GROWTH SIMULATION OF
TREES, SHRUBS, GRASSES AND FORBS
ON A BIG-GAME WINTER RANGE

by

ROBIN V. QUENET

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We accept this thesis as conforming to the required standard

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Department of Zoology

The University of British Columbia
Vancouver 8, Canada

Date 28 Sept. 1973
ABSTRACT

Plant growth, production, competition and, to a limited degree, secondary succession have been simulated for a mixed species forest ecosystem operating on a big-game winter range. The simulation was based on empirically derived relationships. The major plant species investigated included *Pseudotsuga menziesii* (Mirb.) Franco (Douglas-fir)\(^1\), *Amelanchier alnifolia*, *Ceanothus sanguineus*, *Shepherdia canadensis*, *Prunus virginiana*, *Rosa nutkana*, *Symphoricarpos albus*, *Agropyron spicatum*, *Poa compressa* and *scabrella*, *Calamagrostis rubescens* and *Koeleria cristata*. Distinction was not made among forb species.

The simulation model predicts plant community development and production by species for a maximum period of 100 years following establishment, with up to 20 calculation intervals. Individual plants form the basic simulation unit. Variable data inputs include simulation period, calculation interval, species composition, density, inherent biological variability and site quality. Output is expressed in terms of wood production, weight of annual twig production of shrubs, current annual growth and carry-over of grasses, and current annual growth of forbs.

Designed to be used on the Wigwam big-game winter range in the East Kootenay district of British Columbia, the model provides a quantitative comparison of the land's capability to produce wood, browse, grasses and forbs. It also provides a basis for the solution of forestry-wildlife

\(^1\) All other common and scientific names with authorities are listed in Appendix I.
conflicts, such as assessment of the implications of management for wood production on ungulate food production, and formulation and testing of strategies designed to increase yields of wood, browse, grass and forbs.
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INTRODUCTION

The purpose of the study is to develop a means of predicting the effect of plant community development on ungulate food production. The method used is computer simulation of plant growth and competition. Abstract mathematical representation of the system in a computer allows (1) incorporation of an otherwise prohibitive number of inter-relationships, (2) manipulation and study not feasible in real life, and (3) representation of years of plant community development in seconds.

The simulation model to be constructed would attempt to duplicate, albeit in a simpler manner, the growth and competitive interactions of trees, shrubs, grasses and forbs.

JUSTIFICATION FOR THE STUDY

Quantitative assessment of the land's capability to produce wood and ungulate food is essential for the rational solution of forestry-wildlife conflicts and maximization of land productivity. The number and complexity of interactions among individual plants and species necessitates a large and complex bookkeeping system if more than an extremely superficial and often incomplete assessment of the interactions is to be made.

The primary application of the model would be the assessment of productive capability for wood, shrubs, grasses and forbs under different
plant community structures and isolation of critical interactions affecting productivity. The ability to simulate tree growth alone allows the model to be used for estimations of growth and yield and other related forestry problems.

Growth, yield and response to competition under different spacing patterns, stand densities and species composition should be capable of being tested. The model should approximate the development of mixed species plant communities and provide estimates of (1) mortality, height and diameter frequency distributions, crown closure, height to base of live crown, crown width and volumes for trees, (2) mortality, crown diameter frequency distributions and production for shrubs and (3) mortality and production for grasses and forbs. Knowledge of inter- and intra specific dynamics will allow assessment of the implications of management for wood production on ungulate food production, and testing of strategies designed to increase yields of wood, browse, grass and forbs.

OBJECTIVES

The objectives of the study were to:

(1) Quantitatively assess the capability of land to produce wood, browse, grass and forbs.

(2) Assess the implications of management for wood production on range carrying capacity for ungulates.

(3) Allow formulation and testing of strategies of plant community manipulation designed to increase yields of wood, browse, grass and forb production.
(4) Determine trade-off functions between wood and ungulate food production.

The model would be structured to allow general application through the inclusion of additional growth and competitive functions. However, for initial development and testing of its predictive capability, application was restricted to two plant communities on the Wigwam big-game winter range in the East Kootenay District of British Columbia.

METHODS

The basic structure of the model and the components of tree growth and competition incorporate the approach taken by Mitchell (1967) in the *Simulation of the Growth of Even-Aged Stands of White Spruce*. Determination of the growth and competitive functions, and construction and programming of the model were performed by the investigator. The model employs empirically derived functions, three dimensional spatial distribution of aerial growing space, and normal random deviates with specified means and standard deviations (henceforth termed "normal random deviates") to express genetic variability in situations where relationships are incapable of rigorous solution or data are incomplete.

The Approach

Definition of the basic processes operating within the system (the vegetative ecosystem of the Wigwam big-game winter range) was approached on the basis of an experimental components analysis (Holling, 1963) which implies that a process can be explained by the action and interaction of a number of
discrete components. Each process is studied individually but in such a manner that it can be integrated into a biologically realistic whole.

The achievement of a realistic representation of the system under consideration depends on the attainment of a sufficient degree of:

(1) Realism, the ability of the model to duplicate the general form of the real system.

(2) Precision, the ability to predict the time course of the variables.

(3) Resolution, the number of attributes of the system represented in the model.

The diversity and size of the system precluded detailed examination of all components; however, the model adequately represents those aspects regarded as essential.

The Variables

The current variables used in the model include age, site quality, plant community, species composition, density, competition and inherent biological variability. Such variables as water regimes, root competition and grafting, phytotoxicity and damaging agencies were not investigated due to their complexity.

**Age** - The maximum simulation period is 100 years with a maximum of 20 calculation intervals. Both simulation period and calculation interval are variable within the limits prescribed.

**Site Quality** - Site index of Douglas-fir is used as the integrated expression of environmental factors influencing plant growth.
Plant Community - The model is capable of handling two plant communities, a *Pseudotsuga-Agropyron* and a *Pseudotsuga-Poa* community.

Species Composition - Due to the large number of plant species on the study area, only the most commonly occurring species are treated individually. They include *Pseudotsuga menziesii*, *Amelanchier alnifolia*, *Ceonothus sanguineus*, *Shepherdia canadensis*, *Prunus emarginata*, *Rosa nutkana*, *Symphoricarpos albus*, *Agropyron spicatum*, *Poa compressa* and *scabrella*, *Festuca idahoensis*, *Calamagrostis rubescens* and *Koeleria cristata*. Forbs were treated as a group rather than as separate species.

Density - Variable density of all species can be accommodated.

Competition - The degree of competition is indirectly controlled through changes in density.

The System

For the purpose of the study, the system was defined as the vegetative ecosystem operating on the Wigwam big-game winter range. It was classified into subsystems on the basis of the concept of levels of organization (Odum and Odum, 1959). These include the vegetative ecosystem (System), plant communities (Subsystem 1), populations (Subsystem 2), organisms (Subsystem 3), organ systems (Subsystem 4) and the components or variables that affect the development of the organ systems (Figure 1).

The model incorporates the concept that the internal forces moulding the development of the ecosystem are generated by individual organisms, be they trees, grasses, shrubs or forbs; hence the individual plant forms the basis unit of simulation. Emphasis was placed on the growth and
Figure 1. The system and its levels of organization.
competitive ability of the few species which were judged to be dominant, the
theory being that these species largely control the community and thereby the
occurrence of rarer species (Odum and Odum, 1959).

The growth and competitive status of individual plants was expressed
through the development of their organ systems, namely, crowns and stems.
The components determining crown and stem development were the lowest level
of organization intensively investigated. Each level of organization repre­
sents the components of the next higher level.

The Components

Isolation of the components thought to be important features of the
system was accomplished by constructing a simplified flow chart of the system
(Figure 2). The boxes represent the components investigated. The variables
associated with each component are too numerous to list by individual com­
ponents. They include such factors as age, species, relative spatial
distribution and density, growth rates, crown growth and size, crown closure
of trees and shrubs, competitive ability, inherent biological variability,
unexplained variability and environmental factors, including soil and climate.
The arrows depict the direction and flow of interactions in the model.

The Functions

Since the model predicts plant community development, the functions
derived must, of necessity, reflect a time-course development, or be directly
and easily related to some other variable exhibiting a time-course develop­
ment. In addition, the functions should be expressed in unambiguous terms
Figure 2. Components of the system.
if they are to be applied elsewhere. For instance, basal area or age of a forest stand used as a measure of competition are somewhat ambiguous since they only imply, and do not specify, crown closure or degree of crown competition.

Despite a considerable volume of literature, it was deemed advisable to derive all necessary functions to ensure that they adequately represented (1) the actions and interactions occurring on the particular study area, and (2) a time-course development. The functions derived by Mitchell (1967) for white spruce growth met the requirements of this study and hence were used as a basis for derivation of similar functions for Douglas-fir. Mean height, diameter and surface area (Ferguson, 1968) as well as mean volume were used as measures of shrub growth. Non-random sampling was used to evaluate variability in density of all species (Lyon, 1968) as well as the use of 1/10th-meter plots to determine floristic composition of shrubs, grasses and forbs (Daubenmire, 1959). Production of grasses and forbs was determined on both square-yard and 1/10th-meter plots. Response of understory vegetation to the presence of a forest canopy has been reported in numerous studies (Young, McArthur and Hendrick, 1967; Jameson, 1967; Anderson, Loucks and Swain, 1969; and others). In the vast majority of these studies, stand development was expressed as number of stems per unit area, basal area or stand age, rather than as a complete stand description including such factors as crown closure and crown width to diameter ratios. Consequently, the degree of competition exerted by the forest stand is uncertain. The most detailed and applicable study is that of Kemper (1971) conducted on Premier Ridge in the East Kootenay District of British Columbia.
Kemper (1971) expressed stand development in terms of both age and crown closure and hence his relationships can be applied elsewhere. Competition between individual understory plants have been studied by Donald (1951), Hozumi, Koyama and Kira (1955), Mead (1968) and others, using spatial relationships as a measure of competition. Determination of competitive response between understory plants in this study was based on both plant density and spatial relationships, depending on the size of the individual plants. Density measures were made where the individual plants were small, and spatial relationships were used where the individual plants were large.

The Analytical Methods

In the analyses, the components were segregated into those determining (1) growth and (2) competitive response. The components of growth should ideally be derived from individuals or populations not subject to competition. In the absence of competition, growth is a direct expression of age, site quality and genetics. In actuality, it was not always possible to derive the components of growth for individuals or populations completely free from competition. The degree of competition to which an individual was subjected was used to adjust its growth rate during simulation. Measurement of competitive stress was based on the availability of aerial growing space and the degree of light interception. While this method does not take root competition into account, and hence has obvious limitations, it is easily measured and appears to be a fairly good indirect measure of competition.
If root spread is approximately proportional to crown width, as shown by Smith (1964) for Douglas-fir and other tree species, then crown competition can be used as an approximation of root competition. In considering competition, it was necessary to distinguish between inter- and intra-specific competition. In intra-specific competition, competitive advantage was assumed to be proportional to growth rate. In inter-specific competition, competitive advantage was assigned on the basis of plant height, trees were assumed to have the greatest competitive advantage, followed by shrubs, grasses and finally forbs. While this is obviously a simplistic approach which ignores such factors as density, age, root competition and phytotoxicity, it was deemed acceptable for the initial development of the model.

The functional relationships shown throughout this paper were derived empirically except where otherwise shown. Direct descriptive techniques (Jensen, 1964) were used in curve fitting. The expected spatial relationship between dependent and independent variables was initially expressed graphically, and then algebraically. Where a single algebraic expression could not be fitted, two or more expressions were used. In these cases the expressions were fitted to pass through common points. Because of the nature of the data, the change from one to another equation is often quite abrupt. Iterative techniques were used to reduce algebraically introduced curve form bias. Following each iteration the equation was solved for the predicted Y values. Simple linear regressions of the form

\[ Y = a + bX \]

where: \( Y \) = predicted Y value
\( X \) = actual Y value

were used to select the best fitting equation.
In cases where the intensity of association of actual to predicted Y values was low ($R^2$ less than 0.7), normal random deviates with specified means and standard deviations were generated. Generation of normal random deviates along the fitted curves allowed close approximation of naturally occurring variability and circumvented the problems normally associated with inconclusive relationships.

Where plant community structure precluded derivation of relationships required for the model, theoretical functions were constructed based on the response of similar species. For example, the response of *Amelanchier alnifolia* to increasing crown closure of Douglas-fir could not be determined due to the lack of sufficient areas on which the two species occurred in association. The function derived for *Ceonothus sanguineus* was applied in its place.

THE STUDY AREA

The study was conducted on the Wigwam big-game winter range located between the Elk and Wigwam rivers (latitude 49° 15' N, longitude 115° 10' W), near Elko in the East Kootenay District of British Columbia.

Climatically, the area corresponds to Köpens' (Trewartha, 1954) Dsk zone. The average total annual precipitation at Elko is 19.6 inches.

Geologically, the area is highly diverse. It includes such surficial deposits as glacial tills, lacustrine silts, colluvial deposits, talus slopes, outwash gravel terraces and a glacial outwash delta.

The range supports significant wintering populations of elk, mule deer and Rocky mountain bighorn sheep.
The study was centered on two plant communities occurring on the winter range, a *Pseudotsuga-Agropyron* and a *Pseudotsuga-Poa* community (Figure 3). The major plant species occurring in the *Pseudotsuga-Agropyron* community included *Pseudotsuga menziesii*, *Acer glabrum*, *Shepherdia canadensis*, *Prunus emarginata*, *Rosa nutkana*, *Juniperis horizontalis*, *Apocyanum androsaemifolium*, *Agropyron spicatum*, *Calamagrostis rubescens*, *Koeleria cristata*, *Festuca idahoensis*, *Achillea millefolium*, *Aster conspicuus*, *Erigeron* spp., *Monarda fistulosa* and *Phlox caespitosa*. The major plant species occurring in the *Pseudotsuga-Poa* community included *Pseudotsuga menziesii*, *Acer glabrum*, *Populus tremuloides*, *Amelanchier alnifolia*, *Ceanothus sanguineus*, *Rosa nutkana*, *Symphoricarpos albus*, *Berberis repens*, *Poa compressa* and *scabrella*, *Calamagrostis rubescens*, *Stipa columbiana*, *Bromus tectorum*, *Aster conspicuus*, *Balsamorhiza sagittata*, *Erigeron* spp., *Fragaria* spp., and *Penstemon* spp.

As a result of a number of severe forest fires, the last occurring in 1931, the plant communities exhibit a wide diversity in age, plant density, productivity and species composition. While no attempt was made to describe the variability in detail, it would be worthwhile to present a general description of the communities and to show the variability found on the sample plots.

The plant communities on the area are very similar to those described for the *Pseudotsuga menziesii* zone of McLean (1969) and comparable to those of the lower grassland zone of Tisdale (1947), the *Agropyron spicatum* (grassland) associations of Brayshaw (1955, 1965) and the *Agropyron spicati* order, alliances *Agropyretum spicati* and *Agropyro (spicati) - Juniperetum scopulorum* of Beil (1969).
Figure 3. Study area showing location and extent of *Pseudotsuga-Agropyron* and *Pseudotsuga-Poa* communities.
The vegetation is characterized by large grassland openings, the predominant species being *Agropyron spicatum* on coarse dry soils and *Poa compressa* and *scabrella* on the finer textured wetter soils, interspersed with stands of Douglas-fir. Of the major shrub species, *Amelanchier alnifolia*, *Prunus emarginata* and *Shepherdia canadensis* occur predominantly in the *Agropyron* grasslands while *Ceanothus sanguineus*, *Rosa nutkana* and *Symphoricarpos albus* occur in the *Poa* grasslands. The predominant species occurring beneath Douglas-fir stands include *Symphoricarpos albus*, *Calamagrostis rubescens* and *Koeleria cristata*.

Douglas-fir occurs in stands ranging in age from 20 to 130 years, in density from single scattered trees to approximately 2000 stems per acre and in site index (base 100 years) from 50 to 80. Table 1 shows the variability found on seven 1/10-acre plots which were measured to provide a basis for determining the predictive accuracy of the model. All values were converted to a per acre basis. The variability among individual trees within the plot having a density of 500 trees per acre is shown in Table 2.

Measurements of density and productivity in shrub and grass stands were made to evaluate growth capability and the effect of competition and hence can not be used to properly describe the variability occurring on the study area. Table 3 shows the approximate variability in density found for the most commonly occurring shrub species. The distribution of shrub species was found to be highly variable, depending on plant association and particular species. The presence of trees appeared to control both the distribution and density of shrubs. In the absence of trees, *Amelanchier*, *Ceanothus*, *Shepherdia* and *Symphoricarpos* individuals appear to be independent and randomly distributed while *Prunus* and *Rosa* appear to occur in clones.
Table 1. The degree of variability found on seven 1/10-th acre Douglas-fir sample plots.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of trees per acre 1&quot; + DBH</td>
<td>20</td>
<td>253</td>
<td>500</td>
</tr>
<tr>
<td>Volume -cu ft per acre 1&quot; + DBH</td>
<td>357</td>
<td>1344</td>
<td>2121</td>
</tr>
<tr>
<td>DBH -ins</td>
<td>2.4</td>
<td>7.33</td>
<td>16.6</td>
</tr>
<tr>
<td>Height -ft</td>
<td>17.0</td>
<td>37.8</td>
<td>68.5</td>
</tr>
<tr>
<td>Basal area -sq ft</td>
<td>0.031</td>
<td>0.337</td>
<td>1.503</td>
</tr>
<tr>
<td>Basal area -sq ft per acre</td>
<td>21.9</td>
<td>85.2</td>
<td>124.2</td>
</tr>
<tr>
<td>Total age -yrs</td>
<td>72</td>
<td>92</td>
<td>106</td>
</tr>
<tr>
<td>Crown width/DBH</td>
<td>0.978</td>
<td>1.544</td>
<td>2.620</td>
</tr>
</tbody>
</table>

Table 2. The degree of variability found within a 1/10-th acre Douglas-fir plot having a density of 500 stems per acre.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
<th>SD</th>
<th>CV %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height -ft</td>
<td>20.0</td>
<td>35.5</td>
<td>61.5</td>
<td>10.13</td>
<td>28.5</td>
</tr>
<tr>
<td>DBH -in</td>
<td>2.6</td>
<td>6.3</td>
<td>15.5</td>
<td>2.9</td>
<td>45.4</td>
</tr>
<tr>
<td>Basal area -sq ft</td>
<td>0.037</td>
<td>0.26</td>
<td>1.31</td>
<td>0.26</td>
<td>98.3</td>
</tr>
<tr>
<td>Volume -cu ft</td>
<td>0.32</td>
<td>4.03</td>
<td>26.4</td>
<td>4.8</td>
<td>119.0</td>
</tr>
<tr>
<td>CW/DBH</td>
<td>0.978</td>
<td>1.53</td>
<td>2.37</td>
<td>0.33</td>
<td>21.4</td>
</tr>
<tr>
<td>Age -yrs</td>
<td>56</td>
<td>95</td>
<td>111</td>
<td>14.0</td>
<td>14.8</td>
</tr>
</tbody>
</table>

Where: SD is standard deviation  
CV is coefficient of variation  
CW is crown width  
DBH is diameter at breast height
Table 3. Maximum and minimum densities found for the most commonly occurring shrub species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Density per 1/40 acre</th>
<th>Density per sq yd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amelanchier alnifolia</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ceanothus sanguineus</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Shepherdia canadensis</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Prunus emarginata</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rosa nutkana</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Symphoricarpos albus</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Measurement of grasses and forbs was restricted to the weight of current annual growth and carryover. Again, the variability in production was high. Table 4 shows the maximum and minimum weights of current annual growth measured after the cessation of growth in stands not subject to shading by trees or shrubs.

Table 4. Variability found in current annual growth for Agropyron, Poa and forbs in the absence of tree and shrub shade.

<table>
<thead>
<tr>
<th>Species</th>
<th>Production gms/sq yd</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>Agropyron</td>
<td>13.5</td>
</tr>
<tr>
<td>Poa</td>
<td>10.1</td>
</tr>
<tr>
<td>Forbs</td>
<td>0.3</td>
</tr>
</tbody>
</table>
ANALYSIS OF PLANT GROWTH

The primary aim in the plant growth portion of the simulation was to define patterns of growth, variation in growth rates due to genetic and unexplained variation, and growth rate as a function of site quality, age and competition.

COMPONENTS OF TREE GROWTH

Several tree growth simulation models have been developed, using different approaches (Newnham, 1964; Lee, 1967; Mitchell, 1967; Lin, 1969; Bella, 1970; Arney, 1971). The method adopted was based on Mitchell's (1967) approach because it appeared to be realistic in a biological sense and also allowed a highly detailed bookkeeping of occurrences in each unit of growing space. The components investigated included site quality, height, crown, diameter and volume growth, height to maximum crown width and height to base of live crown.

Site quality was measured indirectly through its effect on tree growth by determining site index of dominant and codominant Douglas-fir trees (B.C.F.S., Field Pocket Manual). No attempt was made to explain site quality in terms of environmental factors.

Height Growth

Height-age curves, used here to define the pattern of height growth, were adjusted by site index and normal random deviates drawn from a measured height frequency distribution to give the growth rate of individual simulated trees. This procedure allowed the generation of populations of simulated trees having the same site indices and height frequency distributions as measured stands.
Height-age curves were derived by conducting stem analyses on five open-grown trees selected as being representative of the maximum attainable growth rate. The average height (HT) at each five year interval (Figure 4) was used to derive the height-age relationship (Equations 1 and 2). The stem analyses were conducted on open-grown trees to remove the effect of competition; however, growth rate can be reduced to allow for the effect of competition during the course of simulation.

The five trees used to derive the height-age curve (Equations 1 and 2) had a mean site index of 76 feet at 100 years. To adjust the curve for a different site index, the equations are multiplied by the new site index divided by 76. This procedure adjusts the curve either upward or downward depending on the magnitude of the new site index.

The plotted "average" line on the height-age curve (Figure 4) does not exhibit the expected decline in growth rate with advanced age. This discrepancy is probably attributable to the small number of sample trees. Until such time as the number of sample trees is increased, the B. C. Forest Service site index curves (Forestry Handbook for British Columbia, 1971) for interior Douglas-fir will be used in the model.

The variability in growth rate of individual trees was determined by constructing a height frequency distribution from two hundred 20-year-old open-grown Douglas-fir trees (Figure 5). Normal random deviates drawn from the distribution were used to adjust the growth rate of individual trees, thereby duplicating the naturally occurring variability. The somewhat skewed distribution probably resulted from browsing damage to the trees in the 2-, 4- and 6-foot height classes. Sections taken through the pith showed that leader damage had occurred over a number of years.
if Age \leq 45 \text{ yrs} \\
HT = 18.05(\sin(Age(\frac{\pi}{50}) - \frac{\pi}{2}) + 1) \text{ ft} \tag{1} \\
if Age > 45 \text{ yrs} \\
HT = 1.87 + (0.74066)(Age) \text{ ft} \tag{2} \\
where: \text{ No. of Obs.} = 89 \nonumber \\
R^2 = 0.925 \nonumber \\
SE_E = 5.81 \text{ ft} \nonumber

Figure 4. Relationship between height and age for dominant Douglas-fir.
Figure 5. Height frequency distribution for 20-year-old open-grown Douglas-fir.

Crown Growth

Prediction of crown expansion was based on the relationship derived between branch length (BL) and height above the branch base (HTAB) (See Appendix II for definition of terms). The relationship was obtained by measuring total branch length and tree height above the branch base on 115 trees, both juvenile and mature (Figure 6, Equation 3). Branches were measured at and above the point of maximum crown width.
\[ BL = (0.98)(HTAB^{0.7}) \text{ ft} \]  

where:  
No. of Obs. = 404  
\[ R^2 = 0.920 \]  
\[ SE_E = 1.18 \text{ ft} \]

Figure 6. Relationship between branch length and height above branch base.

Crown width was measured as the vertical projection from the edge of the crown. Since branch angle and total branch length determine crown width, it was necessary to convert total branch length to horizontal branch length (HBL) (Figure 7, Equation 4). Equation 4 represents potential crown radius in the absence of competition, but where branches compete for growing
HBL = \(0.9(\text{BL}) - (3.3)((\text{BL}/20)^3)\) ft \(\text{(4)}\)

where: No. of Obs. = 65  
\[R^2 = 0.896\]  
\[\text{SE}_E = 0.90 \text{ ft}\]

Figure 7. Relationship between horizontal branch length and total branch length.

