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

by

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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

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

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

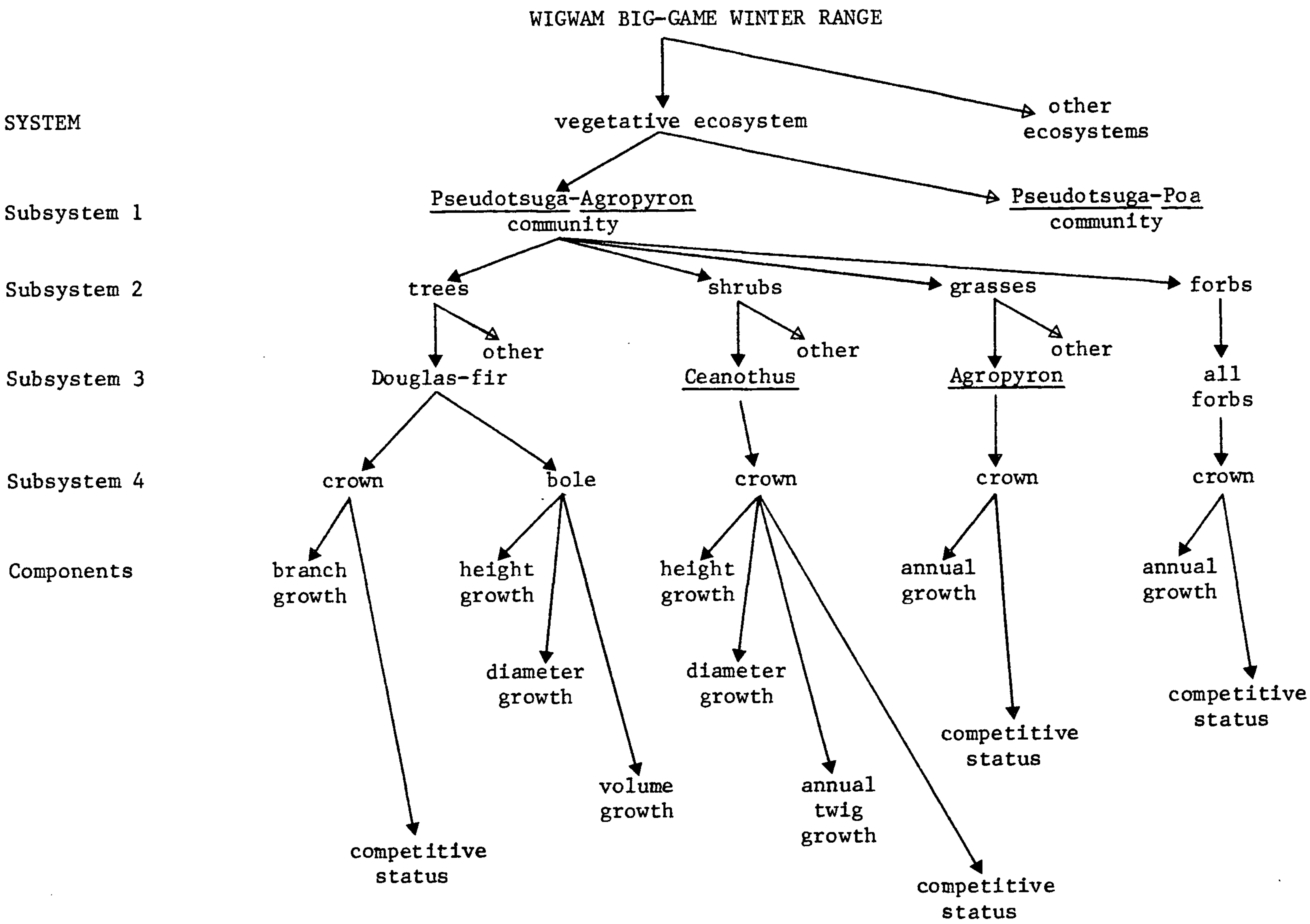


Figure 1. The system and its levels of organization.

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 represents 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 components. 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 development. In addition, the functions should be expressed in unambiguous terms

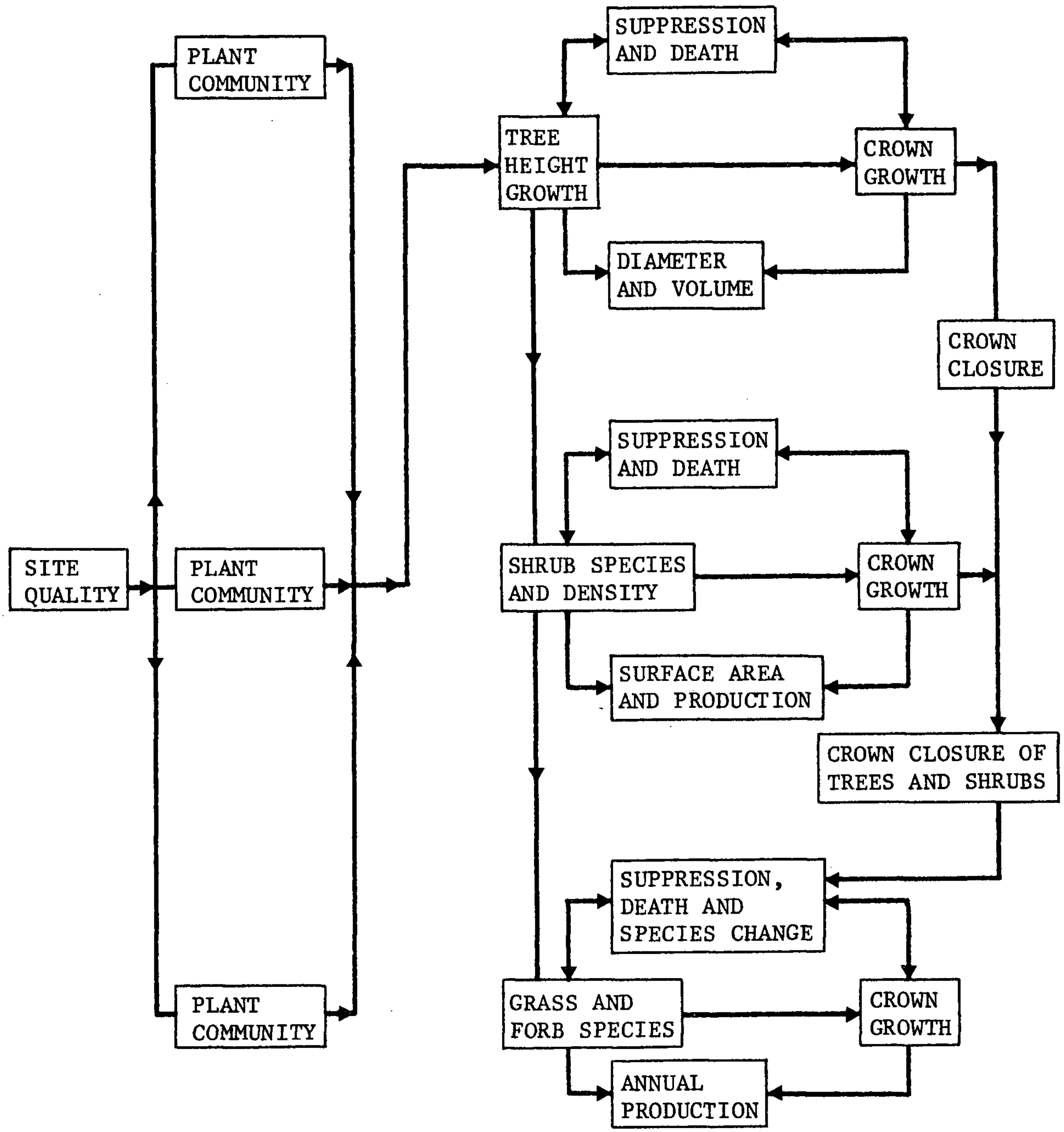


Figure 2. Components of the system.

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 deposts, 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 Agropyrion spicati order, alliances Agropyretum spicati and Agropyro (spicati) - Juniperetum scopulorum of Beil (1969).

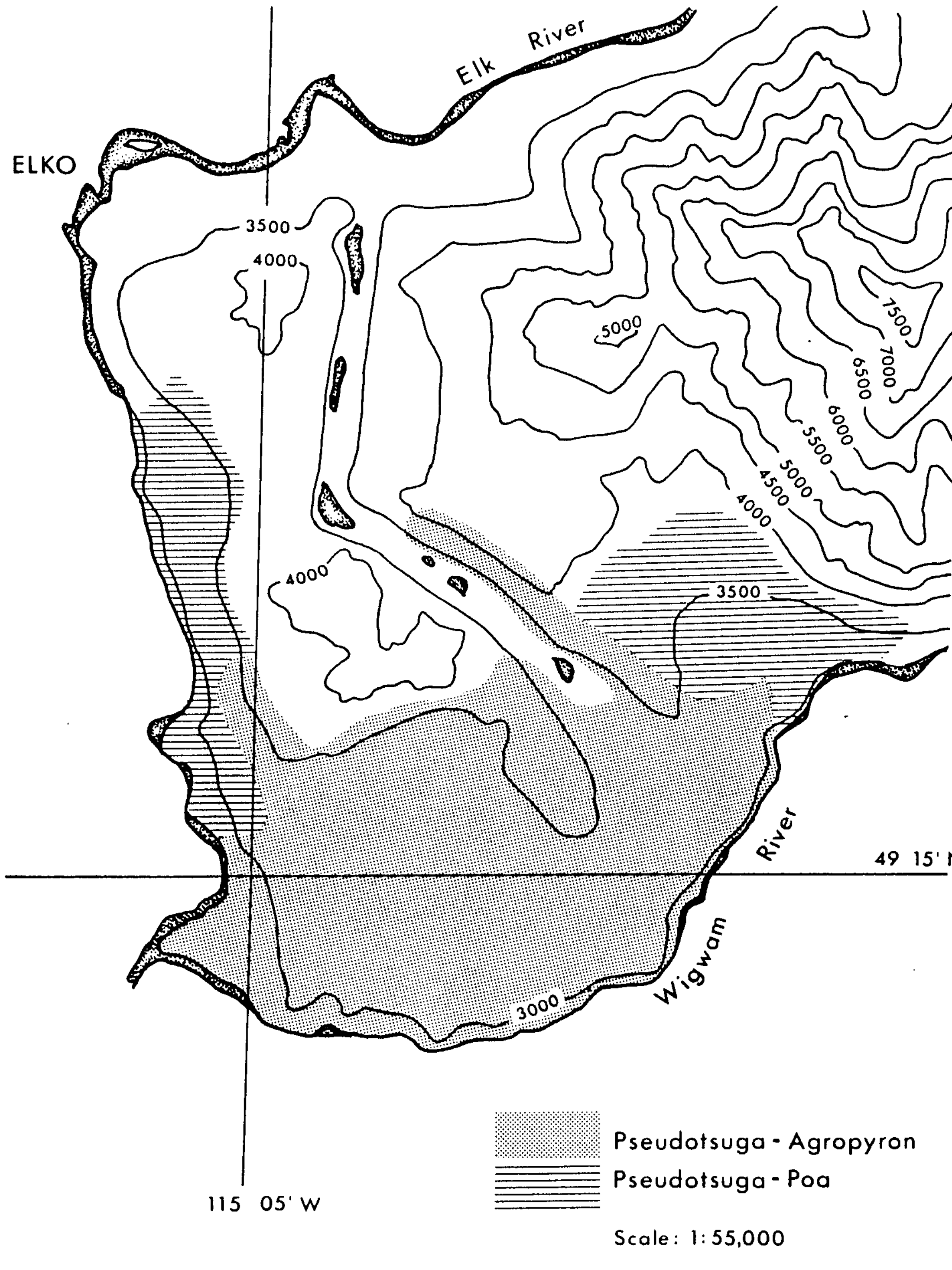


Figure 3. Study area showing location and extent of <u>Pseudotsuga</u>-<u>Agropyron</u> and <u>Pseudotsuga</u>-<u>Poa</u> communities.

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-th 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.

Variable	Values		
	Minimum	Average	Maximum
Number of trees per acre 1" + DBH	20	253	500
Volume -cu ft per acre 1" + DBH	357	1344	2121
DBH -ins	2.4	7.33	16.6
Height -ft	17.0	37.8	68.5
Basal area -sq ft	0.031	0.337	1.503
Basal area -sq ft per acre	21.9	85.2	124.2
Total age -yrs	72	92	106
Crown width/DBH	0.978	1.544	2.620

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

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

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.

Species	Density per 1/40 acre Minimum	Maximum
Amelanchier alnifolia	0	30
Ceanothus sanguineus	0	42
Shepherdia canadensis	0	44
	Density per sq yd Minimum	Maximum
Prunus emarginata	0	18
Rosa nutkana	0	16
Symphoricarpos albus	0	35

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.

