00175 -C
00176 -C      C(I,1)      NOMINAL % NEW FOL.  Z(2) IN S0      ALL
00177 -C      C(I,2)      NOMINAL TOTAL FOL.  Z(3) IN S0      ALL
00178 -C      C(I,3)      ACTUAL NEW FOL.     X(5) IN S0      I
00179 -C      C(I,4)      ACTUAL OLD FOL.     X(6) IN S0      I
00180 -C      C(I,5)      %CROWN DEFOLIATION
00181 -C
00182 -C      WT(I)      WEIGHTING FACTOR    Z(5) IN S0      ALL
00183 -C
00184 -C      A(I,1)      NO. OF TREES      Z(4) IN S0      ALL
00185 -C      A(I,2)      NO. OF VIABLE EGGS X(7) IN S0      I
00186 -C      A(I,3)      TOTAL FOLIAGE      X(5)+X(6) IN S0 I
00187 -C      A(I,4)      ACTUAL % NEW FOL.
00188 -C      A(I,5)      % DEFOLIATION      FROM Y(2) IN S1 I
00189 -C      A(I,6)      EGGS LAID          Y(3) IN S1      I
00190 -C      A(I,7)      REDIST. EGGS       G(2) IN S0      I
00191 -C      A(I,8)      NO. OF VIABLE EGGS X(7) IN S0      II
00192 -C      A(I,9)      TOTAL FOLIAGE      X(5)+X(6) IN S0 II

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00192 -C      A(I,10)  ACTUAL % NEW FOL.
00193 -C      A(I,11)  % DEFOLIATION      FROM Y(2) IN S1
00194 -C      A(I,12)  EGGS LAID          Y(3) IN S1
00195 -C      A(I,13)  REDIST. EGGS        G(2) IN S0
00196 -C      A(I,14)  NO. OF VIABLE EGGS  X(7) IN S0
00197 -C      A(I,15)  TOTAL FOLIAGE       X(5)+X(6) IN S0
00198 -C      A(I,16)  ACTUAL % NEW FOL.
00199 -C      A(I,17)  % DEFOLIATION      FROM Y(2) IN S1
00200 -C      A(I,18)  EGGS LAID          Y(3) IN S1
00201 -C      A(I,19)  REDIST. EGGS        G(2) IN S0
00202 -C      A(I,20)  NO. OF VIABLE EGGS  X(7) IN S0
00203 -C      A(I,21)  TOTAL FOLIAGE       X(6)+X(5) IN S0
00204 -C      A(I,22)  ACTUAL % NEW FOL.
00205 -C      A(I,23)  % DEFOLIATION      FROM Y(2) IN S1
00206 -C      A(I,24)  EGGS LAID          Y(3) IN S1
00207 -C      A(I,25)  REDIST. EGGS        G(2) IN S0
00208 -C      A(I,26)  % OF TREE NOT DEFOLIATED
00209 -C
00210 -C      READ(1,1001) IC(I,1),A(I,1),WT(I),C(I,1),C(I,2),C(I,3),C(I,4),
00211 -C      C A(I,2),IC(I,2)
00212 -C      1001 FORMAT (12,7F11.5,I3)
00213 -C      A(I,3)=C(I,3)+C(I,4)
00214 -C      A(I,4)=100.*C(I,3)/A(I,3)
00215 -C      READ(2,1002) C(I,4),A(I,6)
00216 -C      1002 FORMAT (12X,2F12.6)
00217 -C      A(I,5)=100.0-1(0.0*C(I,4)/C(I,2)
00218 -C      READ(3,1003) A(I,7)
00219 -C      1003 FORMAT(1F12.6)
00220 -C      READ(4,1004) C(I,3),C(I,4),A(I,8)
00221 -C      1004 FORMAT (46X,3F11.5,3X)
00222 -C      A(I,9)=C(I,3)+C(I,4)
00223 -C      A(I,10)=C(I,3)*100./A(I,9)
00224 -C      READ(5,1002) C(I,4),A(I,12)
00225 -C      A(I,11)=100.0-C(I,4)*100.0/C(I,2)
00226 -C      READ(6,1003) A(I,13)
00227 -C      READ(7,1004) C(I,3),C(I,4),A(I,14)
00228 -C      A(I,15)=C(I,3)+C(I,4)
00229 -C      A(I,16)=C(I,3)*100./A(I,15)
00230 -C      READ(8,1002) C(I,4),A(I,18)
00231 -C      A(I,17)=100.0-C(I,4)*100.0/C(I,2)
00232 -C      READ(9,1003) A(I,19)
00233 -C      READ(10,1004) C(I,3),C(I,4),A(I,20)
00234 -C      A(I,21)=C(I,3)+C(I,4)
00235 -C      A(I,22)=C(I,3)*100.0/A(I,21)
00236 -C      READ(11,1002) C(I,4),A(I,24)
00237 -C      A(I,23)=100.0-C(I,4)*100.0/C(I,2)
00238 -C      READ(12,1003) A(I,25)
00239 -C
00240 -C      CALCULATE MAXIMUM % OF FOLIAGE WHICH SURVIVED INTACT
00241 -C
00242 -C      X1=FMAX(A(I,5),A(I,11))
00243 -C      X2=FMAX(A(I,17),A(I,23))
00244 -C      A(I,26)=100.-FMAX(X1,X2)
00245 -C
00246 -C      IF FIRST LINE, GO WRITE PAGE HEADER
00247 -C
00248 -C      IF (I.EQ.1) GO TO 4
00249 -C
00250 -C      CHECK FOR NEW HOST SPECIES OR DIFFERENT NOMINAL
00251 -C      FOLIAGE COMPLEMENT. IF DIFFERENT, SET FLAG AND GO TO 3;
00252 -C      START NEW PAGE
00253 -C
00254 -C      IF (IC(I-1,1).NE.IC(I,1)) JMPFLAG=1

00255 -C      INC1=IFIX(100.*C(I-1,1)+0.5)
00256 -C      INC2=IFIX(100.*C(I,1)+.5)
00257 -C      IF (INC1.NE.INC2) JMPFLAG=1
00258 -C      IF (JMPFLAG.EQ.1) GO TO 3
00259 -C
00260 -C      IF LAST LINE ON PAGE, SET IFLAG=1; WRITE LINE.
00261 -C
00262 -C      IF (I.EQ.15) IFLAG=1
00263 -C
00264 -C      COMPUTE CROWN DEFOLIATION AND FIND ASSOCIATED LINE
00265 -C      OF MORTALITY AND TCP-KILL TABLE (AMORT)
00266 -C
00267 -C      CONTINUE
00268 -C      IF (A(I,17).GT.95.) GO TO 15
00269 -C      T=(P1/(P2+P3*EXP(P1*A(I,17)/100.)))*100.
00270 -C      GO TO 16
00271 -C      15 T=96.9689+((A(I,17)-95.)/5.)*3.0311

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00272 - 16 IF (T.LE.15.) IC(I,3)=1
00273 - IF (T.GT.15..AND.T.LE.35.) IC(I,3)=2
00274 - IF (T.GT.35..AND.T.LE.65.) IC(I,3)=3
00275 - IF (T.GT.65..AND.T.LE.85.) IC(I,3)=4
00276 - IF (T.GT.85..AND.T.LE.95.) IC(I,3)=5
00277 - IF (T.GT.95..AND.T.LE.99.5) IC(I,3)=6
00278 - IF (T.GT.99.5) IC(I,3)=7
00279 - IF (IC(I,1).EQ.2) IC(I,3)=IC(I,3)+7
00280 - C(I,5)=T
00281 - -C
00282 - -C WRITE LINE(I) FOR TABLE 1 AND 2
00283 - -C ON UPPER HALF OF PAGE
00284 - -C
00285 - WRITE(15,2002) IC(I,2), (A(I,JJ),JJ=1,13)
00286 - ICK=IC(I,3)
00287 - WRITE(16,3002) IC(I,2),A(I,1),WT(I),A(I,2),A(I,5),A(I,11),
00288 - CA(I,17),A(I,23),C(I,5), (AMORT(ICK,JJ),JJ=1,4)
00289 - -C
00290 - -C CHECK FOR FULL PAGE AND EOD
00291 - -C
00292 - IF (IFLAG.EQ.1) GO TO 18
00293 - IF (INDEX.LT.INDEXLIM) GO TO 2
00294 - -C
00295 - -C DOUBLE SPACE TO BOTTOM HALF OF PAGE
00296 - -C
00297 - 3 CONTINUE
00298 - IJ=16-I
00299 - DO 12 JJ=1,IJ
00300 - WRITE (15,2002)
00301 - WRITE (16,3002)
00302 - 12 CONTINUE
00303 - -C
00304 - -C FINISH PRESENT PAGE HALF
00305 - -C
00306 - 18 WRITE (15,2003)
00307 - WRITE (16,3003)
00308 - IX=I-JMPFLAG
00309 - IF (IFLAG.EQ.1) IX=15
00310 - DO 10 II=1,IX
00311 - WRITE (15,2002) IC(II,2),A(II,1), (A(II,JJ),JJ=14,25)
00312 - ICK=IC(II,3)
00313 - WRITE(16,3004) IC(II,2),A(II,1),WT(II),A(II,2),
00314 - C(AMORT(ICK,JJ),JJ=5,9),
00315 - CA(II,26),A(II,26),A(II,26)
00316 - 10 CONTINUE
00317 - DO 200 K1=1,4
00318 - WRITE(18,10000) J, (ISPECIES(JJ),JJ=IS,IM),C(1,1),
00319 - C COMP,TIME,IPHASE(K1),DATE
00320 - K3=K1*6-4
00321 - K4=6*K1+1
00322 - DO 210 K2=1,IX
00323 - WRITE(18,10100) IC(K2,2),A(K2,1), (A(K2,JJ),JJ=K3,K4)
00324 - 210 CONTINUE
00325 - ENDFILE 18
00326 - 200 CONTINUE
00327 - WRITE(22,20000) J, (ISPECIES(JJ),JJ=IS,IM),C(1,1),COMP,
00328 - C TIME,DATE
00329 - WRITE(22,21000)
00330 - DO 220 K1=1,IX
00331 - ICK=IC(K1,3)
00332 - WRITE(22,21100) IC(K1,2),A(K1,2),A(K1,5),A(K1,11),
00333 - C A(K1,17),C(K1,5),AMORT(ICK,1)
00334 - 220 CONTINUE
00335 - ENDFILE 22
00336 - WRITE(23,20000) J, (ISPECIES(JJ),JJ=IS,IM),C(1,1)
00337 - C ,COMP,TIME,DATE
00338 - WRITE(23,22000)
00339 - DO 230 K1=1,IX
00340 - ICK=IC(K1,3)
00341 - WRITE(23,22100) IC(K1,2),A(K1,2),C(K1,5),
00342 - C (AMORT(ICK,KJJ),KJJ=1,4)
00343 - 230 CONTINUE
00344 - ENDFILE 23
00345 - WRITE(24,20000) J, (ISPECIES(JJ),JJ=IS,IM),C(1,1),
00346 - C COMP,TIME,DATE
00347 - WRITE(24,23000)
00348 - DO 240 K1=1,IX
00349 - ICK=IC(K1,3)
00350 - WRITE(24,23100) IC(K1,2),A(K1,2),AMORT(ICK,2),
00351 - C (AMORT(ICK,JJ),JJ=5,9)
00352 - 240 CONTINUE

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00353 -      ENDFILE 24
00354 -
00355 -      IF NO MORE DATA, CHECK JMPFLAG FOR RETURN.