Since simulation of tree crowns was restricted to the visible crown area (the area of that portion of the crown which forms a photographic image when viewed directly from above), it was necessary to define the point of maximum crown width. Prediction of the height of maximum crown width was based
on the measurement of total tree height (HT) and height to maximum crown width (HTCW max) on 94 open-grown Douglas-fir (Figure 8, Equations 5 and 6). Equations 5 and 6 apply only to those trees free from competition. Otherwise, height to maximum crown width is simulated.

\[
\text{if } HT \leq 30 \text{ ft} \quad \text{HTCW}_{\text{max}} = (0.06)(HT) + (0.008)(HT^{1.9}) \text{ ft} \quad (5)
\]

\[
\text{if } HT > 30 \text{ ft} \quad \text{HTCW}_{\text{max}} = -5.5 + (0.425)(HT) \text{ ft} \quad (6)
\]

where: No. Obs. = 94

\[R^2 = 0.828\]

\[SE_E = 2.63 \text{ ft}\]

Figure 8. Relationship between height to maximum crown width (HTCW max) and total tree height.
Estimation of height to the base of the live crown (HTblc) as a function of height to maximum crown width circumvents the restriction imposed by simulating only the visible crown area. Measurements were made on 50 trees selected from various stocking densities and age classes (Figure 9, Equations 7 and 8). All sample trees were highlined; that is, their lower branches had been killed through browsing by ungulates. Where trees are highlined, HTblc is approximately 7 feet.

\[
\begin{align*}
\text{if } & \text{HTCmax } \leq 10 \text{ ft} \\
HTblc & = 0.0 \text{ ft} \\
\text{if } & \text{HTCmax } > 10 \text{ ft} \\
HTblc & = -10 + \text{HTCmax}
\end{align*}
\]

where: No. of Obs. = 50

\[
\begin{align*}
R^2 & = 0.694 \\
SE_{E} & = 9.84 \text{ ft}
\end{align*}
\]

Figure 9. Relationship between height to base of live crown and height to maximum crown width.
Diameter Growth

Prediction of diameter at breast height (DBH) was based on the derived relationship of DBH against tree height minus 4.5 feet (breast height) and crown area (CA) (Figure 10, Equation 9). The relationship

\[ DBH = (0.165)((CA(HT - 4.5))^{0.48}) - (0.0011)(CA(HT - 4.5)) \text{ ins (9)} \]

where: No. of Obs. = 299

\[ R^2 = 0.908 \]

\[ SE_E = 1.08 \text{ ins} \]

Figure 10. Relationship between diameter at breast height and the product of crown area and tree height minus 4.5 feet.
was derived from open-grown, open, normal and overstocked stands from various age classes. Crown area was calculated from four measures of crown radius taken at right angles. The data were not analyzed by individual stocking or age classes.

Volume Growth

Volume (V) estimations were based on the application of the simulated tree height and DBH to the B.C. Forest Service volume equations for Interior Douglas-fir (Browne, 1962). No attempt was made to localize the equation, or to estimate effects of dbh limits or decay, waste, and breakage.

\[
\log V = -2.734532 + 1.739418 \log D + 1.166033 \log H \quad (10)
\]

\[SE_E \text{ for single trees: } \pm 11.3 \text{ per cent}\]

COMPONENTS OF SHRUB GROWTH

The components of shrub growth investigated included site quality, height and crown growth and annual twig production. The species examined were *Amelanchier alnifolia*, *Ceanothus sanguineus*, *Shepherdia canadensis*, *Prunus emarginata*, *Rosa nutkana* and *Symphoricarpos albus*. Preliminary regressions of age and annual twig production against shrub height, volume, surface area and diameter growth indicated that crown diameter growth was the best independent variable. Shrub age was determined by making cross-sections of the stem, or where suckering was prevalent rootstocks, and counting the number of annual rings. Annual twig production was determined by taking the oven-dry weight (24 hrs at 105°C) of the current annual twig growth immediately after leaf fall. Shrub height was measured as height to
the highest part of the general crown profile (Figure 11). The average of two measures of crown width, taken at right angles, were used to calculate shrub diameter. Volume was calculated as the volume of a hemisphere with a radius equal to the shrub radius. Surface area was calculated as the surface area of a circle with a diameter equal to the shrub diameter.

Large variations in rate of growth and small variations in site quality precluded definition of variations in growth rate due to site.
Crown Diameter Growth

As previously stated, two measures of crown diameter (D) taken at right angles, were made on each shrub and expressed as a function of age. The relationships are presented in Figures 12, 14, 16 and 17, and Equations 11 to 21.

**Amelanchier**

\[ D = -1 + (0.15)(\text{Age}) + (1 - \text{Age}/30)^{1.996} \]  

where: No. of Obs. = 64  
\[ R^2 = 0.471 \]  
\[ SE_E = 1.246 \text{ ft} \]  

**Ceanothus**

if Age \(\leq\) 40 yrs \[ D = 2.8(\sin(\text{Age} \cdot \pi/60) - \pi/5.2) + .5) \text{ ft} \]  
if Age > 40 yrs \[ D = 4.1 + (0.016667)(\text{Age}) \text{ ft} \]  

where: No. of Obs. = 96  
\[ R^2 = 0.127 \]  
\[ SE_E = 1.30 \text{ ft} \]  

**Shepherdia**

if Age \(\leq\) 50 yrs \[ D = 4.5(\sin(\text{Age} \cdot \pi/70) - \pi/4) + .6) \text{ ft} \]  
if Age > 50 yrs \[ D = 7.17 + (0.0046)(\text{Age}) \text{ ft} \]  

where: No. of Obs. = 54  
\[ R^2 = 0.438 \]  
\[ SE_E = 1.287 \text{ ft} \]
The prediction of crown diameter was complicated by the fact that the measured age fell short of the time period (100 years) used in the simulation. Stebbins (1951) stated that the lifespan of individual plants sprouting from roots or crowns cannot be estimated because, barring the influence of man, they can only be killed by disease, competition from other plants or by radical changes in habitat. He further stated that in stable plant
communities seriously diseased plants are rare, so the age of the plant must approach that of the community itself. In the model, those species which exhibited sprouting from crowns or rootstocks, *Amelanchier*, *Ceanothus*, *Prunus* and *Rosa*, were, in the absence of competition, assumed to have a lifespan exceeding the simulation period. The remaining species, *Shepherdia* and *Symphoricarpos*, were replaced when the age of individual plants exceeded the maximum measured age. The application of normal random deviates, as shown in the simulated populations of *Amelanchier* and *Ceanothus* (Figures 13 and 15) having the same age distributions as the real populations shown in Figures 12 and 14, allows duplication of the naturally occurring variability.

Figure 12. Crown diameter to age relationship for *Amelanchier*. 
Figure 13. Simulated population of *Amelanchier*.

Figure 14. Crown diameter to age relationship for *Ceanothus*.
Figure 15. Simulated population of *Ceanothus*.

Figure 16. Crown diameter to age relationship for *Shepherdia*.
Figure 17. Relationship of shrub diameter to age. A: *Symphoricarpos*

B: *Rosa*  C: *Prunus*
Annual Twig Production

Prediction of the weight of annual twig production (WT) was based on the relationship between weight of the current year's production of twigs and shrub diameter (D). Shrub diameter was converted to area for Amelanchier, Ceanothus and Shepherdia to simplify modelling procedures. These species occupy and compete for specific volumes of growing space and hence may develop asymmetrical crowns. Weight of leaf production was not investigated, as fallen leaves do not contribute directly to the winter food supply of ungulates. The relationships are presented in Figures 18 and 19, and Equations 22 to 28. Data used to derive these relationships were collected from individuals free from competition.

Amelanchier

\[ WT = (4.1)(\text{Area}) \text{ gms} \]  

(22)

where: No. of Obs. = 8

\[ R^2 = 0.981 \]

\[ SE_E = 9.05 \text{ gms} \]

Ceanothus

\[ WT = 810 - (1.45454)(110 - \text{Area}) - (700)((1 - \text{Area}/110)^2.7) \text{ gms} \]  

(23)

where: No. of Obs. = 10

\[ R^2 = 0.992 \]

\[ SE_E = 17.17 \text{ gms} \]
Figure 18. Relationship between weight of annual twig production and shrub area. A: *Amelanchier*  B: *Ceanothus*  C: *Symphoricarpos*
Figure 19. Relationship between weight of annual twig production and shrub diameter. A: Prunus  B: Rosa  C: Symphoricarpos
Shepherdia

\[ WT = 250 - (254.92)((1 - \text{Area/100})^{4.1}) \text{ gms} \]  

where: No. of Obs. = 10
\[ R^2 = 0.580 \]
\[ SE_E = 36.27 \text{ gms} \]

Prunus

if \( D \leq 1.37 \)

\[ WT = 0.4 + (0.6)(D) \text{ gms} \]  

if \( D > 1.37 \)

\[ WT = -8.8 + (7.1)(D) \text{ gms} \]  

where: No. of Obs. = 20
\[ R^2 = 0.995 \]
\[ SE_E = 0.221 \text{ gms} \]

Rosa

\[ WT = 0.1 + (1.4)(D^{1.5}) \text{ gms} \]  

where: No. of Obs. = 20
\[ R^2 = 0.527 \]
\[ SE_E = 1.078 \text{ gms} \]

Symphoricarpos

\[ WT = (0.4)(D) \text{ gms} \]  

where: No. of Obs. = 20
\[ R^2 = 0.503 \]
\[ SE_E = 0.119 \text{ gms} \]
COMPONENTS OF GRASS AND FORB GROWTH

The components of grass growth investigated include rate and pattern of growth, carryover and total annual growth. Investigation of rate and pattern of growth was restricted to an Agropyron spicatum community. Measurements of carryover and annual growth were made on Agropyron spicatum, Poa compressa and scabrella, Festuca idahoensis, Stipa columbiana and Calamagrstis rubescens communities.

Rate and Pattern of Growth

Measurement of rate and pattern of Agropyron growth was made on an 80- by 80-ft enclosure containing an Agropyron stand free from shrub and tree competition. The experimental procedure was designed to allow the derivation of mathematical relationships describing both the shape and slope of the growth curves from the time of initiation of spring growth until cessation of growth in the fall. Spring growth, as denoted by the germination of forbs and the obvious presence of new grass, was initiated in the last week of April. The cessation of growth in the fall occurred in the second week of September, based on the maturation of Agropyron seed heads and a continuous period of 10 weeks of production measurements showing no upward trend. These production measurements were made during the course of the experiment. The procedures used may be summarized as follows:

1. Two hundred and thirty square-yard plots were laid out and their boundaries were strung with haywire.

2. Twenty control plots (2 sets of 10 plots) were not subjected to any treatment until cessation of growth in the fall (17 weeks after initiation
of spring growth). The plots were then clipped to a height of 1½ inches and the clippings were separated into carryover and current annual growth. The clippings were then oven-dried and weighed.

(3) The remaining 210 plots were clipped to a height of 1½ inches prior to the initiation of spring growth (April 1 to 3, 1970). The clippings (carryover) were oven-dried and weighed.

(4) The treatments consisted of clipping and weighing the current annual growth. The plots (10 plots per treatment) in treatment 1 were clipped at the end of the first week (May 1), and in treatment 2, at the end of the second week (May 8), etc. The treatments were continued until the end of the 17th week (September 11), at which time growth had ceased.

(5) All weights represent oven-dried weight (24 hrs at 105°C).

(6) A completely randomized design was used in the allocation of control and treatment plots.

Figures 20 and 21 show the mean and range in weight of current annual growth by weekly intervals for Agropyron and forbs. The wide variations in current annual growth within treatments for Agropyron can be reduced by plotting current annual growth (CAG) against carryover (C) by weekly intervals (Figure 22). The 17 curves, one for each week, fitted to the data have the general form

\[ \text{CAG} = a \text{TANH}(Cb) \]

where "a" represents the maximum attainable growth and "b" represents the shape of the growth curve as a function of carryover. The use of this procedure assumes that carryover, in the absence of utilization by ungulates,
Figure 20. Current annual growth of *Agropyron* by weekly intervals.

Figure 21. Current annual production of forbs by weekly intervals.
Figure 22. Selected relationships between current annual growth and carryover for Agropyron. A: Production for weeks 2, 5 and 10
B: Production for weeks 16 and 17 and the control plots
is an approximate measure of the productive capacity of the site. To simplify calculation and modelling procedures, both the "a" and "b" variables were expressed as a function of their respective week (Figure 23, Equations 29 to 31).

variable 'a'

if Week ≤ 9

\[ a = (2.833)(\text{Week}^{1.2}) \]  

(29)

if Week 9

\[ a = 38 + (11)\text{TANH}((\text{Week} - 9)(0.43)) \]  

(30)

variable 'b'

\[ b = 0.037 - (0.016)(\text{TANH}((\text{Week})(0.13))) \]  

(31)

Figure 23. Plot of the 'a' and 'b' variables from the equation CAG = aTANH(Cb) expressed as a function of weeks since the initiation of spring growth.
These functions were then applied in the general equation and tested against actual weekly production. Growth was slightly overestimated from week 1 to 9. The relationships shown in equations 29 to 31 were combined and are presented in Equations 32 and 33.

\[
\text{if Week } \leq 9 \\
\text{CAG} = (2.833)(\text{Week}^{1.2})\text{TANH}((C)(0.037 - (0.016)(\text{TANH}((\text{Week})(0.13)))))) \text{ gms} 
\]

\[
\text{if Week } > 9 \\
\text{CAG} = (38 + (11)\text{TANH}((\text{Week} - 9)(0.43))\text{TANH}((C)(0.037 - (0.016)(\text{TANH}((\text{Week})(0.13)))))) \text{ gms} 
\]

In applying these equations to grass species other than \textit{Agropyron}, it was assumed that the species differences are expressed only in terms of maximum attainable growth ("a" variable). Consequently, only equations 29 and 30 will require modification for species change.

The foregoing relationships were derived from data collected during a single growing season (1970). Modifications of the "a" variable will accommodate variations in annual growth.

**Total Grass and Forb Production**

Twenty-four enclosures, each containing 16 square-yard plots, and the 80- by 80-foot enclosure were used to measure total annual growth for \textit{Agropyron spicatum}, \textit{Poa compressa} and \textit{scabrella}, \textit{Festuca idahoensis}, \textit{Stipa columbiana}, \textit{Calamagrostis rubescens} and forbs. Forbs were treated as a group rather than as individual species, due to the large number of species represented by relatively few individuals. The 24 enclosures were clipped
to a height of 1½ inches prior to initiation of spring growth and then reclipped after cessation of growth in the fall. The clippings were separated into grasses and forbs, oven dried, and weighed. Clippings made on the 80- by 80-foot enclosure from the 10th to the 17th week, inclusive, were included. The measured values were used to define production levels and variability in production on different sites.
ANALYSIS OF PLANT COMPETITION

The primary aim of the competition portion of the simulation model was to permit modification of growth potential and survival rates of individuals and populations subject to inter- and intra-specific competition. Emphasis was placed on the ability to duplicate changes in growth response and survival rather than on understanding the underlying processes. The components of tree, shrub, forb and grass growth derived in the Plant Growth section provide benchmarks for growth potential and survival in the absence of competition. The functions derived in this section serve to modify the above-mentioned components.

Components of Tree Competition

The components of tree competition investigated include branch competition for aerial growing space, height and diameter growth response to crown competition, and criteria for mortality. The effect of competition from shrubs, grasses and forbs was not investigated.

Observation of crowns of competing trees indicated that branches of adjacent crowns seldom interlocked in immature and mature stands. Maintenance of crown integrity is probably due to cessation of apical growth resulting from severe shading or mechanical injury due to wind-induced branch motion (Mitchell, 1967). Crowns of juvenile trees, less subject to both shading and wind-induced motion, exhibit extensive interlocking. Modification of the branch length functions in the presence of crown competition was based on the availability of aerial growing space during simulation. Simulation of actual branch length, and hence crown area, was accomplished by allowing
branches to compete for growing space in a three-dimensional matrix. The simulation is discussed in the Model section.

Tree height-growth response to crown competition was not investigated in detail. Four suppressed Douglas-fir were analyzed and their pattern of growth was compared to that of the five open-grown dominants. The shape of the curves was found to be essentially similar, the only difference being in the slope of the curve. Until further investigation, inter-tree competition is assumed to have no effect on rate of height growth, except when crown area becomes so restricted that mortality occurs. Simulating variability in rate of height growth was accomplished by applying normal random deviates, sampled from the height frequency distribution described earlier, to the height-age relationship (Figure 4, Equations 1 and 2).

Diameter-growth response to crown competition is implicit in the relationship between DBH, crown area and height (Figure 10, Equation 9). This relationship was derived from sample trees selected as being representative of open-grown individuals and individuals occurring in stands of various densities.

The ability to duplicate tree mortality during stand development is an essential feature in the model. The removal of trees subjected to insufficient growing space or excessive shading prevents abnormal stand stagnation and allows competing tree crowns to increase in size. In the model, a tree is eliminated if the ratio of the simulated crown area in the presence of competition to the simulated crown area in the absence of competition is less than or equal to 0.1, regardless of tree age. The value
(0.1) was derived by testing the model on stands where the history of natural mortality was known. Mortality due to causes other than crown competition was not included in the model.

Removal of understory vegetation has been shown to increase height growth, limb diameter and volume increment of ponderosa pine (Barrett, 1970). Exclusion of the effect of understory vegetation does not seriously affect the tree growth simulation because all of the tree growth functions were derived on individuals subject to understory competition, and the model is not structured to allow its complete removal.

Components of Shrub Competition

The components of shrub competition investigated included crown competition between shrubs and the effect of forest crown closure on shrub survival. Shrub response to competition from grasses and forbs was not investigated.

Large variations in the rate of height and diameter growth, irregular crown shape and extensive interlocking of crowns precluded direct assessment of the effect of inter-shrub competition on both shrub crown growth and production. General observations indicated that the crowns of species achieving a relatively large size (Amelanchier, Ceanothus and Shepherdia) competed for aerial growing space, while small shrub species (Prunus, Rosa and Symphoricarpos) did not appear to compete for aerial growing space to any extent. The absence of small shrub species in the immediate proximity of large shrub species, in areas where the two grew in
association was, for the purpose of modelling, assumed to indicate that crown competition between the two resulted in the mortality of the small shrub species.

Modification of the shrub crown diameter to age relationships, in the presence of competition, was based on the availability of aerial growing space during the course of simulation. Distinction was made between what were defined as large shrub species (Amelanchier, Ceanothus and Shepherdia) and small shrub species (Prunus, Rosa and Symphoricarpos). This distinction was necessary because the units of growing space allocated for shrub growth in the simulation (¼ square foot) were too large to accommodate the growth increments of the small shrub species. Allocation of units of growing space of less than ¼ square feet was impractical because of the associated increase in both calculation time and computer storage requirements.

Investigation of shrub mortality was restricted to the measurement of shrub density as a function of degree of shading, the inference being that tree shade provides a measure of the degree of competition exerted by the forest stand. Ceanothus and Prunus shrub density was measured through a range of crown closures and plotted as a function of crown closure (Figures 24 and 25). Ceanothus density (Equations 34 and 35) was measured on 20 1/40th-acre plots ranging from 0 to 83 percent crown closure, and Symphoricarpos density (Equations 36 and 37) was measured on 60 square-yard plots ranging from 0 to 85 percent crown closure. The lack of associations between Douglas-fir and Amelanchier, Shepherdia, Prunus and Rosa precluded derivation of relationships for these species. The relationship derived
Figure 24. Relationship between number of Ceanothus and crown closure of trees.

Figure 25. Relationship between number of Symphoricarpos and crown closure of trees.
for Ceanothus (Equations 34 and 35) was applied to Amelanchier and Shepherdia in the simulation model. Theoretical functions were applied to Prunus and Rosa (Figure 26, Equations 38 and 39). The use of the Ceanothus function for Amelanchier and Shepherdia and the theoretical functions for Prunus and Rosa reduces the accuracy of the model. However, they can be replaced with more accurate functions at a later date.

Figure 26. Theoretical relationship between number of Prunus and Rosa and crown closure of trees.
Ceanothus (Applied to Amelanchier and Shepherdia)

if $CC \leq 75\%$

$$N = 8 - (0.10606)(CC) + (19)((1 - CC/75)^{2.5})$$ (34)

if $CC > 75\%$

$$N = 0.0$$ (35)

where: No. of Obs. = 20

\[N\] = number of individuals

Symphoricarpos

if $CC \leq 90\%$

$$N = 35 - (0.38889)(CC)$$ (36)

if $CC > 90\%$

$$N = 0.0$$ (37)

where: No. of Obs. = 60

\[Prunus\] and \[Rosa\] (Theoretical)

if $CC \leq 65\%$

$$N = 7 - (0.1167)(CC) + (9)((1 - CC/65)^{2.5})$$ (38)

if $CC > 65\%$

$$N = 0.0$$ (39)

The curves for Ceanothus and Symphoricarpos were fitted to pass through the maximum values and consequently regression analyses were not used to determine the goodness of fit. Points lower than the maximum values were assumed to be the result of low initial stocking densities rather than competition. For example, where 8 Ceanothus per 1/40th acre were found for crown closures of 12, 24 and 33 percent (Figure 24), the density at 12 and 24 percent crown closure was assumed to reflect low initial stocking, while
the density at 33 percent was assumed to represent the maximum density for that crown closure.

Exclusion of the effect of grass and forb competition on shrub production should not seriously affect the accuracy of the simulation as all shrubs measured were growing in association with grasses and forbs, and the model is not structured to allow the removal of these plants.

Components of Grass and Forb Competition

The components of grass and forb competition investigated include response to crown closure, shading by large shrub species, and to changes in density of small shrub species. Competition between grasses and forbs was not investigated.

Productivity and species composition for both grasses and forbs was determined on 1/40th-acre plots ranging 0 to 85 percent crown closure. On each plot, 40 floristic descriptions (Daubenmire, 1959) and 10 clippings, segregated into Agropyron or Poa, other grasses (Calamagrostis, Koeleria and Bromus), were made on 1/10th square-meter sub-plots. The relationships between the oven-dry weight of the clippings and crown closure (CC) are shown in Figures 27, 28 and 29, and Equations 41 to 46.
Figure 27. Relationship between Agropyron production and crown closure of trees.

Figure 28. Relationship between forb production and crown closure of trees.

Figure 29. Relationship between combined Calamagrostis, Koeleria and Bromus production and crown closure of trees.
Agropyron

if $CC \leq 85$

$$WT = (0.2353)(85 - CC) + (63.3)((1 - CC)^2) \text{ gms/m}^2$$  \hspace{1cm} (40)

if $CC > 85$

$$WT = 0.0 \text{ gms/m}^2$$  \hspace{1cm} (41)

where: No. of Obs. = 120

$R^2 = 0.706$

$SE_E = 13.39 \text{ gms/m}^2$

Koeleria, Calamagrostis and Bromus

if $CC \leq 80$

$$WT = (0.05625)(CC) \text{ gms/m}^2$$  \hspace{1cm} (42)

if $CC > 80$

$$WT = 0.0 \text{ gms/m}^2$$  \hspace{1cm} (43)

where: No. of Obs. = 120

$R^2 = 0.50$

$SE_E = 1.219 \text{ gms/m}^2$

Forbs

if $CC \leq 18.75$

$$WT = 10\left(\sin\left(CC\left(\pi/28\right) - \pi/6\right) + 1\right) \text{ gms/m}^2$$  \hspace{1cm} (44)

if $CC > 18.75$

$$WT = 0.5 + (18/60^{2.7})((100 - CC)^{2.52}) \text{ gms/m}^2$$  \hspace{1cm} (45)

where: No. of Obs. = 120

$R^2 = 0.505$

$SE_E = 4.606 \text{ gms/m}^2$
In determining the response of grasses and forbs to shrubs, distinction was made between large and small shrub species. Competitive response to large shrub species was determined by comparing production in the open, along the border of the shrub and beneath the shrub (Figure 30).

Figure 30. Definition of zones of influence for large shrub species.
Production was measured using a 1/10th-meter frame and clipping and weighing grass and forb production. A strip of the shrub, running east-west one-foot wide, was removed prior to clipping. The frame was initially placed straddling the eastern edge of the shrub, corresponding to the border area, and the vegetation was clipped. The width of the border area, 1.64 feet, equals the length of the 1/10th-meter frame. Successive clips were made to the centre of the shrub and two clips were made on the outside of the shrub. Mean production was calculated for the open, border and inside areas of the shrubs. The values, presented in Table 5, are expressed as a percentage of the production outside the shrub. Competitive response of grasses and forbs to small shrub-species was determined by expressing production as a function of the number of shrubs per square yard. The plots, located to cover a range in shrub density, were clipped and the clippings separated into grasses and forbs and weighed. The relationship found for Prunus, the only species investigated in the *Agropyron* community, is shown in Figure 31 and Equations 46 to 48.

Table 5. Comparative productivity of *Agropyron*, *Poa* and forbs growing in association with *Amelanchier*, *Ceanothus* and *Shepherdia*.

<table>
<thead>
<tr>
<th>SHRUB SPECIES</th>
<th># of Shrubs examined</th>
<th>Position</th>
<th>Production as % of open</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Poa</td>
</tr>
<tr>
<td>Amelanchier</td>
<td>10</td>
<td>Open</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Border</td>
<td>68.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inside</td>
<td>13.4</td>
</tr>
<tr>
<td>Ceanothus</td>
<td>10</td>
<td>Open</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Border</td>
<td>89.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inside</td>
<td>13.7</td>
</tr>
<tr>
<td>Shepherdia</td>
<td>7</td>
<td>Open</td>
<td><em>Agropyron</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Border</td>
<td>136.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inside</td>
<td>1.8</td>
</tr>
</tbody>
</table>
Agropyron

if $N \leq 14$
\[
WT = \frac{PDN}{85}(3 + 0.13334(15 - N) + 0.0918((15 - N)^{2.5})) \quad \text{gms/}yd^2
\]  
(46)

if $N > 14$
\[
WT = (0.0353)(PDN) \quad \text{gms/}yd^2
\]  
(47)

where: No. of Obs. = 10
\[
R^2 = 0.898
\]
\[
SE_E = 7.15 \text{ gms/}yd^2
\]
\[
N = \text{number of Prunus}
\]
\[
PDN = \text{Agropyron production in absence of Prunus}
\]

Forbs

\[
WT = -12.3 + (3.6)(N) - (0.80752)((N - 7.5)^{1.5}) \quad \text{gms/}yd^2
\]  
(48)

where: No. of Obs. = 10
\[
R^2 = 0.580
\]
\[
SE_E = 5.06 \text{ gms/}yd^2
\]
\[
N = \text{number of Prunus}
\]
Figure 31. Response of Agropyron and forb production to Prunus density.
THE MODEL

Simulation of complex forest ecosystems is a logical outgrowth of tree growth models. Models of individual tree and stand growth have been developed by Newnham (1964), Lee (1967), Mitchell (1967), Bella (1970), Paille (1970), Arney (1971), Goulding (1972) and others. Botkin, Janak and Wallis (1971) developed the first mixed species, mixed age model. Their model reproduces the major characteristics of competition, secondary succession and changes in vegetation accompanying changes in elevation from a conceptual basis. The model described here attempts to duplicate growth, competition, production and, to a limited degree, secondary succession from an empirical basis. An empirical rather than a conceptual approach was taken in order to achieve a high predictive ability.