Species	Production gms/sq yd Minimum	Maximum
Agropyron	13.5	66.3
Poa	10.1	72.3
Forbs	0.3	22.4

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 yrs

$$HT = 18.05(SIN(Age(\Pi/50) - \Pi/2) + 1) \quad ft \qquad (1)$$

if Age > 45 yrs

$$HT = 1.87 + (0.74066)(Age) \quad ft \qquad (2)$$

where: No. of Obs. = 89

R^2 = 0.925

SE_E = 5.81 ft

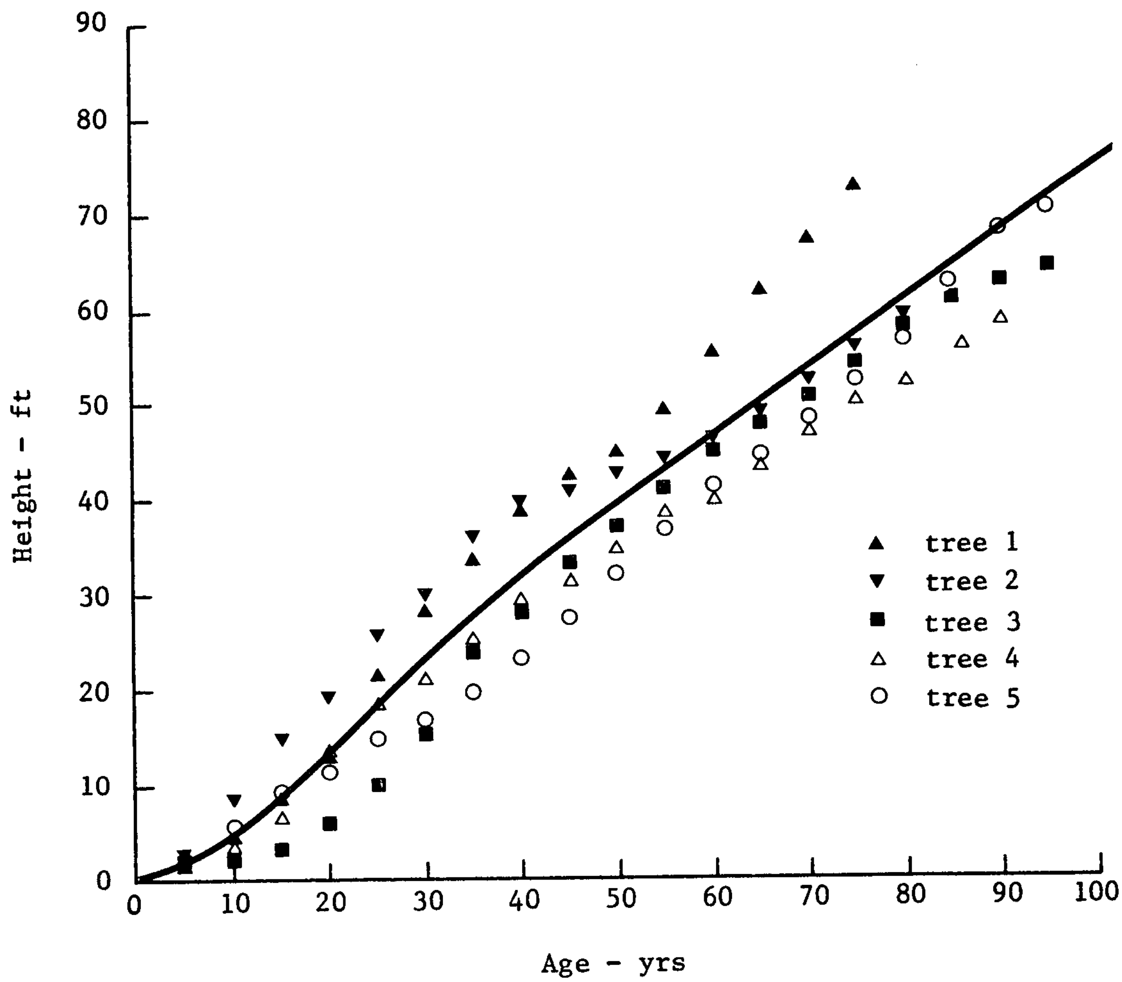


Figure 4. Relationship between height and age for dominant Douglas-fir.

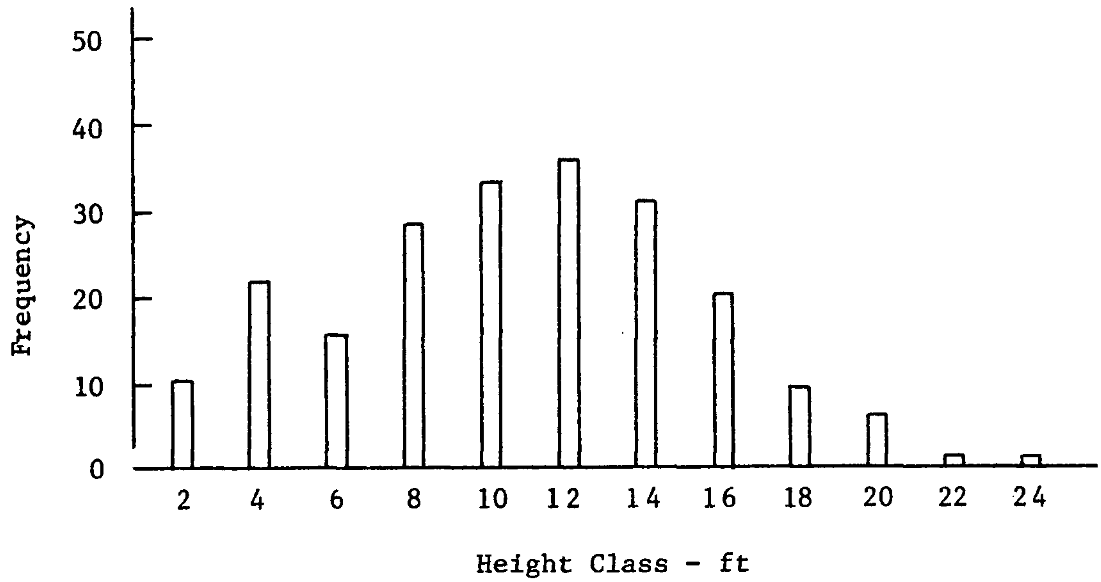


Figure 5. Height frequency distribution for 20-year-old open-grown Douglas-fir.

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.

$$BL = (0.98)(HTAB^{0.7}) \quad ft \qquad (3)$$

where: No. of Obs. = 404

R^2 = 0.920

SE_E = 1.18 ft

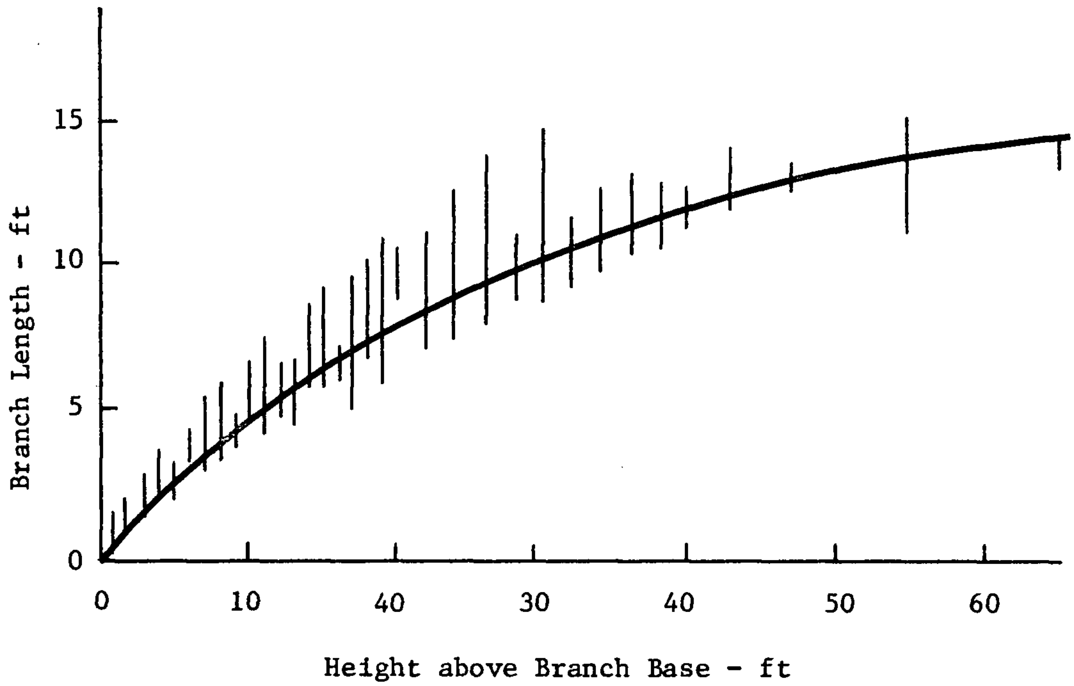


Figure 6. Relationship between branch length and height above branch base.

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

$$HBL = (0.9)(BL) - (3.3)((BL/20)^3) \quad ft \qquad (4)$$

where: No. of Obs. = 65

R^2 = 0.896

SE_E = 0.90 ft

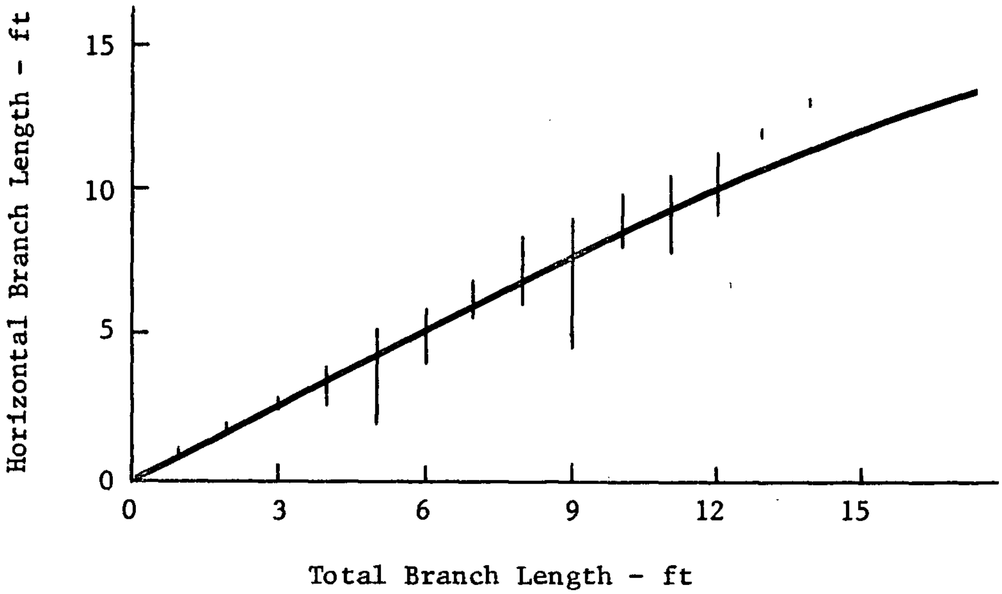


Figure 7. Relationship between horizontal branch length and total branch length.

space at points of crown contact, potential crown radius will not be realized. Branch competition is discussed in the Model section.