00356 -      IF MORE DATA, CHECK IFLAG FOR FULL PAGE.
00357 -
00358 -      IF(INDEX.LT.INDEXLIM) GO TO 20
00359 -      IF(JMPFLAG.NE.1) RETURN
00360 -      GO TO 19
00361 - 20      IF(IFLAG.EQ.1) GO TO 1
00362 -
00363 -      *** LINE(I) IS FIRST LINE OF NEXT PAGE. ***
00364 -      REPLACE A(I,J) WITH A(I,J), J=1,26
00365 -      REPLACE IC(I,K) AND C(I,K) WITH
00366 -      IC(I,K) AND C(I,K),K=1,2
00367 -
00368 - 19      CONTINUE
00369 -      DO 7 II=1,26
00370 -      A(I,II)=A(I,II)
00371 -      CONTINUE
00372 - 7      IC(I,1)=IC(I,1)
00373 -      IC(I,2)=IC(I,2)
00374 -      C(I,1)=C(I,1)
00375 -      C(I,2)=C(I,2)
00376 -
00377 -      WRITE OUT HEADER AND BEGIN NEW PAGE
00378 -
00379 - 4      CONTINUE
00380 -      J=J+1
00381 -      I=1
00382 -      JMPFLAG=0
00383 -      IS=1
00384 -      IF (IC(I,1).EQ.2) IS=4
00385 -      IM = IS+2
00386 -      COMP=100.-C(I,1)
00387 -      WRITE (16,2001) J,TIME,DATE,(ISPECIES(JJ),JJ=IS,IM),C(I,1),COMP
00388 -      WRITE (16,3001) J,TIME,DATE,(ISPECIES(JJ),JJ=IS,IM),C(I,1),COMP
00389 -      GO TO 5
00390 -
00391 - ***** FORMAT STATEMENTS *****
00392 -
00393 - 2001 FORMAT(11,9X,1TABLE 1,1,1I2,1: INPUT-OUTPUT VARIABLE#
00394 -      C# VALUES OVER THE OUTBREAK CYCLE#,32X,2(2X,A8),//
00395 -      C# 28X,1FOR THE 1,3A4,
00396 -      C# F6.3,1 / 1, F6.3,1 TREE CLASSES#//42X,1PHASE I,1,49X,
00397 -      C# PHASE II,1/30X,1INPUTS,1,21X,1OUTPUTS,1,21X,1INPUTS,1,21X,
00398 -      C# OUTPUTS,1/1,129(1-1)/1#0 TREE NUMBER OF 1,2(1 VIAB#
00399 -      C# LE TOTAL PERCENT DEFOLIA- VIABLE REDIS- 1,
00400 -      C# 1 CLASS STEMS 1,2(1 EGGS FOLIAGE NEW,1,6X,
00401 -      C# TION EGGS TRIBUTED 1/1 NO.1,14X,2(10X,1BIOMASS #
00402 -      C# FOLTA,1,13X,1LAI, EGGS 1)/20X,2(1 (NO.) 1
00403 -      C# (GRAMS) (1) (1) EGGS (NO.) (NO.) 1/1 1,
00404 -      C129(1-1))
00405 -
00406 -
00407 - 2002 FORMAT(10 1,1I3,5X,F8.3,X,2(X,6(F7.3,2X),X))
00408 - 2003 FORMAT(101,129(1-1)/42X,1PHASE III,1,47X,1PHASE IV,1/1 1,
00409 -      C 129(1-1))
00410 -
00411 -
00412 - 3001 FORMAT(11,9X,1TABLE 2,1,1I2,1: OUTBREAK DEFOLIATION SUMMARY1,
00413 -      C# AND THE EXPECTED MORTALITY AND GROWTH REDUCTION1,
00414 -      C14X,2(2X,A8),//,35X,1FOR THE 1,
00415 -      C3A4,X,F6.3,1 / 1, F6.3,1 TREE CLASSES#//X,125(1-1)/
00416 -      C# TREE NUMBER WEIGHT INITIAL : MODEL BRANCH:1,
00417 -      C17X,1PERCENT OF : PROPORTION OF TREES RECEIVING:1/
00418 -      C# CLASS OF FACTOR VIABLE : PERCENT DEFOLIATION1,
00419 -      C# BY PHASE1,8X,1TREE 1,1,45(1-1)/
00420 -      C# NO. TREES PER EGGS 1,1,34(1-1),1 TOTALLY : 1,
00421 -      C# DIRECT SECONDARY TOP ONLY GROWTH1/
00422 -      C18X,1TREE PHASE I : 1,7X,1II,7X,1III,6X,1IV 1,
00423 -      C# DEFOLIATED : MORTALITY MORTALITY KILL REDUCTION1/
00424 -      C# 125(1-1))
00425 -
00426 - 3002 FORMAT (10 1,1I3,3X,2(F6.1,2X),X,F7.3,3X,
00427 -      C F6.3,2X,4(F7.3,2X),2X,4(F7.4,4X))
00428 -
00429 -
00430 - 3003 FORMAT(101,120(1-1)/1 TREE NUMBER WEIGHT INITIAL 1,
00431 -      C6X,1PROPORTION OF TREES BY1,7X,1: GROWTH IN SURVIVING 1,1,X,
00432 -      C# DIAMETER GROWTH IN1/
00433 -      C# CLASS OF FACTOR VIABLE : PERCENT REDUCTION IN 1,

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00434 - C#CROWN HEIGHT : TREES WITH NO TOP KILL : TREES WITH TOP KILL# /
00435 - C# NO. TREES PER EGGS : #,33(#+-#),# : #,
00436 - C#PERCENT OF NOMINAL : #,19(#+-#)/
00437 - C18X,#TREE PHASE I : 0.0 5.0 17.5 37.5 70.0 : #,
00438 - C#DIAMETER HEIGHT : PERCENT OF NOMINAL# /X,120(#+-#)
00439 - 3004 FORMAT(10 #,I3,3X,F6.1,3X,F5.1,3X,F5.2,3X,4(F6.4,X),X,
00440 - CF6.4,3X,2(F6.2,4X),10X,F6.2)
00441 -
00442 -10000 FORMAT (1# TABLE 1.#,I2,#: INPUT-OUTPUT VARIABLE VALUES #,
00443 - C #OVER THE OUTBREAK# /5X,#CYCLE FOR THE #,3A4,F5.2,
00444 - C # /#,F5.2,# TREE CLASSES.# /57X,A8/35X,#PHASE #,A3,