The model simulates growth, competition and production of trees, shrubs, grasses and forbs. Variable inputs include site quality, species composition, density and spatial distribution of individual plants. Output is expressed in terms of wood production, weight of annual twig production of shrubs, current annual growth and carryover of grasses, and current annual growth of forbs. Procedures allowing cultural practices during the course of the simulation have yet to be included.

STRUCTURE

The computer program written to simulate the growth, competition and production of trees, shrubs, grasses and forbs can conveniently be divided into three sections: the main program, the tree-growth subroutines and the understory (shrubs, grasses and forbs) growth subroutines. A listing of the program is contained in Appendix III.
The Main Program

The main program controls the optional pathways through the tree and understory subroutines (Figure 32). Variable data inputs allow by-passing of either the tree or understory subroutines, thereby allowing (1) simulation of trees alone, (2) shrubs, grasses and forbs in the absence of trees, and (3) the entire plant community. Application of the model to the Pseudotsuga-Poa community is accomplished by substitution of a "POA AND FORB PRODUCTION" subroutine in place of the "AGROPYRON AND FORB PRODUCTION" subroutine. Where shrub, grass and forb growth is simulated in the absence of trees, crown closure of an actual or hypothetical forest stand can be read in as data. The crown closure can remain constant or be incremented at a pre-specified rate. A simplified flow chart of the main program is presented in Figure 33.

The organization, and hence sequence of calculations and decisions, of the model is based on an assumed hierarchy of competitive ability among trees, shrubs, grasses and forbs. Trees are assumed to have the greatest competitive ability, followed by shrubs and finally grasses and forbs. The hierarchial order is directly related to the height at which plant crowns compete for, and occupy, aerial growing space. Development of a hierarchial order of computation was necessary because simulated systems are not able to duplicate the simultaneous occurrence of growth found in natural systems. Assessment of the degree of inter-specific competition exerted on an individual plant is accomplished by the transfer of information summaries between the tree and understory-growth subroutines. The transfers, following a definite time sequence, are as follows:
START

MAIN PROGRAM

NORMAL AND UNIFORM RANDOM NUMBER GENERATOR

TREE GROWTH AND COMPETITION

CROWN PROFILES AND CROSS-SECTIONS

UNDERSTORY

SHRUB GROWTH

SHRUB MORTALITY

SHRUB AREA

SHRUB PRODUCTION

AGROPYRON AND FORB PRODUCTION

--- Trees only

--- Understory only

--- Trees and Understory combined

Figure 32. Flow chart of subroutines showing optional pathways.
Figure 33. Simplified flow chart of the main program showing its control over optional pathways through the model.
(1) Computation - Tree height and branch growth, competition for growing space and mortality.
Transfer - Locations occupied by branches and percent crown closure to shrub, grass and forb sub-arrays.

(2) Computation - Differential mortality, crown diameter growth and competition for growing space of large shrub species.
Transfer - Locations occupied by branches and crown closure of trees, and locations occupied by large shrub species to the subroutine responsible for small shrub species growth.

(3) Computation - Differential mortality and crown diameter growth for small shrub species.
Transfer - Locations occupied by branches and crown closure of trees, locations occupied by large shrub species and area of border and inside zones, and density of small shrub species to the subroutine responsible for grass and forb growth.

(4) Computation - Mortality, species change and crown growth of grasses and forbs.

Simulation of Tree Growth

In the tree growth simulation, growth of the stand is based on the aggregate growth of individual trees occupying a 1/10th-acre plot subdivided into square-foot units of growing space (66 x 66). A simplified flow chart of the sequence of calculations and decisions is presented in Figure 34.
Start

Read input data

Generate tree locations

Set calculation interval

Take first tree

Proceed to next tree

Calculate tree height and branch lengths

Proceed to next branch

Generate first branch location to be occupied

Have all branches been tested?

Yes

Generate next location

Have all locations been tested?

Yes

Is this location occupied?

No

Yes

Is this location occupied at a lower height than the current branch?

No

Yes

Occupied

Do not occupy

(continued)
Figure 34. Simplified flow chart of tree-growth subroutines.
Briefly, trees are assigned to locations within the plot, height and crown radius are incremented, and branches test for and occupy available units of growing space within a three-dimensional matrix. Diameter is incremented, based on simulated crown area and height. Overtopped trees are removed from the stand, thereby freeing growing space for adjacent trees. Individual tree and stand parameters are calculated for each period. A more detailed discussion of the tree-growth simulation is presented in the remainder of this section.

The data requirements include specification of site index at 100 years, number of trees per 1/10th acre, mean and variance of a measured height-growth frequency distribution for immature open-grown Douglas-fir, option to read or randomly assign tree locations, simulation period to a maximum of 100 years and number of calculation intervals to a maximum of 20. If a simulation period of 100 years and 20 calculation intervals are specified, the calculation interval is 5 years. Where random tree locations are specified, a uniform random number generator is used to assign locations with the proviso that no two trees occupy the same unit of growing space.

The growth rate and height of individual trees is determined by (1) adjusting the slope of the height-age relationship derived for open-grown dominant Douglas-fir (Equations 1 and 2) to give the pre-specified site index, (2) drawing normal random deviates from the height frequency distribution (Figure 5), and (3) solving the relationship for the particular stand age in question.

Crown growth of trees is simulated on the 1/10th-acre plot which is subdivided into units of growing space referenced by their location in a two-dimensional matrix or array; the third, or vertical dimension, is
referenced by coded values held in each unit. The array may be visualized as square units of growing space containing a numeric code designating plant occupancy. Prior to computation, the codes are initialized at 10000000, signifying that the unit is unoccupied. The code, as illustrated below, is broken down into element nests used to identify the individual plant, its species and stem position, and the height at which the unit is occupied.

```
10 0000 00
```

Free element nest  Individual plant, species and stem position (99 in this location indicates the location of the tree bole)

Height of occupancy in hundredths of feet

In the simulation of crown growth, total branch length is calculated by determining tree height above the branch node and solving the relationship between branch length and height above branch (Equation 3). Total branch length is then converted to horizontal branch length by solving the relationship between horizontal branch length and total branch length (Equation 4). Determination of the actual crown area of individual trees is accomplished by allowing branches to compete at various heights in the two-dimensional matrix. In the simulation of branch competition, it is assumed that a unit of growing space can only be occupied by a single tree, and branches of competing trees do not interlock. The sequence in the simulation of branch competition may be summarized as follows:
(1) Starting from the top of each tree, a circle, with radius equal to horizontal branch length, is swept for each branch whorl being considered. The number of branch whorls considered is equal to the number of calculation intervals.

(2) Units of growing space are considered to be occupied if horizontal branch length is greater than the distance from the tree bole to the center of the unit.

(3) A previously occupied unit can only be reoccupied at a greater height.

(4) When all trees have been processed, crown area is determined for individual trees by counting the number of units occupied by each tree.

(5) The degree of competition exerted on each tree is expressed as a function of actual crown area ($CA_{act}$) to expected crown area in the absence of competition ($CA_{exp}$). If the ratio of $CA_{act}$ to $CA_{exp}$ is less than or equal to 0.1, the tree is assumed to die and is removed from the plot.

Figure 35 illustrates the coding of two Douglas-fir occupying growing space (refer to Figure 34 for mechanism of branch competition). Codes 10008499 and 10044299 represent the bole position and heights of trees 11 and 18, respectively. Codes 10000118 and 10013418 represent the units occupied by branches originating from nodes at 0.01 and 1.34 feet on tree 18. Code 10000111 represents the units occupied by branches originating from a node at 0.01 feet on tree 11. The array coding can be printed in the form of developmental stand maps showing vertical and cross-sectional projections. Inevitably tree crowns will attempt to grow beyond the plot confines. Any
where:

- \( t = \) tree number
- \( th = \) tree height in hundredths of feet
- \( s = \) stem position
- \( b = \) branch height in hundredths of feet

**Figure 35.** Array coding for two Douglas-fir occupying growing space.
portion of a plant crossing the boundary is returned on the opposite side of the plot (Figure 36). This procedure prevents the loss of those portions of plants crossing the boundary and approximates competition from plants growing near the plot periphery.

Estimation of crown width, crown length and height to live crown base are derived from the results of the crown-growth simulation. Crown width is determined by calculating the diameter of a circle having an area equal to the simulated crown area. Calculation of crown length is more complex. In the absence of inter-tree competition, height to maximum crown width is determined as a function of total tree height (Equations 5 and 6) and then height to base of live crown is determined as a function of height to maximum crown width (Equations 7 and 8). Crown length is determined by subtracting the height to base of live crown from total tree height. Where crowns are subject to competition for aerial growing space, the height of the longest branch is taken to represent the point at which crown width is maximum. The calculation sequence follows that for trees not subject to inter-tree competition.

Diameter at breast height (DBH) is calculated by solving the relationship between DBH, height and crown area (Equation 9). Volume estimation is based on the application of the simulated height and DBH to the B.C. Forest Service volume equation for interior Douglas-fir (Equation 10). Basal area is calculated from the simulated DBH.

The sequence of decisions and calculations involved in the simulation of tree growth are repeated at each calculation interval until the simulation period is exceeded. The information and array coding generated at each calculation interval are retained for incrementation at the next calculation
where:

B = bole position
1 = branch locations of tree 1
2 = branch locations of tree 2
etc.

Figure 36. Graphical representation of the return of portions of tree crowns crossing the plot boundary.
interval and, where the understory option is specified, are passed to the 
understory-growth subroutines.

The degree of detail required in the simulation results is specified 
by output options supplied as data. At the most detailed level, the following 
information is summarized at each calculation interval:

1. Internal coding of the tree matrix.
2. Develop stand maps showing vertical and cross-sectional 
profiles of the stand.
3. Detailed information on each individual tree, including 
location, height, diameter, basal area, volume, height to crown base and 
crown width, area and length.
4. Mean tree height, diameter, basal area, volume, height to 
crown base, and crown width, area and length.
5. Initial and current number of trees.
6. Number of trees having died.
8. Crown closure for each quarter of the tree plot.

At the lowest level of detail, total volume, crown closure, number 
of trees and mean tree height, diameter, basal area, volume, height to crown 
base and crown width, area and length are printed.

Simulation of Understory Growth

In the understory simulation shrub growth is based on the aggregate 
growth of individuals, grass on the aggregate growth of species and forbs on 
the aggregate growth of communities. The small size of individual grasses
and forbs and the great diversity of forb species precluded simulation of individuals. Growth is simulated on a 1/10th-acre plot underlying, and receiving information from the 1/10th-acre tree array. The understory array is subdivided into ¼ square foot units (132 by 132) partitioned into 4 independent 66 by 66 element sub-arrays (Figure 37); each sub-array is

Figure 37. Arrangement of arrays showing relationship between tree and shrub, grass and forb arrays.
associated with a specific quarter of the tree array. A flow chart showing
the sequence of calculations and decisions made during the course of simulation
is presented in Figure 38. In general terms, the sequence may be summarized
as follows.

(1) Input data are read.

(2) Locations of large shrub species (Amelanchier, Ceanothus and
Shepherdia) are either directly or randomly assigned.

(3) Crown closure of the overstory (Douglas-fir stand) is set at
zero, specified at a constant level, set at zero and incremented at a pre-
specified rate, or passed from the tree-growth simulation.

(4) Mortality of large shrub species is determined as a function of
direct tree shading, crown closure of the forest stand or both.

(5) Crown diameter of large shrub species is incremented and crowns
are allowed to compete for aerial growing space.

(6) Density of small shrub species (Prunus, Rosa and Symphoricarpos)
is determined as a function of crown closure of trees and large shrub species.
Crown diameter of individual shrubs is then incremented.

(7) Diameter, area and production are calculated for individual
shrubs, and mortality by species, total number and production by species and
the area occupied by trees, and large and small shrub species are summarized.

(8) Production of Agropyron (or Poa), other grasses (Koelaria,
Calamagrostis and Bromus) and forbs is calculated in the absence of both
trees and shrubs.

(9) Their production is then readjusted as a function of tree shading,
location beneath large shrub species (i.e. border and inside areas) and density
and age of small shrub species.
Start

Read input data

Generate shrub locations

Set calculation interval

Take first sub-plot

Increment age by one calculation interval

Proceed to next sub-plot

Proceed to next shrub species

Take first species

Take first shrub

Is shrub shade tolerant?

Yes

Is shrub growing in shade?

Yes

Remove Shrub

No

Count living shrubs by species

Have all shrubs been tested?

Yes

(continued)
Calculate potential # of shrubs as a function of crown closure of the forest stand

Is actual # greater than potential # for that crown closure?

Yes

Remove that number of shrubs required to reduce actual # to potential #

No

Have all species been tested?

Yes

Take first species

Proceed to next species

No

Take first shrub

Proceed to next shrub

No

Calculate shrub diameter

Does this species occupy specific units of growing space (Amelanchier, Ceanothus, Shepherdia)?

Yes

No

(continued)
Generate first location to be occupied

Generate next location

Have all locations been tested?

Yes

No

Is this location occupied?

Yes

No

Do not occupy

Calculate area not occupied by large shrub species (Amelanchier, Ceanothus, Shepherdia)

Calculate density of small shrub species (Prunus, Rosa, Symphoricarpos) as a function of forest crown closure

Calculate area available to small shrub species and total number of small shrubs by species

Calculate for individual shrubs:

Diameter

Area

Summarize:

Mortality by species
Total number and production of shrubs by species
Inside and border areas of large shrub species by species
Total area shaded by trees and large shrub species
Total area not shaded by trees or large shrub species

(continued)
Calculate production for Agropyron, forbs and other grasses (Calamagrostis, Koeleria, Bromus) per unit area for unshaded condition

Adjust production per unit area as a function of tree crown closure

Readjust production per unit area for border and inside area of large shrub species

Readjust production per unit area as a function of small shrub density and age for (1) area in direct tree shade and (2) area not shaded by trees or large shrub species

Using precalculated areas of direct tree shade, large shrub species shade and area not shaded by trees or large shrub species, calculate total production for:
- Agropyron
- Forbs
- Other grasses (Calamagrostis, Koeleria, Bromus)

Are all four sub-plots completed?

Yes

Is simulation period exceeded?

Yes

Print results

Stop

No

Is tree growth option specified?

Yes

Return to tree growth subroutine

No

Figure 38. Simplified flow chart of shrub, grass and forb growth (understory subroutines).
A more detailed discussion of the simulation is presented in the remainder of this section.

The data requirements for the simulation of the understory development include specification of (1) the number of large shrub species, (Amelanchier, Ceanothus and Shepherdia), by species per 1/40th acre, for each of the four sub-plots, (2) number of small shrub species (Prunus, Rosa and Symphoricarpos), by species per square yard, for each sub-plot, (3) mean and variance of crown diameter frequency distributions for all shrub species, and (4) carryover of Agropyron or Poa in grams per square yard. If tree growth is not simulated, it is necessary to specify the calculation interval, simulation period and the crown closure of the forest stand. As previously stated, crown closure can be specified at zero, a constant value, or set at zero and incremented during the course of simulation. Where large shrub species are assigned specific locations, their locations are read in as data; otherwise, a uniform random number generator is used to assign locations.

The first step in the understory simulation is to evaluate the influence of the forest stand, whether simulated or specified in terms of crown closure, on shrub mortality. Two methods are used to "kill" shrubs. In the first method, shrubs are tested for shade tolerance (read as input data); if shade tolerant, they survive in direct shade; if shade intolerant, they "die" when directly shaded. Large shrub species are only shaded by trees, while small shrub species may be shaded by trees and large shrub species. Surviving shrubs are then counted by species and the number surviving is compared to the potential number capable of surviving at the
particular crown closure in question (Equations 34 to 39). If the actual number exceeds the potential number, shrubs are randomly "killed" until the two are equal. This sequence in mortality is important in that it ensures that shade intolerant shrubs closest to trees die first. Shrubs subject to mortality are removed from the plot, thereby freeing aerial growing space.

Growth of individual shrubs is expressed in terms of crown diameter which is derived from the relationships between crown diameter and age (Equations 11 to 21) distributions. In simulating crown diameter growth and competition for aerial growing space, distinction is made between small and large shrub species. Large shrub species compete for designated units of growing space held in the sub-arrays; small shrub species are allocated to those units of growing space not occupied by large shrub species. Crown competition among large shrub species is handled in the same manner as tree crowns except that height of occupancy is not taken into account. The near vertical growth habit of shrub branches and more or less similar heights precludes the necessity of allowing over-topping. Following simulation of crown growth and competition among individuals belonging to the large shrub species, the total number of small shrub species individuals is calculated. The number of individuals is calculated by determining the area available to small shrub species and multiplying this area by the density of surviving individuals. If the species being considered is shade intolerant, the available area is that portion of the plot not shaded by trees or large shrubs; if the species is shade tolerant, the area is that portion of the plot not shaded by large shrub species. Crown competition among small shrub species individuals is not simulated
due to their small size and the tremendously increased computer memory requirements and calculation time which would be necessary (approximately 310,000 additional words of computer memory and up to 29,000,000 additional decisions and calculations - present storage requirement is 75,000 words).

The determination of crown diameter and area of the simulated large shrub species is accomplished by counting the number of units of growing space occupied by each individual, expressing the result in square feet (each unit represents 0.25 square feet), and calculating the diameter of a circle whose area is equal to the area of the individual shrub. At the same time, the area occupied by each shrub is segregated into those portions representing the inside and border areas of the shrub (Figure 11). Where the crowns of two or more shrubs are in contact, the border area is expressed as a function of the perimeter of the group, and the remaining area constitutes the inside area. For small shrub species, the diameters calculated from the diameter-age relationships (Equations 16 to 21) are not modified.

Conversion of shrub diameter (small shrub species) or area (large shrub species) to production is accomplished by substituting the simulated values in Equations 22 to 28.

Following calculation of diameter, area and production for individual shrubs, the simulated results are summarized in terms of total number and production of shrubs by species and mortality by species. The calculated values for the border and inside areas of large shrub species, the areas shaded by trees, large shrub species, trees and large shrub species combined and the unshaded area, and the density of small shrub species is passed to the subroutine responsible for grass and forb growth.
The sequence of calculations in the determination of grass and forb production is to calculate production (1) in the absence of interspecific competition, (2) adjust production as a function of forest crown closure (Equations 40 to 45), (3) readjust production for border and inside areas of large shrubs (Table 2) and (4) finally readjust production as a function of age and density of small shrub species (Equations 46 to 49).

Production in the absence of interspecific competition is based on the measurement of the previous year's carryover of grass (Agropyron or Poa) which has not been subject to grazing by ungulates. The conversion of carryover to the current year's production is achieved by substituting the value for carryover in Equations 32 and 33 and defining the number of weeks since the initiation of spring growth. Modification of the equations to accommodate variations in annual growth requires the derivation of cause-effect relationships between climatic influences and annual grass growth. Since these relationships were not investigated, growth is based on the growing season of 1970. The production of forbs is based on the relationship between forb weight and weeks since the initiation of spring growth (Figure 21). The weight of forbs produced refers to the standing crop present at the time of clipping.

Adjustment of grass and forb production in response to increasing crown closure of trees is accomplished by solving the relationships between production and crown closure (Equations 40 to 45), calculating the percentage decrease as compared to production at zero crown closure, and then reducing current annual production by this percentage.
The adjusted production of grasses and forbs is then readjusted in response to the presence of large and small shrub species. In the case of large shrub species, production is readjusted as a percentage of production in the open, according to the location beneath the shrub. The correction factors applied are shown in Table 1. Where grasses and forbs are growing in association with small shrub species, production is adjusted as a function of small shrub density (Equations 46 to 49). Obviously, the size of the individual shrubs will affect the degree of reduction in productivity. Equations 46 to 48 represent relationships derived in a Prunus community with a mean age of 15 years. For shrub stands of less than 15 years of age, the effect is reduced in direct proportion to the reduction in age as shown in Figure 39.

The sequence of calculations and decisions described for the growth of shrubs, grasses and forbs is conducted on each of the four sub-plots at each calculation interval until the simulation period is exceeded. The level of output detail required is specified by data statements. At the most detailed level, output is summarized in terms of:

1. Developmental stand map showing a vertical projection of the shrub stand.
2. Initial and current number of shrubs by species.
3. Number of shrubs having died by species.
4. Cause of mortality (from direct shading or as a function of crown closure of the forest stand).
5. Detailed information on Amelanchier, Ceanothus and Shepherdia including diameter, inside and border areas, total area and production.
Figure 39. Relationship between Agropyron production and Prunus density by shrub age.

(6) Total production by shrub species.
(7) Area in tree shade.
(8) Area shaded by Amelanchier, Ceanothus and Shepherdia.
(9) Area not shaded.
(10) Production of grass by species.
(11) Carryover of grasses.
(12) Forb production.

At the lowest level of detail, output is in the form of summary tables showing the number of individuals and production by species (Table 6).

CURRENT STATUS OF THE MODEL

The mathematical model, programmed in Fortran IV on a dual IBM 360/67 at the University of British Columbia, represents a prototype simulator of growth, competition, production and, to a limited degree, secondary succession in a mixed species forest ecosystem. The current version of the model handles 1 tree species (Douglas-fir), 6 shrub species (Amelanchier, Ceanothus, Shepherdia, Prunus, Rosa and Symphoricarpos), and 4 grass species (Agropyron, Poa, Calamagrostis and Koeleria); distinction is not made among forb species. The model is presently being converted for application on a PDP 11/20, with a 48K byte core, at the Pacific Forest Research Centre, of the Canada Department of the Environment.

The model structure provides an adequate bookkeeping system for the actions and interactions that occur during the development of a complex forest ecosystem. However, refinement, expansion and testing of the system and its components are necessary for achievement of its full potential as a sound accurate predictive tool.

OUTPUT

The model can be applied as a tree growth, a shrub growth and a grass and forb growth simulator, or as a vegetative community simulator.
Table 6. Output at lowest level of detail for shrubs, grasses and forbs.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crown closure - %</td>
<td>0</td>
<td>8.6</td>
<td>37.0</td>
<td>64.1</td>
<td>73.9</td>
<td>77.7</td>
</tr>
<tr>
<td>Agropyron production - kg/ha</td>
<td>475</td>
<td>223</td>
<td>180</td>
<td>156</td>
<td>10.7</td>
<td>3.6</td>
</tr>
<tr>
<td>Forb production - kg/ha</td>
<td>13.8</td>
<td>57.3</td>
<td>45.0</td>
<td>5.7</td>
<td>3.1</td>
<td>4.1</td>
</tr>
<tr>
<td>Calamagrostis and Koeleria production - kg/ha</td>
<td>0</td>
<td>1.6</td>
<td>7.2</td>
<td>16.5</td>
<td>19.1</td>
<td>20.0</td>
</tr>
<tr>
<td>No. of Shepherdia per ha</td>
<td>988</td>
<td>889</td>
<td>593</td>
<td>98</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Shepherdia production - kg/ha</td>
<td>0</td>
<td>10.3</td>
<td>45.2</td>
<td>17.7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No. of Prunus per ha</td>
<td>95638</td>
<td>85363</td>
<td>28849</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Prunus production - kg/ha</td>
<td>0</td>
<td>82.0</td>
<td>38.9</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
which allows the inclusion of trees, shrubs, grasses and forbs. It can be used to predict above ground plant production, to determine trade-offs between products and to evaluate the consequence of management decisions. Before presenting examples of the application of the model it is necessary to discuss the problems validating the model.

Validation

The advantage in adopting a systems approach is that a number of functional relationships can be linked in a computer program, thereby allowing interactions among relationships and consequently providing dynamic rather than static or average solutions. While the individual functions may duplicate reality to a high degree, there is no guarantee that the model as a whole is correct. Goulding (1972) summed up the validity problem in saying "the problem of validity is that if the real system was known exactly so that the model can be compared, there would have been little point in creating the simulation model." The problem then is one of comparing simulated results against static or average solutions which in themselves represent simple models of the real system and in turn need not necessarily be valid.

Van Horn (1968) defined validation as the process of building an acceptable level of confidence that the inference about a simulated process is a correct or valid inference of the actual process. This applies to the individual functional relationships, the organization and linkage of the functions and the results of the model itself. A number of procedures have been proposed for testing the validity of simulation models. These include:
1) Testing the model against other models (Forrester, 1968).
3) Sensitivity testing (Van Horn, 1968).
4) Regression of simulated series on real series and testing whether the coefficient was significantly different from one and the intercept significantly different from zero (Cohen and Cyert, 1961).
5) Turing tests (Van Horn, 1968) in which people directly involved in the field are asked to distinguish between real and simulated results without prior knowledge as to which were which.

Testing of the tree simulation was relatively simple as compared with the vegetative community simulations. The amount of data available for testing the understory simulation results are severely limited, to the extent that only sensitivity testing and some empirical testing could be carried out.

Examples of the application of the model and the results of the validity tests are presented in the remainder of this section.