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.

if HT $\leq$ 30 ft

$$HTCWmax = (0.06)(HT) + (0.008)(HT^{1.9}) \quad ft \tag{5}$$

if HT > 30 ft

$$HTCWmax = -5.5 + (0.425)(HT) \quad ft \tag{6}$$

where: No. Obs. = 94

R^2 = 0.828

SE_E = 2.63 ft

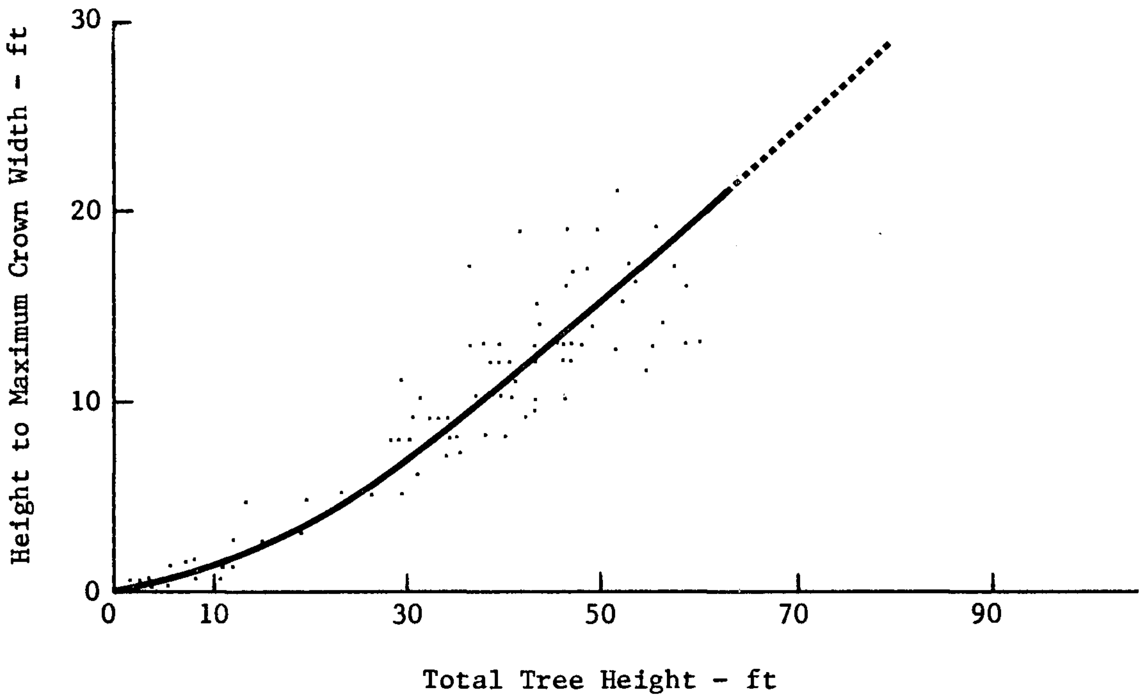


Figure 8. Relationship between height to maximum crown width (HTCW max) and total tree height.

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.

if HTCWmax $\leq$ 10 ft

$$\text{HTblc} = 0.0 \quad \text{ft} \tag{7}$$

if HTCWmax > 10 ft

$$\text{HTblc} = -10 + \text{HTCWmax} \tag{8}$$

where: No. of Obs. = 50

R^2 = 0.694

SE_E = 9.84 ft

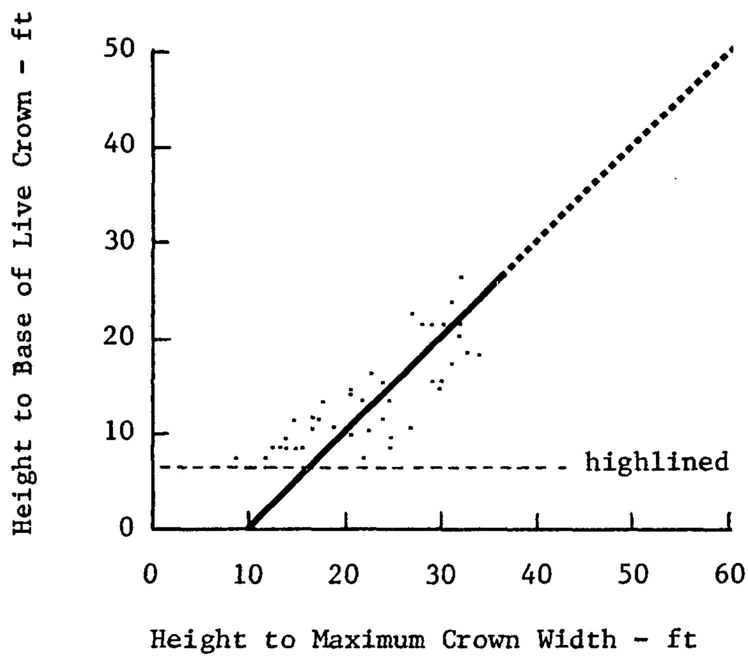


Figure 9. Relationship between height to base of live crown and height to maximum crown width.

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

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

where: No. of Obs. = 299

R^2 = 0.908

SE_E = 1.08 ins

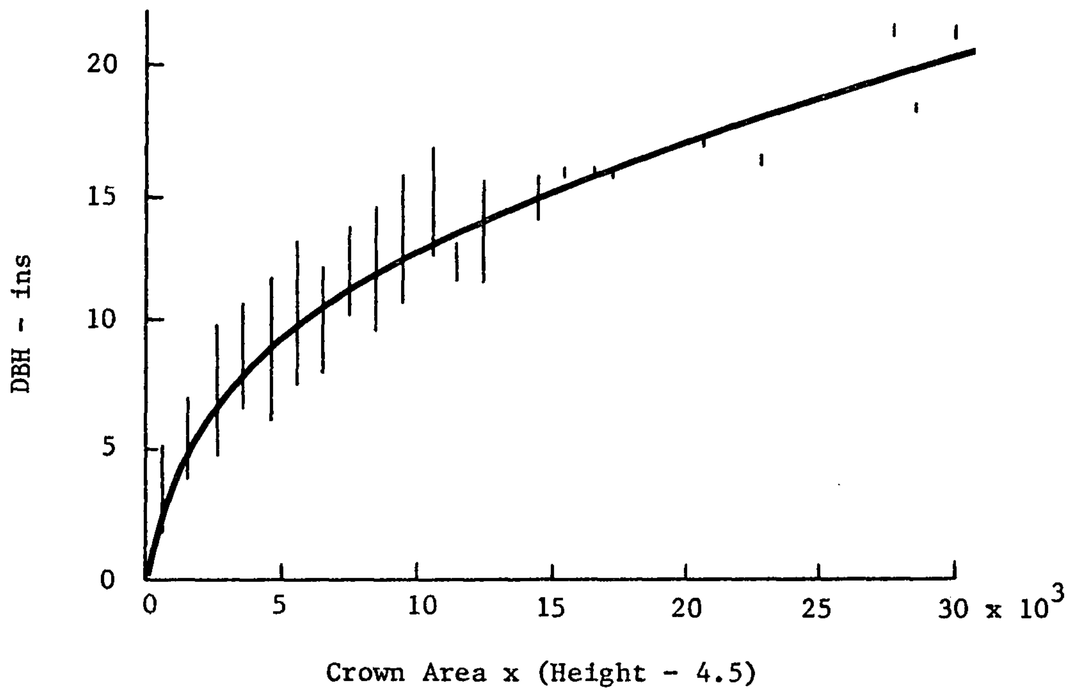


Figure 10. Relationship between diameter at breast height and the product of crown area and tree height minus 4.5 feet.

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.

$$\text{Log } V = -2.734532 + 1.739418 \text{Log } D + 1.166033 \text{ Log } H \qquad (10)$$

SE_E for single trees: ± 11.3 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

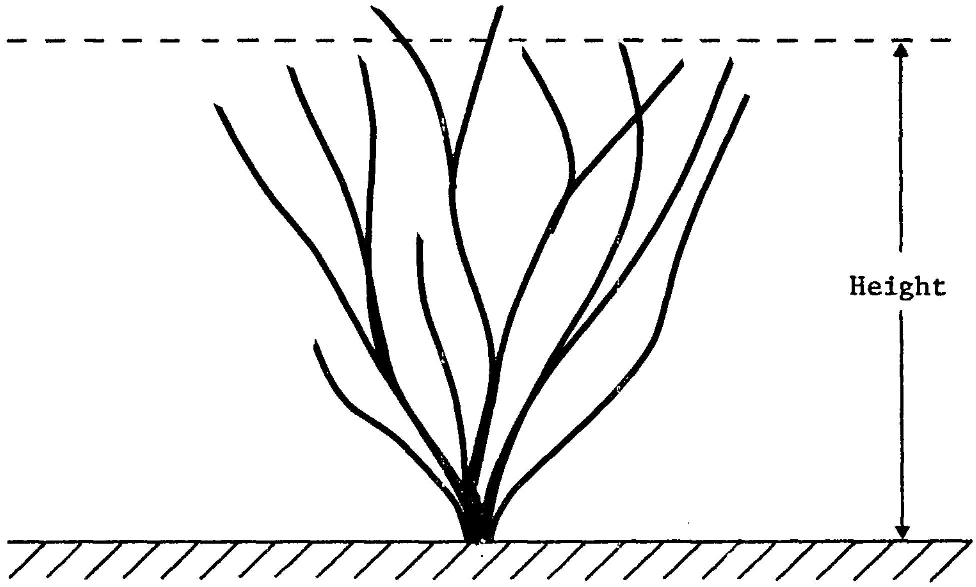


Figure 11. Measurement of shrub height.

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

$$D = -1 + (0.15)(\text{Age}) + (1 - \text{Age}/30)^{1.996} \qquad (11)$$

where: No. of Obs. = 64

R^2 = 0.471

SE_E = 1.246 ft

Ceanothus

$$\text{if Age} \leq 40 \text{ yrs} \quad D = 2.8(\text{SIN}(\text{Age}(\Pi/60) - \Pi/5.2) + .5) \text{ ft} \qquad (12)$$

$$\text{if Age} > 40 \text{ yrs} \quad D = 4.1 + (0.016667)(\text{Age}) \text{ ft} \qquad (13)$$

where: No. of Obs. = 96

R^2 = 0.127

SE_E = 1.30 ft

Shepherdia

$$\text{if Age} \leq 50 \text{ yrs} \quad D = 4.5(\text{SIN}(\text{Age}(\Pi/70) - \Pi/4) + .6) \text{ ft} \qquad (14)$$

$$\text{if Age} > 50 \text{ yrs} \quad D = 7.17 + (0.0046)(\text{Age}) \text{ ft} \qquad (15)$$

where: No. of Obs. = 54

R^2 = 0.438

SE_E = 1.287 ft

Prunus

if Age $\leq$ 16 yrs $D = SIN(Age(\pi/18) - \pi/2.5) + 1)$ ft (16)

if Age > 16 yrs $D = 2.0$ ft (17)

where: No. of Obs. = 100

R^2 = 0.488

SE_E = 0.228 ft

Rosa

if Age $\leq$ 16 yrs $D = SIN(Age(\pi/18) - \pi/2.5) + 1)$ ft (18)

if Age > 16 yrs $D = 2.0$ ft (19)

where: No. of Obs. = 98

R^2 = 0.166

SE_E = 0.445 ft

Symphoricarpos

if Age $\leq$ 18 yrs $D = 0.8(SIN(Age(\pi/26) - \pi/6) + 1)$ ft (20)

if Age > 18 yrs $D = 1.2$ ft (21)

where: No. of Obs. = 48

R^2 = 0.352

SE_E = 0.802 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.

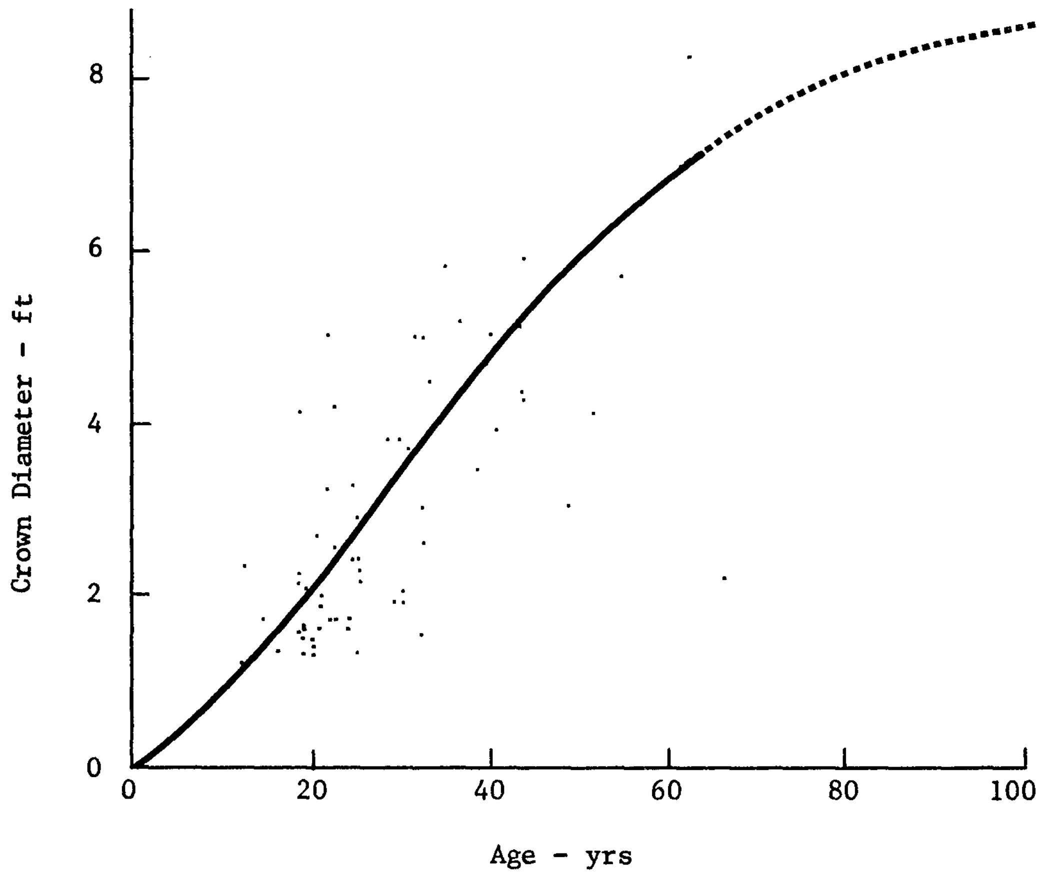


Figure 12. Crown diameter to age relationship for Amelanchier.