00445 - C 13X,A8/1X,13(#+-#),# [----- INPUTS -----] #,
00446 - C # [----- OUTPUTS -----] # /# TREE NUMBER INITIAL TOTAL#,
00447 - C # PERCENT DEFOLIATION VIABLE RECIS-# /# CLASS OF VIA#,
00448 - C #BLE FOLIAGE NEW -TION EGGS TRIBUTED # /# NO.#,
00449 - C # STEMS EGGS BIOMASS FOLIAGE#,11X,#LAID EGGS# /,
00450 - C 16X,#(NO.) (GRAMS) (%)#6X,#(%) (NO.) (NO.)# /,
00451 - C 1X,64(#+-#))
00452 -10100 FORMAT (1X,I3,2X,F7.2,1X,6(1X,F7.3))
00453 -20000 FORMAT(1# TABLE 2.#,I2,#: OUTBREAK DEFOLIATION SUMMARY #,
00454 - C#AND THE ASSOCIATED# /5X,#MORTALITY PROBABILITIES FOR THE #
00455 - C,3A4,F5.2,# /#,F5.2/5X,#TREE CLASSES.#,22X,2(2X,A8)/)
00456 -21000 FORMAT(1# ----- A: DEFOLIATION SUMMARY #,35(#+-#)/# TREE #,
00457 - C# INITIAL#,5X,#BRANCH PERCENT PERCENT OF EXPECTATION#,
00458 - C /# CLASS VIABLE DEFOLIATION BY PHASE#,7X,#TREE#,8X,#OF# /,
00459 - C# NO. EGGS #,22(#+-#),# TOTALLY DIRECT# /7X,
00460 - C#PHASE I I II III DEFOLIATED MORTALITY#,
00461 - C /# #,64(#+-#))
00462 -21100 FORMAT(2X,I3,1X,4(1X,F7.3),2X,F7.3,5X,F7.4)
00463 -22000 FORMAT(1# ----- B: MORTALITY PROBABILITIES #,31(#+-#)/,
00464 - C# TREE INITIAL PERCENT#,13X,#EXPECTATION OF# /# CLASS#
00465 - C,# VIABLE OF TREE #,41(#+-#)/# NO. EGGS DEFOL-#,
00466 - C# DIRECT SECONDARY TOP NO TOP KILL# /7X,#PHASE I#,
00467 - C# IATED MORTALITY MORTALITY KILL DAMAGE# /# #,64(#+-#))
00468 -22100 FORMAT(1X,I3,3X,2(F7.3,2X),4(F7.4,2X))
00469 -23000 FORMAT (1# ----- C: TOP KILL PROBABILITIES #,31(#+-#)/,
00470 - C# TREE INITIAL# /# CLASS VIABLE#,14X,#EXPECTATION OF TOP#,
00471 - C# KILL# /# NO. EGGS #,50(#+-#)/7X,#PHASE I ANY L#,
00472 - C#EADER 1-10% 11-25% 26-50% 51-90% # /# #,64(#+-#))
00473 -23100 FORMAT(1X,I3,3X,F7.3,2X,6(F7.4,1X))
00474 - END
EOF CN INPUT UNIT

```

```

00001 - SUBROUTINE TABLE32(B)
00002 - DIMENSION B(1)
00003 -C
00004 -C
00005 -C
00006 -C
00007 -C
00008 -C
00009 -C
00010 -C
00011 -C
00012 -C
00013 -C
00014 -C
00015 -C
00016 -C
00017 -C
00018 -C
00019 -C
00020 -C
00021 -C
00022 -C
00023 -C
00024 -C
00025 -C
00026 -C
00027 -C
00028 -C
00029 -C
00030 -C
00031 -C
00032 -C
00033 -C
00034 -C
00035 -C
00036 -C
00037 -C
00038 -C
00039 -C
00040 -C
00041 -C
00042 -C
00043 -C
00044 -C
00045 -C
00046 -C
00047 -C
00048 -C
00049 -C
EOF CN INPUT UNIT

SUBROUTINE TABLE32(B)
DIMENSION B(1)

WRITE THE DESTRUCTION/CONSUMPTION PATIOS AND
INDIVIDUAL PIOMASS GROWTH RATES ON TABLE 3, LUN 17

WRITE (17,1500) (B(J),J=7,12)
1500 FORMAT(17,24(*-#)/#0 DESTRUCTION/CONSUMPTION#/,
C7,10X,1PATIOS#/#,24(*-#)/#0#8X,NEW FOLIAGE#,
C8X,11,1111 DF,GF#,5X,6(F6.3,X))
WRITE (17,1550) (R(J),J=13,18)
1550 FORMAT(17,8X,10LD FOLIAGE#,8X,11,111 CF,GF#,5X,
C6(F6.3,X))
WRITE (17,1600) B(22),B(22),B(23),B(24),B(24)
1600 FORMAT(17,24(*-#)/#0#5X,INDIVIDUAL#/#,
C7 GROWTH RATE#,5X,11,111 CF,GF#,5X,6(F6.4,X))
RETURN
END

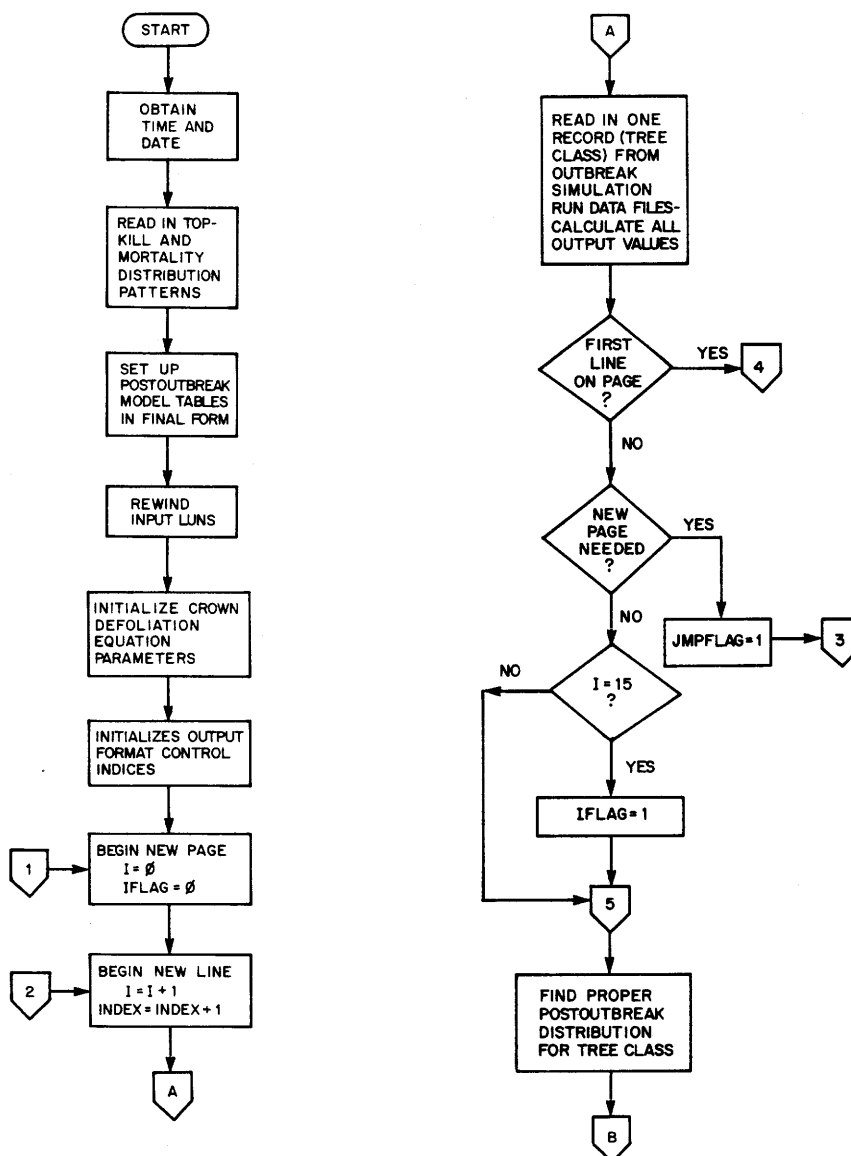
SUBROUTINE S2(X,KP,F0404)
DIMENSION IBOUT(8),IXOUT(8),XOUT(4)
DIMENSION X(1)
EQUIVALENCE ((IBOUT(1),X1),((IBOUT(3),X2),((IBOUT(5),X3),
EQUIVALENCE ((IBOUT(7),X4),((IXOUT(1),XOUT(1)),((IXOUT(3),XOUT(2)),
EQUIVALENCE ((IXOUT(5),XOUT(3)),XOUT(4)))

AT KP=0, WRITE CURRENT STATE VARIABLES ON LUNS 21 AND 25;
AT ALL OTHER TIME STEPS WRITE UPDATED
VALUES ONLY ON 21 AND 25

X1=X(1)+(F(1,1))-F(1,2))*0.10
X2=X(2)+(F(2,2))+F(1,2))*0.10
X3=X(3)+F(3,3)*0.10
X4=X(4)+F(0404)*0.10
IF(KP.EQ.0) WRITE(21,1000) X(1),X(2),X(3),X(4)
1000 FORMAT(14,(2X,F14.7))
WRITE (4,(2X,F14.7))
IF (KP.EQ.9) WRITE (21,1000)
DO 1 I=1,4
XOUT(I)=X(I)
1 XOUT(1)=X(1)
IF(KP.EQ.0) BUFFER OUT(25,1) (IXOUT(1),IXOUT(8))
CALL UNITST(25,1B25)
IF(KP.NE.9) BUFFER OUT(25,1) (IBOUT(1),IRCUT(8))
RETURN
END
EOF CN INPUT UNIT

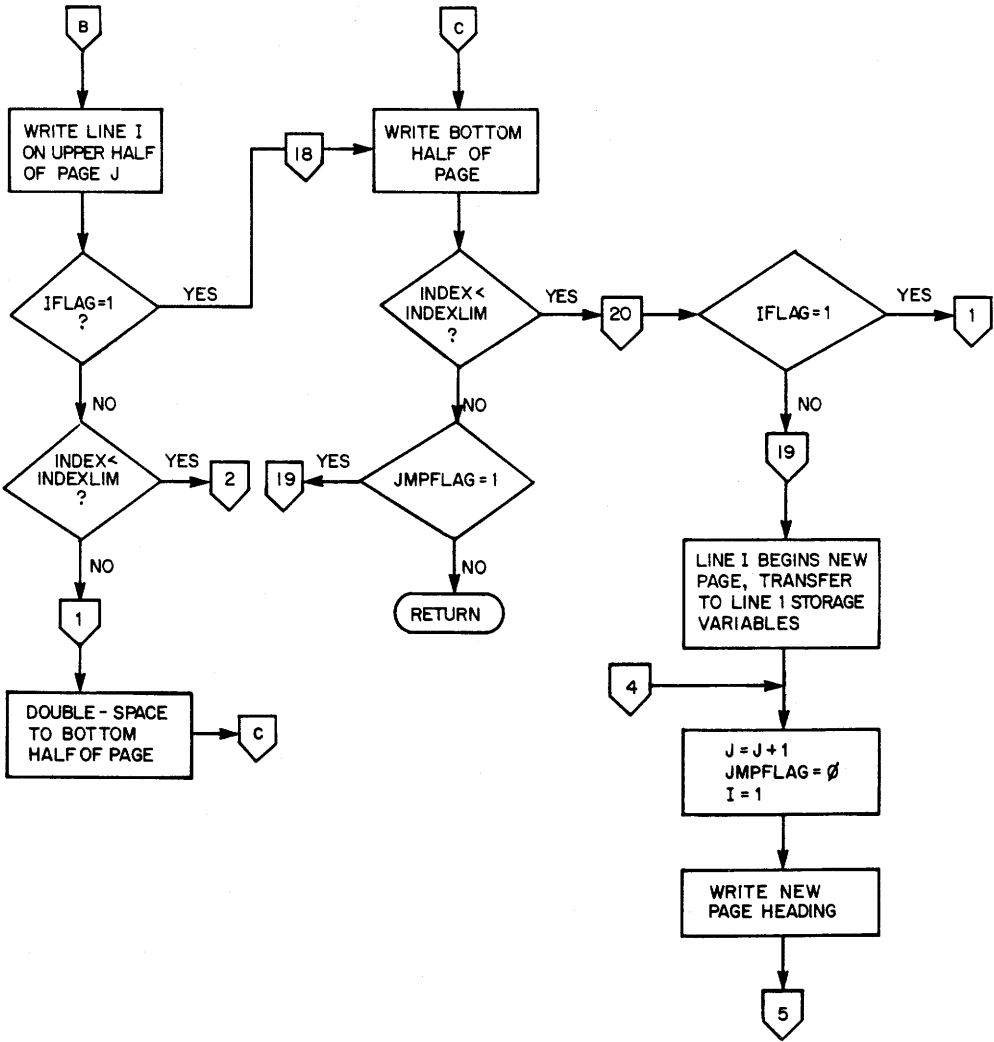
```

# Subroutine TABLE12 flowchart



Note: The numbers inside symbol  are statement labels in the code for the subroutine TABLE12.