Tree Growth Simulation

The principle application of tree growth simulations is in determining yield predictions for young stands. To date, yield tables, a term applied to presentations of expected yields of forest stands based upon growth inferred by the study of other stands, have been used in the estimation of future yields. For example, in British Columbia, a kind of empirical yield estimation called volume/age curves, of which more than 1000 are available, form the basis of the "Forest Service Method" for
determining annual allowable cut. Yield at culmination age and rotation age are calculated from the curves which are based on empirical plot data from variously aged natural stands. Localized curves may be necessary to overcome particular differences caused by site, stand density and decay factors (Forestry Handbook for British Columbia, 1971). Validated tree growth simulation models could obviate the necessity for generating local curves as site index and stand density can be varied.

The tree growth simulation was tested against the B. C. Forest Service volume/age curves, Goulding's (1972) model, data collected on the study area and by the Turing method.

Figures 40 and 41 show a comparison of the simulated results and the B. C. Forest Service volume/age curves for F, F mixtures and Py on medium and poor sites in the Cranbrook, Fernie, Upper Kootenay and Windermere P. S. Y. U.'s. The simulated data are based on specific stand conditions, namely a site index of 80 with 350 stems per acre for the medium site and a site index of 65 with 400 stems per acre for the poor site. Under these conditions the model adequately duplicates the volume over age curves. Average DBH is adequately duplicated on the medium site for both 7.1" + and 11.1" +, but is underestimated in the 11.1"+ class on the poor site. By increasing the site index, but still remaining within the range for poor site, and decreasing the number of stems, similar volumes can be achieved but with an increase in average DBH.

Of six persons questioned, none was able to distinguish between the B. C. Forest Service or simulated data. When asked to make a choice, four guessed correctly but again none was able to give any valid reason for the choice.
Figure 40. Comparison between simulated volume and DBH and B.C. Forest Service volume and DBH taken from V.A.C. 1012, medium site.
Figure 41. Comparison between simulated volume and DBH and B.C. Forest Service volume and DBH taken from V.A.C. 1013, poor site.
The model was then tested against the growth curves for unthinned stands prepared by Goulding (1972) to show gross volume and mean DBH for site indices 90, 120 and 150 with 300 and 800 trees per acre at age 20. Considerable difficulty was encountered in attempting to duplicate these stand conditions. The model developed allows site index to change during the course of the simulation and stand density is defined at age zero. After numerous runs, conditions approximating those of Goulding were achieved. The results obtained show that the two models, derived independently and using very different approaches, yield similar volumes with differences of up to 250 cubic feet per acre on high sites (Figures 42, 43 and 44). The simulated diameters of Goulding (Figure 45) are considerably lower than those generated in this model for all site classes. This divergence is not considered to be serious as my model tends to underestimate DBH taken from the B. C. Forest Service volume/age curves.

The simulation was tested against 6 stands measured on the study area which were not used in the derivation of any of the functional relationships. Data collected on the stands included individual tree locations, DBH, crown width, volume and number and location of trees having died since stand establishment. Stumps were used to locate trees which had died. While this method for determining past mortality is subject to underestimation, the absence of stands with recorded past histories of mortality in the study area necessitated its use. Table 7 shows the actual and simulated plot volumes in cubic feet per acre.
Figure 42. Comparison of Goulding's and my simulated gross cubic foot volume per acre for site index 150.
Figure 43. Comparison of Goulding's and my simulated gross cubic foot volume per acre for site index 120.
Figure 44. Comparison of Goulding's and my simulated gross cubic foot volume per acre for site index 90.
Figure 45. Comparison of Goulding's and my simulated mean DBH for site index 120.
Table 7. Comparison of simulated and actual stand volumes measured on the study area.

<table>
<thead>
<tr>
<th>Stand</th>
<th>Actual Total Volume</th>
<th>Simulated Total Volume</th>
<th>Simulated as % of Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1&quot; + DBH cu ft/acre</td>
<td>1&quot; + DBH cu ft/acre</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1710</td>
<td>1510</td>
<td>88.3</td>
</tr>
<tr>
<td>2</td>
<td>2001</td>
<td>1991</td>
<td>99.5</td>
</tr>
<tr>
<td>3</td>
<td>1832</td>
<td>2031</td>
<td>110.9</td>
</tr>
<tr>
<td>4</td>
<td>2131</td>
<td>2339</td>
<td>109.8</td>
</tr>
<tr>
<td>5</td>
<td>780</td>
<td>1000</td>
<td>128.2</td>
</tr>
<tr>
<td>6</td>
<td>857</td>
<td>777</td>
<td>90.7</td>
</tr>
</tbody>
</table>

Stand 2 was also simulated at both 2- and 10-year intervals to ascertain the effect of reducing the calculation interval on both simulation costs and results. Cost was found to be a direct function of the number of calculation intervals; the costs at 2- and 10-year intervals were approximately $43 and $9, respectively. Decreasing the calculation interval from 10 to 2 years had a minor effect on the simulated parameters. Selected stand parameters are shown at 20 year intervals (Table 8).

On the basis of these results, the model appears to approximate the real system. Obviously, the model will require further testing and refinement if it is to be used to generate yield tables. However, it is sufficiently accurate to give an approximation of yield for use in the determination of trade-offs between wood and ungulate food production.
Table 8. Comparison of selected mean tree parameters for calculation intervals of 2 and 10 years.

<table>
<thead>
<tr>
<th>Stand Age yrs</th>
<th>Calculation Interval yrs</th>
<th>Average Height ft</th>
<th>Average DBH ins</th>
<th>Average Volume 1&quot; + DBH cu ft</th>
<th>No. of Trees per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>2</td>
<td>5.3</td>
<td>0.63</td>
<td>0.007</td>
<td>840</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>5.2</td>
<td>0.59</td>
<td>0.007</td>
<td>830</td>
</tr>
<tr>
<td>40</td>
<td>2</td>
<td>14.0</td>
<td>2.6</td>
<td>0.360</td>
<td>770</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>14.8</td>
<td>2.7</td>
<td>0.381</td>
<td>660</td>
</tr>
<tr>
<td>60</td>
<td>2</td>
<td>20.6</td>
<td>3.8</td>
<td>1.020</td>
<td>650</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>21.3</td>
<td>3.9</td>
<td>1.076</td>
<td>540</td>
</tr>
<tr>
<td>80</td>
<td>2</td>
<td>29.4</td>
<td>5.2</td>
<td>2.451</td>
<td>550</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>30.8</td>
<td>5.6</td>
<td>2.648</td>
<td>450</td>
</tr>
<tr>
<td>100</td>
<td>2</td>
<td>38.0</td>
<td>6.5</td>
<td>5.038</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>38.9</td>
<td>6.7</td>
<td>4.940</td>
<td>410</td>
</tr>
</tbody>
</table>

The Vegetative Community Simulation

The models for shrub growth and grass and forb growth were constructed after completion of the tree growth model. Initial sensitivity testing showed that the models were capable of approximating solutions in the absence of trees. As was previously stated, difficulty was encountered in validating the understory simulations due to the lack of data with which to compare the simulated results.

Two types of sensitivity tests were undertaken, plant species abundance was varied from absent to the highest densities encountered on the study area and changes were made to the functional relationships and growth rate frequency distributions.
On the basis of the results obtained in testing the model over a range of plant densities, it appeared that the model performed adequately except at very low tree and shrub densities. The production of both trees and shrubs appeared to be underestimated and the death of a single individual at these low densities resulted in rather abrupt and marked increases in grass production. Examination of height frequency distribution of naturally occurring, mature, open-grown stands indicated the presence of a disproportionate number of faster than average growing individuals, the reason for which is not clear. The normal random deviates generated in the model did not allow for this upward shift in average growth rate at low densities. Therefore, an additional function which increases the mean value and reduces the standard deviation at low densities was added. The addition of this function has apparently solved the problem of growth underestimation. The abrupt and marked increase in grass production following the death of a tree or shrub is a result of the removal of the dead individual from the system, thereby freeing a large amount of growing space. Modification to the system to allow the gradual withdrawal of dead individuals is presently being undertaken.

The changes made to the functional relationships and the growth rate frequency distributions showed the system to be fairly stable; small modifications to the functions resulted in small changes in the results and large modifications resulted in large changes in the results.

The model was tested against the results obtained by Kemper (1971) on Premier Ridge some 60 miles north of the study area. Unfortunately, due
to the lack of uniformity in the calculation of productivity, the number of comparisons that could be made is limited. Comparison of Kemper's (1971) data for grass production as a function of forest crown closure with that of the simulation shows that the simulated curve describes the data well except at crown closures greater than 70 per cent, where it underestimated production. The response of simulated forb production to changing crown closure exhibits similar trends to those found by Kemper, but was significantly lower. The lower production values probably result from the fact that Kemper's measurements were made on plant communities in secondary grazing succession in which forb production is greatly increased. Shrub production follows the trends found by Kemper but can't be compared directly because of the different methods of measurement and presentation of results.

Insufficient data were collected to allow testing of the model's predictive accuracy for understory production on the study area. On the basis of the small amount of data available, the model appears to duplicate observed production trends.

Extensive validity testing of the understory model must be carried out before it can be used as a management tool for predicting future yields of ungulate food production. Despite the uncertainty as to its predictive accuracy, the understory model can be used to investigate plant interactions and to isolate critical relationships affecting productivity.

The most interesting and instructive results obtained from the vegetative community simulator are those showing response of shrubs, grasses and forbs to the presence of trees and to competition among one another. Production and density were converted to metric units because this is the
usual system used in range studies.

Figure 46 shows the response of *Amelanchier* numbers and production under two tree stands, site index 60 with 2224 and 1112 trees per hectare, respectively, at age zero, as compared to growth in the absence of trees. The initial number of *Amelanchier* was set at 2700 per hectare, representing the upper density found. The most striking feature in the comparison is the tremendous reduction in number and production when trees are introduced into the system. Clearly, the production of wood and *Amelanchier* browse are incompatible. Similar relationships were found for all shade intolerant shrub species. Figure 47 shows a comparison of the rate of mortality and production of a shade intolerant species, *Prunus*, and an intermediate shade tolerant species, *Symphoricarpos*, as a function of changing forest crown closure and time. Both species show a decrease in numbers as crown closure increases, the rate of decrease being greatest in the shade intolerant species. In both cases production shows a lag effect; that is, production initially increases despite a decrease in shrub numbers. The production increase is explained by the fact that although the number of individuals is decreasing, the relative size, and hence productivity, of each individual is increasing.

The response of *Agropyron* to the presence of trees is essentially similar to that of shade intolerant shrubs. Figure 48 shows the response of *Agropyron* production under the same conditions used to determine *Amelanchier* response to tree shade. Production was set at 475 kilograms per hectare which represents good production on the study area. Again production shows
Figure 46. Simulated effect of tree crown closure on Amelanchier numbers and production.
Figure 47. Simulated shrub mortality and production response to changing crown closure for a shade intolerant and an intermediate shade tolerant species. A: Prunus  B: Symphoricarpos
Figure 48. Comparison of simulated *Agropyron* production for site index 60 with 2224, 1112 and zero trees per hectare.
a very rapid decrease as tree crown closure increases. A change in crown closure from 0 to 10 per cent causes a fifty per cent reduction in production.

The production response of forbs and *Calamagrostis* and *Koeleria* to changing crown closure as affected by the presence and absence of shrubs, in this case *Shepherdia*, *Prunus* and *Symphoricarpos*, is shown in Figure 49. The production curves are a product of a number of complex interactions. Production of *Calamagrostis* and *Koeleria* increases in response to increasing crown closure both in the presence and absence of shrubs. However, the presence of shrubs depresses the rate of increase. In the absence of shrubs, forb production shows an initial increase in response to increasing crown closure, and decreases when crown closure exceeds 30 percent. In the presence of shrubs, forb production initially shows a faster and more pronounced increase, followed by a more rapid and pronounced decrease. The shift from a pronounced increase to a pronounced decrease in production results from the opposing effect of *Shepherdia*, *Prunus* and *Symphoricarpos* on forb production and differing mortality rates for the shrubs. *Shepherdia* results in a decrease in forb production, while *Prunus* and *Symphoricarpos* increase production. The decrease in forb production resulting from the presence of *Shepherdia* is masked by a greater increase due to the presence of *Prunus* and *Symphoricarpos* until age 20. At age 20, or crown closure of approximately 12 percent, mortality of *Prunus* and *Symphoricarpos* reduces their compensatory effect, and forb production shows a net decrease due to the effect of the surviving *Shepherdia*. 
Figure 49. Comparison of simulated forb and Calamagrostis and Koeleria production response to tree crown closure in the presence and absence of shrubs.
Forest crown closure appears to be the most critical factor determining understory production. Therefore, the ungulate manager, faced with the problem of providing browse and grazing, must be able to predict future tree crown closures if he is to manage the resource. The tree growth model can provide this information. Figure 50 illustrates the effect of site index and stand density, the two most important factors affecting crown closure, on the rate of crown closure for three stand densities, 2224, 988 and 247 trees per hectare at year zero, and two site indices, 80 and 60. Tree locations were randomly assigned.

Determination of trade-off functions between production of wood and *Agropyron* demonstrates even more clearly the degree of incompatibility between the two products (Figure 51). *Agropyron* production was specified at 475 kilograms per acre and the tree stands were assigned a site index of 60 with 2224 and 741 trees per hectare at age zero. Wood production was converted to cubic meters per hectare for the comparison. Under both stand conditions *Agropyron* production was decreased by approximately 55 per cent before any volume increment occurred. Reduction of stand density from 2224 to 741 trees per hectare resulted in a short term net increase in *Agropyron* production at the cost of a loss of 111 cubic meters of wood per hectare.

The response of *Agropyron* to the presence of *Amelanchier*, and other shrub species, is similar to that of trees in that there is a reduction in production, but this loss is compensated by the production of browse (Figure 52). *Agropyron* production was specified at 475 kilograms per hectare and *Amelanchier* density at 2700 individuals per hectare. The trade-off function shows a straight line almost one-to-one conversion with a slight loss in production in the change from *Agropyron* to *Amelanchier*.
Figure 50. Effect of forest stand density and site index on forest crown closure.
Figure 51. Trade-off between wood and Agropyron production.
Figure 52. Trade-off between Agropyron production and annual twig production of Amelanchier.
The discussion of the simulation results gives a brief insight into the complexity of interactions handled by the model and the form of output. The model appears capable of predicting the production of trees, shrubs, grasses and forbs in complex plant communities with a reasonable degree of accuracy, allows isolation of the effect and response of individual plant species and provides a basis for determining production trade-offs among different plant species and hence providing a management tool for the optimization of land productivity for specified management goals.

It would seem worth while to give a brief example of how the model could be applied on the study area to evaluate the consequence of reducing the density of Douglas-fir stands on the production of wood and ungulate food. *Amelanchier*, *Agropyron* and forb production are compared under two Douglas-fir densities, 2224 and 247 trees per hectare at year zero with a site index of 60. *Amelanchier* production was calculated for 2700 individuals per hectare and *Agropyron* for a mean production of 40 grams per square meter. Table 9 shows the comparative productions. At 2224 trees per hectare, wood production reaches 8,000 cubic feet per hectare, while the production of *Amelanchier*, *Agropyron* and forbs is essentially confined to the first 30 years. *Amelanchier* production reaches a maximum of 25 kg/ha at 20 years and then declines rapidly to zero at 32 years; *Agropyron* production reaches a maximum of 210 kg/ha at 10 years and declines to zero at 36 years, and forb production reaches a maximum of 55 kg/ha at 10 years and declines gradually to 10 kg/ha at 100 years. Reduction of stand density to 247 stems per hectare reduces wood production by approximately 70 per cent to 62.3 cubic meters per hectare but results in very significant increases in the...
Table 9. Comparative productivities of wood, *Amelanchier*, *Agropyron* and forbs for two Douglas-fir stands with 2224 and 247 stems per acre and site index 60.

<table>
<thead>
<tr>
<th>Age</th>
<th>2224 trees per ha</th>
<th>247 trees per ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wood cu ft/ha</td>
<td>Amel. kg/ha</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>30</td>
<td>250</td>
<td>3</td>
</tr>
<tr>
<td>40</td>
<td>1200</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>2500</td>
<td>0</td>
</tr>
<tr>
<td>60</td>
<td>3500</td>
<td>0</td>
</tr>
<tr>
<td>70</td>
<td>5000</td>
<td>0</td>
</tr>
<tr>
<td>80</td>
<td>6300</td>
<td>0</td>
</tr>
<tr>
<td>90</td>
<td>7500</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>8000</td>
<td>0</td>
</tr>
</tbody>
</table>
production of Amelanchier, Agropyron and forbs. Amelanchier production increases steadily to a maximum of 41 kg/ha at 100 years; Agropyron production reaches a maximum of 400 kg/ha at 10 years and then declines to 200 kg/ha at 100 years, and forb production reaches a maximum of 60 kg/ha at 50 years and then declines to 50 kg/ha at 100 years. In the absence of trees, Amelanchier production would have reached 380 kg/ha, Agropyron 475 kg/ha and forbs 42 kg/ha. Whether the increase in ungulate food production justifies the associated reduction in wood production is beyond the scope of this study.
POTENTIAL FOR APPLICATION

At the present stage of development, the model has a number of limitations that should be overcome if it is to achieve its full potential as a research, educational or management tool. The limitations may be segregated into (1) system or (2) component oriented restraints.

The system oriented limitations result from system design and are relatively easily overcome. They include:

(1) Inability to allow natural regeneration or cultural practices during the course of simulation.
(2) Simulation plot must be square.
(3) Definite upper limit on number of species and individuals within each species.
(4) Excessive amounts of information generated.

The component oriented limitations are of a more serious nature than the system restraints, depending on the purpose of the study. As a feasibility study in using mathematical modelling to simulate plant ecosystem development, to approximate productive capabilities for alternate species or combinations of species, isolate critical functional relationships, assess probable implications of management for wood production on ungulate food production or as a learning tool, the limitations are of little consequence. However, if the model is to be used in management decision making, it will be necessary to (1) improve and elaborate the functional relationships, (2) derive additional relationships, and (3) undertake further validity testing. Additional information required would include (1) a more precise
definition of site quality, (2) the ability to account for large variations in understory production due to annual climatic variations, (3) the ability to allow mortality from causes other than competition, and (4) the development of methods for converting total plant production to utilizable production will be necessary.

Following these inclusions, the model would have direct application in:

1) Determining production capabilities for alternate species or combinations of species.

2) Testing various combinations of species to determine the best combination in terms of ungulate food production.

3) Predicting food availability through the winter.

4) Predicting plant succession and the duration and amount of food produced by individual species and combinations of species.

5) Deriving trade-off functions between wood and ungulate food production.

6) Prediction of wood yield.
BIBLIOGRAPHY


Jensen, C. E. 1964. Algebraic descriptions of forms in space. Columbus, Central States Forest Experimental Station. 75 pp.


APPENDIX I. COMMON AND SCIENTIFIC NAMES

PLANTS

Douglas-fir  Pseudotsuga menziesii (Mirb.) Franco
Serviceberry  Amelanchier alnifolia Nutt.
Buckbrush  Ceanothus sanguineus Pursh.
Buffalo berry  Shepherdia canadensis Nutt.
Cherry  Prunus emarginata (Dougl.)
Rose  Rosa nutkana Presl.
Snowberry  Symphoricarpos albus (L.) Blake
Wheatgrass  Agropyron spicatum (Pursh) Scribn. and Smith
Bluegrass  Poa compressa L.
           Poa scabrella (Churb.) Benth. ex Vasey.
Fescue  Festuca idahoensis Elmer
Reedgrass  Calamagrostis rubescens Buckl.
Junegrass  Koeleria cristata Pers.
Brome grass  Bromus tectorum L.
Trembling aspen  Populus tremuloides Michx.
Douglas maple  Acer glabrum Torr. var. douglasii (Hook.) Dipp.
Juniper  Juniperus horizontalis Moench.
Mahonia  Berberis repens Lindl.
Needlegrass  Stipa columbiana Macoun.
Yarrow  Achillea millefolium L.

---

<table>
<thead>
<tr>
<th>Plant</th>
<th>Scientific Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large purple aster</td>
<td><em>Aster conspicuus</em> Lindl.</td>
</tr>
<tr>
<td>Pasture wormwood</td>
<td><em>Artemisia frigida</em> Willd.</td>
</tr>
<tr>
<td>Spring sunflower</td>
<td><em>Balsamorhiza sagittata</em> (Pursh.) Nutt.</td>
</tr>
<tr>
<td>Beardtongue</td>
<td><em>Monarda fistulosa</em> L.</td>
</tr>
<tr>
<td>Tuffted phlox</td>
<td><em>Penstemon</em> spp.</td>
</tr>
<tr>
<td></td>
<td><em>Phlox caespitosa</em> Nutt.</td>
</tr>
</tbody>
</table>

**UNGULATES**

<table>
<thead>
<tr>
<th>Animal</th>
<th>Scientific Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elk</td>
<td><em>Cervus canadensis nelsoni</em>, Bailey²</td>
</tr>
<tr>
<td>Mule deer</td>
<td><em>Odocoileus hemionus hemionus</em> (Rafinsque)</td>
</tr>
<tr>
<td>Rocky mountain big-horn sheep</td>
<td><em>Ovis canadensis canadensis</em> Shaw</td>
</tr>
</tbody>
</table>

where:

- **a** - tree height (HT)
- **b** - crown radius (CR)
- **c** - height to live crown base (HTblc)
- **d** - maximum crown width (CWmax)
- **e** - horizontal branch length (HBL)
- **f** - branch length (BL)
- **g** - height above branch base (HTAB)
- **h** - height to maximum crown width (HTCWmax)
- **i** - length of live crown
- **j** - point of maximum crown width
APPENDIX III

PROGRAM LISTING FOR
THE
GROWTH SIMULATION OF
TREES, SHRUBS, GRASSES AND FORBS
ON A BIG-GAME WINTER RANGE

MAIN PROGRAM

TREE GROWTH SIMULATION

TREE GROWTH AND COMPETITION = SUBROUTINE TREE
STAND MAPS = SUBROUTINE XSECT

VEGETATIVE COMMUNITY SIMULATION

PROGRAM CONTROL AND SPECIFICATIONS = SUBROUTINE AGROP
SHRUB GROWTH = SUBROUTINE BRANCH
SHRUB MORTALITY = SUBROUTINE REM
SHRUB AREA = SUBROUTINE AREA
SHRUB PRODUCTION = SUBROUTINE SGPDN
GRASS AND FORB PRODUCTION = SUBROUTINE SUM

UTILITY PROGRAMS

UNIFORM AND RANDOM NUMBER GENERATORS
MAIN PROGRAM

SIMULATION OF THE GROWTH AND COMPETITIVE INTERACTIONS OF TREES, SHRUBS AND GRASSES

ON A BIG-GAME WINTER RANGE IN THE EAST KOOTENAY DISTRICT OF BRITISH COLUMBIA

DIMENSION IARRA(66,66), BL2(96), ACC(4,21), ATA(4,21), ATG(4,21), ATF(4,21), APDNA(4,21), APDNC(4,21), APDNS(4,21), APDNPR(4,21), APDNRO(4,21)

INTEGER*2 JARRA(66,66), NSET(96), IQQ(96,5), JQQ(96,5), NAGE(50), NNAMES(41), LRAND(50), LRRAND(100), JRAND(100), JPRUN(20), JROSE(20), JSYMP(20), ISC(150), JCOM(150), IDEAD1(150), IDEAD2(150), IDEAD3(150), IDEAD4(150)

COMMON IARRA, BL2, ACC, ATA, ATG, ATF, APDNA, APDNC, APDNS, APDNPR, APDNRO, A1PONSY, CSUB1, CSUB2, CSUB3, CSUB4, RAD, BORDA, XINA, UTILA, BORDC, XINC, UTIL2C, BORDS, XINS, UTILS, AGE, C, CC, TAUT, TAUTS, TAUTT, TAUC, YNOC, YNOC, PDN1, ITHRU, M, ISTRAT, IINT, IEND, IYUNOC, IAUTT, IYNOCC, IYNOCC, ILOOP, IX, ISUB, ICOUNT3, IHT, IBB, JARRA, LARR1, LARR2, LARR3, LARR4, IQQ, JQQ, IAREA, PER, KCHAR, ICO4M, JCOM, IDEAD1, IDEAD2, IDEAD3, IDEAD4, IDIAML, IDIAM2, IDIAM3, IDIAM4, JRXAND, KKRAND, LLRRAND, ICHAR, IRAND, IXX, IVOL, IYB, IYBH, ICL, IAPER, ICW, ICB, IBA, IDEAD, NSET, KAMEL, KCEON, KSHEP, KPRUN, KROSE, KSYMP, NAGE, JRAND, KRAD, LDAND, JAMEL, JCEON, JSHEP, JPRUN, JROSE, JSYMP, EPER, NNAME, NCEON, NNSYMP, NNAME, JCHAR

IR0=5
IODUT=6
ITHRU=0
DO 2 I=1,66
DO 2 J=1,66
IARRA(I,J)=1000000
JARRA(I,J)=0

READS BRANCH LENGTH-OCCUPANCY DATA DECK
DO 3 I=1,96
READ(IRO,5) BL2(I),NS,(IQQ(I,II),JQO(I,II),II=1,NS)
3 NSET(I)=NS
5 FORMAT(F6.4,13I3)

C
DELOPT *** DELETE OPTION FOR TREE SUBROUTINE ***
**** IF DELOPT .LE. 0 TREE SUB CALLED *****

C
READ(IRO,10) DELOPT
10 FORMAT(I2)

C
READS STARTING AGE

C
READ(IRO,15) ISTRT
15 FORMAT(I3)

C
READS GROWTH INTERVAL

C
READ(IRO,20) IINT
20 FORMAT(I3)