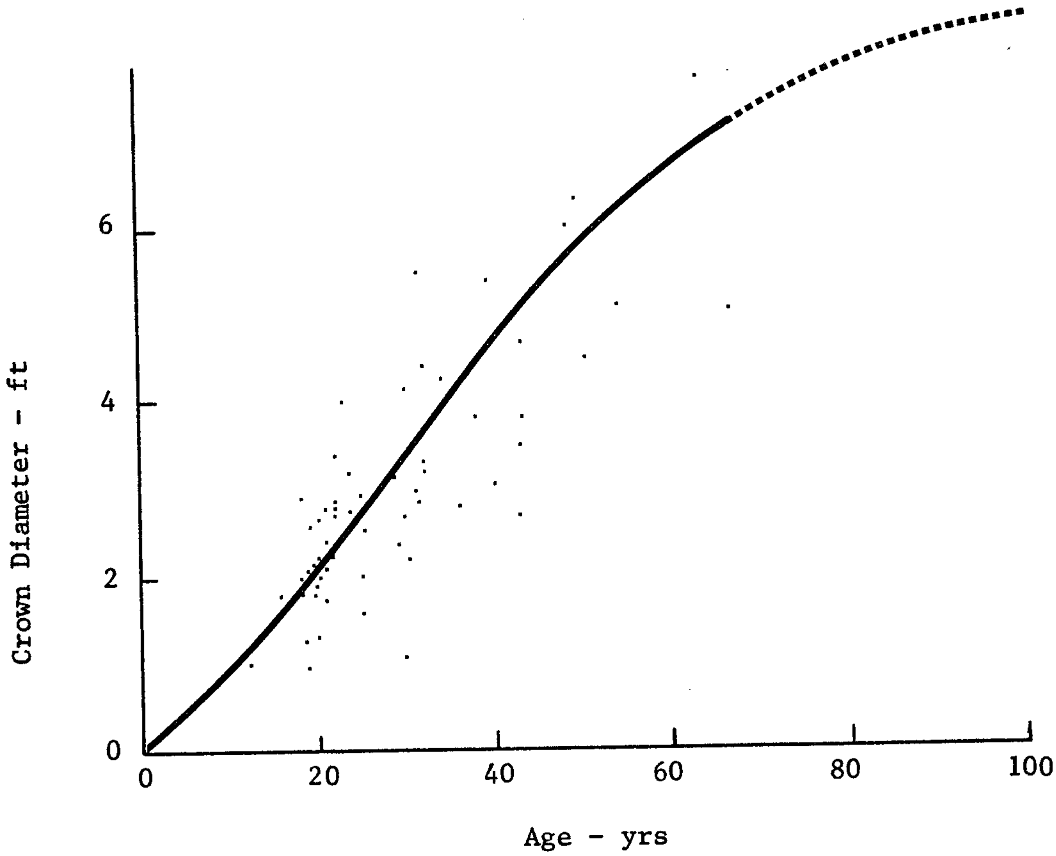


Figure 13. Simulated population of Amelanchier.

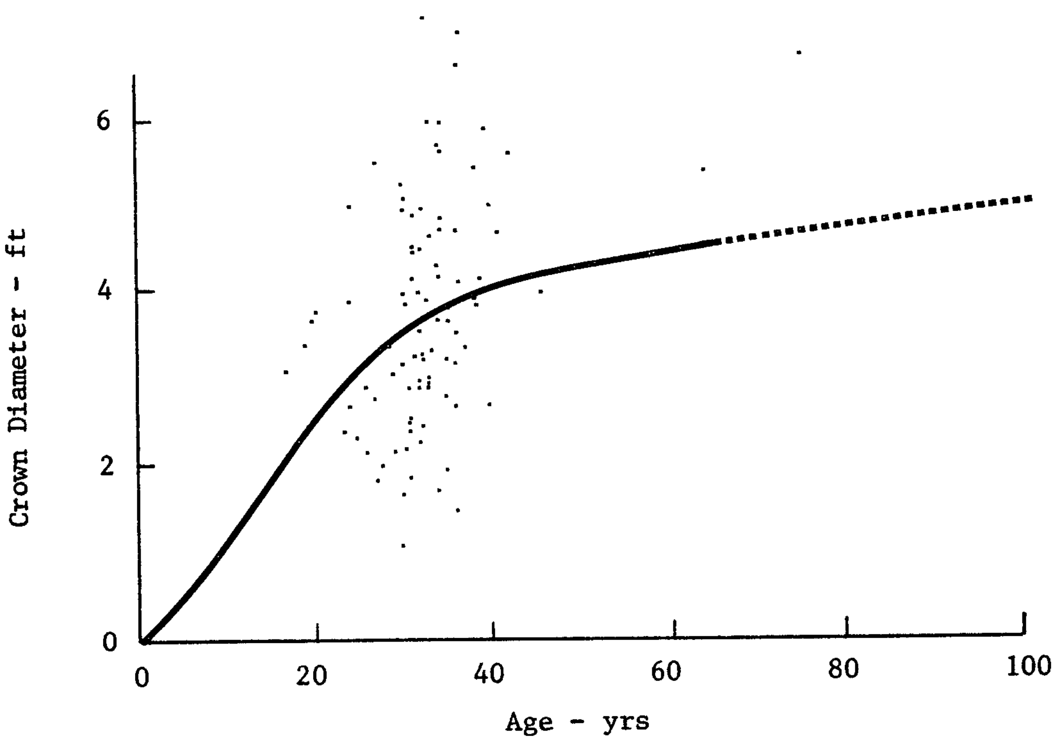


Figure 14. Crown diameter to age relationship for Ceanothus.

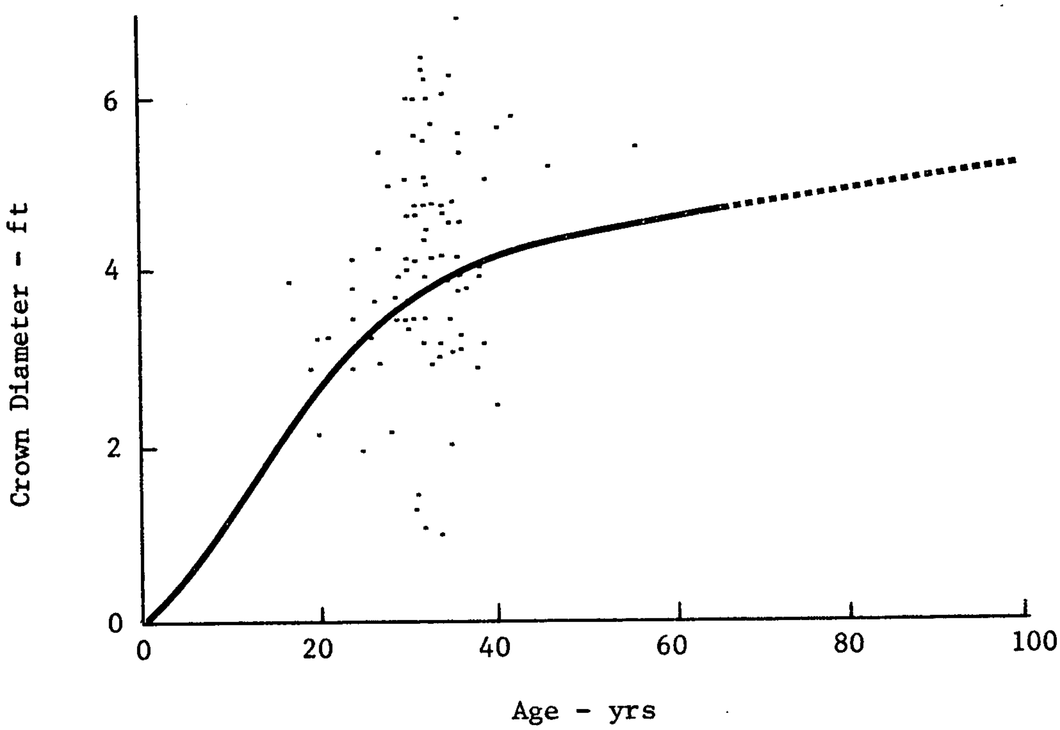


Figure 15. Simulated population of Ceanothus.

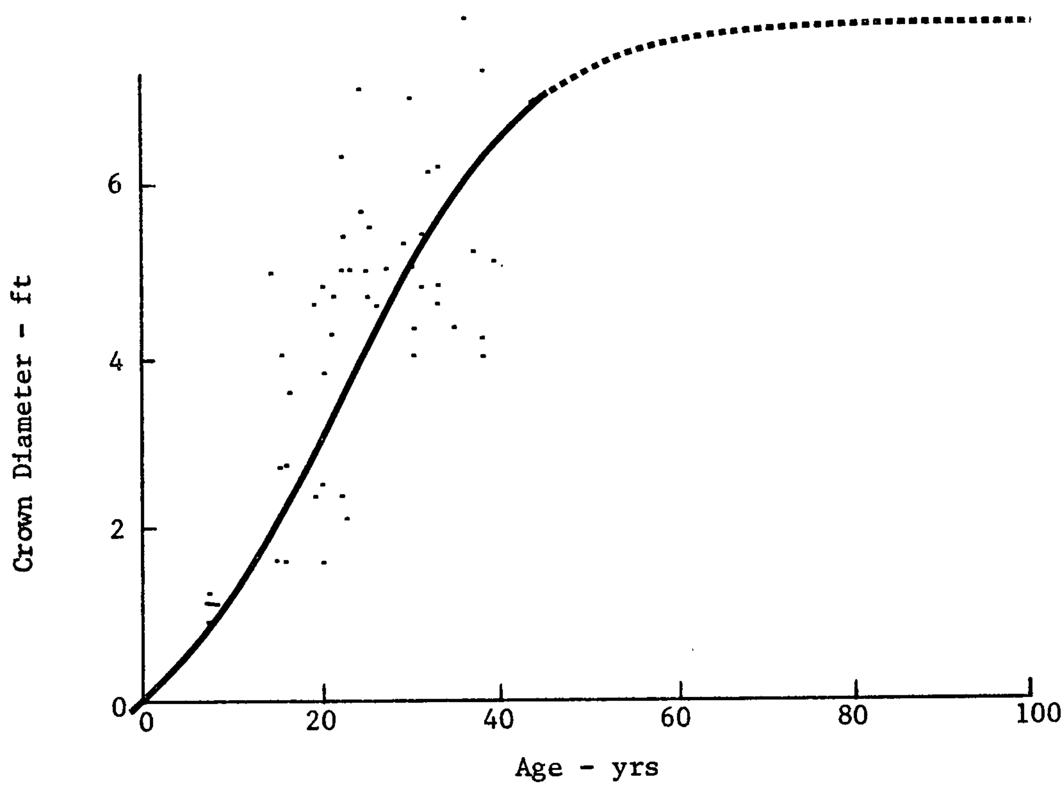


Figure 16. Crown diameter to age relationship for Shepherdia.