Subroutine TABLE12 flowchart (continued)



## APPENDIX B VERSION 2.2 VERIFICATION OUTPUT

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|------------------------|------|
| Model parameterization | 77   |
| Simulation output      | 77   |



## APPENDIX C VERSION 3.1 VERIFICATION INPUT AND OUTPUT

|          | Page |
|----------|------|
| Inputs:  |      |
| LUN1     | 79   |
| LUN13    | 79   |
| LUN14    | 79   |
| Outputs: |      |
| Table 1  | 80   |
| Table 2  | 82   |
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| Table 4  | 85   |

## LUN1

|        |   |   |     |     |      |       |       |       |      |    |
|--------|---|---|-----|-----|------|-------|-------|-------|------|----|
| 000001 | - | 2 | 1.0 | 1.0 | 35.0 | 144.0 | 50.40 | 93.60 | 0.1  | 1  |
| 000002 | - | 2 | 1.0 | 1.0 | 35.0 | 144.0 | 50.40 | 93.60 | 0.5  | 2  |
| 000003 | - | 2 | 1.0 | 1.0 | 35.0 | 144.0 | 50.40 | 93.60 | 1.0  | 3  |
| 000004 | - | 2 | 1.0 | 1.0 | 35.0 | 144.0 | 50.40 | 93.60 | 2.0  | 4  |
| 000005 | - | 2 | 1.0 | 1.0 | 35.0 | 144.0 | 50.40 | 93.60 | 3.0  | 5  |
| 000006 | - | 2 | 1.0 | 1.0 | 35.0 | 144.0 | 50.40 | 93.60 | 3.5  | 6  |
| 000007 | - | 2 | 1.0 | 1.0 | 35.0 | 144.0 | 50.40 | 93.60 | 4.0  | 7  |
| 000008 | - | 2 | 1.0 | 1.0 | 35.0 | 144.0 | 50.40 | 93.60 | 4.5  | 8  |
| 000009 | - | 2 | 1.0 | 1.0 | 35.0 | 144.0 | 50.40 | 93.60 | 5.0  | 9  |
| 000010 | - | 2 | 1.0 | 1.0 | 35.0 | 144.0 | 50.40 | 93.60 | 6.0  | 10 |
| 000011 | - | 2 | 1.0 | 1.0 | 35.0 | 144.0 | 50.40 | 93.60 | 8.0  | 11 |
| 000012 | - | 2 | 1.0 | 1.0 | 35.0 | 144.0 | 50.40 | 93.60 | 10.0 | 12 |
| 000013 | - | 1 | 1.0 | 1.0 | 30.0 | 100.0 | 30.0  | 70.0  | 0.1  | 13 |
| 000014 | - | 1 | 1.0 | 1.0 | 30.0 | 100.0 | 30.0  | 70.0  | 0.5  | 14 |
| 000015 | - | 1 | 1.0 | 1.0 | 30.0 | 100.0 | 30.0  | 70.0  | 1.0  | 15 |
| 000016 | - | 1 | 1.0 | 1.0 | 30.0 | 100.0 | 30.0  | 70.0  | 2.0  | 16 |
| 000017 | - | 1 | 1.0 | 1.0 | 30.0 | 100.0 | 30.0  | 70.0  | 3.0  | 17 |
| 000018 | - | 1 | 1.0 | 1.0 | 30.0 | 100.0 | 30.0  | 70.0  | 3.5  | 18 |
| 000019 | - | 1 | 1.0 | 1.0 | 30.0 | 100.0 | 30.0  | 70.0  | 4.0  | 19 |
| 000020 | - | 1 | 1.0 | 1.0 | 30.0 | 100.0 | 30.0  | 70.0  | 4.5  | 20 |
| 000021 | - | 1 | 1.0 | 1.0 | 30.0 | 100.0 | 30.0  | 70.0  | 5.0  | 21 |
| 000022 | - | 1 | 1.0 | 1.0 | 30.0 | 100.0 | 30.0  | 70.0  | 6.0  | 22 |
| 000023 | - | 1 | 1.0 | 1.0 | 30.0 | 100.0 | 30.0  | 70.0  | 8.0  | 23 |
| 000024 | - | 1 | 1.0 | 1.0 | 30.0 | 100.0 | 30.0  | 70.0  | 10.0 | 24 |

EOF ON INPUT UNIT

## LUN13

|        |        |       |       |       |       |       |       |
|--------|--------|-------|-------|-------|-------|-------|-------|
| 000001 | -0.000 | 0.879 | 0.673 | 0.048 | 0.048 | 0.048 | 0.048 |
| 000002 | -0.000 | 0.762 | 0.143 | 0.072 | 0.072 | 0.072 | 0.095 |
| 000003 | -0.009 | 0.555 | 0.191 | 0.222 | 0.222 | 0.254 | 0.254 |
| 000004 | -0.028 | 0.457 | 0.257 | 0.171 | 0.171 | 0.286 | 0.286 |
| 000005 | -0.173 | 0.475 | 0.175 | 0.075 | 0.075 | 0.200 | 0.350 |
| 000006 | -0.477 | 0.462 | 0.308 | 0.076 | 0.076 | 0.076 | 0.230 |
| 000007 | -0.923 | 0.462 | 0.308 | 0.076 | 0.076 | 0.076 | 0.230 |
| 000008 | -0.068 | 0.000 | 0.034 | 0.333 | 0.250 | 0.667 |       |
| 000009 | -0.076 | 0.049 | 0.000 | 0.143 | 0.000 | 0.667 |       |

EOF ON INPUT UNIT

## LUN14

|        |        |       |       |       |       |       |       |
|--------|--------|-------|-------|-------|-------|-------|-------|
| 000001 | -0.000 | 0.940 | 0.035 | 0.013 | 0.017 | 0.021 | 0.025 |
| 000002 | -0.000 | 0.867 | 0.090 | 0.031 | 0.039 | 0.041 | 0.042 |
| 000003 | -0.009 | 0.712 | 0.138 | 0.095 | 0.128 | 0.141 | 0.150 |
| 000004 | -0.028 | 0.569 | 0.183 | 0.111 | 0.157 | 0.209 | 0.248 |
| 000005 | -0.173 | 0.493 | 0.240 | 0.075 | 0.103 | 0.123 | 0.267 |
| 000006 | -0.477 | 0.460 | 0.189 | 0.081 | 0.135 | 0.135 | 0.351 |
| 000007 | -0.923 | 0.460 | 0.189 | 0.081 | 0.135 | 0.135 | 0.351 |
| 000008 | -0.014 | 0.005 | 0.022 | 0.333 | 0.053 | 0.472 |       |
| 000009 | -0.029 | 0.021 | 0.032 | 0.000 | 0.000 | 0.143 |       |

EOF ON INPUT UNIT

<sup>1/</sup> The value 0.333 for this parameter was used for validation simulations. The updated value 0.030 should be substituted for any further use of this parameter.