C
READS UPPER AGE LIMIT

C
READ(IRO,30) IEND
30 FORMAT(I3)
IF(DELOPT).LE.00,100,40
40 J=0
DO 50 I=ISTRT,IEND,IINT
   J=J+1
50 NAGE(J)=I-1
READ(IRO,55) IX
55 FORMAT(I5)
TINT=IINT
NINT=IEND/IINT

C
INCREASES CROWN CLOSURE IF TREE SUBROUTINE NOT CALLED

C
CSUB1=0,
CSUB2=10,
CSUB3=20,
CSUB4=30,
GO TO 65
60 CSUB1=CSUB1+40,
CSUB2=CSUB2+40,
CSUB3=CSUB3+40,
CSUB4=CSUB4+40,
GO TO 65
62 CSUB1=CSUB1+40,
CSUB2=CSUB2+40,
CSUB3=CSUB3+40,
CSUB4=CSUB4+40,
CALLS UNDERSTORY ROUTINES

CALL AGROP
 DO 70 I=1,NINT
 M=0
 CALLS UNDERSTORY ROUTINES

70 CALL AGROP
 IF(CSUB1.LT.10.) GO TO 60
 IF(CSUB1.LT.50.) GO TO 62
 M = STAND AGE
 ITREE = ITH TREE
 IPOS = ITH BRANCH
 HABM = HEIGHT TO MAXIMUM CROWN WIDTH
 BL = BRANCH LENGTH
 HBL = HORIZONTAL BRANCH LENGTH
 IOC = TEST VALUE FOR BRANCH OCCUPANCY
 BB = HEIGHT TO BRANCH BASE
 HT,HTA,HTS = TREE HEIGHTS
 ICW,CWS,CH,ACW = MEASURES OF CROWN WIDTH
 IVOL, VOLS, AVOL = MEASURES OF VOLUME
 IDBH,DBH,ADB = MEASURES OF DIAMETER AT BREAST HEIGHT
 IBA, BAS, BA, ABA = MEASURES OF BASAL AREA
 ICL,CLS,CL,ACL = MEASURES OF CROWN LENGTH
 IAPER = % CROWN CLOSURE

XWD=5
 IOUT=6
 IDELAG ***** OPTION TO DELETE AGROPYRON SUBROUTINE CALL *****
 $$$$$$$ IF IDELAG .GT. 0 = CALL SUBROUTINE AGRO $$$$$$$

READ(IRD,3) IDELAG
 FORMAT(I2)

INTEGER TO START GAUSS

READ(IRD,10) IIX
 FORMAT(I5)

SI *** READS SITE INDEX ***

READ(IRD,20) SI
 FORMAT(F5.2)

ALL TREES INITIALIZED AS BEING ALIVE *** IDEAD ***
 NUMTR *** OPTION TO CHANGE NUMBER OF TREES ***
C
READ(IROD,30)NUMTR
30 FORMAT(I3)
C
C MATRIX *** OPTION TO ALLOCATE TREE LOCATIONS RANDOMLY ***
C
READ(IROD,31) MATRIX
31 FORMAT(I2)
IF(MATRIX.GT.1) GO TO 51
C
DO 55 I=1,NUMTR
CALL RANDU (IX,IY,YFL)
IXX(I)=YFL*65.+1.
IDEAD(I)=0
55 I=IY
DO 56 I=1,NUMTR
CALL RANDU (IX,IY,YFL)
JXX(I)=YFL*65.+1.
56 I=YI
ICHK=0
DO 39 I=1,NUMTR
DO 39 J=1,NUMTR
IF(I.EQ.J) GO TO 39
IF(IXX(I).NE.IXX(J)) GO TO 39
IF(JXX(I).NE.JXX(J)) GO TO 39
LI=JXX(J)
38 CALL RANDU (IX,IY,YFL)
JXX(J)=YFL*65.+1.
IX=IY
IF(JXX(J).NE.L) GO TO 38
ICHK=1
39 CONTINUE
IF(ICHK).NE.59,59,37
51 DO 40 I=1,NUMTR
IDEAD(I)=0
40 READ(IROD,50)IXX(I),JXX(I)
50 FORMAT(213)
59 READ(IROD,60)ICHAR
60 FORMAT(40A2)
C
C READS OPTIONS
C
C IPRIN *** OPTION TO PRINT OUT STAND MAP ***
C
****** IF .LE. 1 = NO MAP *** IF .GT. 1 = MAP ******
C
READ(IROD,70)IPRIN
70 FORMAT(I2)
C
C NCODE *** OPTION TO PRINT IARRA CODE ***
C ****** IF .LE. 1 = NO CODE *** IF .GT. 1 = CODE ******
C
READ(IRO,80) CODE
80 FORMAT(I2)
C
NTREE *** OPTION TO PRINT INDIVIDUAL TREE PARAMETERS ***
C ****** IF .LE. 1 = NO TREES *** IF .GT. 1 = TREES ******
C
READ(IRO,90) NTREE
90 FORMAT(I2)
C
ITRFN *** OPTION TO PRINT TREE FUNCTIONS AS GRAPHS ***
C ****** IF .LE. 1 = NO FUNCTIONS *** IF .GT. 1 = FUNCTIONS ******
C
READ(IRO,220) ITRFN
220 FORMAT(I2)
 READ(IRO,230) JCHAR
230 FORMAT(2A1)
C
LINPR *** OPTION TO DISPLAY VERTICAL XSECT THROUGH STAND ***
C ****** IF .LE. 0 = NO XSECT *** IF .GE. 1 AND .LE. 66 XSECT
C PRINTED THROUGH LINE = TO VALUE OF LINPR ******
C
READ(IRO,240) LINPR
240 FORMAT(I2)
C
GENERATES RANDOM NUMBERS FOR ALLOCATION TO INDIVIDUAL TREES
C
UMTRE = NUMTR
VV*1.45*((100.-UMTRE)**6./100.**6.)
AM* 5231.+25*((100.-UMTRE)**6./100.**6.)
C
DO 250 IM, NUMTR
   CALL GAUSS(IX,2322,AM,V)
   IF(V.LT.VV) V=VV
   IF(V.GT.1.1) V=1.1
250 IRAND(I)=V*1100.
C
DO 310 II=1,19
   DO 310 JJ=1,19
      IHT(II, JJ)=0
310 IBB(II, JJ)=0
      ILOOP=(IEND-ISTRT)/IINT+1
      JLOOP=ILOOP-1
C
CALCULATES TREE HEIGHTS FOR SPECIFIED AGE INTERVAL
C TREE HEIGHTS PLACED IN ARRAY
C
J=0
C
DO 350 I=ISTRT, IEND, IINT
J=J+1
MAGE(J)=I=1
X=1=1
DO 350 K=1,NUMTR
RAND1=IRAND(K)
RAND2=RAND1/1000.
IF(X=05) 320,330,330
320  HT=RAND*(18.05*(SIN(X*3.14159/50.*3.14159/2.)+1.)*.7-.038
175*X)
GO TO 340
330  HT=RAND*(1.66222+.7044*X)
IF(HT.LT..01) HT=01
340  HT2=HT*100.
350  IHT(J,K)=HT2
CALCULATES HEIGHT AT AGE 1 * REPRESENTS LOWEST BRANCH WHORL
DO 360 J=1,1
DO 360 K=1,NUMTR
RAND1=IRAND(K)
RAND2=RAND1/1000.
BB=RAND1*1805.*(SIN(3.14159/50.*3.14159/2.)+1.)
IF(BB.LT.1.) BB=1.
360  IBB(J,K)=BB
PLACES HEIGHTS TO BRANCH BASE FROM AGE INTERVAL 2 TO IMAX IN ARRAY
DO 370 J=2,1000
L=J-1
DO 370 K=1,NUMTR
370  IBB(J,K)=IHT(L,K)
PRINTS HEIGHT AND BRANCH BASE ARRAYS FOR TREES 1 TO 9
WRITE(IOUT,380)
380  FORMAT("1",5X,"TREE HEIGHTS STORED IN ARRAY",/)
WRITE(IOUT,390)
390  FORMAT(3X," TREE 1 TREE 2 TREE 3 TREE 4 TREE 5 TREE 6 TREE
17 TREE 8 TREE 9")
DO 400 I=1,1000
400  WRITE(IOUT,410)(IHT(I,J),J=1,9)
410  FORMAT(3X,12I3)
WRITE(IOUT,420)
420  FORMAT(///,5X,"HEIGHTS TO BRANCH BASE STORED IN ARRAY",/)
C
WRITE(IOUT,390)

DO 430 I=1,IL00P

430 WRITE(IOUT,410)(IBB(I,J),J=1,9)

SETS IARRA(I,J)=1000000

DO 440 I=1,66

440 IARRA(I,J)=1000000

450 M=0

WRITE(IOUT,451)

451 FORMAT(/,5x,"STAND AGE = 0 YRS. ** TREES NOT YET ESTABLISHED")

CSUB1=0

CSUB2=0

CSUB3=0

CSUB4=0

IF(IGELAG.LE.0) GO TO 460

GO TO 130

CALLS TREE GROWTH ROUTINES

100 CALL TREE

130 CALL EXIT

STOP

END

SUBROUTINE GAUSS(Ix,S,AM,V)

RANDOM NUMBER GENERATOR FOR NORMAL DISTRIBUTION

A=0.0

DO 50 I=1,12

CALL RANDU(Ix,IY,Y)

IX=IY

50 A=A+Y

V=(A-6.0)*S+AM

RETURN

END

SUBROUTINE RANDU(Ix,IY,YFL)

RANDOM NUMBER GENERATOR
C

IY=IX*65539
IF(IY)5,6,6
      IY=IY+2147483647+1
6       YFL=IY
      YFL=YFL*4656613E9
      RETURN
END
SUBROUTINE TREE

STAND GROWTH SIMULATION FOR INTERIOR DOUGLAS-FIR

DIMENSION IARRA(bb,bb),BL2(96),ACC(4,21),ATA(4,21),ATG(4,21),ATF(4,21),APDNA(4,21),APDNC(4,21),APDNS(4,21),APDNPR(4,21),APDNRO(4,21),2,APDNSY(4,21)

INTEGER*2 JARRA(bb,bb),NSET(96),IOQ(96,5),JQQ(96,5),NAGE(50),NNAME1L(4),NNCEON(4),NNSHP(4),NNPRUN(4),NNROSE(4),NNSYM(4),JRAND(50),K2RAND(50),LRAND(50),JLRAND(100),JRRAND(100),K3RAND(100),LLRAND(100),J3AMEL(20),JCEON(20),JSHEP(20),JPRUN(20),JROSE(20),JSYM(20),I5COM(150),JCOM(150),IDEAD1(150),IDEAD2(150),IDEAD3(150),IDEAD4(150),6,LARR1(66,66),LARR2(66,66),LARR3(66,66),LARR4(66,66),LAREA(153),IO71AM1(150),IDIAM2(150),IDIAM3(150),IDIAM4(150),PER(153),EPER(16),KAM8AMEL(4,21),KCEON(4,21),KSHEP(4,21),KPRUN(4,21),KROSE(4,21),KSYM(4,921),KCHAR(160),IHT(100,97),ICHAR(99),IBB(50,97),IRAND(97),IXX(97),1JXX(97),IVOL(97),IDBM(97),ICL(97),IAPER(97),IC8(97),ICB(97),JCHAR(2),IDEAD97).

COMMON IARRA,BL2,ACC,ATA,ATG,ATF,APDNA,APDNC,APDNS,APDNPR,APDNRO,APDNSY,CSUB1,CSUB2,CSUB3,CSUB4,RAD,BORDA,XINA,UTILLA,BORDC,XINC,UTIL2C,BORDS,XINS,UTILS,AGE,C,CC,TAUT,TAUTS,TAUTT,TAUG,UNOC,YUNOC,PON1,ITHRU,M,ISTRT,INT,END,IYUNOC,IAUTY,IUNOC,_LOOP,IX,ISUB,ICOUNT3,HIT,IBB,JARRA,LARR1,LARR2,LARR3,LARR4,IOQ,JQQ,IAREA,PER,KCHAR,ICO4M,JCOM,IDEAD1,IDEAD2,IDEAD3,IDEAD4,IDIAM1,IDIAM2,IDIAM3,IDIAM4,JJR5AND,KRRAND,LRRAND,ICHR,IRAND,IXX,IXX,IVOL,IDBH,ICL,IAPER,IC8,ICB6,IBA,IDEAD,NSET,KAMEL,KCEON,KSHEP,KPRUN,KROSE,KSYM,NNAME,JRAND,KRAN7D,LRAND,JAMEL,JCEON,JSHEP,JPRUN,JROSE,JSYM,EPER,NNAMEL,NCEON,NNS8HEP,NNPRUN,NNROSE,NNSYM,ICHAR

IARRA = ARRAY REPRESENTING 1/10 ACRE PLOT
JARRA = ARRAY FOR PLOTTING CROWN PROFILES
CSUB1,...,4 = CROWN CLOSURE OF SUB-PLOTS
SUB1,...,4 = CROWN AREAS FOR 1/40TH ACRE PLOTS
HTAB = HEIGHT ABOVE BRANCH
CAE = EXPECTED CROWN AREA
NUMTR = # OF TREES
ICHAR = TREE NUMBERS
IXX, JXX = I,J TREE LOCATIONS
IRAND = TREE GROWTH POTENTIAL
CALL AGROP

INCREMENTS AGE INTERVAL

400 M=M+1

DO 500 I=1,66

DO 500 J=1,66

500 JARRA(I,J)=0

IF (M-1_LOOP) 510,510,1470
510  ITREE=0
C    STARTS NEW TREE
C
520  ITREE=ITREE+1
   L2=1
   KTHBR=1
   IF(ITREE-NUMTR)530,530,790
530  HT1=HHT(M,ITREE)
   IF(HT1.LE.0.)GO TO 520
C    GOES TO NEXT LOWER BRANCH AND CALCULATES BRANCH LENGTH
C
   DO 780 IBK=1,M
   IP=IP+1=IBR
   BB1=BB(BB(IP,ITREE))
   IF(BB1.LE.0.)GO TO 520
   BB=BB1/100.
   HT=HT1/100.-BB
   HTA=HT1/100.
   HABM=5.5+.425*HTA
   IF(HT.GT.0.) GO TO 539
   HT=.1
539  IF(HABM)560,560,540
C    TESTS AND ADJUSTS HEIGHT TO CROWN WIDTH MAX
C
540  IF((HTA-HABM)-HT)550,550,560
550  BL=.98*(HTA-HABM)**.7
   GO TO 570
560  BL=.98*HT**.7
570  HBL=.9*BL-3.3*(BL**3./20.*3.)
   JX=JXX(ITREE)
   IX=IXX(ITREE)
C    DESIGNATES POSITION OF TREE BOLE
C
   KARRA(IX,JX)=97+HHT(M,ITREE)*100+10000000
   KTHBR=L2
C
   DO 760 L=KTHBR,96
   NS=NSET(L)
   L2=L
C
C    CROWN GROWTH AND COMPETITION
C    CROWN GROWTH
C
   DO 760 K=1,NS
   IF(HBL-BL2(L))770,580,580
580  INCR=0
590  INCR=INCR+1
GO TO (600, 610, 620, 630, 760), INCR
600 J=JX+JQQ(L,K)
I=IX+IQQ(L,K)
GO TO 640
610 J=JX+JQQ(L,K)
I=IX+IQQ(L,K)
GO TO 640
620 J=JX+JQQ(L,K)
I=IX+IQQ(L,K)
GO TO 640
630 J=JX+JQQ(L,K)
I=IX+IQQ(L,K)
GO TO 640
640 IF(I) 670, 670, 650
650 IF(I=66) 670, 670, 660
660 I=I+I
670 IF(J) 700, 700, 680
680 IF(J=66) 700, 700, 690
690 J=J-66
700 IF(I) 710, 710, 720
710 I=I+I
720 IF(J) 730, 730, 740
730 J=J-66

TEST FOR OCCUPANCY
740 IOCC=10000000+(IBB(IPOS,ITREE) * 100)
IF(IARRA(I,J)/100-IOCC/100) 750, 590, 590
750 IARRA(I,J)=10000000
IARRA(I,J)=IARRA(I,J)+ITREE+IBB(IPOS,ITREE) * 100
GO TO 590
760 CONTINUE
770 GO TO 780
780 CONTINUE

GOES TO NEXT TREE
GO TO 520

PRINTS MATRIX CODES IN IARRA (CROWN COMETITION)
790 IF(NCODE=1) 880, 880, 800
800 WRITE(IOUT, 990) NAGE(M)
810 WRITE(IOUT, 810)
810 FORMAT(2X, "CODES STORED IN IARRA MATRIX=LOCATIONS I=10 TO 40
    J=1 TO 14")
820 WRITE(IOUT, 820) ICODE=40, 50
830 WRITE(IOUT, 830) IARRA(ICODE, JCODE), JCODE=1, 14
830 FORMAT(2X, 14, JCODE)
C WRITE(OUT,840)
840 FORMAT('1',2X,'LOCATIONS J=15 TO 28')
C DO 850 ICODE=40,50
C 850 WRITE(OUT,830)(IARRA(ICODE,JCODE),JCODE=15,28)
C WRITE(OUT,860)
860 FORMAT('1',2X,'LOCATIONS J = 29 TO 42')
C DO 870 ICODE=40,50
C 870 WRITE(OUT,830)(IARRA(ICODE,JCODE),JCODE=29,42)
C DO 880 LL=1,NUMTR
  ICW(LL)=0
  IVOL(LL)=0
  ICBH(LL)=0
  IBA(LL)=0
  ICL(LL)=0
  IAPER(LL)=0
890 IAREA(LL)=1
   DO 900 LL=1,NUMTR
900 ICW(LL)=9999
   DO 980 I=1,66
   C DETERMINES HEIGHT TO CROWN WIDTH MAX
   DO 980 J=1,66
     NEW=IARRA(I,J)/100*100
     LTREE=IARRA(I,J)-NEW
     IF(LTREE)920,930,910
   910 IF((NEW/100-100000) -ICB(LTREE))920,930,930
   920 ICB(LTREE)=NEW/100-100000
     JARRA(I,J)=IARRA(I,J)-NEW
     NB=JARRA(I,J)
     IF(NB)960,960,940
   940 IF(NB=97)950,960,940
   950 IAREA(NB)=IAREA(NB)+1
   960 IF(NB)970,970,980
   970 NB=98
   980 JARRA(I,J)=ICHAR(NB)
C WRITE(OUT,990)NAGE(M)
990 FORMAT('1',2X,'STAND AGE=',2X,I3,/')
C CALCULATES STAND PARAMETERS
C
1000 DO 1100 MM=1,NUMTR
   HT1=IHT(M,MM)
   HT=HT1/100.
   1010 CRAR=IAREA(MM)
C
   NATURAL MORTALITY
   HABM=5.5+4.25*HT
   IF(HABM)1001,1001,1002
   1001 HTAB=HT
   GO TO 1003
   1002 HTAB=HT-HABM
   IF(HTAB.LE.0.) HTAB=1
   1003 BL=.98*HTAB**.7
       HBL=.9*BL-3.3*(6**3./20.*2.3**3.)
       IF(HBL.LE.0.) HBL=1
       CAE=3.14159*MBL**2.
       IF((CRAR/CAE).GT.1.) GO TO 1015
       MAGE=M+1
       IHT(MAGE,MM)=IHT(M,MM)
       IDEAD(MM)=1
   1015 IF(CRAR*(HT-4.5))1020,1020,1030
   1020 DBH=0.
   GO TO 1040
   1030 DBH=.143*(CRAR*(HT-4.5))**.48
   1040 IDBH(MM)=DBH*100.
   IF(DBH)1050,1050,1060
   1050 IBA(MM)=0
   GO TO 1070
   1060 IBA(MM)=(DBH/2.)**2.*3.14159*100.
   1070 ICW(MM)=IHT(M,MM)-ICB(MM)
       ARE1=IAREA(MM)
       ICW(MM)=2.*SQRT(ARE1/3.14159)*100.
       IF(DBH)1080,1080,1090
   1080 VOL=0.
   GO TO 1100
   1090 VOL=-2.734532+(1.739410*ALOG(DBH)+1.166933*ALOG(HT))/2.302585
       VOL=10.*VOL
   1100 IVOL(MM)=VOL*100.
C
   PRINTS MAP OF CROWN OCCUPANCY
   IF(IPRIN-1)1150,1150,1110
   1110 WRITE(IOUT,1120)
   1120 FORMAT(*9',128(*'))
C
   DO 1130 I=1,66
C
1130 WRITE (IOUT, 1140) (JARRA (I, J), J=1, 65)
1140 FORMAT ('9', 65A2)
C
1150 WRITE (IOUT, 1120)
1160 NEWTR = 0
DO 1220 NB = 1, NUMTR
MORT = IDEAD (NB)
IF (MORT .GT. 0) GO TO 1220
NEWTR = NEWTR + 1
HTI = IHT (M, NB)
HT = HTI / 100.
DBHI = IDBM (NB)
DBH = DBHI / 100.
BAI = IBA (NB)
BA = BAI / 14400.
CBI = ICB (NB)
IF (CBI = 9000) GO TO 1190
CBI = CBI + 1
1170 NEWTR = NEWTR + 1
1180 CBI = 0
1190 CB = CB1 / 100.
CL = HT = CB
CW = CW1 / 100.
AREA = AREA (NB)
APER = 100. * AREA / 4356.
VOLI = IVOL (NB)
VOL = VOLI / 100.
HTS = HTS + HT
DBHS = DBHS + DBH
BAS = BAS + BA
CBS = CBS + CB
CLS = CLS + CL
CWS = CWS + CW
AREAS = AREAS + AREA
VOLS = VOLS + VOL
C
C PRINTS INDIVIDUAL TREE PARAMETERS
C
1200 FORMAT ('1', '9', '1x', ',', '9', '1x', 'TREE # I J HEIGHT DBH BA')
1. **CR. BASE CR. LENGTH**
   **C. W.**
   **C. AREA C. A. AS % VOLUME**

```c
1210 WRITE(IOUT, 1230) NB, IXX(NB), JXX(NB), HT, DBH, BA, CB, CL, CW, AREA, APER, VOL
1220 CONTINUE
C
C CALCULATES STAND AVERAGES
C
1230 FORMAT(3X, 3I6, 9F11.2)
1240 TREES = NEWTR
AHT = HTS / TREES
ADBH = DBHS / TREES
ABA = BAS / TREES
ACB = CBS / TREES
ACL = CLS / TREES
ACW = CWS / TREES
AAREA = AREAS / TREES
AAPER = AREAS / 4356 * 100.
AVOL = VOLS / TREES
C
C PRINTS STAND AVERAGES
C
1250 FORMAT(///, 5X, "STAND TOTALS", /)
1260 FORMAT(2X, "NUMBER OF TREES HEIGHT DBH B. A. CR. BAS 1E CR. LENGTH CW C. AREA VOLUME")
C
1270 WRITE(IOUT, 1270) NEWTR, HTS, DBHS, BAS, CBS, CLS, CWS, AREAS, VOLS
C
1280 FORMA(7X, 13, 5X, 7F11.2, F22.2)
LOSTR = NUMTH - NEWTR
C
1290 WRITE(IOUT, 1290) LOSTR
C
C CALCULATES CROWN AREAS AND CROWN CLOSURES FOR SUBSETS
SUBSETS FORM BASIS FOR EVALUATION OF SHRUB AND GRASS RESPONSE TO STAND CONDITIONS
```
DO 1320 I=1,66
C
DO 1320 J=1,66
1320 JARRA(I,J)=0
C
DO 1330 I=1,66
C
DO 1330 J=1,66
NEW=IARRA(I,J)/100*100
1330 JARRA(I,J)=IARRA(I,J)-NEW
SUB1=0
SUB2=0
SUB3=0
SUB4=0
ISUB=0
1340 ISUB=ISUB+1
GO TO (1350,1370,1390,1410),ISUB
C
SUBSET # 1 ** I=1,33; J=1,33 **
C
DO 1350 I=1,33
C
DO 1350 J=1,33
NB=JARRA(I,J)
IF(NB.GE.1) SUB1=SUB1+1
1350 CONTINUE
GO TO 1340
C
SUBSET # 2 ** I = 1,33; J = 34,66 **
C
DO 1370 I=1,33
C
DO 1370 J=34,66
NB=JARRA(I,J)
IF(NB.GE.1) SUB2=SUB2+1
1370 CONTINUE
GO TO 1340
C
SUBSET # 3 ** I = 34,66; J = 1,33 **
C
DO 1390 I=34,66
C
DO 1390 J=1,33
NB=JARRA(I,J)
IF(NB.GE.1) SUB3=SUB3+1
1390 CONTINUE
GO TO 1340
C
SUBSET # 4 ** I = 34,66; J = 34,66 **
DO 1420 I=34,66

DO 1420 J=34,66
NB=JARRA(I,J)
IF(NB,GE,1) SUB4=SUB4+1 CONTINUE
CSUB1=SUB1/1089.*100.
CSUB2=SUB2/1089.*100.
CSUB3=SUB3/1089.*100.
CSUB4=SUB4/1089.*100.