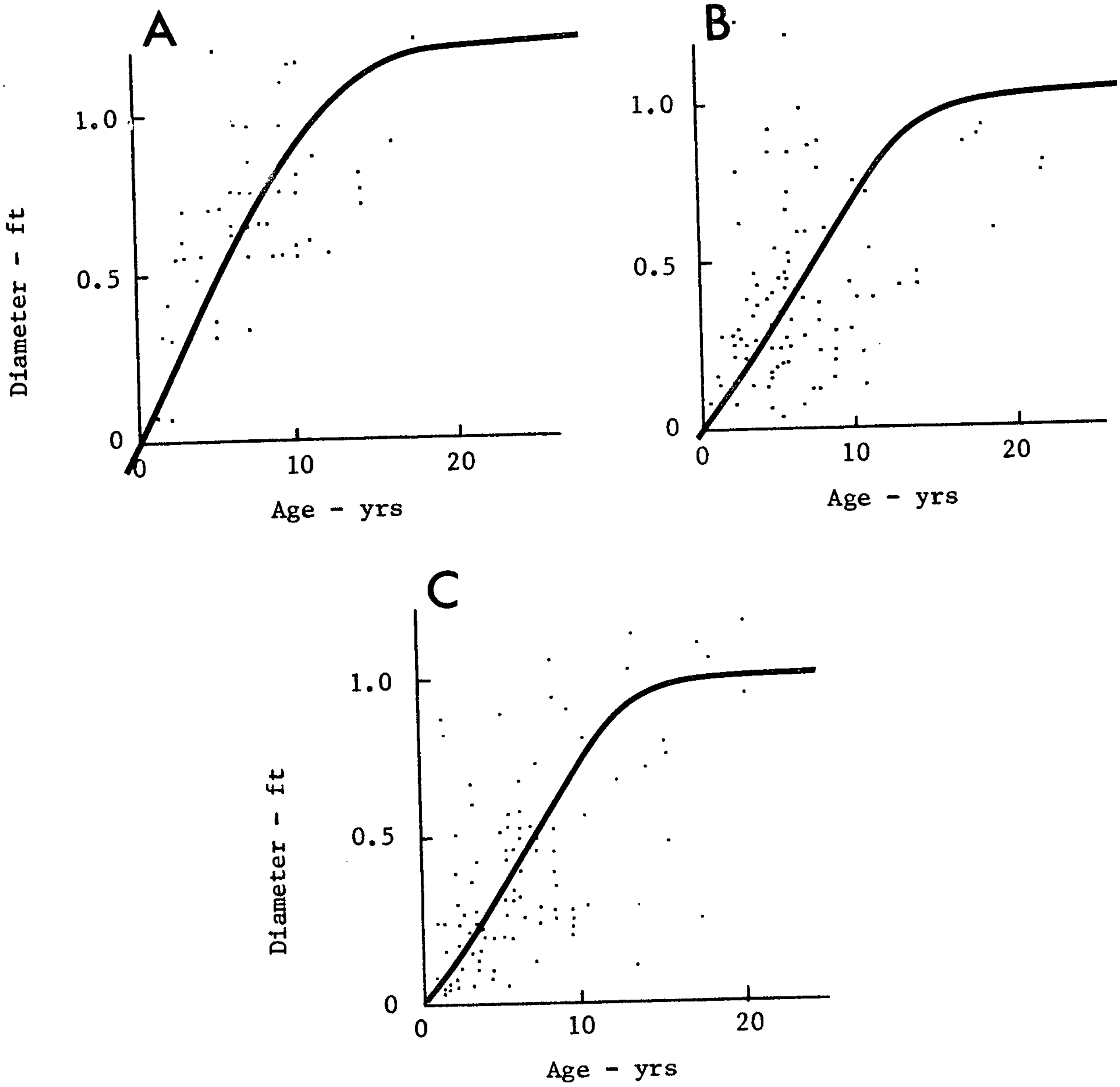


Figure 17. Relationship of shrub diameter to age. A: *Symphoricarpos* B: *Rosa* C: *Prunus*

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

$$WT = (4.1)(\text{Area}) \quad \text{gms} \tag{22}$$

where: No. of Obs. = 8

R^2 = 0.981

SE_E = 9.05 gms

Ceanothus

$$WT = 810 - (1.45454)(110 - \text{Area}) - (700)((1 - \text{Area}/110)^{2.7}) \quad \text{gms} \tag{23}$$

where: No. of Obs. = 10

R^2 = 0.992

SE_E = 17.17 gms

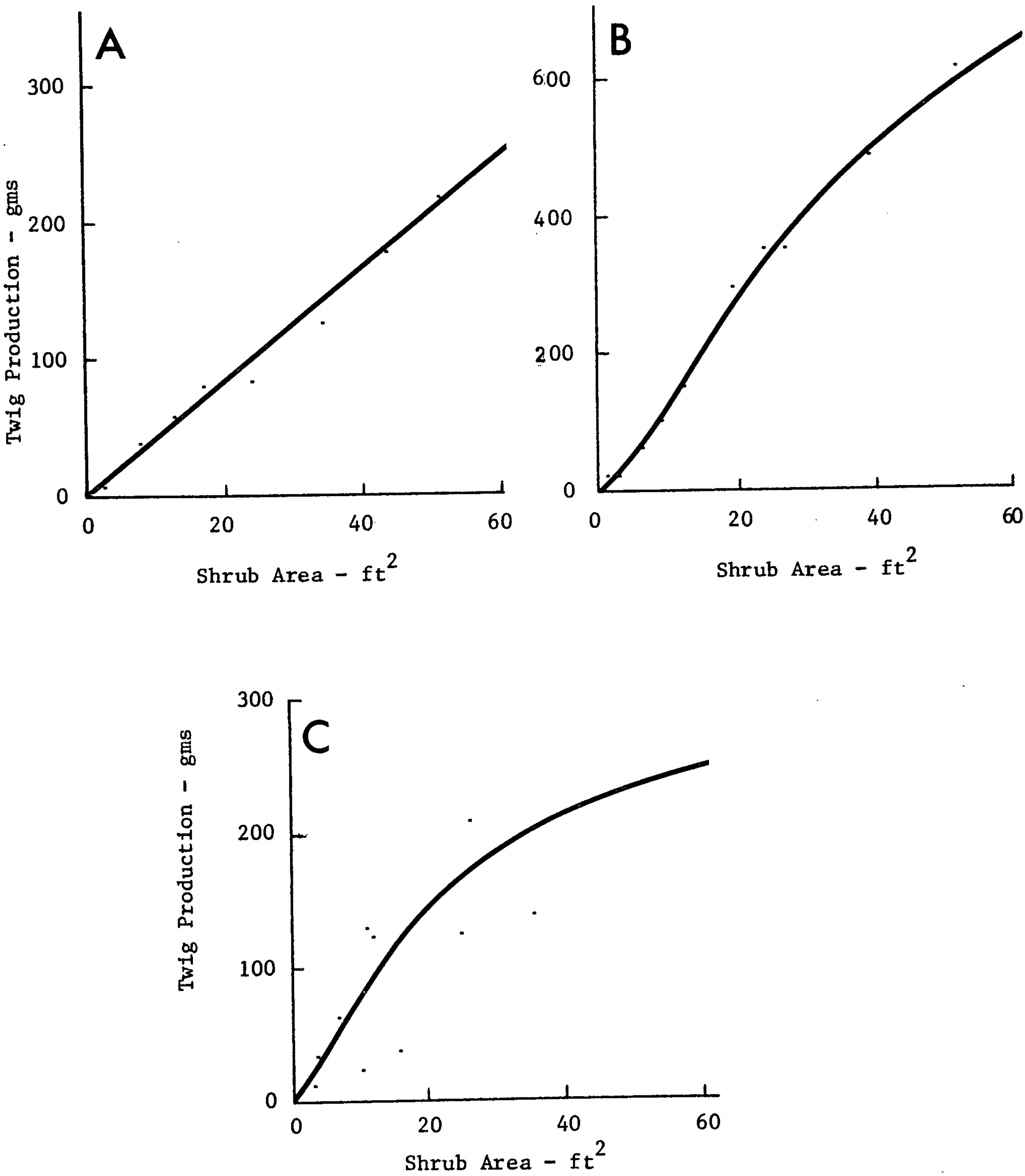


Figure 18. Relationship between weight of annual twig production and shrub area. A: *Amelanchier* B: *Ceanothus* C: *Symphoricarpos*

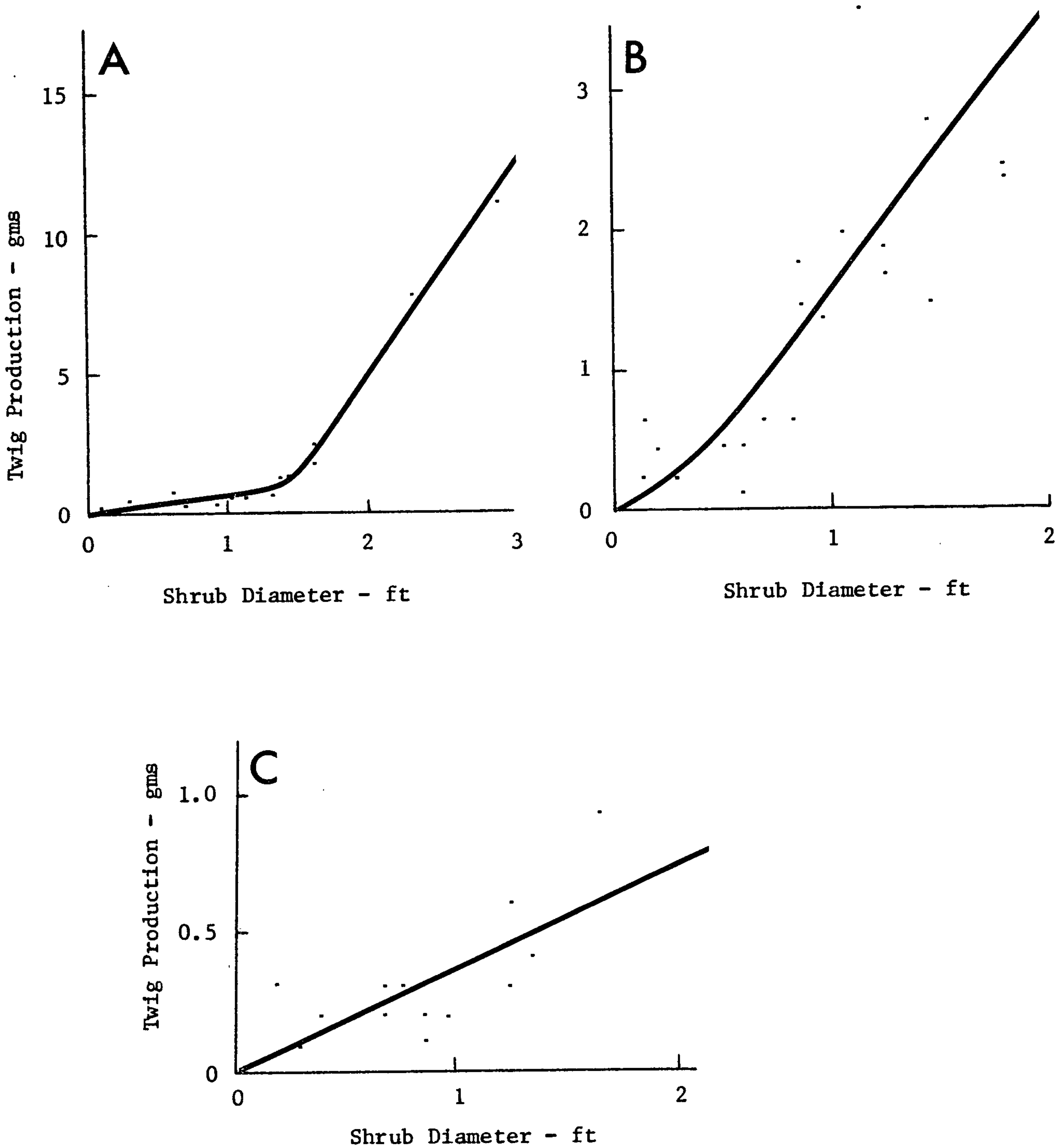


Figure 19. Relationship between weight of annual twig production and shrub diameter. A: Prunus B: Rosa C: Symphoricarpos