TABLE 1. 1: INPUT-OUTPUT VARIABLE VALUES OVER THE OUTBREAK CYCLE  
FOR THE GRAND FIR 35,000 / 65,000 TREE CLASSES

23:31:45 08/18/77

| TREE CLASS NO. | NUMBER OF STEMS | PHASE I           |                               |                         |                 | PHASE II               |                           |                   |                               | PHASE III               |                 |                        |                           | PHASE IV          |                               |                         |                 |
|----------------|-----------------|-------------------|-------------------------------|-------------------------|-----------------|------------------------|---------------------------|-------------------|-------------------------------|-------------------------|-----------------|------------------------|---------------------------|-------------------|-------------------------------|-------------------------|-----------------|
|                |                 | INPUTS            |                               | OUTPUTS                 |                 | INPUTS                 |                           | OUTPUTS           |                               | INPUTS                  |                 | OUTPUTS                |                           | INPUTS            |                               | OUTPUTS                 |                 |
|                |                 | VIABLE EGGS (NO.) | TOTAL FOLIAGE BIOMASS (GRAMS) | PERCENT NEW FOLIAGE (%) | DEFOLIATION (%) | VIABLE EGGS LAID (NO.) | REDIS-TRIBUTED EGGS (NO.) | VIABLE EGGS (NO.) | TOTAL FOLIAGE BIOMASS (GRAMS) | PERCENT NEW FOLIAGE (%) | DEFOLIATION (%) | VIABLE EGGS LAID (NO.) | REDIS-TRIBUTED EGGS (NO.) | VIABLE EGGS (NO.) | TOTAL FOLIAGE BIOMASS (GRAMS) | PERCENT NEW FOLIAGE (%) | DEFOLIATION (%) |
| 1              | 1.000           | .100              | 144.000                       | 35.000                  | .083            | 1.488                  | 1.488                     | .744              | 143.979                       | 34.991                  | .626            | 8.081                  | 8.081                     |                   |                               |                         |                 |
| 2              | 1.000           | .500              | 144.000                       | 35.000                  | .414            | 7.439                  | 7.439                     | 3.719             | 143.896                       | 34.953                  | 3.128           | 40.406                 | 40.406                    |                   |                               |                         |                 |
| 3              | 1.000           | 1.000             | 144.000                       | 35.000                  | .828            | 14.878                 | 14.878                    | 7.439             | 143.791                       | 34.908                  | 6.256           | 80.811                 | 80.811                    |                   |                               |                         |                 |
| 4              | 1.000           | 2.000             | 144.000                       | 35.000                  | 1.655           | 29.755                 | 29.755                    | 14.878            | 143.583                       | 34.811                  | 12.513          | 161.623                | 161.623                   |                   |                               |                         |                 |
| 5              | 1.000           | 3.000             | 144.000                       | 35.000                  | 2.483           | 44.633                 | 44.633                    | 22.316            | 143.374                       | 34.716                  | 18.769          | 242.434                | 242.434                   |                   |                               |                         |                 |
| 6              | 1.000           | 3.500             | 144.000                       | 35.000                  | 2.897           | 52.072                 | 52.072                    | 26.036            | 143.270                       | 34.669                  | 21.898          | 282.840                | 282.840                   |                   |                               |                         |                 |
| 7              | 1.000           | 4.000             | 144.000                       | 35.000                  | 3.310           | 59.511                 | 59.511                    | 29.755            | 143.166                       | 34.621                  | 25.026          | 323.245                | 323.245                   |                   |                               |                         |                 |
| 8              | 1.000           | 4.500             | 144.000                       | 35.000                  | 3.724           | 66.949                 | 66.949                    | 33.475            | 143.062                       | 34.574                  | 28.154          | 363.651                | 363.651                   |                   |                               |                         |                 |
| 9              | 1.000           | 5.000             | 144.000                       | 35.000                  | 4.138           | 74.388                 | 74.388                    | 37.194            | 142.957                       | 34.526                  | 31.282          | 404.057                | 404.057                   |                   |                               |                         |                 |
| 10             | 1.000           | 6.000             | 144.000                       | 35.000                  | 4.966           | 89.266                 | 89.266                    | 44.633            | 142.749                       | 34.430                  | 38.878          | 465.473                | 465.473                   |                   |                               |                         |                 |
| 11             | 1.000           | 8.000             | 144.000                       | 35.000                  | 6.621           | 119.021                | 119.021                   | 59.511            | 142.332                       | 34.238                  | 57.540          | 543.052                | 543.052                   |                   |                               |                         |                 |
| 12             | 1.000           | 10.000            | 144.000                       | 35.000                  | 8.276           | 148.777                | 148.777                   | 74.388            | 141.914                       | 34.045                  | 68.281          | 510.566                | 510.566                   |                   |                               |                         |                 |
|                |                 |                   |                               |                         |                 |                        |                           |                   |                               |                         |                 |                        |                           |                   |                               |                         |                 |
|                |                 |                   |                               |                         |                 |                        |                           |                   |                               |                         |                 |                        |                           |                   |                               |                         |                 |
| 1              | 1.000           | 3.232             | 143.842                       | 34.929                  | 1.922           | 3.525                  | 3.525                     | .529              | 143.516                       | 34.781                  | .467            | .095                   | .095                      |                   |                               |                         |                 |
| 2              | 1.000           | 16.162            | 143.212                       | 34.642                  | 9.610           | 17.626                 | 17.626                    | 2.644             | 141.578                       | 33.888                  | 2.337           | .474                   | .474                      |                   |                               |                         |                 |
| 3              | 1.000           | 32.325            | 142.423                       | 34.280                  | 19.219          | 35.253                 | 35.253                    | 5.288             | 139.157                       | 32.738                  | 4.674           | .948                   | .948                      |                   |                               |                         |                 |
| 4              | 1.000           | 64.649            | 140.847                       | 33.545                  | 40.324          | 62.045                 | 62.045                    | 9.307             | 126.172                       | 31.892                  | 14.688          | 1.668                  | 1.668                     |                   |                               |                         |                 |
| 5              | 1.000           | 96.974            | 139.270                       | 32.792                  | 53.323          | 36.926                 | 36.926                    | 5.539             | 104.178                       | 35.480                  | 29.028          | .993                   | .993                      |                   |                               |                         |                 |
| 6              | 1.000           | 113.136           | 138.482                       | 32.410                  | 46.510          | 14.843                 | 14.843                    | 2.226             | 115.705                       | 33.429                  | 20.201          | .399                   | .399                      |                   |                               |                         |                 |
| 7              | 1.000           | 129.298           | 137.693                       | 32.023                  | 45.504          | 8.359                  | 8.359                     | 1.254             | 117.407                       | 33.161                  | 18.778          | .225                   | .225                      |                   |                               |                         |                 |
| 8              | 1.000           | 145.460           | 136.905                       | 31.632                  | 40.543          | 2.282                  | 2.282                     | .342              | 125.802                       | 31.942                  | 12.722          | .061                   | .061                      |                   |                               |                         |                 |
| 9              | 1.000           | 161.623           | 136.117                       | 31.236                  | 40.860          | 1.248                  | 1.248                     | .187              | 125.264                       | 32.015                  | 13.057          | .034                   | .034                      |                   |                               |                         |                 |
| 10             | 1.000           | 186.189           | 129.619                       | 31.568                  | 43.673          | .348                   | .348                      | .052              | 120.585                       | 32.691                  | 16.329          | .009                   | .009                      |                   |                               |                         |                 |
| 11             | 1.000           | 217.221           | 97.042                        | 36.994                  | 63.828          | .098                   | .098                      | .015              | 86.404                        | 39.715                  | 40.001          | .003                   | .003                      |                   |                               |                         |                 |
| 12             | 1.000           | 204.226           | 78.869                        | 42.087                  | 71.615          | .046                   | .046                      | .007              | 73.227                        | 44.182                  | 49.150          | .001                   | .001                      |                   |                               |                         |                 |

TABLE 1. 2: INPUT-OUTPUT VARIABLE VALUES OVER THE OUTBREAK CYCLE  
FOR THE DOUGLAS-FIR 30.000 / 70.000 TREE CLASSES

| TREE CLASS NO. | NUMBER OF STEPS | PHASE I           |                               |                         |                 | PHASE II                 |                          |                   |                               | PHASE III               |                 |                          |                          | PHASE IV          |                               |                         |                 |