WRITE(IOUT,1430)
1430 FORMAT(///,'CROWN AREA AND CROWN CLOSURES FOR SUBSETS',///)
WRITE(IOUT,1440)
1440 FORMAT(12X,'SUB-PLOT 1 - I=1,33 J=1,33',2X,'SUB-PLOT 2 - I=1,33 J=34,66',2X,'SUB-PLOT 3 - I=34,66 J=1,33',2X,'SUB-PLOT 4 - I=34,66 J=34,66',//)
WRITE(IOUT,1450)SUB1,SUB2,SUB3,SUB4
1450 FORMAT(1X,'CROWN AREA = ',F15.2,3F29.2,//)
WRITE(IOUT,1460)CSUB1,CSUB2,CSUB3,CSUB4
1460 FORMAT(1X,'CROWN CLOSURE = ',F12.2,3F29.2)
IF(LINPR.LE.0) GO TO 1463
CALL XSECT(LINPR)
1463 IF(IDELAG.LE.0) GO TO 460
CALL AGROP
GO TO 460
1470 IF(ITRFN-1)1490,1490,1480
CALL TRFUN
1490 RETURN
END
SUBROUTINE XSECT (LINPR)

PRINTS VERTICAL X SECTION THROUGH STAND

DIMENSION IARRA(66,66),BL2(96),ACC(4,21),ATA(4,21),ATG(4,21),ATF(4,21),APDNA(4,21),APDNRC(4,21),APDNS(4,21),APDNPR(4,21),APDNRO(4,21)

INTEGER*2 JARRA(66,66),NSET(96),IQQ(96,5),JQQ(96,5),NAGE(50),NNAME1L(4),NNAMEON(4),NNAMEP(4),NNPRUN(4),NNROSE(4),NNSYM(4),JRAND(50),K2RAND(50),LRAND(50),JLRAND(100),KKRAND(100),LLRAND(100),I3AMEL(20),IJEON(20),JSHEP(20),JPRUN(20),JROSE(20),JSYM(20),I5COM(150),JCOM(150),JEAD1(150),JEAD2(150),JEAD3(150),JEAD4(150)

6,LARR(66,66),LARR2(66,66),LARR3(66,66),LARR4(66,66),IAREA(153),ID7IAM(150),IDIAM2(150),IDIAM3(150),IDIAM4(150),PER(153),EPERT(16),KAM6EL(4,21),KCEON(4,21),KNAMEP(4,21),KPRUN(4,21),KRROSE(4,21),KSYMP(4,21)

KCHAR(160),IHT(100,97),ICHAR(99),IBB(90,97),JRAND(97),IXX(97),JYXX(97),IVOL(97),IDBH(97),IICL(97),ICW(97),ICB(97),IBA(97)

COMMON IARRA,BL2,ACC,ATA,ATG,ATF,APDNA,APDNS,APDNPR,APDNRO,A1PDNSY,CSUB1,CSUB2,CSUB3,CSUB4,RAD,BORDA,XINA,UTILA,BORDC,XINC,UTIL2C,BORDS,XINS,UTILS,AGE,C,CC,TAUT,TAUTS,TAUTT,TAUD,UNCCC,YUNC,PDN1,ITHRU,M,ISTRAT,INT,IE0D,IUNCCC,AUTT,YUNC,ICL00P,IX,ISUB,ICOUNT

3,INT,IBB,JARRA,LARR1,LARR2,LARR3,LARR4,IPQ,JQQ,ISHED,PER,KCHAR,ICO4M,JCOM,JEAD1,JEAD2,JEAD3,JEAD4,JIDAM1,JIDAM2,JIDAM3,JIDAM4,JJRA5ND,JKRAN,LLRAND,JCHAR,IRAND,IXX,JXX,IVOL,IDBH,ICL,IAPER,ICW,ICB,

6IBA,IDEAD,NSET,KAMEL,KCEON,KRSHEP,KPRUN,KRROSE,KSYMP,NA0E,JEAD,KRAN7D,LMRAND,JAMEL,JCEON,JNAMEP,JPRUN,JROSE,JSYM,EPERT,NNAME1,NNAMEP,NNSYM,JCHAR

JLOC = LOCATION ON LINE
ILINE = LINE
ISCLE = SCALING FACTOR
NB = CHARACTER TO BE PRINTED

IGUT=6
ISCLE=0

DO 992 KCL=1,66

DO 992 JCL=1,66

991 JARRA(KCL,JCL)=0

DO 993 JLOC=1,66

ILINE=IARRA(LINPR,JLOC)

N=ILINE=ILINE/100*100

ILOC=(ILINE+5000/10000*10000-10000)/10000

993 IF(ILOC,LT,1) ILOC=1

IF(ISCLE,GT,0) GO TO 995

IF(ILINE,J66) ISCLE=2

IF(ISCLE=1)994,994,991
JARRA(ILOC,JLOC) = N
GO TO 993
ILOC = (ILOC + 1) / 2
IF (ILOC, LT, 1) ILOC = 1
JARRA(ILOC,JLOC) = N
CONTINUE
C
DO 998 J = 1, 66
C
DO 998 I = 1, 66
NB = JARRA(I, J)
IF (NB) 997, 997, 996
997 NB = 99
998 JARRA(I, J) = ICHAR(NB)
C
WRITE (IOUT, 961) LINPR
981 FORMAT ('1', /*, 'CROSS-SECTIONAL PROFILE OF STAND - SECTION THROUGH LINE ', I2, '/*)
IF (ISCLE, GT, 1) GO TO 987
C
WRITE (IOUT, 982)
982 FORMAT (60X, 'VERTICAL SCALE = 1 FT. = 1 LINE', /*, 58X, 'HORIZONTAL SCALE = 1 FT. = 2 SPACES', /*)
GO TO 988
C
WRITE (IOUT, 983)
983 FORMAT (60X, 'VERTICAL SCALE = 2 FT. = 1 LINE', /*, 58X, 'HORIZONTAL SCALE = 1 FT. = 2 SPACES', /*)
C
WRITE (IOUT, 984)
984 FORMAT (63X, 'LEGEND', /*, 65X, 'NUMBERS REFER TO TREE NUMBER', /*, 65X, '1B REPRESENTS BOLE POSITION', /*, 126X, 'LINES')
C
DO 985 I = 1, 66
K = 67 - I
985 WRITE (IOUT, 986) (JARRA(K, J), J = 1, 63), K
986 FORMAT ('9', 63A2, I2)
C
WRITE (IOUT, 971)
971 FORMAT ('9', 131 ('*'))
RETURN
END
SUBROUTINE AGROP

DIMENSION IARRA(66,66), BL2(96), ACC(4,21), ATA(4,21), ATG(4,21), ATF(4,21), APDNA(4,21), APDNC(4,21), APDNS(4,21), APDNPR(4,21), APDNRO(4,21), 2, APDNSY(4,21)

INTEGER*2 JARRA(66,66), NSET(96), IQQ(96,5), JQQ(96,5), NAGE(50), NNAME(4), NNSYM(4), JRand(50), KRand(50), LRand(50), JRAND(100), KKRAND(100), LLRAND(100), 3, JAMEL(20), JCEON(20), JSHEP(20), JPRUN(20), JROSE(20), JSYMP(20), K 5COMM(150), JCOM(150), IDEAD1(150), IDEAD2(150), IDEAD3(150), IDEAD4(150), 6, LARR1(66,66), LARR2(66,66), LARR3(66,66), LARR4(66,66), LAREA(153), ID 7IAM1(150), IDIAM2(150), IDIAM3(150), IDIAM4(150), PER(153), EPER(16), K 8MEL(4,21), KCEON(4,21), KSHEP(4,21), KPRUN(4,21), KR0SE(4,21), KSYMP(4, 921), KCHAR(160), IHT(100,97), ICHAR(99), IBB(50,97), IRAND(97), IXX(97), 1, JRXX(97), IXVOL(97), IDBH(97), ICL(97), IAPER(97), ICW(97), ICB(97), IB(97) 1, JCHAR(2), IDEAD(97)

COMMON IARRA, BL2, ACC, ATA, ATG, ATF, APDNA, APDNC, APDNS, APDNPR, APDNRO, A 1PDNSY, CSUB1, CSUB2, CSUB3, CSUB4, RAD, BORDA, XIN, UTILA, BORDC, XINC, UTIL 2C, BORDS, XINS, UTILS, AGE, C, CC, TAUT, TAUTS, TAUC, UNOC, UNOCC, PON 3, 1, ITHRU, M, ISTRT, IINT, IEND, IYUNOC, IAUUTY, IUNOCC, ILOOP, IX, ISUB, ICOUNT 3, IHT, IBB, JARRA, LARR1, LARR2, LARR3, LARR4, IQQ, JQQ, LAREA, PER, KCHAR, ICO 4M, JCOM, IDEAD1, IDEAD2, IDEAD3, IDEAD4, IDIAM1, IDIAM2, IDIAM3, IDIAM4, JR 5AND, KKRAND, LKRAND, LCHAR, LRAND, IXX, JXX, JXXVOL, IDBH, ICL, IAPER, ICW, ICB, 6ISIA, IDEAS, NSET, KAMEL, KCEON, KSHEP, KR0SE, KSYMP, NAGE, JRAND, KRAND 7D, LRAND, JAMEL, JCEON, JSHEP, JPRUN, JROSE, JSYMP, EPER, NNAM, NNAME, NNS 8HEP, NPNNPR, NNPNOSE, NNSYMP, JCHAR

LARR1,... = SHRUB, GRASS & FORB GROWTH ARRAYS
ITHRU = COUNTER
KCHAR = SHRUB NUMBER
EPER = EXPECTED PERIMETER OF SHRUBS
IDIAM1,... = SHRUB DIAMETER
IDEAD1,... = DEAD SHRUBS
LAMEL,... = VARIABILITY IN SIZE OF SHRUB SPECIES
NNAMEL,... = NUMBER OF SHRUBS BY SPECIES / SUB-PLOT
ZERO ARRAYS FOR PRINTING # SHRUBS AND PRODUCTION, AGE, CROWN
CLOSURE
JRAND,... = SHRUB SPECIES GROWTH POTENTIAL
LAREA, AREAS, AAREAS = CROWN AREA MEASUREMENTS

IRD=5
IOUT=6

DO 3 I=1,66
  DO 3 J=1,66
    JARRA(I,J)=0
  3 IF(ITHRU.GT.0) GO TO 150
    IF(M.GT.0) GO TO 150

READ(IRO,2) EPER
2 FORMAT(16I3)

C

READ(IRD,4) KCHAR

4 FORMAT(40A2)

C

DO 5 I=1,150
IDIM1(I)=0
IDIM2(I)=0
IDIM3(I)=0
IDIM4(I)=0
IDEA01(I)=0
IDEA02(I)=0
IDEA03(I)=0
IDEA04(I)=0

5

C

DO 7 J=1,66
LARR1(I,J)=0
LARR2(I,J)=0
LARR3(I,J)=0
LARR4(I,J)=0

7

C

READ(IRD,10) LAMEL, LCEON, LSHEP, LPRUN, LROSE, LSYM

10 FORMAT(61B)

C

READ(IRD,15) ISHNUP, INDISH

15 FORMAT(213)

C

READ(IRD,20) IDU

20 FORMAT(13)

C

DO 30 I=1,4

30 READ(IRD,40) NNAMEL(I), NNCEON(I), NNSHEP(I), NNPRUN(I), NNRose(I), NNSYMP(I)

40 FORMAT(614)

C

DO 45 J=1,21
ACC(I,J)=0.
ATA(I,J)=0.
ATG(I,J)=0.
ATF(I,J)=0.
APDNA(I,J)=0.
APDNC(I,J)=0.
APDNS(I,J)=0.
APDNPRI(I,J)=0.
APDNRD(I,J)=0.
APDNSY(I,J)=0.

45

C
KAMEL(I,J) = 0
KCEON(I,J) = 0
KSHEP(I,J) = 0
KPRUN(I,J) = 0
KROSE(I,J) = 0
KSYP(I,J) = 0

CALCULATE SHRUB SPECIES GROWTH POTENTIAL

VAMEL = VAMEL/10000.
VCEON = VCEON/10000.
VSHEP = VSHEP/10000.
VPRUN = VPRUN/10000.
VROSE = VROSE/10000.
VSYP = VSYP/10000.

DO 60 I = 1, 50
CALL GAUSS (IX, VAMEL, 1.0000, V)
IF (V.LT.1) V = 1
IF (V.GT.1.6) V = 1.6
60 JRAND(I) = V*1000.

DO 70 I = 1, 50
CALL GAUSS (IX, VCEON, 1.0000, V)
IF (V.LT.1) V = 1
IF (V.GT.1.6) V = 1.6
70 KRAND(I) = V*1000.

DO 80 I = 1, 100
CALL GAUSS (IX, VSHEP, 1.0000, V)
IF (V.LT.1) V = 1
IF (V.GT.1.6) V = 1.6
80 LRAND(I) = V*1000.

DO 90 I = 1, 100
CALL GAUSS (IX, VPRUN, 1.0000, V)
IF (V.LT.1) V = 1
IF (V.GT.1.6) V = 1.6
90 JRAND(I) = V*1000.

DO 100 I = 1, 100
CALL GAUSS (IX, VROSE, 1.0000, V)
IF (V.LT.1) V = 1
IF (V.GT.1.6) V = 1.6
100 KKRAND(I) = V*1000.
DO 110 I=1,100
CALL GAUSS (IX, VSYMP, 1.0000, V)
IF (V.LT.1.0) V=.1
IF (V.GT.1.6) V=1.6
110 LLRAND(I)=V*1000,

DO 130 IRD,140)PDN
140 FORMAT (F6,2)

WRITE(IOUT,160)
160 FORMAT (2X, "NUMBER OF SHRUBS BY SPECIES AT AGE 1", //, T24, "AMEL", T34, "CEON", T44, "SHEP", T54, "PRUN", T64, "ROSE", T74, "SYMP", //)

DO 170 I=1,4
170 WRITE(IOUT, 180)I,NNAME(I),NNCEON(I),NSHEP(I),NNPRUN(I),NNROSE(I)
180 FORMAT(2X,"SUB-LOT=",I2,5X,6I10)

ISUB=0

INCREMENTS SUB-SETS

190 ISUB=ISUB+1
199 WRITE(IOUT,200)ISUB,M
GO TO 210

WRITE(IOUT,200)ISUB,NAGE(M)
210 CONTINUE

DO 220 I=1,66
DO 220 J=1,66
220 JARRAC(I,J)=0
IF (ITHRU.GT.0) GO TO 430
IF (ISUB.GT.1) GO TO 430
C ASSIGNS SHRUB LOCATIONS

280 DO 290 I=1,150
   CALL RANDU (IX,IY,YFL)
   ICOM(I)=YFL*65. +1.
   IX=IY
   CALL RANDU (IX,IY,YFL)
   JCOM(I)=YFL*65. +1.
   290 IX=IY
C
300 ICHKS=0
C
DO 320 I=1,150
C
DO 320 J=1,150
   IF(I.EQ.J) GO TO 320
   IF(ICOM(I).NE.ICOM(J)) GO TO 320
   IF(JCOM(I).NE.JCOM(J)) GO TO 320
   IXL=JCOM(J)
310 CALL RANDU (IX,IY,YFL)
   JCOM(J)=YFL*65. +1.
   IX=IY
   IF(JCOM(J).EQ.IXL) GO TO 310
   ICHKS=1
   320 CONTINUE
C
IF(ICHKS.GE.1) GO TO 300
C
C SHRUB MORTALITY DUE TO SHADING
C AMELANCHIER
C CEONOTHUS
C SHEPHERDIA
C PRUNUS
C ROSA
C SYMPHORICARPOS
C
430 WRITE(IOUT,431)
431 FORMAT(2X,'MORTALITY DUE TO TREE SHRUB COMPETITION'//)
   IF(ITA.EQ.0) GO TO 481
   INUM=0
C
DO 480 I=1,ITA
   K=ICOM(I)
   L=JCOM(I)
   INUM=INUM+1
C
GO TO (435,440,445,450),ISUB
435 II=(K+1)/2
   JJ=(L+1)/2
   LARR1(K,L)=151
GO TO 455
440  II=(K+1)/2
     JJ=(L+1)/2+33
     LARR2(K,L)=151
     GO TO 455
445  II=(K+1)/2+33
     JJ=(L+1)/2
     LARR3(K,L)=151
     GO TO 455
450  II=(K+1)/2+33
     JJ=(L+1)/2+33
     LARR4(K,L)=151
455  IF (IARRA(II,JJ)=100000000) .EQ. 0) GO TO 480
     INUM=INUM+1
C
     GO TO (460,465,470,475),ISUB
460  IDEAD1(I)=1
     LARR1(K,L)=0
     GO TO 460
465  IDEAD2(I)=1
     LARR2(K,L)=0
     GO TO 460
470  IDEAD3(I)=1
     LARR3(K,L)=0
     GO TO 460
475  IDEAD4(I)=1
     LARR4(K,L)=0
480  CONTINUE
     IKILLA=ITA-INUM
     NAMEL=NAMEL-IKILLA
     WRITE(IOUT,2050)ISUB,IKILLA,NAMEL
2050  FORMAT(2X,'SUB-PLOT = ',I2,5X,'NO. AMEL. DEAD. = ',I2,5X,'NO. AMEL. 1 = ',I2)
C
481  ITC=58+INAME
     IF (ITC.EQ.50) GO TO 545
     INUM=0
C
     DO 540 I=51,ITC
     K=ICOM(I)
     L=JCOM(I)
     INUM=INUM+1
C
     GO TO (485,490,495,500),ISUB
485  II=(K+1)/2
     JJ=(L+1)/2
     LARR1(K,L)=152
     GO TO 510
490  II=(K+1)/2
     JJ=(L+1)/2+33
     LARR2(K,L)=152
GO TO 510

495 II=(K+1)/2+33
JJ=(L+1)/2
LARR3(K,L)=152
GO TO 510

500 II=(K+1)/2+33
JJ=(L+1)/2+33
LARR4(K,L)=152

510 IF((IARRA(I,JJ)=10000000).EQ.0) GO TO 540
INUM=INUM+1

GO TO (515,520,525,530),ISUB

515 IDEAD1(I)=1
LARR1(K,L)=0
GO TO 540

520 IDEAD2(I)=1
LARR2(K,L)=0
GO TO 540

525 IDEAD3(I)=1
LARR3(K,L)=0
GO TO 540

530 IDEAD4(I)=1
LARR4(K,L)=0

540 CONTINUE
IKILLC=NCEON-INUM
NCEON=NCEON-1
WRITE(IOUT,2060)ISUB,IKILLC,NCEON

2060 FORMAT(2X,"SUB-PLT =",I2,5X,"NO. CEON. DEAD =",I2,5X,"NO. CEON. =")

C
545 ITS=100+NSHEP
IF(ITS.EQ.100) GO TO 602

C
INUM=0
DO 600 I=101,ITS
K=ICOM(I)
L=JCOM(I)
INUM=INUM+1

C
GO TO (550,560,565,570),ISUB

550 II=(K+1)/2
JJ=(L+1)/2
LARR1(K,L)=153
GO TO 575

560 II=(K+1)/2
JJ=(L+1)/2+33
LARR2(K,L)=153
GO TO 575

565 II=(K+1)/2+33
JJ=(L+1)/2
LARR3(K,L) = 153
GO TO 575
570 II = (K+1)/2 + 33
JJ = (L+1)/2 + 33
LARR4(K,L) = 153
575 IF ((IARRA(II,JJ) = 10000000), EQ, 0) GO TO 600
INUM = INUM + 1

GO TO (580, 565, 590, 595), ISUB
580 IDEA1(I) = 1
LARR1(K,L) = 0
GO TO 600
585 IDEA2(I) = 1
LARR2(K,L) = 0
GO TO 600
590 IDEA3(I) = 1
LARR3(K,L) = 0
GO TO 600
595 IDEA4(I) = 1
LARR4(K,L) = 0
600 CONTINUE

IKILLS = NSHEP - INUM
NSHEP = NSHEP - IKILLS

WRITE (IOUT, 2070) ISUB, IKILLS, NSHEP
2070 FORMAT (2X, 'SUB- PLOT #', I2, 5X, 'NO. SHEP. DEAD = ', I2, 5X, 'NO. SHEP. ', 1 = '', I2)
602 GO TO (605, 610, 615, 620), ISUB
605 CC = CSUB1
GO TO 625
610 CC = CSUB2
GO TO 625
615 CC = CSUB3
GO TO 625
620 CC = CSUB4
625 CONTINUE

WRITE (IOUT, 635) CC
635 FORMAT (1X, 'CROWN CLOSURE = ', F6.2, 5X, 'C *')
670 IF (CC .GT. 74.5) CC = 74.5
IF (CC .LE. 0) CC = .01
IF (M.EQ.0) GO TO 695

DETERMINES NO. OF CEWNOTHUS AS A FUNCTION OF CROWN CLOSURE

IF (NAMEL.EQ.0) GO TO 675
MAMEL = .8 + 16006 * CC + 19. * (75 - CC) .25 / 75 .25
IF (NAMEL .GT. MAMEL) NAMEL = MAMEL
ITA = NAMEL + IKILLA

C
DETERMINES NO. OF AMELANCHIER AS A FUNCTION OF CROWN CLOSURE

675 IF(NCEON.EQ.0) GO TO 680
MCEON=8.*1.0606*CC+19.*((75.-CC)**2.5/75.**2.5)+.5
IF(NCEON.GT.MCEON) NCEON=MCEON
ITC=NCEON+IKILLC +50

DETERMINES NO. OF SHEPHERDIA AS A FUNCTION OF CROWN CLOSURE

680 IF(NSHEP.EQ.0) GO TO 685
MSHEP=8.*1.0606*CC+19.*((75.-CC)**2.5/75.**2.5)+.5
IF(NSHEP.GT.MSHEP) NSHEP=MSHEP
ITS=NSHEP+IKILLS + 100

DETERMINES NO. OF PRUNUS AS A FUNCTION OF CROWN CLOSURE

685 IF(CC.GT.65.) NPRUN=0
IF(NPRUN.EQ.0) GO TO 688
MPRUN=7.*1.167*CC+9.*((65.-CC)**2./65.**2.)+.5
IF(NPRUN.GT.MPRUN) NPRUN=MPRUN

DETERMINES NO. OF ROSES AS A FUNCTION OF CROWN CLOSURE

688 IF(CC.GT.65.) NROSE=0
IF(NROSE.EQ.0) GO TO 690
MROSE=7.*1.167*CC+9.*((65.-CC)**2./65.**2.)+.5
IF(NROSE.GT.MROSE) NROSE=MROSE

DETERMINES NO. OF SYMPHORICARPOS AS A FUNCTION OF CROWN CLOSURE

690 IF(C.GT.90.) NSYMP=0
IF(NSYMP.EQ.0) GO TO 695
MSYMP=35.*.33389*CC+.5
IF(NSYMP.GT.MSYMP) NSYMP=MSYMP

SETS BORDER, INSIDE AND TOTAL AREA OF AMELANCHIER TO ZERO

695 BORDA=0.
XINA=0.
UTILA=0.

SETS BORDER, INSIDE AND TOTAL AREA OF CEONOTHUS TO ZERO

BOKOC=0.
XINC=0.
UTILC=0.

SETS BORDER, INSIDE AND TOTAL AREA OF SHEPHERDIA TO ZERO

BORDS=0.
XI.NS = 0.
UTILS = 0.

SETS PRODUCTION OF AMELANCHIER, CEONOTHUS, SHEPHERDIA, PRUNUS,
ROSE AND SYMPHORICARPOS TO ZERO

PDNA = 0.
PDNC = 0.
PDNS = 0.
PDNPR = 0.
PDRNO = 0.
PDNSY = 0.
IF(M.EQ.0) GO TO 2000
AGE = NAGE(M)
XDIAM = 0.