Shepherdia

$$WT = 250 - (254.92)((1 - Area/100)^{4.1}) \quad \text{gms} \tag{24}$$

where: No. of Obs. = 10

R^2 = 0.580

SE_E = 36.27 gms

Prunus

if $D \leq 1.37$

$$WT = 0.4 + (0.6)(D) \quad \text{gms} \tag{25}$$

if $D > 1.37$

$$WT = -8.8 + (7.1)(D) \quad \text{gms} \tag{26}$$

where: No. of Obs. = 20

R^2 = 0.995

SE_E = 0.221 gms

Rosa

$$WT = 0.1 + (1.4)(D^{1.5}) \quad \text{gms} \tag{27}$$

where: No. of Obs. = 20

R^2 = 0.527

SE_E = 1.078 gms

Symphoricarpos

$$WT = (0.4)(D) \quad \text{gms} \tag{28}$$

where: No. of Obs. = 20

R^2 = 0.503

SE_E = 0.119 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

$$CAG = a\,TANH(Cb)$$

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,

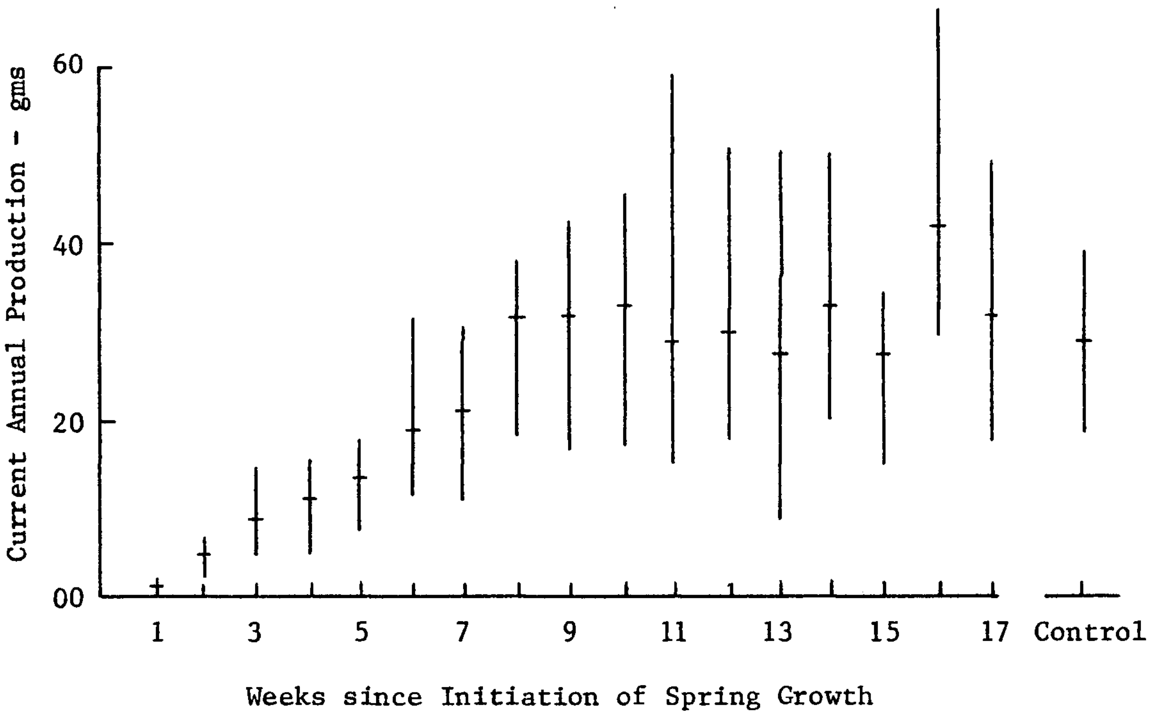


Figure 20. Current annual growth of Agropyron by weekly intervals.

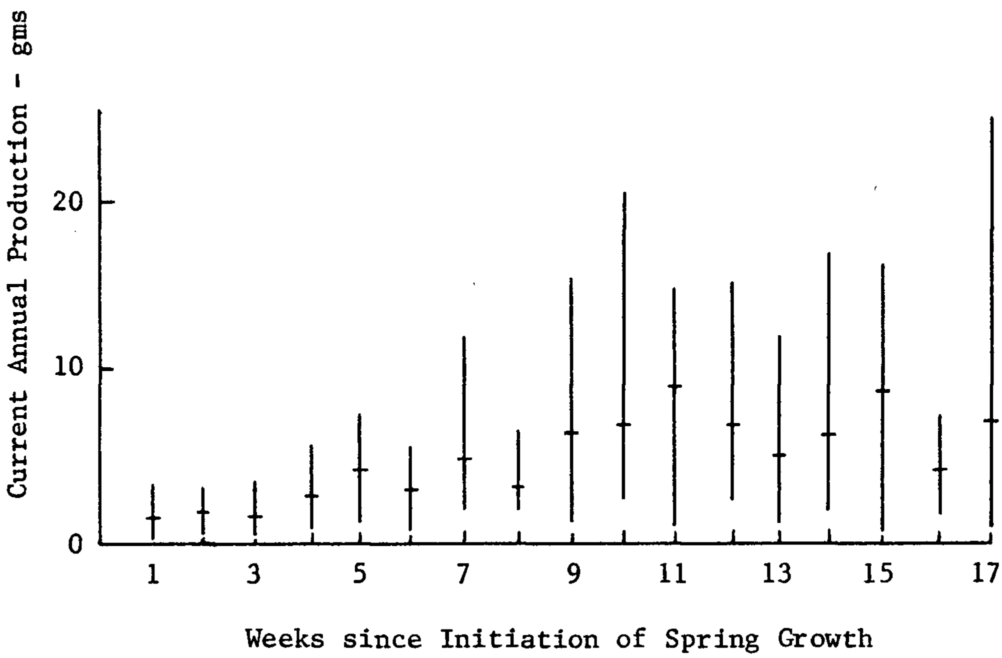
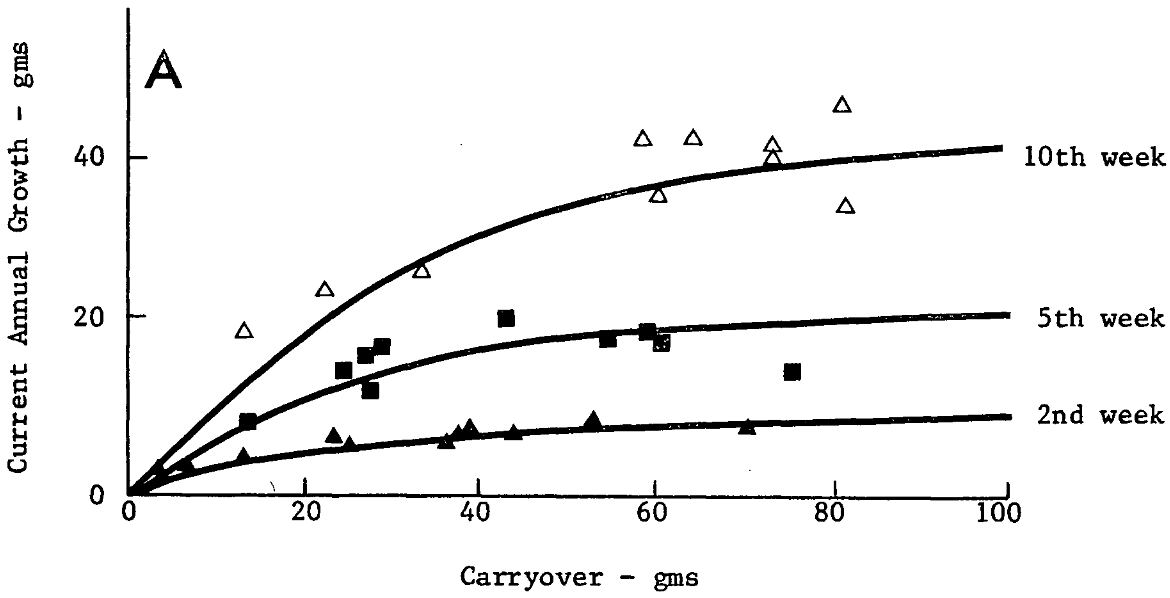


Figure 21. Current annual production of forbs by weekly intervals.



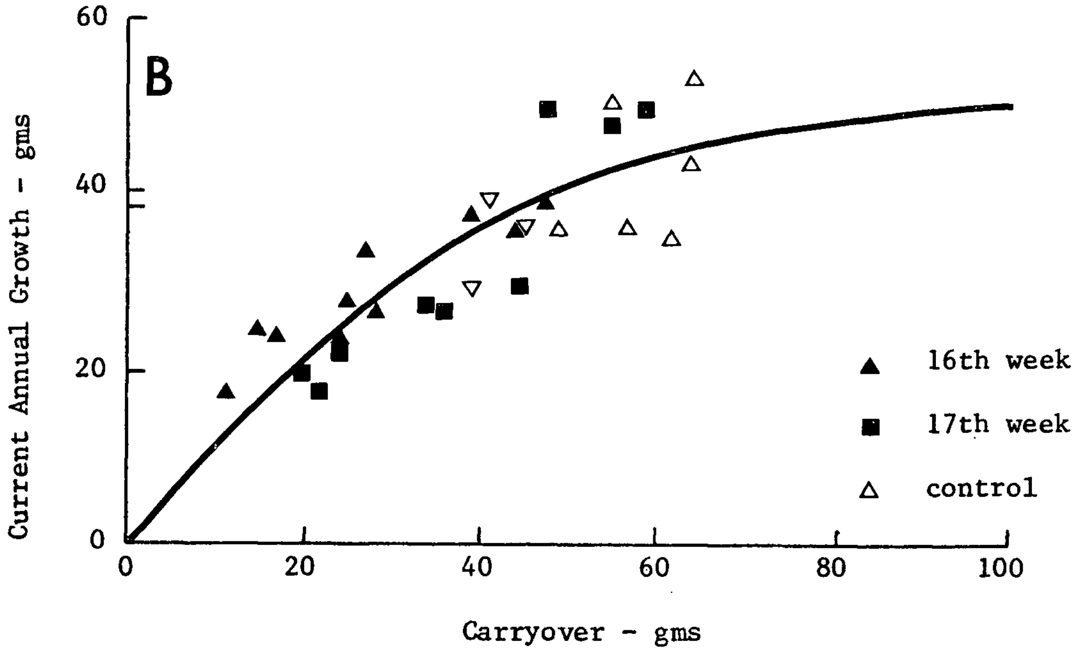


Figure 22. Selected relationships between current annual growth and carryover for Agropyron. A: Production for weeks 2, 5 and 10 B: Production for weeks 16 and 17 and the control plots

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

$$a = (2.833)(\text{Week}^{1.2}) \qquad (29)$$

if Week 9

$$a = 38 + (11)\text{TANH}((\text{Week} - 9)(0.43)) \qquad (30)$$

variable 'b'

$$b = 0.037 - (0.016)(\text{TANH}((\text{Week})(0.13))) \qquad (31)$$

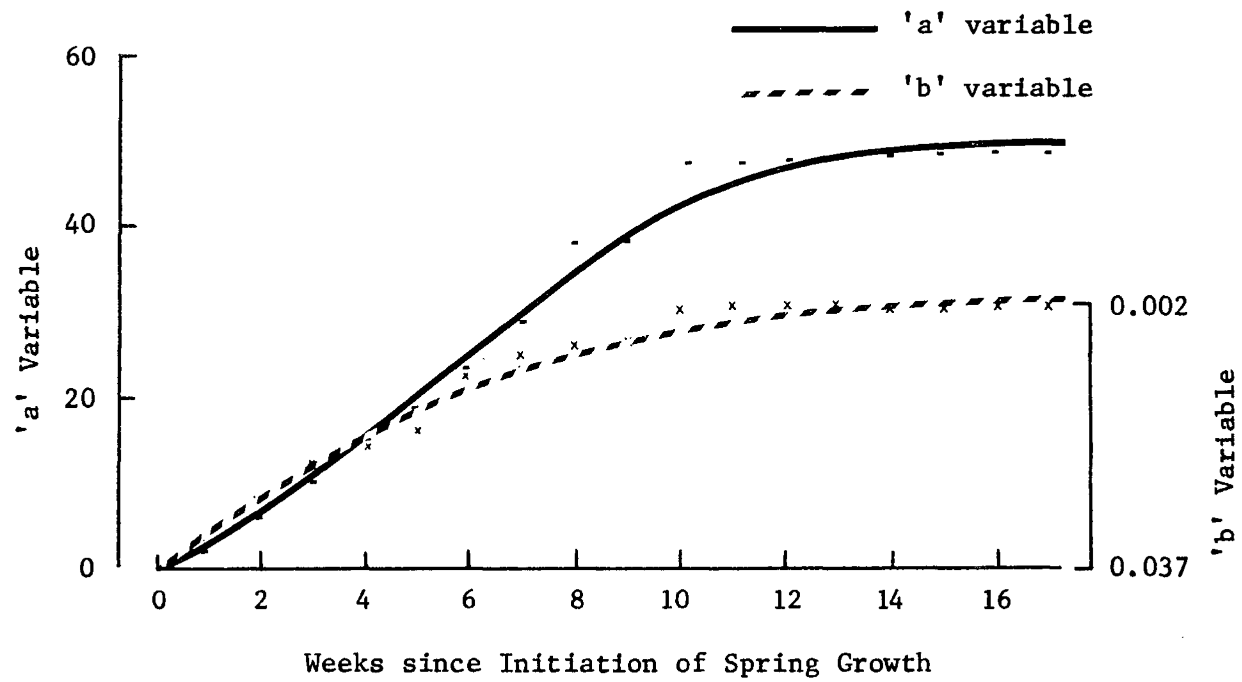


Figure 23. Plot of the 'a' and 'b' variables from the equation CAG = aTANH(Çb) expressed as a function of weeks since the initiation of spring growth.