|----------------|-----------------|-------------------|-------------------------------|-------------------------|-----------------|--------------------------|--------------------------|-------------------|-------------------------------|-------------------------|-----------------|--------------------------|--------------------------|-------------------|-------------------------------|-------------------------|-----------------|
|                |                 | INPUTS            |                               | OUTPUTS                 |                 | INPUTS                   |                          | OUTPUTS           |                               | INPUTS                  |                 | OUTPUTS                  |                          | INPUTS            |                               | OUTPUTS                 |                 |
|                |                 | VIABLE EGGS (NO.) | TOTAL FOLIAGE BIOMASS (GRAMS) | PERCENT NEW FOLIAGE (%) | DEFOLIATION (%) | VIABLE EGGS LARVAE (NO.) | REDISTRIBUTED EGGS (NO.) | VIABLE EGGS (NO.) | TOTAL FOLIAGE BIOMASS (GRAMS) | PERCENT NEW FOLIAGE (%) | DEFOLIATION (%) | VIABLE EGGS LARVAE (NO.) | REDISTRIBUTED EGGS (NO.) | VIABLE EGGS (NO.) | TOTAL FOLIAGE BIOMASS (GRAMS) | PERCENT NEW FOLIAGE (%) | DEFOLIATION (%) |
| 13             | 1.000           | .100              | 100.000                       | 30.000                  | .119            | 14.88                    | 14.88                    | .744              | 99.982                        | 29.937                  | .898            | 8.081                    | 8.081                    | 8.081             | 99.982                        | 29.937                  | .898            |
| 14             | 1.000           | .500              | 100.000                       | 30.000                  | .596            | 7.439                    | 7.439                    | 3.719             | 99.911                        | 29.937                  | 4.490           | 40.406                   | 40.406                   | 40.406            | 99.911                        | 29.937                  | 4.490           |
| 15             | 1.000           | 1.000             | 100.000                       | 30.000                  | 1.192           | 14.878                   | 14.878                   | 7.439             | 99.821                        | 29.875                  | 8.988           | 80.811                   | 80.811                   | 80.811            | 99.821                        | 29.875                  | 8.988           |
| 16             | 1.000           | 2.000             | 100.000                       | 30.000                  | 2.383           | 29.755                   | 29.755                   | 14.878            | 99.642                        | 29.749                  | 17.959          | 161.623                  | 161.623                  | 161.623           | 99.642                        | 29.749                  | 17.959          |
| 17             | 1.000           | 3.000             | 100.000                       | 30.000                  | 3.575           | 44.633                   | 44.633                   | 22.316            | 99.464                        | 29.623                  | 26.938          | 242.434                  | 242.434                  | 242.434           | 99.464                        | 29.623                  | 26.938          |
| 18             | 1.000           | 3.500             | 100.000                       | 30.000                  | 4.171           | 52.072                   | 52.072                   | 26.036            | 99.374                        | 29.559                  | 32.289          | 274.354                  | 274.354                  | 274.354           | 99.374                        | 29.559                  | 32.289          |
| 19             | 1.000           | 4.000             | 100.000                       | 30.000                  | 4.767           | 59.511                   | 59.511                   | 29.755            | 99.285                        | 29.496                  | 39.247          | 287.688                  | 287.688                  | 287.688           | 99.285                        | 29.496                  | 39.247          |
| 20             | 1.000           | 4.500             | 100.000                       | 30.000                  | 5.363           | 66.949                   | 66.949                   | 33.475            | 99.196                        | 29.432                  | 45.601          | 312.740                  | 312.740                  | 312.740           | 99.196                        | 29.432                  | 45.601          |
| 21             | 1.000           | 5.000             | 100.000                       | 30.000                  | 5.959           | 74.388                   | 74.388                   | 37.194            | 99.106                        | 29.369                  | 52.094          | 335.367                  | 335.367                  | 335.367           | 99.106                        | 29.369                  | 52.094          |
| 22             | 1.000           | 6.000             | 100.000                       | 30.000                  | 7.150           | 89.266                   | 89.266                   | 44.633            | 98.927                        | 29.241                  | 65.053          | 378.197                  | 378.197                  | 378.197           | 98.927                        | 29.241                  | 65.053          |
| 23             | 1.000           | 8.000             | 100.000                       | 30.000                  | 9.534           | 119.821                  | 119.821                  | 59.511            | 98.570                        | 28.984                  | 90.280          | 459.888                  | 459.888                  | 459.888           | 98.570                        | 28.984                  | 90.280          |
| 24             | 1.000           | 10.000            | 100.000                       | 30.000                  | 11.917          | 148.777                  | 148.777                  | 74.388            | 98.212                        | 28.726                  | 98.207          | 445.109                  | 445.109                  | 445.109           | 98.212                        | 28.726                  | 98.207          |

| TREE CLASS NO. | NUMBER OF STEPS | PHASE III         |                               |                         |                 | PHASE IV                 |                          |                   |                               | PHASE V                 |                 |                          |                          |
|----------------|-----------------|-------------------|-------------------------------|-------------------------|-----------------|--------------------------|--------------------------|-------------------|-------------------------------|-------------------------|-----------------|--------------------------|--------------------------|
|                |                 | INPUTS            |                               | OUTPUTS                 |                 | INPUTS                   |                          | OUTPUTS           |                               | INPUTS                  |                 | OUTPUTS                  |                          |
|                |                 | VIABLE EGGS (NO.) | TOTAL FOLIAGE BIOMASS (GRAMS) | PERCENT NEW FOLIAGE (%) | DEFOLIATION (%) | VIABLE EGGS LARVAE (NO.) | REDISTRIBUTED EGGS (NO.) | VIABLE EGGS (NO.) | TOTAL FOLIAGE BIOMASS (GRAMS) | PERCENT NEW FOLIAGE (%) | DEFOLIATION (%) | VIABLE EGGS LARVAE (NO.) | REDISTRIBUTED EGGS (NO.) |
| 13             | 1.000           | 3.232             | 99.865                        | 29.986                  | 2.745           | 3.525                    | 3.525                    | .529              | 99.588                        | 29.741                  | .680            | .095                     | .095                     |
| 14             | 1.000           | 16.162            | 99.327                        | 29.525                  | 13.723          | 17.626                   | 17.626                   | 2.644             | 97.942                        | 28.529                  | 3.002           | .474                     | .474                     |
| 15             | 1.000           | 32.325            | 98.653                        | 29.044                  | 27.446          | 35.253                   | 35.253                   | 5.288             | 95.883                        | 26.994                  | 6.005           | .948                     | .948                     |
| 16             | 1.000           | 64.649            | 97.306                        | 28.062                  | 65.568          | 49.354                   | 49.354                   | 7.403             | 94.596                        | 36.934                  | 48.047          | 1.327                    | 1.327                    |
| 17             | 1.000           | 96.974            | 95.959                        | 27.852                  | 73.009          | 40.592                   | 40.592                   | 6.089             | 93.039                        | 41.375                  | 56.135          | 1.891                    | 1.891                    |
| 18             | 1.000           | 109.742           | 92.868                        | 27.089                  | 80.135          | 40.707                   | 40.707                   | 6.106             | 91.845                        | 47.509                  | 64.336          | 1.094                    | 1.094                    |
| 19             | 1.000           | 115.075           | 84.866                        | 28.413                  | 86.642          | 37.817                   | 37.817                   | 5.673             | 90.362                        | 56.004                  | 71.664          | 1.016                    | 1.016                    |
| 20             | 1.000           | 125.096           | 77.559                        | 29.861                  | 94.562          | 36.412                   | 36.412                   | 5.462             | 88.794                        | 75.771                  | 81.156          | .979                     | .979                     |
| 21             | 1.000           | 134.147           | 70.092                        | 31.653                  | 100.000         | 16.511                   | 16.511                   | 2.477             | 87.400                        | 100.000                 | 89.484          | .444                     | .444                     |
| 22             | 1.000           | 151.279           | 55.189                        | 36.678                  | 80.590          | 8.485                    | 8.485                    | 1.273             | 86.321                        | 47.993                  | 63.133          | .228                     | .228                     |
| 23             | 1.000           | 183.603           | 26.178                        | 62.869                  | 91.553          | .037                     | .037                     | .006              | 85.714                        | 65.822                  | 75.288          | .001                     | .001                     |
| 24             | 1.000           | 178.044           | 17.062                        | 89.491                  | 100.000         | 0                        | 0                        | 0                 | 84.200                        | 100.000                 | 86.800          | 0                        | 0                        |

TABLE 2. 1: OUTBREAK DEFOLIATION SUMMARY AND THE EXPECTED MORTALITY AND GROWTH REDUCTION

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FOR THE GRAND FIR 35.000 / 65.000 TREE CLASSES

| TREE CLASS NO. | NUMBER OF TREES | WEIGHT FACTOR PER TREE | INITIAL Viable EGGS PHASE I | MODEL BRANCH: PERCENT DEFOLIATION BY PHASE |        |        |        | PERCENT OF TREE TOTALLY DEFOLIATED | PROPORTION OF TREES RECEIVING: |                     |          |                       |
|----------------|-----------------|------------------------|-----------------------------|--------------------------------------------|--------|--------|--------|------------------------------------|--------------------------------|---------------------|----------|-----------------------|
|                |                 |                        |                             | I                                          | II     | III    | IV     |                                    | DIRECT MORTALITY               | SECONDARY MORTALITY | TOP KILL | ONLY GROWTH REDUCTION |
| 1              | 1.0             | 1.0                    | .100                        | .093                                       | .626   | 1.922  | .467   | .000                               | 0                              | .0454               | .0547    | .9000                 |
| 2              | 1.0             | 1.0                    | .500                        | .414                                       | 3.128  | 9.610  | 2.337  | .000                               | 0                              | .0454               | .0547    | .9000                 |