WRITE(IOUT,699)ISUB,NAMEL,NCEON,NSHEP,NPRUN,NROSE,NSYMP
699 FORMAT(//,5X,'SHRUB #,5 SURVIVING IN UNSHADED AREA',//,5X,'SUB=PLO'
IT = ',I5,2X,'# AMEL = ',I5,2X,'# CEON = ',I5,2X,'# SHEP = ',I5,2X,'# P'
RUN = ',I5,2X,'# ROSE = ',I5,2X,'# SYMP = ',I5,/,)

IDIAM(I),..4(I) = DIAMETER OF INDIVIDUAL SHRUBS

AMELANCHIER CALCULATIONS

NCOUN1 = 0

DO 745 I = 1,50

GO TO (700,705,710,715),ISUB
700 IF(NCOUN1.GE.NAMEL) IDEAD1(I) = 1
IF(IDEAD1(I).EQ.1) GO TO 745
GO TO 720
705 IF(NCOUN1.GE.NAMEL) IDEAD2(I) = 1
IF(IDEAD2(I).EQ.1) GO TO 745
GO TO 720
710 IF(NCOUN1.GE.NAMEL) IDEAD3(I) = 1
IF(IDEAD3(I).EQ.1) GO TO 745
GO TO 720
715 IF(NCOUN1.GE.NAMEL) IDEAD4(I) = 1
IF(IDEAD4(I).EQ.1) GO TO 745
720 NCOUN1 = NCOUN1 + 1
RANDJ = JRAND(I)
RANDJ = RANDJ/1000.
X2 = 1. * 30. ** 1.996
IF(AGE = 30.) 725,730,730
725 X1 = 1. * (-1. * (AGE = 30.)) ** 1.996
GO TO 735
\begin{verbatim}
730  x1 = (age = 30.) ** 1.996
735  diam = randj * (-1. + 15 * age + 1. * (x1 / x2))
C
    go to (737, 739, 741, 743), isub
737  idiam1(i) = diam * 100.
    go to 745
739  idiam2(i) = diam * 100.
    go to 745
741  idiam3(i) = diam * 100.
    go to 745
743  idiam4(i) = diam * 100.
745  continue
C
    calculates diameter of ceonothus
C
755  ncount2 = 0
C
    do 805 i = 51, 100
C
    go to (760, 763, 769, 772), isub
760  if (ncount2 .ge. nceon) ideal1(i) = 1
    if (ideal1(i), eq, 1) go to 805
    go to 775
763  if (ncount2 .ge. nceon) ideal2(i) = 1
    if (ideal2(i), eq, 1) go to 805
    go to 775
769  if (ncount2 .ge. nceon) ideal3(i) = 1
    if (ideal3(i), eq, 1) go to 805
    go to 775
772  if (ncount2 .ge. nceon) ideal4(i) = 1
    if (ideal4(i), eq, 1) go to 805
775  ncount2 = ncount2 + 1
    randk = rand(l = 50)
    randk = randk / 1000.
    diam = randk * (5.5 * tanh(age * 0.03))
    go to (780, 785, 790, 795), isub
780  idiam1(i) = diam * 100.
    go to 805
785  idiam2(i) = diam * 100.
    go to 805
790  idiam3(i) = diam * 100.
    go to 805
795  idiam4(i) = diam * 100.
805  continue
C
    shepherdia calculations
C
810  ncount3 = 0
C
    do 865 i = 101, 150
    go to (815, 820, 825, 830), isub
\end{verbatim}
815 IF(NCOUN3.GE.NSHEP) IDEAD1(I)=1
IF(IDEAD1(I).EQ.1) GO TO 865
GO TO 835
820 IF(NCOUN3.GE.NSHEP) IDEAD2(I)=1
IF(IDEAD2(I).EQ.1) GO TO 865
GO TO 835
825 IF(NCOUN3.GE.NSHEP) IDEAD3(I)=1
IF(IDEAD3(I).EQ.1) GO TO 865
GO TO 835
830 IF(NCOUN3.GE.NSHEP) IDEAD4(I)=1
IF(IDEAD4(I).EQ.1) GO TO 865
835 NCOUN3=NCOUN3+1
RANDL=RAND(I=100)
RANL=RANDL/1000.
IF(AGE.LT.28.) DIAM=RANL*(.18*AGE)
IF(AGE.GE.28.) DIAM=RANL*(5.+2.5*TANH((AGE-28.)*.033))
C
845 GO TO (847,849,851,853),ISUB
847 IDIAM1(I)=DIAM*100.
GO TO 865
849 IDIAM2(I)=DIAM*100.
GO TO 865
851 IDIAM3(I)=DIAM*100.
GO TO 865
853 IDIAM4(I)=DIAM*100.
865 CONTINUE
C
870 CONTINUE
ICOUNT=0
880 ICOUNT=ICOUNT+1
STARTS NEW SHRUB
IF(ICOUNT.GT.ITS) GO TO 997
C
C CALCULATES SHRUB RADIUS
RAD=RADIUS
GO TO (885,890,895,900),ISUB
885 IF(IDEAD1(ICOUNT).EQ.1) GO TO 880
IF(IDIAM1(ICOUNT).EQ.0) GO TO 880
RAD=IDIAM1(ICOUNT)
RAD=RAD/200.
IIX=ICOM(ICOUNT)
JJX=JCOM(ICOUNT)
GO TO 905
890 IF(IDEAD2(ICOUNT).EQ.1) GO TO 880
IF(IDIAM2(ICOUNT).EQ.0) GO TO 880
RAD=IDIAM2(ICOUNT)
RAD=RAD/200.
IIX=ICOM(ICOUNT)
JJX=JCOM(ICOUNT)
GO TO 905
895 IF( IVEAD3( ICOUNT ).EQ.1 ) GO TO 880
IF( IDIAM3( ICOUNT ).EQ.0 ) GO TO 880
RAD=IDIAM3( ICOUNT )
RAD=RAD/200.
IIX=ICOM( ICOUNT )
JGX=JCOM( ICOUNT )
GO TO 905
900 IF( IDEAD4( ICOUNT ).EQ.1 ) GO TO 880
IF( IDIAM4( ICOUNT ).EQ.0 ) GO TO 880
RAD=IDIAM4( ICOUNT )
RAD=RAD/200.
IIX=ICOM( ICOUNT )
JGX=JCOM( ICOUNT )
905 CONTINUE
IF( ISHRUB.GT.0 ) GO TO 995
IF( ICOUNT.GT.50.AND.ICOUNT.LE.100 ) GO TO 910
IF( ICOUNT.GT.100 ) GO TO 920
C WRITE(IOUT,906)ICOUNT,RAD,ICOM( ICOUNT ),JCOM( ICOUNT )
906 FORMAT(2X,'AMEL # =",I4,5X,'RADlUS IN FT. =",F8.2,5X,'ILOC =",I5,5
1X,"J LOC =",I5)
GO TO 995
C WRITE(IOUT,915)ICOUNT,RAD,ICOM( ICOUNT ),JCOM( ICOUNT )
915 FORMAT(2X,'CEON # =",I4,5X,'RADlUS IN FT. =",F8.2,5X,'ILOC =",I5,5
1X,"J LOC =",I5)
GO TO 995
C WRITE(IOUT,925)ICOUNT,RAD,ICOM( ICOUNT ),JCOM( ICOUNT )
925 FORMAT(2X,'SHEP # =",I4,5X,'RADlUS IN FT. =",F8.2,5X,'ILOC =",I5,5
1X,"J LOC =",I5)
C C SHRUB GROWTH
995 CALL BRANCH
GO TO 880
C C SHRUB REMOVAL IF DEAD
CALL REM
C C SHRUB AREA CALCULATION
C CALL AREA (NAMEL,NCEON,Nshep,NPRUN,NROSE,NSYMP,PDNS,PDNA,PD
INC,PUNPR,PDNRO,PDNSY,INDISH)
C C PRODUCTION CALC FOR SHRUBS, GRASSES & FORBS
CALL SGPDN (NAMEL,NCEON,Nshep,NPRUN,NROSE,NSYMP,PDNS,PDNA,PD
INC,PUNPR,PDNRO,PDNSY,INDISH)
2000 CALL SUM (NAM1,NCEON,NSHEP,NPRUN,NROSE,NSYMP,PDNS,PDNA,PD1C,PDNPR,PDNRO,PDNSY,INOISH)

IF(ISUB.LE.3) GO TO 190
IF(IDD.LE.0) GO TO 3900

PRINTS SHRUB MAPS

DO 3600 I=1,66
DO 3600 J=1,66
NB=LARR1(I,J)
IF(NB.EQ.0) NB=154
3600 JARRA(I,J)=KCHAR(NB)

WRITE(IOUT,3700)
3700 FORMAT("1",2X,"SUB-PL0T # 1",/,2X,"SHRUB MAP",/,1X,130("")

DO 3800 I=1,66
3800 WRITE(IOUT,3850)(JARRA(I,J),J=1,64)

WRITE(IOUT,3889)
3889 IF(IDD.LE.1) GO TO 3900

DO 3601 I=1,66
DO 3601 J=1,66
NB=LARR2(I,J)
IF(NB.EQ.0) NB=154
3601 JARRA(I,J)=KCHAR(NB)

WRITE(IOUT,3701)
3701 FORMAT("1",2X,"SUB-PL0T # 2",/,2X,"SHRUB MAP",/,1X,130("")

DO 3801 I=1,66
3801 WRITE(IOUT,3850)(JARRA(I,J),J=1,64)

WRITE(IOUT,3889)
3889 IF(IDD.LE.2) GO TO 3900

DO 3602 I=1,66
DO 3602 J=1,66
NB=LARR3(I,J)
IF(NB.EQ.0) NB=154
3602 JARRA(I,J)=KCHAR(NB)

WRITE(IOUT,3702)
3702 FORMAT("1",2X,"SUB-PL0T # 3",/,2X,"SHRUB MAP",/,1X,130("")
DO 3802 I=1,66
C
3802 WRITE(IOUT,3850)(JARRA(I,J),J=1,64)
C
WRITE(IOUT,3889)
IF(IDD.LE.3) GO TO 3900
C
DO 3603 I=1,66
DO 3603 J=1,66
NB=LARR4(I,J)
IF(NB.EQ.0) NB=154
3603 JARRA(I,J)=KCHAR(NB)
C
WRITE(IOUT,3703)
3703 FORMAT("1",2X,"SUB- PLOT # 4",//,2X,"SHRUB MAP",//,1X,130("*"))
DO 3803 I=1,66
C
3803 WRITE(IOUT,3850)(JARRA(I,J),J=1,64)
3850 FORMAT("9",1X,64A2)
C
WRITE(IOUT,3889)
3889 FORMAT(2X,128("*"))
3900 ITHRU=ITHRU+1
4000 RETURN
END
SUBROUTINE AREA  (NAMEL, NCEO, NSHEP, NPRUN, NROSE, NSYM, PDNS, PDNA, PDNC
1NC, PDNPR, PDNRO, PDNSY, INDISH)

DIMENSION IARRA(66, 66), BL2(96), ACC(4, 21), ATA(4, 21), ATG(4, 21), ATP(4,
1, 21), APDNA(4, 21), APDNC(4, 21), APDNS(4, 21), APDNPR(4, 21), APDNRO(4, 21)
2, APDNSY(4, 21)

INTEGER JARRA(66, 66), NSET(96), IQQ(96, 5), JQQ(96, 5), NAGE(50), NAME
1L(4), NCEO(4), NSHEP(4), NPRUN(4), NROSE(4), NSYM(4), JRAND(50), K
RAND(50), LRAND(50), JMRAND(100), KMRAND(100), LLRAND(100), J
AMEL(20), JCEO(20), JSHEP(20), JPRUN(20), JROSE(20), JSYM(20), I
SCOM(150), JCOM(150), IDEAD1(150), IDEAD2(150), IDEAD3(150), IDEAD4(150)
6, LARR1(66, 66), LARR2(66, 66), LARR3(66, 66), LARR4(66, 66), IAREA(153), ID
7IA1(150), IDIA2(150), IDIA3(150), IDIA4(150), PER(153), EPER(16), KA
8MEL(4, 21), KCEO(4, 21), KSHEP(4, 21), KPRUN(4, 21), KROSE(4, 21), KSYMP(4,
921), KCHAR(160), HIT(100, 97), ICHAR(99), IBB(50, 97), IRRAND(97), IXX(97),
1JXX(97), IVOL(97), IDBM(97), ICL(97), IAPER(97), ICH(97), ICW(97), IBA(97,
1), JCHAR(2), IDEAD(97)

COMMON IARRA, BL2, ACC, ATA, ATG, ATP, APDNA, APDNC, APDNS, PDNPR, PDNRO, A
1PDNSY, CSUB1, CSUB2, CSUB3, CSUB4, RAD, BORDA, XINA, UTILA, BORDC, XINC, U
2L2, BORDS, XINS, UTILS, AGE, CC, TAUT, TAUTS, TAUTT, TAUD, UNOC, YUNOC, PDN
1, ITHRU, M, ISTRT, INT, ENDT, YUNOC, IUTTY, YUNOC, ILDC, M, 3, IH, IB, JARRA, LARR1, LARR2, LARR3, LARR4, IQQ, JQQ, IREA, P
4ER, KCHAR, ICO
54, JCOM, IDEAD1, IDEAD2, IDEAD3, IDEAD4, IDIA1, IDIA2, IDIA3, IDIA4, JFR
6AND, KRAND, LLRAND, ICHAR, IRRAND, IX, JXX, IVOL, IDBM, ICL, IAPER, ICW, I
7CB, 6IB, IDEAD, NSET, KAMEL, KCEO, KSHEP, KPRUN, KROSE, KSYM, NAGE, JRAND, K
8N TO, LRAND, JAMEL, JCEO, JSHEP, JPRUN, JROSE, JSYM, EPER, NNNAMEL, NCEO,
9NS SHEP, NPRUN, NROSE, NSYM, JCHAR

IDOUT=6
IF (AGE.EQ.0) GO TO 2000

OCUPATION OF AREA BY SHRUBS

DO 1041 I=1, 66

DO 1040 J=1, 66
K=J+1
IF (K.EQ.0) K=66
L=I+1
IF (L.EQ.0) L=66
GO TO (1000, 1010, 1020, 1030), ISUB

1000 NB=LARR1(I,J)
IB=LARR1(I,K)
JB=LARR1(L,J)
IF (NB.GT.0) IAREA(NB)=IAREA(NB)+1
IF (LARR1(I,J).GT.0.AND.LARR1(I,K).NE.0) GO TO 1003
IF (NB.EQ.0) GO TO 1003
PER(NB)=PER(NB)+1

1003 IF (LARR1(I,J).GT.0.AND.LARR1(I,K).GT.0) GO TO 1006
IF (IB.EQ.0) GO TO 1006
PER(IB)=PER(IB)+1

1006 IF (LARR1(I,J).GT.0.AND.LARR1(L,J).NE.0) GO TO 1009
IF (NB.EQ.0) GO TO 1009
PER(NB) = PER(NB) + 1

1009 IF(LARR1(I,J) .NE. 0 .AND. LARR1(L,J) .GT. 0) GO TO 1040
IF(JB .EQ. 0) GO TO 1040
PER(JB) = PER(JB) + 1
GO TO 1040

1010 NB = LARR2(I,J)
JB = LARR2(L,J)
IB = LARR2(I,K)
IF(NB .GT. 0) IAREA(NB) = IAREA(NB) + 1
IF(LARR2(I,J) .GT. 0 .AND. LARR2(I,K) .NE. 0) GO TO 1013
IF(NB .EQ. 0) GO TO 1013
PER(NB) = PER(NB) + 1

1013 IF(LARR2(I,J) .NE. 0 .AND. LARR2(I,K) .GT. 0) GO TO 1016
IF(IB .EQ. 0) GO TO 1016
PER(IB) = PER(IB) + 1

1016 IF(LARR2(I,J) .GT. 0 .AND. LARR2(L,J) .NE. 0) GO TO 1019
IF(NB .EQ. 0) GO TO 1019
PER(NB) = PER(NB) + 1

1019 IF(LARR2(I,J) .NE. 0 .AND. LARR2(L,J) .GT. 0) GO TO 1040
IF(JB .EQ. 0) GO TO 1040
PER(JB) = PER(JB) + 1
GO TO 1040

1020 NB = LARR3(I,J)
JB = LARR3(L,J)
IB = LARR3(I,K)
IF(NB .GT. 0) IAREA(NB) = IAREA(NB) + 1
IF(LARR3(I,J) .GT. 0 .AND. LARR3(I,K) .NE. 0) GO TO 1023
IF(NB .EQ. 0) GO TO 1023
PER(NB) = PER(NB) + 1

1023 IF(LARR3(I,J) .NE. 0 .AND. LARR3(I,K) .GT. 0) GO TO 1026
IF(IB .EQ. 0) GO TO 1026
PER(IB) = PER(IB) + 1

1026 IF(LARR3(I,J) .GT. 0 .AND. LARR3(L,J) .NE. 0) GO TO 1029
IF(NB .EQ. 0) GO TO 1029
PER(NB) = PER(NB) + 1

1029 IF(LARR3(I,J) .NE. 0 .AND. LARR3(L,J) .GT. 0) GO TO 1040
IF(JB .EQ. 0) GO TO 1040
PER(JB) = PER(JB) + 1
GO TO 1040

1030 NB = LARR4(I,J)
JB = LARR4(L,J)
IB = LARR4(I,K)
IF(NB .GT. 0) IAREA(NB) = IAREA(NB) + 1
IF(LARR4(I,J) .GT. 0 .AND. LARR4(I,K) .NE. 0) GO TO 1033
IF(NB .EQ. 0) GO TO 1033
PER(NB) = PER(NB) + 1

1033 IF(LARR4(I,J) .NE. 0 .AND. LARR4(I,K) .GT. 0) GO TO 1036
IF(IB .EQ. 0) GO TO 1036
PER(IB) = PER(IB) + 1

1036 IF(LARR4(I,J) .GT. 0 .AND. LARR4(L,J) .NE. 0) GO TO 1039
IF(NB .EQ. 0) GO TO 1039
PER(NB) = PER(NB) + 1
1039 IF (LARR4(I,J) .NE. 0 .AND. LARR4(L,J) .GT. 0) GO TO 1040
   IF (JB .EQ. 0) GO TO 1040
   PER(JB) = PER(JB) + 1
1040 CONTINUE
1041 CONTINUE
2000 RETURN
END
SUBROUTINE BRANCH

DIMENSION IARRA(66,66), BL2(96), ACC(4, 21), APA(4, 21), ATG(4, 21), ATF(4, 21), APDNA(4, 21), APDNS(4, 21), APDNPR(4, 21), APDNRO(4, 21), APDNSY(4, 21)

INTEGER*2 JARRA(66,66), NSET(96), IQQ(96,5), JQQ(96,5), NAGE(50), NNAME, 1L(4), NNAMEC(4), NNSHEP(4), NNPRUN(4), NNROSE(4), NNSYMP(4), JRAND(50), KRAND(50), LRAND(50), JRand(100), KRand(100), LLRAND(100), JRAND(50), JCEON(20), JSHEP(20), JPRUN(20), JROSE(20), JSYMP(20)

500 COM(150), JCOM(150), IDEAD1(150), IDEAD2(150), IDEAD3(150), IDEAD4(150), 6, LARR1(66,66), LARR2(66,66), LARR3(66,66), LARR4(66,66), LAREA(153), ID7IAM1(150), IDIAM2(150), IDIAM3(150), IDIAM4(150), PER(153), EPER(16), KAMEL(4, 21), KCEON(4, 21), KSHEP(4, 21), KPRUN(4, 21), KROSE(4, 21), KSYMP(4, 921), KCHAR(160), IMT(100, 97), ICHEAR(99), IBB(50, 97), IRAND(97), IXX(97), IX(97), IVOL(97), IDBH(97), ICL(97), IAPER(97), ICW(97), ICB(97), IBA(97)

COMMON IARRA, BL2, ACC, APA, ATG, ATF, APDNA, APDNS, APDNPR, APDNRO, APDNSY, CSUB1, CSUB2, CSUB3, CSUB4, RAD, BORDA, XINA, UTILA, BORDC, XINC, UTIL2C, BORDS, XINS, UTILS, AGE, C, CC, TAUT, TAUTS, TAUTT, TAUD, UNOCC, YUNOCC, PDN 1, ITHRU, M, ISTRT, INT, IEND, IVUNOC, IAUITY, IUNOCC, ILOOP, IX, ISUB, ICOUNT 3, IMT, IBB, JARRA, LARR1, LARR2, LARR3, LARR4, IQQ, JQQ, IAREA, PER, KCHAR, ICOC 4M, JCOM, IDEAD1, IDEAD2, IDEAD3, IDEAD4, IDIAM1, IDIAM2, IDIAM3, IDIAM4, JVRAND, LLRAND, JCHAR, IRAND, IX, JXX, IXVOL, IDBH, ICL, IAPER, ICW, ICB, 61A, IDEAD, NSET, KAMEL, KCEON, KSHEP, KPRUN, KROSE, KSYMMP, NAGE, JRAND, KRAND 70, RAN, JAMEL, JCEON, JSHF, JPRUN, JROSE, JSYMP, EPER, NNAME, NNAMEC, NNSHEP, NNPRUN, NNROSE, NNSYMP, JCHAR

C C C C C

DETERMINES SHRUB SPECIES
IIK, JXX = LOCATIONS OCCUPIED
C C C C

IIK=ICOM(ICOUNT)
JXX=JCOM(ICOUNT)
GO TO (800, 810, 820, 830), ISUB

800 IF (ICOUNT.LE.50.) LARR1(IIK,JXX)=151
IF (ICOUNT.GT.50. AND ICOUNT.LE.100) LARR1(IIK,JXX)=152
IF (ICOUNT.GT.100) LARR1(IIK,JXX)=153
GO TO 900

810 IF (ICOUNT.LE.50.) LARR2(IIK,JXX)=151
IF (ICOUNT.GT.50. AND ICOUNT.LE.100) LARR2(IIK,JXX)=152
IF (ICOUNT.GT.100) LARR2(IIK,JXX)=153
GO TO 900

820 IF (ICOUNT.LE.50.) LARR3(IIK,JXX)=151
IF (ICOUNT.GT.50. AND ICOUNT.LE.100) LARR3(IIK,JXX)=152
IF (ICOUNT.GT.100) LARR3(IIK,JXX)=153
GO TO 900

830 IF (ICOUNT.LE.50.) LARR4(IIK,JXX)=151
IF (ICOUNT.GT.50. AND ICOUNT.LE.100) LARR4(IIK,JXX)=152
IF (ICOUNT.GT.100) LARR4(IIK,JXX)=153

900 DO 1000 L=1, 96
NS=NSET(L)
DO 1000 K=1, NS
IF (RAD*2 .EQ. BL2(L)) 996, 910, 910

C C C C C

DETERMINES SHRUB SPECIES
910 INCR=0
915 INCR=INCR+1
    GO TO (920,925,930,935,1000),INCR
920 J=JJX+JQQ(L,K)
    I=IIX+IQQ(L,K)
    GO TO 940
925 J=JJX-JQQ(L,K)
    I=IIX-IQQ(L,K)
    GO TO 940
930 J=JJX+JQQ(L,K)
    I=IIX+IQQ(L,K)
    GO TO 940
935 J=JJX-JQQ(L,K)
    I=IIX-IQQ(L,K)
940 IF(I)955,955,950
945 IF(I-66)955,955,950
950 I=I-66
955 IF(J)970,970,960
960 IF(J-66)970,970,965
965 J=J-66
970 IF(I)975,975,980
975 I=66+I
980 IF(J)985,985,990
985 J=66+J
990 GO TO (991,992,993,994) ISUB
991 IF(LARR1(I,J),GT,0) GO TO 915
    LARR1(I,J)=ICOUNT
    GO TO 995
992 IF(LARR2(I,J),GT,0) GO TO 915
    LARR2(I,J)=ICOUNT
    GO TO 995
993 IF(LARR3(I,J),GT,0) GO TO 915
    LARR3(I,J)=ICOUNT
    GO TO 995
994 IF(LARR4(I,J),GT,0) GO TO 915
    LARR4(I,J)=ICOUNT
995 GO TO 915
1000 CONTINUE
996 RETURN
END
SUBROUTINE REM

DIMENSION IARRA(66,66), BL2(96), ACC(4,21), ATA(4,21), ATG(4,21), ATF(4,21), APDNA(4,21), APDNS(4,21), APDNPR(4,21), APDNRO(4,21), 2, APDNSY(4,21), INTGEx2 JARRA(66,66), NSET(96), IQQ(96,5), JQQ(96,5), NAGE(50), NNAME(4), NNAMEC(4), NNSHEP(4), NNPRUN(4), NNROSE(4), NNSYMP(4), JRAND(50), KRAND(50), JRAND(100), KRAND(100), J3AMEL(20), JCEON(20), JSHEP(20), JPRUN(20), JROSE(20), JSYMP(20), JSCOM(150), JCOM(150), IDEAD1(150), IDEAD2(150), IDEAD3(150), IDEAD4(150), 6, LARR1(66,66), LARR2(66,66), LARR3(66,66), LARR4(66,66), IAREA(153), IDIAM1(150), IDIAM2(150), IDIAM3(150), IDIAM4(150), IDPER(16), IA8MEL(4,21), KCEON(4,21), KSHEP(4,21), KPRUN(4,21), KRPOSE(4,21), KSYMP(4,21), KCHAR(160), IHT(100,97), ICHAR(99), IBB(50,97), IRAND(97), JXX(97), 1JXX(97), JVoL(97), IDBH(97), ICL(97), ICw(97), ICB(97), IBA(97, 1), JCHAR(2), IDEAD(97)

COMMON IARRA, BL2, ACC, ATA, ATG, ATF, APDNA, APDNS, APDNPR, APDNRO, A1PDNSY, CSUB1, CSUB2, CSUB3, CSUB4, RAB, BORDA, XINA, UTILA, BORDC, XINC, UTIL2C, BORDS, XINS, UTILS, AGE, CC, TAUT, TAUTS, TAUTT, TAUC, UOC, YNUCC, YNUOC, PON1, ITHRU, IM, ISTRT, INT, IEND, IYNUCC, IYNUCC, IYNUCC, ILOOP, IX, ISUB, ICOUNT, 3, IHT, IBB, JARRA, LARR1, LARR2, LARR3, LARR4, IQQ, JQQ, IAREA, PER, KCHAR, ICO4M, JCOM, IDEAD1, IDEAD2, IDEAD3, IDEAD4, IDIAM1, IDIAM2, IDIAM3, IDIAM4, JRF5AND, KRAND, LARRAND, LCHAR, IRRAND, IXX, Jxx, IVoL, IDBH, ICL, IAPR, ICw, ICB, 6IBA, IDEAT, NSET, KAMEL, JCEON, KSHEP, KPRUN, KRPOSE, KSYMP, NAGE, JRAND, KRAN7D, LRAND, JAMEL, JCEON, JSHEP, JPRUN, JROSE, JSYMP, EPER, NNAMEL, NNAMEC, NN8HEP, NNPRUN, NNROSE, NNSYMP, JCHAR