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.

if Week _ 9

$$CAG = ((2.833)(Week^{1.2}))TANH((C)(0.037 - (0.016)(TANH((Week)(0.13))))) \quad gms \qquad (32)$$

if Week 9

$$CAG = (38 + (11)TANH((Week - 9)(0.43))TANH((C)(0.037 - (0.016)(TANH((Week)(0.13))))) \quad gms \qquad (33)$$

In applying these equations to grass species other than *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 *Agropyron spicatum*, *Poa compressa* and *scabrella*, *Festuca idahoensis*, *Stipa columbiana*, *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 $1\frac{1}{2}$ 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 fron 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

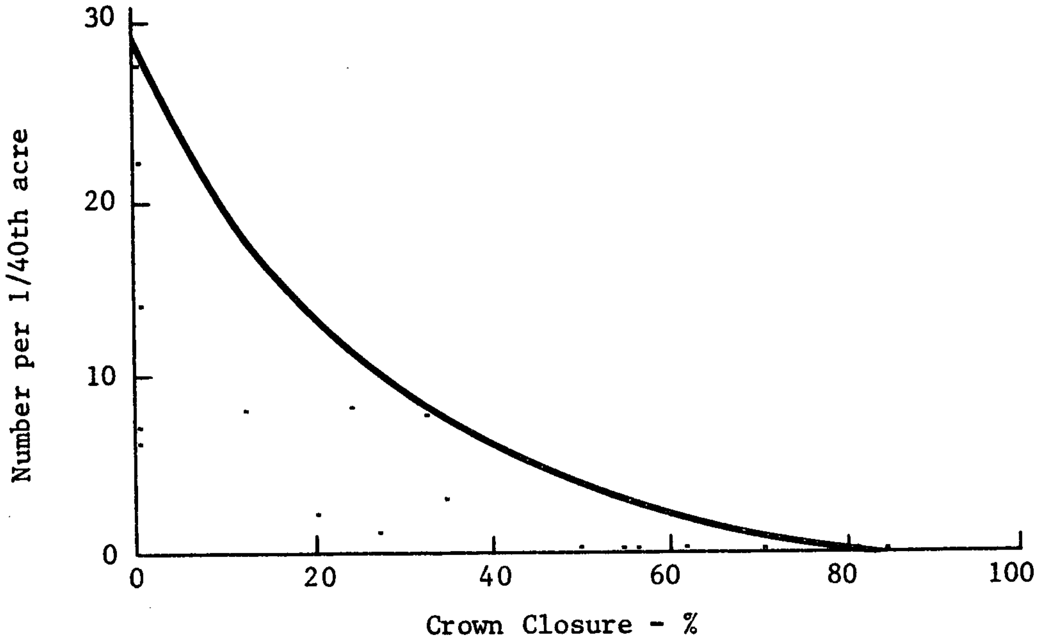


Figure 24. Relationship between number of Ceanothus and crown closure of trees.

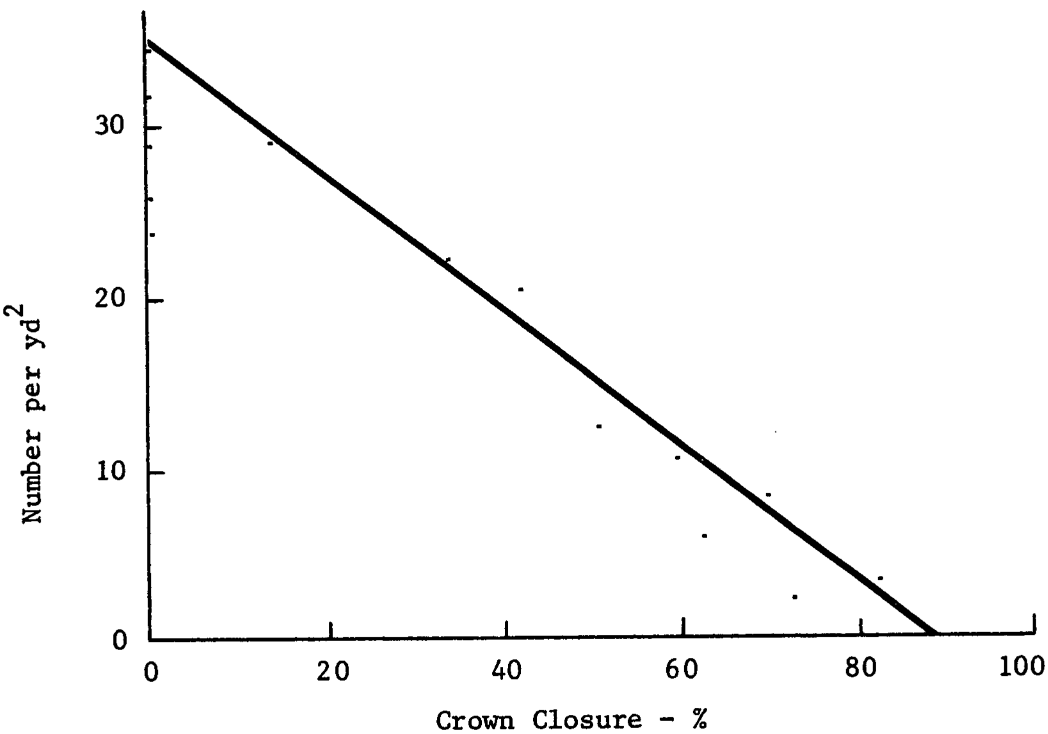


Figure 25. Relationship between number of Symphoricarpos and crown closure of trees.

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.

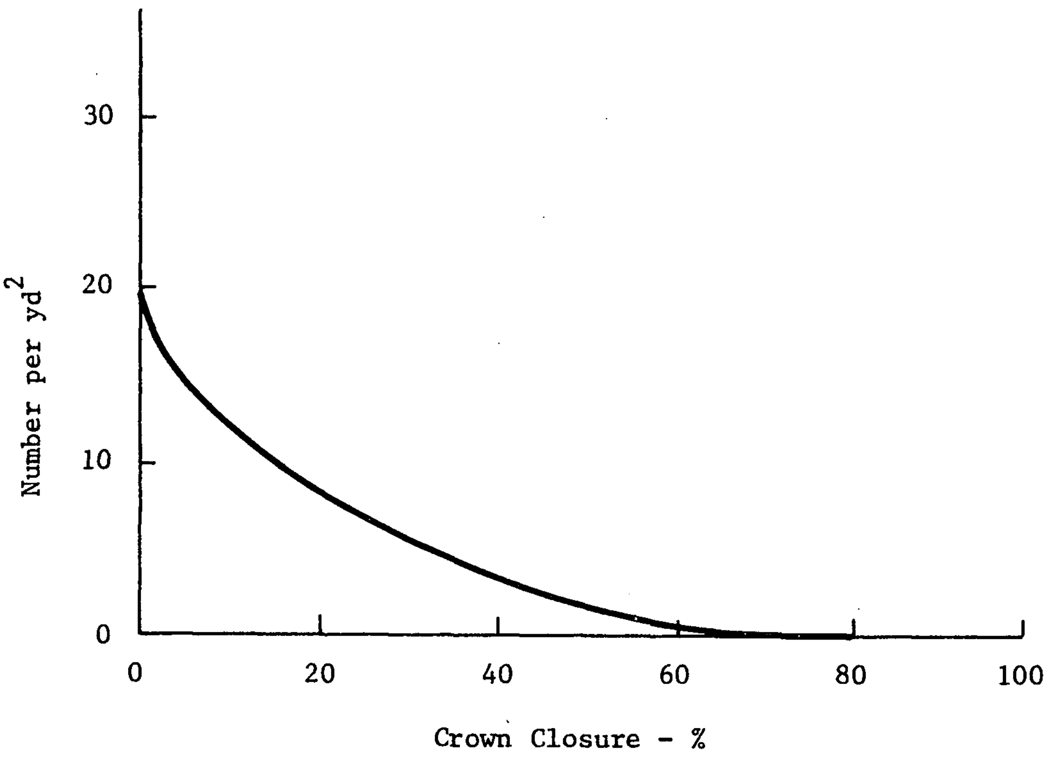


Figure 26. Theoretical relationship between number of Prunus and Rosa and crown closure of trees.

Ceanothus (Applied to Amelanchier and Shepherdia)

if CC $\leq$ 75%

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

if CC > 75%

$$N = 0.0 \qquad (35)$$

where: No. of Obs. = 20

N = number of individuals

Symphoricarpos

if CC $\leq$ 90%

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

if CC > 90%

$$N = 0.0 \qquad (37)$$

where: No. of Obs. = 60

Prunus and Rosa (Theoretical)

if CC $\leq$ 65%

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

if CC > 65%

$$N = 0.0 \qquad (39)$$

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.

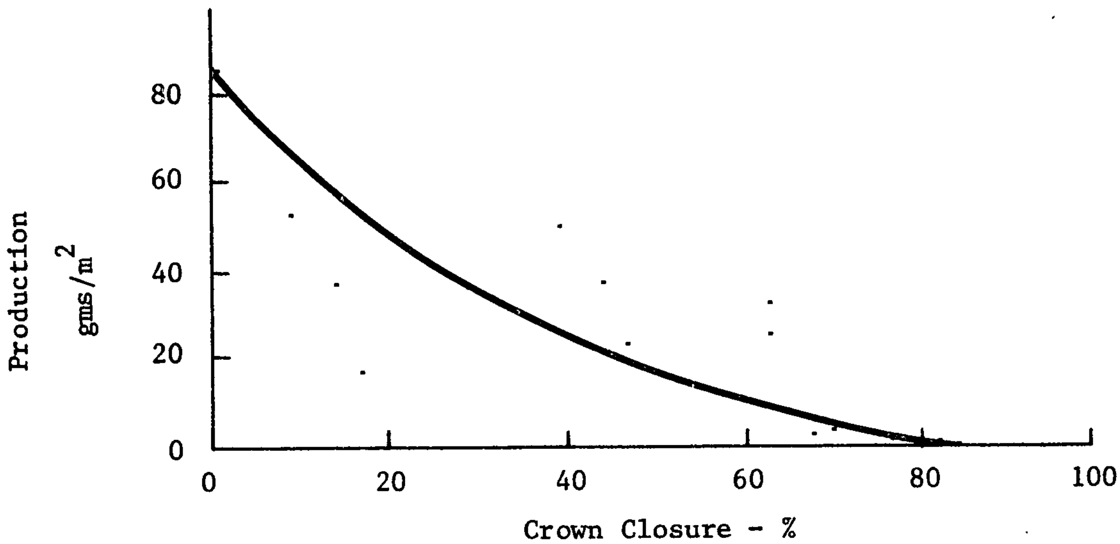


Figure 27. Relationship between <u>Agropyron</u> production and crown closure of trees.

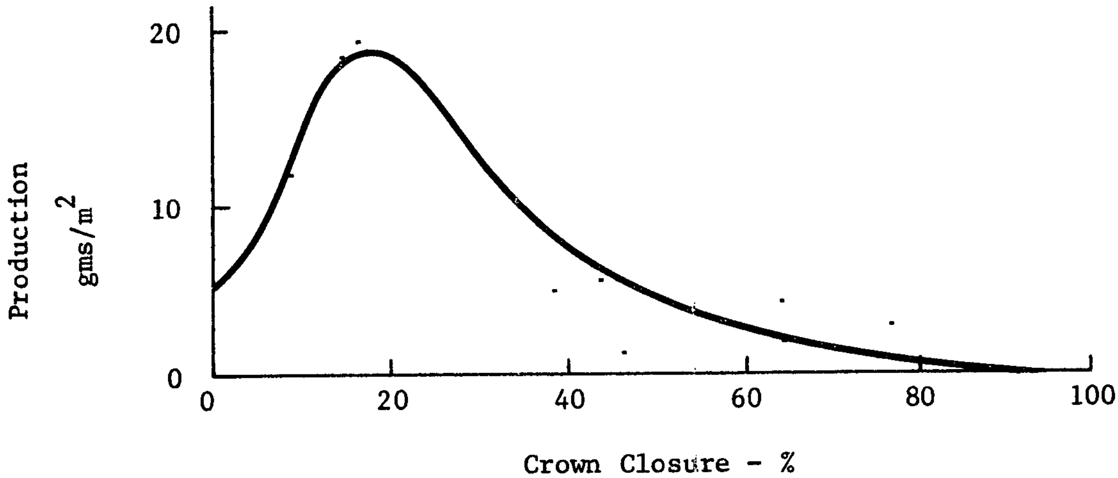


Figure 28. Relationship between forb production and crown closure of trees.