| 3              | 1.0             | 1.0                    | 1.000                       | .828                                       | 6.256  | 19.219 | 4.674  | .000                               | 0                              | .0454               | .0547    | .9000                 |
| 4              | 1.0             | 1.0                    | 2.000                       | 1.655                                      | 12.513 | 40.324 | 14.688 | .034                               | 0                              | .0454               | .0547    | .9000                 |
| 5              | 1.0             | 1.0                    | 3.000                       | 2.483                                      | 18.769 | 53.323 | 29.028 | .635                               | 0                              | .0454               | .0547    | .9000                 |
| 6              | 1.0             | 1.0                    | 3.500                       | 2.897                                      | 21.898 | 46.510 | 20.201 | .137                               | 0                              | .0454               | .0547    | .9000                 |
| 7              | 1.0             | 1.0                    | 4.000                       | 3.310                                      | 25.026 | 45.504 | 18.778 | .109                               | 0                              | .0454               | .0547    | .9000                 |
| 8              | 1.0             | 1.0                    | 4.500                       | 3.724                                      | 28.154 | 40.543 | 12.722 | .036                               | 0                              | .0454               | .0547    | .9000                 |
| 9              | 1.0             | 1.0                    | 5.000                       | 4.138                                      | 31.282 | 40.860 | 13.057 | .038                               | 0                              | .0454               | .0547    | .9000                 |
| 10             | 1.0             | 1.0                    | 6.000                       | 4.966                                      | 38.978 | 43.673 | 16.329 | .072                               | 0                              | .0454               | .0547    | .9000                 |
| 11             | 1.0             | 1.0                    | 8.000                       | 6.621                                      | 57.540 | 63.828 | 40.001 | 6.407                              | 0                              | .0454               | .0547    | .9000                 |
| 12             | 1.0             | 1.0                    | 10.000                      | 8.276                                      | 68.281 | 71.615 | 49.150 | 28.310                             | 0                              | .0452               | .1247    | .8301                 |

| TREE CLASS NO. | NUMBER OF TREES | WEIGHT FACTOR PER TREE | INITIAL Viable EGGS PHASE I | PROPORTION OF TREES BY PERCENT REDUCTION IN CROWN HEIGHT |       |       |       |       | GROWTH IN SURVIVING TREES WITH NO TOP KILL |                           | DIAMETER GROWTH IN TREES WITH TOP KILL |                           |
|----------------|-----------------|------------------------|-----------------------------|----------------------------------------------------------|-------|-------|-------|-------|--------------------------------------------|---------------------------|----------------------------------------|---------------------------|
|                |                 |                        |                             | 0.0                                                      | 5.0   | 17.5  | 37.5  | 70.0  | PERCENT OF NOMINAL DIAMETER                | PERCENT OF NOMINAL HEIGHT | PERCENT OF NOMINAL DIAMETER            | PERCENT OF NOMINAL HEIGHT |
| 1              | 1.0             | 1.0                    | .10                         | .0341                                                    | .0123 | .0027 | .0038 | .0018 | 98.08                                      | 98.08                     |                                        | 98.08                     |
| 2              | 1.0             | 1.0                    | .50                         | .0341                                                    | .0123 | .0027 | .0038 | .0018 | 90.39                                      | 90.39                     |                                        | 90.39                     |
| 3              | 1.0             | 1.0                    | 1.00                        | .0341                                                    | .0123 | .0027 | .0038 | .0018 | 80.78                                      | 80.78                     |                                        | 80.78                     |
| 4              | 1.0             | 1.0                    | 2.00                        | .0341                                                    | .0123 | .0027 | .0038 | .0018 | 59.68                                      | 59.68                     |                                        | 59.68                     |
| 5              | 1.0             | 1.0                    | 3.00                        | .0341                                                    | .0123 | .0027 | .0038 | .0018 | 46.68                                      | 46.68                     |                                        | 46.68                     |
| 6              | 1.0             | 1.0                    | 3.50                        | .0341                                                    | .0123 | .0027 | .0038 | .0018 | 53.49                                      | 53.49                     |                                        | 53.49                     |
| 7              | 1.0             | 1.0                    | 4.00                        | .0341                                                    | .0123 | .0027 | .0038 | .0018 | 54.50                                      | 54.50                     |                                        | 54.50                     |
| 8              | 1.0             | 1.0                    | 4.50                        | .0341                                                    | .0123 | .0027 | .0038 | .0018 | 59.46                                      | 59.46                     |                                        | 59.46                     |
| 9              | 1.0             | 1.0                    | 5.00                        | .0341                                                    | .0123 | .0027 | .0038 | .0018 | 59.14                                      | 59.14                     |                                        | 59.14                     |
| 10             | 1.0             | 1.0                    | 6.00                        | .0341                                                    | .0123 | .0027 | .0038 | .0018 | 56.33                                      | 56.33                     |                                        | 56.33                     |
| 11             | 1.0             | 1.0                    | 8.00                        | .0341                                                    | .0123 | .0027 | .0038 | .0018 | 36.17                                      | 36.17                     |                                        | 36.17                     |
| 12             | 1.0             | 1.0                    | 10.00                       | .0877                                                    | .0293 | .0053 | .0019 | .0005 | 28.38                                      | 28.38                     |                                        | 28.38                     |

TABLE 2-2: OUTBREAK DEFOLIATION SUMMARY AND THE EXPECTED MORTALITY AND GROWTH REDUCTION  
FOR THE DOUGLAS-FIR 30,000 / 70,000 TREE CLASSES

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| TREE CLASS NO. | NUMBER OF TREES | WEIGHT FACTOR PER TREE | INITIAL : MODEL BRANCHES : PERCENT DEFOLIATION BY PHASE |        |        |         | PERCENT OF : PROPORTION OF TREES RECEIVING: |              |                       |                      |                         |            |
|----------------|-----------------|------------------------|---------------------------------------------------------|--------|--------|---------|---------------------------------------------|--------------|-----------------------|----------------------|-------------------------|------------|
|                |                 |                        | PHASE I :                                               | I      | II     | III     | IV                                          | DEFOLIATED : | TOTALLY : MORTALITY : | DIRECT : MORTALITY : | SECONDARY : MORTALITY : | TOP KILL : |
| 13             | 1.0             | 1.0                    | .100                                                    | .119   | .498   | 2.745   | .600                                        | .000         | 0                     | .1272                | .1158                   | .7570      |
| 14             | 1.0             | 1.0                    | .500                                                    | .596   | 4.490  | 13.723  | 3.002                                       | .000         | 0                     | .1272                | .1158                   | .7570      |
| 15             | 1.0             | 1.0                    | 1.000                                                   | 1.192  | 8.980  | 27.446  | 6.005                                       | .002         | 0                     | .1272                | .1158                   | .7570      |
| 16             | 1.0             | 1.0                    | 2.000                                                   | 2.383  | 17.959 | 65.568  | 48.047                                      | 9.203        | 0                     | .1272                | .1158                   | .7570      |
| 17             | 1.0             | 1.0                    | 3.000                                                   | 3.575  | 26.938 | 73.009  | 56.135                                      | 35.045       | .0090                 | .1010                | .4163                   | .4736      |
| 18             | 1.0             | 1.0                    | 3.500                                                   | 4.171  | 32.289 | 80.135  | 64.336                                      | 72.169       | .0280                 | .1075                | .4820                   | .3825      |
| 19             | 1.0             | 1.0                    | 4.000                                                   | 4.767  | 39.247 | 86.642  | 71.664                                      | 90.667       | .1730                 | .1999                | .2888                   | .3383      |
| 20             | 1.0             | 1.0                    | 4.500                                                   | 5.363  | 45.601 | 94.562  | 81.156                                      | 96.959       | .4770                 | .1144                | .2005                   | .2081      |
| 21             | 1.0             | 1.0                    | 5.000                                                   | 5.959  | 52.094 | 100.000 | 89.484                                      | 100.000      | .9230                 | .0168                | .0295                   | .0306      |
| 22             | 1.0             | 1.0                    | 6.000                                                   | 7.150  | 65.053 | 80.590  | 63.133                                      | 74.037       | .0280                 | .1075                | .4820                   | .3825      |
| 23             | 1.0             | 1.0                    | 8.000                                                   | 9.534  | 90.280 | 91.553  | 75.288                                      | 95.573       | .4770                 | .1144                | .2005                   | .2081      |
| 24             | 1.0             | 1.0                    | 13.000                                                  | 11.917 | 98.207 | 100.000 | 86.800                                      | 100.000      | .9230                 | .0168                | .0295                   | .0306      |

| TREE CLASS NO. | NUMBER OF TREES | WEIGHT FACTOR PER TREE | INITIAL : VISIBLE : EGGS : PHASE I : | PROPORTION OF TREES BY : PERCENT REDUCTION IN CROWN HEIGHT : |       |      |       | GROWTH IN SURVIVING : TREES WITH NO TOP KILL : |                   |                      |                      | DIAMETER GROWTH IN : TREES WITH TOP KILL : |                      |
|----------------|-----------------|------------------------|--------------------------------------|--------------------------------------------------------------|-------|------|-------|------------------------------------------------|-------------------|----------------------|----------------------|--------------------------------------------|----------------------|
|                |                 |                        |                                      | 0.0                                                          | 5.0   | 17.5 | 37.5  | 70.0                                           | DIAMETER HEIGHT : | PERCENT OF NOMINAL : | PERCENT OF NOMINAL : | PERCENT OF NOMINAL :                       | PERCENT OF NOMINAL : |