C REMOVES DEAD SHRUBS AND CALCULATES DEGREE OF INTERSHRUB COMPETITION

DO 60 I=1,66

DO 59 J=1,66

GO TO (5,10,15,20),ISUB

5 NB=LARR1(I,J)

IF(NB .GT. 150) GO TO 58
IF(IDEAD1(NB),EQ,1) LARR1(I,J)=0

GO TO 58

10 NB=LARR2(I,J)

IF(NB .GT. 150) GO TO 58
IF(IDEAD2(NB),EQ,1) LARR2(I,J)=0

GO TO 58

15 NB=LARR3(I,J)

IF(NB .GT. 150) GO TO 58
IF(IDEAD3(NB),EQ,1) LARR3(I,J)=0

GO TO 58

20 NB=LARR4(I,J)

IF(NB .GT. 150) GO TO 58
IF(IDEAD4(NB),EQ,1) LARR4(I,J)=0

GO TO 58

58 CONTINUE

59 CONTINUE
60 CONTINUE
RETURN
END
SUBROUTINE SGPON (NAMEL, NCEON, NSHEP, NPRUN, NROSE, NSYMP, PONS, PDNA, PD1, PDNP, PDNPX, PDRO, PDNSY, INDISH)
DIMENSION IARRA(66,66), BL2(96), ACC(4,21), ATA(4,21), ATG(4,21), ATF(4,21), APDNA(4,21), APDNC(4,21), APDNS(4,21), APDNPR(4,21), APDNRO(4,21), APDNSY(4,21)
INTEGER*2 JARRA(66,66), NSET(96), IQQ(96,5), JQQ(96,5), NAGE(50), NAMEL(4), NCEON(4), NSHEP(4), NNPRUN(4), NROSE(4), NSYMP(4), JRAND(50), K2RAND(50), LLRAND(100), LPRAND(100), LNAMEL(20), JCEON(20), JSHEP(20), JJPRUN(20), JROSE(20), JSYMP(20), INCOME(150), ICOM(150), JCOM(150), JREAD1(150), JREAD2(150), JREAD3(150), JREAD4(150), I6, LARR1(66,66), LARR2(66,66), LARR3(66,66), LARR4(66,66), IAREA(153), IDIAM1(150), IDIAM2(150), IDIAM3(150), IDIAM4(150), PER(153), EPER(16), KAMEL(4,21), KCEON(4,21), KSHEP(4,21), KPUMP(4,21), KPROSE(4,21), KSYMP(4,921), KCHAR(160), IHT(100,97), JCHAR(99), IBB(50,97), ITREAD(97), IXJX(97), IVOL(97), IBH(97), ICL(97), IAPR(97), ICW(97), ICB(97), IBA(97)
COMMON IARRA, BL2, ACC, ATA, ATG, ATF, APDNA, APDNC, APDNS, APDNPR, APDNRO, A PONS, CSUB1, CSUB2, CSUB3, CSUB4, RAD, BORDA, XINA, UTILA, BORDC, XINC, UTIL 2C, BORDS, XINS, UTILS, AGE, C, CC, TAU, TAUTS, TAU T, TAUD, UNOC, YUNOC, PDN 1, ITHRU, M, ISTART, IINT, IEND, IYUNOC, IATTY, IYUNOC, ILOOP, IX, ISUB, ICOUNT 3, IHT, IBB, JARRA, LARR1, LARR2, LARR3, LARR4, IQQ, JQQ, IAREA, PER, KCHAR, ICOM4M, JCOM, IDEAD1, IDEAD2, IDEAD3, IDEAD4, IDIAM1, IDIAM2, IDIAM3, IDIAM4, JKRAND, LLRAND, ICHAR, IRAND, IXJX, IVOL, IDBH, ICL, IAPR, ICW, ICB, 61BA, IREAD, NSET, KAMEL, KCEON, KSHEP, KPUMP, KPROSE, KSYMP, NAGE, JRAND, KRAND 70, LLRAND, JNAMEL, JCEON, JSHEP, JPUMP, JROSE, JSYMP, EPER, NNAMEL, NCEON, NNSHEP, NNPRUN, NROSE, NSYMP, JCHAR
IOUT=6

C AL CUL ATES NUMBER AND PRODUCTIVITY OF SHRUBS
SETS PRODUCTION TO 0.
PDNA=0.
PDNC=0.
PDNS=0.
PDNPX=0.
PDRO=0.
PDNSY=0.
IF (AGE, EQ, 0) GO TO 1280
DO 1200 I=1,150
GO TO (1045, 1050, 1055, 1060), ISUB
1045 DIAM=IDIAM1(I)
IMORT=IDEAD1(I)
GO TO 1065
1050 DIAM=IDIAM2(I)
IMORT=IDEAD2(I)
GO TO 1065
1055 DIAM=IDIAM3(I)
IMORT=IDEAD3(I)
GO TO 1065
1060 DIAM=IDIAM4(I)
IMORT=IDEAD4(I)
1065 IF(INRGT.EQ.1) GO TO 1200

CALCULATES BORDER AND INSIDE AREA OF SHRUBS AND PRODUCTION

XINS = INSIDE AREA
BORDS = BORDER AREA

IF(DIAM.EQ.0) GO TO 1200
RAD=DIAM/100.
DIAM=RAD
RDS=RAD/2.
IRAD=RAD

IF(PER CI).LT.EPER(K)) GO TO 1090
IF(CRD8.LT.82) GO TO 1070
BORDB(RDS**,82)**2.*3.14159 = CRDS**,82)**2.*3.14159
XIN=(RDS**,82)**2.*3.14159
IF(I.LE.50) XINA=XINA+XIN
IF(I.GT.50.AND.I.LE.100) XINC=XINC+XIN
IF(I.GT.100) XINS=XINS+XIN
GO TO 1075

1070 BORD=(RDS**,82)**2.*3.14159
XIN=0.

1075 IF(I.GT.50) GO TO 1076
BORDA=BORDA+BORD
XINA=XINA+XIN
XAREA=RDS**2.*3.14159
AMEL=4.1*XAREA
GO TO 1130

1076 IF(I.GT.100) GO TO 1079
BORDC=BORDC+BORD
XINC=XINC+XIN
XAREA=RDS**2.*3.14159
IF(XAREA.LE.6.) CEDNP=60./6.*1.7*XAREA**1.7
IF(XAREA.GT.6.) CEDNP=810.-1.45454*(110.-XAREA)=700.*(110.-XAREA)
1**2.7/110.*2.7
GO TO 1130

1079 BORDS=BORDS+BORD
XINS=XINS+XIN
XAREA=RDS**2.*3.14159
IF(XAREA.LE.3.) SHEPP=25./3.*2.6*XAREA**2.6
IF(XAREA.GT.3.) SHEPP=250.-250.*(100.-XAREA)**4.1/100.*4.1
GO TO 1130

1090 DIFP=PER(I)
DIFE=EPER(K)
DIF=DIFP/DIFE
ACTAR=AREA(I)
ACTAR=ACTAR/4.
IF(EPER(K).NE.4) GO TO 1094
BORD = (RDS + .82)**2 * 3.14159
XIN = 0
GO TO 1100

1094 IF (RDS.LT.+.82) GO TO 1095
EXPINS = (RDS + .82)**2 * 3.14159
BORD = DIF * ((RDS + .82)**2 * 3.14159 = EXPINS)
EXP3 = 3.14159 * RDS**2.
ACTINS = ACTAR * EXPINS / EXPAR
BORD = DIF * (EXPAR - EXPINS)
IF ((BORD + ACTINS) .NE. ACTAR) ACTINS = ACTAR - BORD
XIN = ACTINS
IF (XIN.LT.0) XIN = 0.
GO TO 1100

1095 BORD = DIF * (RDS + .82)**2 * 3.14159
IF (BORD.EQ.0) XIN = ACTAR
IF (BORD.GT.0) XIN = 0.

1100 AREA = IAREA(I)
XAREA = AREA / 4.
IF (I.GT.50) GO TO 1105
BORD = BORDA + BORD
XIN = XIN + XIN
AMELP = 4.1 * XAREA
GO TO 1130

1105 IF (I.GT.100) GO TO 1120
BORD = BORDC + BORD
XINC = XINC + XIN
IF (XAREA.LE.6.) CEQNP = 60.0 / 6.***1.7*XAREA**1.7
IF (XAREA.GT.6.) CEQNP = 810. - 1.45454*(110. - XAREA) - 700. * (110. - XAREA)
1**2.7/110.**2.7
1115 GO TO 1130

1120 BORD = BORDS + BORD
XINC = XINC + XIN
IF (XAREA.LE.3.) SHEPP = 25.0 / 3.***2.6*XAREA**2.6
IF (XAREA.GT.3.) SHEPP = 250. - 250. * (100. - XAREA)**4.1 / 100.**4.1
1130 IF (I.GT.50) PDNA = PDNA + AMELP
IF (I.GT.50) GO TO 1140
IF (INDISH.EQ.0) GO TO 1200

C
WRITE (IDOUT, 1180) I, PER(I), EPER(K), DIAM, XIN, BORD, AMELP, IAREA(I)
GO TO 1200

1140 IF (I.GT.50, AND, I.LE.100) PDNC = PDNC + CEQNP
IF (I.GT.100) GO TO 1150
IF (INDISH.EQ.0) GO TO 1200

C
WRITE (IDOUT, 1180) I, PER(I), EPER(K), DIAM, XIN, BORD, CEQNP, IAREA(I)
GO TO 1200

1150 IF (I.GT.100) PDNS = PDNS + SHEPP
IF (INDISH.EQ.0) GO TO 1200

C
WRITE (IDOUT, 1180) I, PER(I), EPER(K), DIAM, XIN, BORD, SHEPP, IAREA(I)
1180 FORMAT (2X,'# **15,3X,'PER=',15,3X,'EPERS=',15,3X,'DIAM=',F6.2,3X,'X

1IN="F6.2,3X,"BORD="F6.2,3X,"PDNS="F8.2,3X,"AREA="I9)
1200 CONTINUE

PDNA=PDNA/25.
PDNS=PDNS/25.
PDNC=PDNC/25.
WRITE(IOUT,1201)PDNA,PDNC,PDNS
1201 FORMAT(/S2X,"PDNA="F10.4,5X,"PDNC="F10.4,5X,"PDNS="F10.4)

C XIN(A,C,S) = INSIDE AREA FOR LARGE SHRUBS
XINA=XINA/4.
XINC=XINC/4.
XINS=XINS/4.

C BORD(A,C,S) = BORDER AREA FOR LARGE SHRUBS
BORDA=BORDA/4.
BORDC=BORDC/4.
BORDS=BORDS/4.

C UTIL(A,C,S) = AREA UTILIZED (INSIDE + BORDER) FOR LARGE SHRUBS
UTILA=BORDA+XINA
UTILC=BORDC+XINC
UTILS=BORDS+XINS

C TAUTS = TOTAL AREA OCCUPIED BY CEON, AMEL, AND SHEP
TAUTS=UTILA+UTILC+UTILS

C TAUTT = AREA IN SHADE
TAUTT=1069.*C/100.

C TAUT = AREA OCCUPIED BY TREES AND SHRUBS
TAUT=TAUTS+TAUTT

C TAUT = AREA NOT OCCUPIED BY TREES AND SHRUBS
TAUT=1069.-TAUT
IF(TAOT.LT.0)TAOT=0

C IYUNOC = OPEN AREA (AREA NOT OCC. BY TREES AND SHRUBS) IN SQ. YDS.
IYUNOC=1069.-TAUT

C IYUNOC=IYUNOC/9.
C IYUNOC=IYUNOC
IYUNOC=IYUNOC

WRITE(IOUT,1202)TAUTS,TAUTT,TAUT,IYUNOC
IF(NPRUN.LT.1)GO TO 1225
J=100
IF((NPRUN*IYUNOC).LT.100)J=NPRUN*IYUNOC
ITH=0

DO 1220 I=1,J
ITH=ITH+1
RANDJ = JRAND(1)
RANDJ = RANDJ / 1000.
IF (AGE, GT, 20.) GO TO 1212
X2 = 1.* (6. ** 2.14)
IF (AGE = 6.) 1203, 1203, 1206
1203  X1 = 1.* (-1. * (AGE = 6.)) ** 2.14
GO TO 1209
1206  X1 = (AGE = 6.) ** 2.14
1209  DPRUN = RANDJ * (1. -.2 + 1.78 * AGE + 2.* (X1/X2))
GO TO 1215
1212  DPRUN = RANDJ * 2.14
1215  IF (DIAM, LT, 1.37) PDNP = .04 + 6 * DPRUN
IF (DIAM, GE, 1.37) PDNP = 8.8 + 7.1 * DPRUN
1220  PDNP = PDNP + PDNP
PRUN = PRUN
IF (ITH, LT, 100) GO TO 1225
BLOCK = 100./PRUN
XBLK = YUNOCC/BLOCK
PDNP = XBLK * PDNP
C
1225  IF (NSYMP, LT, 1) GO TO 1240
J = 100
IF (NSYMP * YUNOC) .LT. 100) J = NROSE * IYUNOC
ITH = 0
DO 1230 I = 1, J
ITH = ITH + 1
RANDKK = KRAND(1)
RANDKK = RANDKK / 1000.
DSYMP = RANDKK * (2.3 * TANH (AGE * .1776))
PDNS = 1 + 1.4 * DSYMP ** 1.5
1230  PDNS = PDNS + PDNS
ROSE = NROSE
IF (ITH, LT, 100) GO TO 1240
BLOCK = 100./ROSE
XBLK = YUNOCC/BLOCK
PDNS = XBLK * PDNS
1240  IF (NSYMP, LT, 1) GO TO 1260
J = 100
IF ((NSYMP * YUNOC) .LT. 100) J = NSYMP * IYUNOC
ITH = 0
C
DO 1255 I = 1, J
ITH = ITH + 1
RANDLL = LRAND(1)
RANDLL = RANDLL / 1000.
IF (AGE, LE, 18.) DSYMP = RANDLL * (2 * AGE = 2.96 * AGE ** 1.4 / 20.) ** 1.4
IF (AGE, GT, 18.) DSYMP = RANDLL * 1.05
PDNSM = 283 * DSYMP ** 1.5
1255  PDNS = PDNS + PDNSM
SYMP = NSYMP
IF (ITH, LT, 100) GO TO 1260
BLOCK=126. SYMP
XBLK=YUNOCC/BLOCK
PDNSY=XBLK*PDNSY

C
1260 WHITE(ICUT,1258) PDNKO,PDNSY,PDNPR
1260 RETURN
END
SUBROUTINE SUM  (NAMEL,NCEON,NSHEP,NPRUN,NROSE,NSYMP,PDNS,PDNA,PD
INC,PDNPR,PDNRO,PDNSY,INDISH)
DIMENSION IARRA(66,66),BL2(96),ACC(4,21),ATA(4,21),ATG(4,21),ATF(4
1,21),APDNA(4,21),APDNC(4,21),APDNS(4,21),APDNPR(4,21),APDNRO(4,21)
2,APDNSY(4,21)
INTEGER*2 JARRA(66,66),NSET(96),IQQ(96,5),JQQ(96,5),NAGE(50),NNAME
1L(4),NCEON(4),NSHEP(4),NPRUN(4),NROSE(4),NSYMP(4),JRAND(50),K
2RAND(50),LRAND(50),KRAND(100),LLRAND(100),LARR1(66,66),IARRA(66
3,66),IAREA(153),ID
7IAM(150),IDIAM1(150),IDIAM2(150),IDIAM3(150),IDIAM4(150),PER(153),
EPER(16),KAMEL(4,21),KCEON(4,21),KSHEP(4,21),KPRUN(4,21),KROSE(4
921),KSYM(4,21),KCHAR(160),IHT(100,97),ICCHAR(99),IBB(50,97)
3,IRAND(97),IXX(97),JXX(97),IDBH(97),ICL(97),ICW(97),ICB(97),I
5CHAR(2),IDEAD(97)
COMMON IARRA,BL2,ACC,ATA,ATG,ATF,APDNA,APDNC,APDNS,APDNPR,APDNRO,
APDNSY,CSUB1,CSUB2,CSUB3,CSUB4,RAD,BORDA,XINA,UTILA,BORDC,XINC,UTIL
2C,BORDS,XINS,UTILS,AGE,C,CC,TAUT,TAUTS,TAUTT,TAUD,UNOCC,YUNOCC,PDN
1,ITHRU,M,ISTR,INT,END,ITYUNOC,ITYUNTY,ITYUNCC,ILoop,TY,ISUB,ICOUNT
3,INT,IBB,JARRA,LARR1,LARR2,LARR3,LARR4,LAREA,JA\nRCHAR,ICO
4M,JCOM,IDEAD1,IDEAD2,IDEAD3,IDEAD4,IDEAM1,IDEAM2,IDEAM3,IDEAM4,J
5AMAND,JKRAND,LLRAND,ICCHAR,IRAND,IX,XXXX,JXX,irim,ICL,ICW,ICB,
6IBA,IDEAD,NSET,KAMEL,KCEON,KSHEP,KPRUN,KROSE,KSYM,NAGE,JRAND,
KRAN
7D,LRAND,JAMEL,JCEON,JHSEP,JPRUN,JROSE,JSYMP,EP\nER,NNAMEL,NCEON,NNS
8HEP,NPRUN,NRROSE,NSYMP,JCHAR

CALCULATES GRASS AND FORB PRODUCTION
CHECKS CROWN CLOSURE OF TREES AND ADJUSTS GRASS PRODUCTION
ADJUSTS GRASS AND FORB PRODUCTION TO SHRUB INSIDE AND BORDER AREA
AND SHRUB NUMBER

IOUT=6
IF (C.LT.68.) PDNAG=PDN/83.3/9.*(27.+.085294*(68.-C)+50.5/68.)*6.6C
168.-C)**6.6)
IF (C.GE.68. AND C.LE.78.5) PDNAG=PDN/83.3/9.*(26.116-.3281*C)
IF (C.GT.78.5) PDNAG=0.
IF (C.LE.84.) GRAS=PDN/83.3/9.*(.045*C)
IF (C.GT.84.) GRAS=0.
IF (C.LE.18.) FORB=PDN/83.3/9.*(2.4+.67*C)
IF (C.GT.18. AND C.LE.80.) FORB=PDN/83.3/9.*(5+18./60.)*2.7*C
1**2.7)
IF (C.GE.80.) FORB=0.
UBORD=0.
UXIN=0.
UBORD=BORDA+BORDC+BORDS
UXIN=XINA+XINC*XINS
AGROB=PDNAG*UBORD*.365/25.
GRAS=GRAS*UBORD*.365/25.
FORB=FORB*UBORD*.365/25.
AGROB=PDNAG*UXIN*.081/25.
GRASI=GRAS*UXIN*.081/25.
FORBI=FORB*UXIN*.206/25.
AGO=0.
FOO=0.
GRO=0.
AGTO=0.
FOTO=0.
GRO=0.
TA=PDNAG*43.56
TG=GRAS*43.56
TF=FORB*43.56
IF(M.EQ.0) GO TO 2011
IF((NPRUN+NROSE+NSYMP)*GT,0) GO TO 1270
AGTO=PDNAG*(1089.-TAUTS)/25.
FOTO=FORB*(1089.-TAUTS)/25.
GROTO=GRAS*(1089.-TAUTS)/25.
GO TO 2000
1270 AGTO=PDNAG*TAUT/25.
FOTO=FORB*TAUT/25.
GROTO=GRAS*TAUT/25.
IF(NSYMP.EQ.0) GO TO 1280
IF(NSYMP .LE.14) REDUCA=(3.+.13334*(15.-NSYMP )*(80./15.*2.5)*(15
1.-NSYMP )**2.5)/85.
IF(NSYMP .GT.14) REDUCAB=0.0353
RED=1.-REDUCA
IF(AGE.LE.25.) REDPER=.04*AGE
IF(AGE,GT.25.) REDPER=1.
REDUCA=(1.- (RED*REDPER))
INCF=(3.76+1.02*NSYMP)/3.76
AGTO=PDNAG*REDUCA*TAUT/25.
GROTO=GRAS*REDUCA*TAUT/25.
FOTO=FORB*TAUT/25.
1280 NUMSSH=NPRUN+NROSE+NSYMP
IF(NUMSSH.LE.14) REDUCA=(3.+.13334*(15.-NUMSSH)*(80./15.*2.5)*(15
1.-NUMSSH )**2.5)/85.
IF(NUMSSH .GT.14) REDUCA=.0353
RED=1.-REDUCA
IF(AGE.LE.25.) REDPER=.04*AGE
IF(AGE,GT.25.) REDPER=1.
REDUCA=(1.- (RED*REDPER))
INCF=(3.76+1.02*NUMSSH)/3.76
AGO=PDNAG*TAUO*REDUCA/25.
FOO=FORB*TAUO/25.
GRO=GRAS*TAUO*REDUCA/25.
2000 TA=AGO+AGTO+AGROB+AGROI
TG=GRO+GROTO+GRAS1+GRASB
TF=FOO+FOTO+FORBI+FORBB
2011 L=M+1
IF(ISUB.NE.1.OR.M.NE.1) GO TO 2015
C DO 2012 J=1,51
C
SUMMARY OF PRODUCTION OF SHRUBS, GRASSES AND FORBS

2012 IHT(J,97)=0
2015 IF(M.EQ.0) IYUNOC=121
PDNPR=PDNPR/25,
PDNRO=PDNRO/25,
PDNSY=PDNSY/25,
IHT(L,97)=NAGE(M)
ACC(ISUB,L)=C
ATA(ISUB,L)=TA
ATG(ISUB,L)=TG
ATF(ISUB,L)=TF
KAMEL(ISUB,L)=NAMEL
APDNA(ISUB,L)=PDNA
KCE0N(ISUB,L)=NCE0N
APDNS(ISUB,L)=PDNS
KPRUN(ISUB,L)=NPRUN*IYUNOC
APDNP(ISUB,L)=PDPNP
KROSE(ISUB,L)=NROSE*IYUNOC
APDNSY(ISUB,L)=PDNSY
IYUNOC

PRINT PRODUCTION SUMMARIES

WRITE(IOUT,2)
2 FORMAT(2X,T10,'CC',T13,'AGROP PDN',T23,'GRASS PDN',T34,'FORB PDN',
   1T47,'# AMEL',T55,'AMEL PDN',T67,'# CE0N',T75,'CE0N PDN',T87,'# SHE
   2P',T95,'SHEP PDN')

WRITE(IOUT,5)C,TA,TG,TF,NAMEL,PDNA,NCE0N,PDNS,NSHEP,PDNS
5 FORMAT(2X,4F10.4,I10,F10.4,I10,F10.4)

WRITE(IOUT,7)
7 FORMAT(2X,T7,'# PRRN',T15,'PRUN PDN',T23,'# ROSA',T35,'ROS A PDN',T
   47,'# SYMP',T55,'SYMP PDN')

WRITE(IOUT,10)IPRUN,PDPNP,IROSE,PDNRO,ISYMP,PDNSY
10 FORMAT(2X,I10,F10.4,I10,F10.4)
ILOOP=(IEND-ISTRT)/IINT +1
IF(ISUB.EQ.4,.AND.(M-ILOOP).EQ.0) GO TO 2020
GO TO 3000
2020 I00=0

2022 U0 2027 I=1,4
IF(I00.GT.1) GO TO 3000
WRITE(IOUT, 2025) I

2025 FORMAT("1", 2X, 128("*")), //, 2X, T56, "SUB-PLOT =", I2, //, T2, "PARAMETER 1", //, 2X, "AGE")
N = 1
J = 11
IF(IDO .GT. 0) N = 12
IF(N .EQ. 12) J = 21

WRITE(IOUT, 2030) (IHT(K, 97), K=N, J)
WRITE(IOUT, 2031) (ACC(I, K), K=N, J)
WRITE(IOUT, 2032) (ATA(I, K), K=N, J)
WRITE(IOUT, 2033) (ATF(I, K), K=N, J)
WRITE(IOUT, 2034) (ATG(I, K), K=N, J)
WRITE(IOUT, 2035) (KAMEL(I, K), K=N, J)
WRITE(IOUT, 2036) (APDNI(I, K), K=N, J)
WRITE(IOUT, 2037) (KCEON(I, K), K=N, J)
WRITE(IOUT, 2038) (APDNC(I, K), K=N, J)
WRITE(IOUT, 2039) (KSHEP(I, K), K=N, J)
WRITE(IOUT, 2040) (APDNS(I, K), K=N, J)
WRITE(IOUT, 2041) (KPRUN(I, K), K=N, J)
WRITE(IOUT, 2042) (APDNRU(I, K), K=N, J)
WRITE(IOUT, 2043) (KROSE(I, K), K=N, J)
WRITE(IOUT, 2044) (APDNRU(I, K), K=N, J)
WRITE(IOUT, 2045) (KSYMP(I, K), K=N, J)
WRITE(IOUT, 2046) (APDNSY(I, K), K=N, J)

2027 WRITE(IOUT, 2046) (APDNSY(I, K), K=N, J)

IF(I100P.LT.10) GO TO 3000
I100 = I100+1
GO TO 2022

2030 FORMAT(2X, "AGE", 6X, 11I10)
2031 FORMAT(2X, "CR, CLOSE", 1X, (1F10.1)
2032 FORMAT(2X, "AGROP, PDN", 11F10.3)
2033 FORMAT(2X, "FORB PDN", 2X, 11F10.3)
2034 FORMAT(2X, "GHASS PDN", 1X, 11F10.3)
2035 FORMAT(2X, "NO, AMELAN", 11I10)
2036 FORMAT(2X, "AMEL PDN", 1X, 11F10.3)
2037 FORMAT(2X, "NO, CEON", 2X, 11I10)
2038 FORMAT(2X, "CEON PDN", 1X, 11F10.3)
2039 FORMAT(2X, "NO, SHEP", 2X, 11I10)
2040 FORMAT(2X, "SHEP PDN", 1X, 11F10.3)
2041 FORMAT(2X, "NO, PRUN", 2X, 11I10)
2042 FORMAT(2X, "PRUN PDN", 1X, 11F10.3)
2043 FORMAT(2X, "NO, ROSE", 3X, 11I10)
2044 FORMAT(2X, "ROSE PDN", 2X, 11F10.3)
2045 FORMAT(2X, "NO, SYMP", 2X, 11I10)
2046 FORMAT(2X, "SYMP PDN", 1X, 11F10.3)
3000 RETURN
END