| 13             | 1.0             | 1.0                    | .10                                  | .0694                                                        | .0464 | 0    | 0     | 0                                              | 97.26             | 97.26                | 97.26                | 97.26                                      | 97.26                |
| 14             | 1.0             | 1.0                    | .50                                  | .0694                                                        | .0464 | 0    | 0     | 0                                              | 86.28             | 86.28                | 86.28                | 86.28                                      | 86.28                |
| 15             | 1.0             | 1.0                    | 1.00                                 | .0694                                                        | .0464 | 0    | 0     | 0                                              | 72.55             | 72.55                | 72.55                | 72.55                                      | 72.55                |
| 16             | 1.0             | 1.0                    | 2.00                                 | .0694                                                        | .0464 | 0    | 0     | 0                                              | 34.43             | 34.43                | 34.43                | 34.43                                      | 34.43                |
| 17             | 1.0             | 1.0                    | 3.00                                 | .1800                                                        | .2125 | 0    | .0238 | 0                                              | 26.99             | 26.99                | 26.99                | 26.99                                      | 26.99                |
| 18             | 1.0             | 1.0                    | 3.50                                 | .2376                                                        | .1606 | 0    | .0838 | 0                                              | 19.86             | 19.86                | 19.86                | 19.86                                      | 19.86                |
| 19             | 1.0             | 1.0                    | 4.00                                 | .1376                                                        | .0599 | 0    | .0775 | .0138                                          | 13.36             | 13.36                | 13.36                | 13.36                                      | 13.36                |
| 20             | 1.0             | 1.0                    | 4.50                                 | .1532                                                        | .0384 | 0    | 0     | .0089                                          | 5.04              | 5.04                 | 5.04                 | 5.04                                       | 5.04                 |
| 21             | 1.0             | 1.0                    | 5.00                                 | .0226                                                        | .0057 | 0    | 0     | .0013                                          | 0                 | 0                    | 0                    | 0                                          | 0                    |
| 22             | 1.0             | 1.0                    | 6.00                                 | .2376                                                        | .1606 | 0    | .0838 | 0                                              | 19.41             | 19.41                | 19.41                | 19.41                                      | 19.41                |
| 23             | 1.0             | 1.0                    | 8.00                                 | .1532                                                        | .0384 | 0    | 0     | .0089                                          | 8.45              | 8.45                 | 8.45                 | 8.45                                       | 8.45                 |
| 24             | 1.0             | 1.0                    | 10.00                                | .0226                                                        | .0057 | 0    | 0     | .0013                                          | 0                 | 0                    | 0                    | 0                                          | 0                    |



TABLE 4: DETAIL RUN INFORMATION, PAGE 1

| FOURTH INSTAR LARVAE             |       |        |        |       | THIRD INSTAR LARVAE              |        |         |       |  | SIXTH INSTAR LARVAE              |        |       |      |  |
|----------------------------------|-------|--------|--------|-------|----------------------------------|--------|---------|-------|--|----------------------------------|--------|-------|------|--|
| FOR GRAND FIR 35.00% NEW FOLIAGE |       |        |        |       | FOR GRAND FIR 35.00% NEW FOLIAGE |        |         |       |  | FOR GRAND FIR 35.00% NEW FOLIAGE |        |       |      |  |
| TREE CLASS                       | I     | II     | III    | IV    | I                                | II     | III     | IV    |  | I                                | II     | III   | IV   |  |
| 1.                               | .055  | .406   | 1.487  | .103  | .067                             | .497   | 1.992   | .185  |  | .018                             | .133   | .235  | .010 |  |
| 2.                               | .273  | 2.029  | 7.436  | .514  | .334                             | 2.483  | 9.960   | .924  |  | .091                             | .664   | 1.174 | .049 |  |
| 3.                               | .545  | 4.058  | 14.871 | 1.027 | .668                             | 4.966  | 19.919  | 1.848 |  | .182                             | 1.328  | 2.347 | .098 |  |
| 4.                               | 1.091 | 8.116  | 29.742 | 1.838 | 1.335                            | 9.932  | 39.838  | 3.252 |  | .364                             | 2.655  | 4.695 | .173 |  |
| 5.                               | 1.636 | 12.173 | 44.614 | 1.076 | 2.003                            | 14.899 | 59.757  | 4.635 |  | .546                             | 3.983  | 3.368 | .103 |  |
| 6.                               | 1.909 | 14.202 | 26.831 | 1.186 | 2.337                            | 17.382 | 67.626  | 5.377 |  | .637                             | 4.647  | 1.432 | .041 |  |
| 7.                               | 2.182 | 16.231 | 25.322 | 1.102 | 2.670                            | 19.865 | 79.077  | 6.065 |  | .728                             | 5.311  | .818  | .023 |  |
| 8.                               | 2.455 | 18.260 | 24.774 | 1.061 | 3.004                            | 22.348 | 89.536  | 6.778 |  | .819                             | 5.974  | .230  | .006 |  |
| 9.                               | 2.727 | 20.289 | 23.910 | .681  | 3.338                            | 24.831 | 99.596  | .065  |  | .910                             | 6.638  | .128  | .003 |  |
| 10.                              | 3.273 | 24.347 | 6.067  | .247  | 4.006                            | 29.797 | 114.734 | .018  |  | 1.093                            | 7.966  | .037  | .001 |  |
| 11.                              | 4.364 | 32.462 | .029   | .001  | 5.341                            | 39.730 | 133.857 | .005  |  | 1.457                            | 10.621 | .011  | .000 |  |
| 12.                              | 5.455 | 40.578 | .092   | .001  | 6.676                            | 49.662 | 125.849 | .002  |  | 1.821                            | 10.754 | .005  | .000 |  |

| FOURTH INSTAR LARVAE               |       |        |        |       | THIRD INSTAR LARVAE                |        |        |       |  | SIXTH INSTAR LARVAE                |        |       |      |  |
|------------------------------------|-------|--------|--------|-------|------------------------------------|--------|--------|-------|--|------------------------------------|--------|-------|------|--|
| FOR DOUGLAS FIR 30.00% NEW FOLIAGE |       |        |        |       | FOR DOUGLAS FIR 30.00% NEW FOLIAGE |        |        |       |  | FOR DOUGLAS FIR 30.00% NEW FOLIAGE |        |       |      |  |
| TREE CLASS                         | I     | II     | III    | IV    | I                                  | II     | III    | IV    |  | I                                  | II     | III   | IV   |  |
| 13.                                | .055  | .406   | 1.487  | .103  | .067                               | .497   | 1.992  | .185  |  | .018                               | .133   | .235  | .010 |  |
| 14.                                | .273  | 2.029  | 7.436  | .514  | .334                               | 2.483  | 9.960  | .924  |  | .091                               | .664   | 1.174 | .049 |  |
| 15.                                | .545  | 4.058  | 14.871 | 1.027 | .668                               | 4.966  | 19.919 | 1.848 |  | .182                               | 1.328  | 2.347 | .098 |  |
| 16.                                | 1.091 | 8.116  | 29.742 | 1.838 | 1.335                              | 9.932  | 39.838 | 3.252 |  | .364                               | 2.655  | 4.695 | .173 |  |
| 17.                                | 1.636 | 12.173 | 26.831 | 1.186 | 2.003                              | 14.899 | 59.757 | 2.127 |  | .546                               | 3.983  | 4.158 | .113 |  |
| 18.                                | 1.909 | 14.202 | 26.831 | 1.186 | 2.337                              | 17.382 | 67.626 | 2.133 |  | .637                               | 4.647  | 4.235 | .113 |  |
| 19.                                | 2.182 | 16.231 | 25.322 | 1.102 | 2.670                              | 19.865 | 70.912 | 1.982 |  | .728                               | 5.311  | 3.997 | .105 |  |
| 20.                                | 2.455 | 18.260 | 24.774 | 1.061 | 3.004                              | 22.348 | 77.087 | 1.908 |  | .819                               | 5.974  | 3.911 | .101 |  |
| 21.                                | 2.727 | 20.289 | 23.910 | .681  | 3.338                              | 24.831 | 82.665 | .865  |  | .910                               | 6.638  | 3.774 | .046 |  |
| 22.                                | 3.273 | 24.347 | 6.067  | .247  | 4.006                              | 29.797 | 23.305 | .445  |  | 1.093                              | 7.966  | .958  | .024 |  |
| 23.                                | 4.364 | 32.462 | .029   | .001  | 5.341                              | 39.730 | .110   | .002  |  | 1.457                              | 10.621 | .005  | .000 |  |
| 24.                                | 5.455 | 40.578 | .028   | .001  | 6.676                              | 49.662 | .107   | 0     |  | 1.821                              | 10.754 | .004  | .000 |  |

## FALL PUPAE

| FOR GRAND FIR 35.00% NEW FOLIAGE |       |       |       |      |
|----------------------------------|-------|-------|-------|------|
| TREE CLASS                       | I     | II    | III   | IV   |
| 1.                               | .015  | .106  | .094  | .003 |
| 2.                               | .074  | .532  | .470  | .016 |
| 3.                               | .149  | 1.063 | .940  | .032 |
| 4.                               | .298  | 2.127 | 1.880 | .066 |
| 5.                               | .446  | 3.190 | 1.369 | .033 |
| 6.                               | .521  | 3.722 | .574  | .013 |
| 7.                               | .595  | 4.253 | .328  | .007 |
| 8.                               | .669  | 4.785 | .092  | .002 |
| 9.                               | .744  | 5.317 | .051  | .001 |
| 10.                              | .893  | 6.380 | .015  | .000 |
| 11.                              | 1.190 | 8.506 | .004  | .000 |
| 12.                              | 1.488 | 8.613 | .002  | .000 |

## FALL PUPAE

| FOR DOUGLAS FIR 30.00% NEW FOLIAGE |       |       |       |      |
|------------------------------------|-------|-------|-------|------|
| TREE CLASS                         | I     | II    | III   | IV   |
| 13.                                | .015  | .106  | .094  | .003 |
| 14.                                | .074  | .532  | .470  | .016 |
| 15.                                | .149  | 1.063 | .940  | .032 |
| 16.                                | .298  | 2.127 | 1.880 | .066 |
| 17.                                | .446  | 3.190 | 1.665 | .036 |
| 18.                                | .521  | 3.722 | 1.696 | .036 |
| 19.                                | .595  | 4.253 | 1.601 | .034 |
| 20.                                | .669  | 4.785 | 1.566 | .033 |
| 21.                                | .744  | 5.317 | 1.511 | .015 |
| 22.                                | .893  | 6.380 | .384  | .008 |
| 23.                                | 1.190 | 8.506 | .002  | .000 |
| 24.                                | 1.488 | 8.613 | .002  | 0    |

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

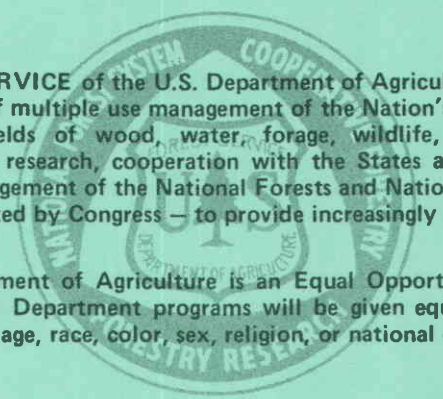
1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Anchorage, Alaska  
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Juneau, Alaska  
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Experiment Station  
809 N.E. 6th Ave.  
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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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