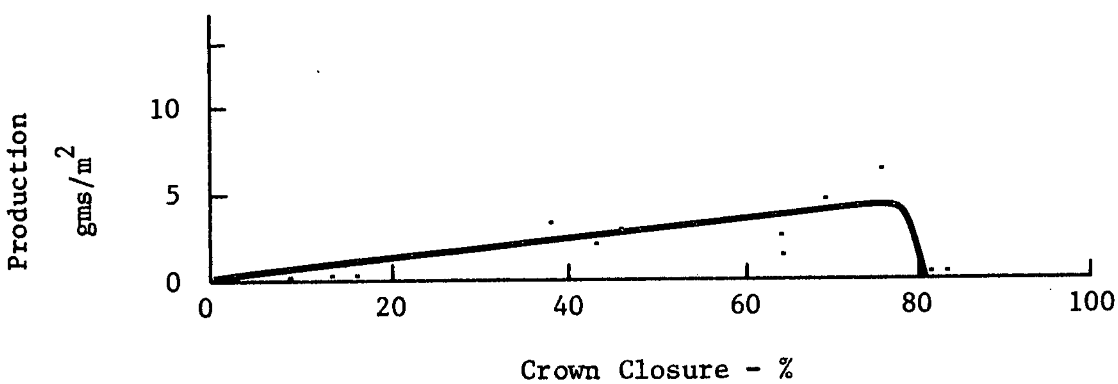


Figure 29. Relationship between combined <u>Calamagrostis</u>, <u>Koeleria</u> and <u>Bromus</u> production and crown closure of trees.

<u>Agropyron</u>

if CC $\leq$ 85%

$$WT = (0.2353)(85 - CC) + (63.3)((1 - CC)^2) \quad gms/m^2 \qquad (40)$$

if CC > 85%

$$WT = 0.0 \quad gms/m^2 \qquad (41)$$

where: No. of Obs. = 120

R^2 = 0.706

SE_E = 13.39 gms/m^2

<u>Koeleria</u>, <u>Calamagrostis</u> and <u>Bromus</u>

if CC $\leq$ 80%

$$WT = (0.05625)(CC) \quad gms/m^2 \qquad (42)$$

if CC > 80%

$$WT = 0.0 \quad gms/m^2 \qquad (43)$$

where: No. of Obs. = 120

R^2 = 0.50-

SE_E = 1.219 gms/m^2

Forbs

if CC $\leq$ 18.75%

$$WT = 10(SIN(CC(\Pi/28) - \Pi/6) + 1) \quad gms/m^2 \qquad (44)$$

if CC > 18.75

$$WT = 0.5 + (18/60^{2.7})((100 - CC)^{2.52}) \quad gms/m^2 \qquad (45)$$

where: No. of Obs. = 120

R^2 = 0.505

SE_E = 4.606 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).

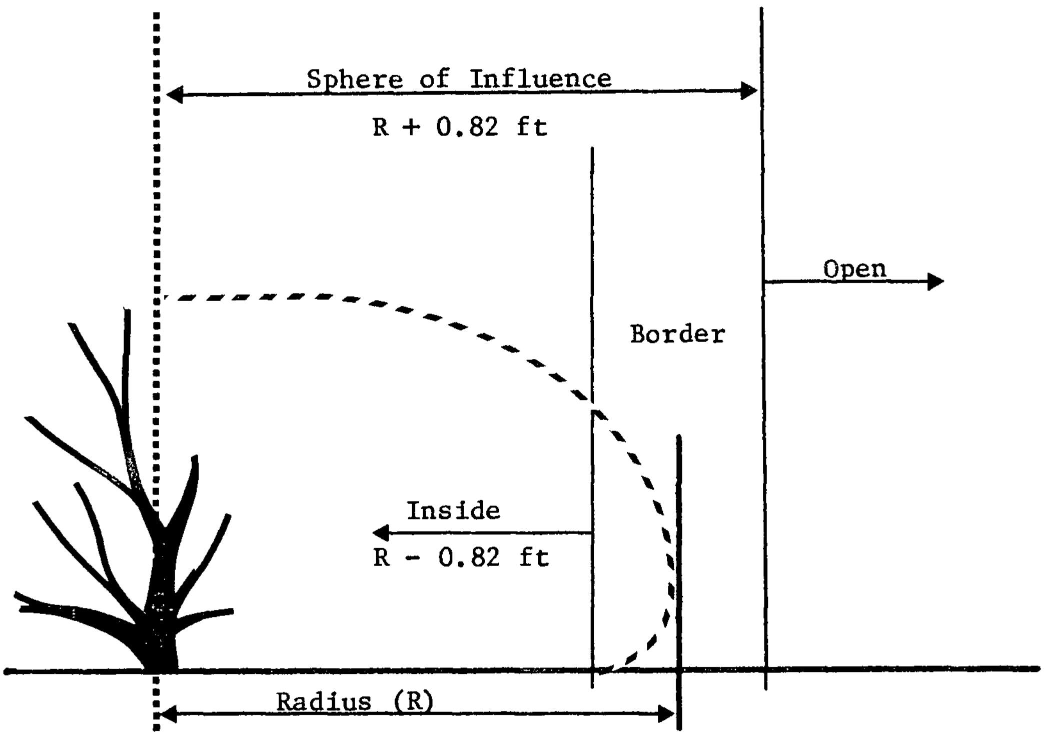


Figure 30. Definition of zones of influence for large shrub species.

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.

SHRUB SPECIES	# of Shrubs examined	Position	Production as % of open	
			Poa	Forbs
Amelanchier	10	Open	100	100
		Border	68.5	106.3
		Inside	13.4	53.9
			Poa	Forbs
Ceanothus	10	Open	100	100
		Border	89.5	46.5
		Inside	13.7	77.0
			Agropyron	Forbs
Shepherdia	7	Open	100	100
		Border	136.5	30.6
		Inside	1.8	20.6

Agropyron

if $N \leq 14$

$$WT = (PDN/85)(3 + (0.13334)(15 - N) + (0.0918)((15 - N)^{2.5})) \quad gms/yd^2 \qquad (46)$$

if $N > 14$

$$WT = (0.0353)(PDN) \quad gms/yd^2 \qquad (47)$$

where: No. of Obs. = 10

R^2 = 0.898

SE_E = 7.15 gms/yd^2

N = number of Prunus

PDN = Agropyron production in absence of Prunus

Forbs

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

where: No. of Obs. = 10

R^2 = 0.580

SE_E = 5.06 gms/yd^2

N = number of Prunus

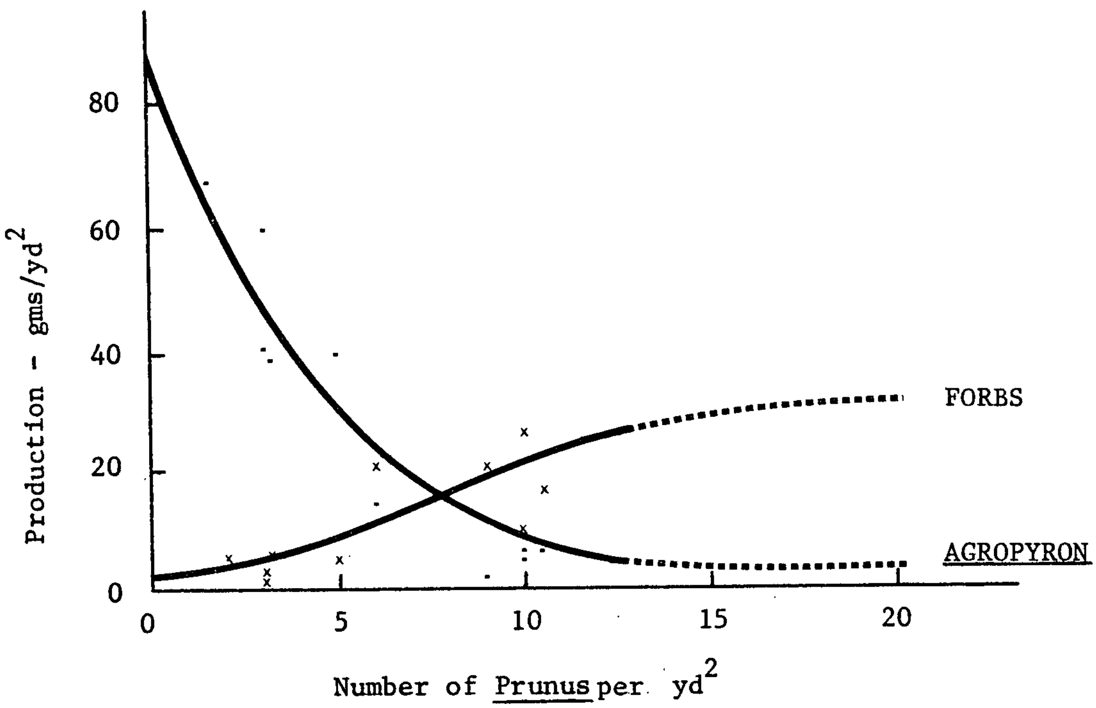


Figure 31. Response of Agropyron and forb production to Prunus density.

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 bypassing 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:

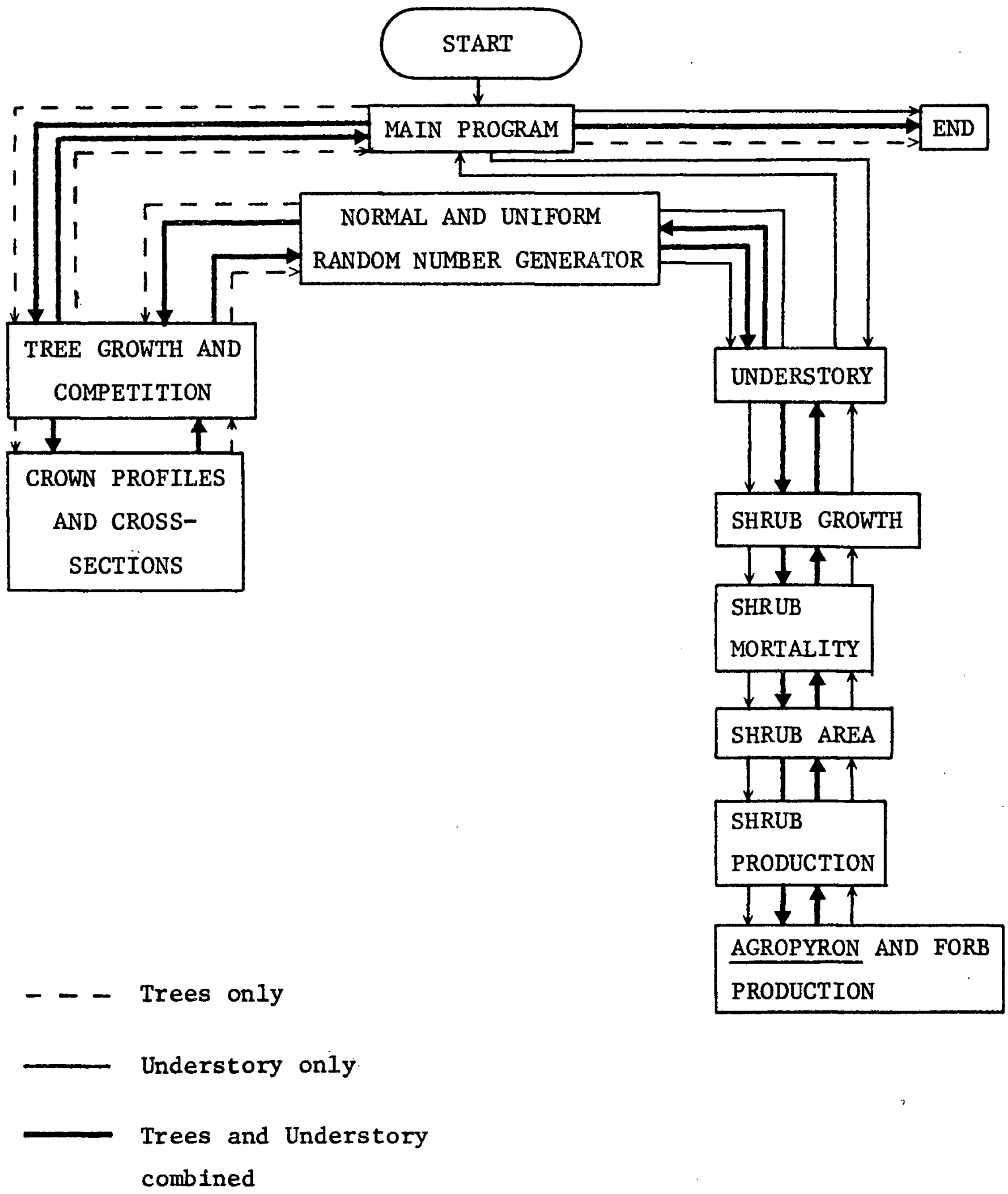


Figure 32. Flow chart of subroutines showing optional pathways.

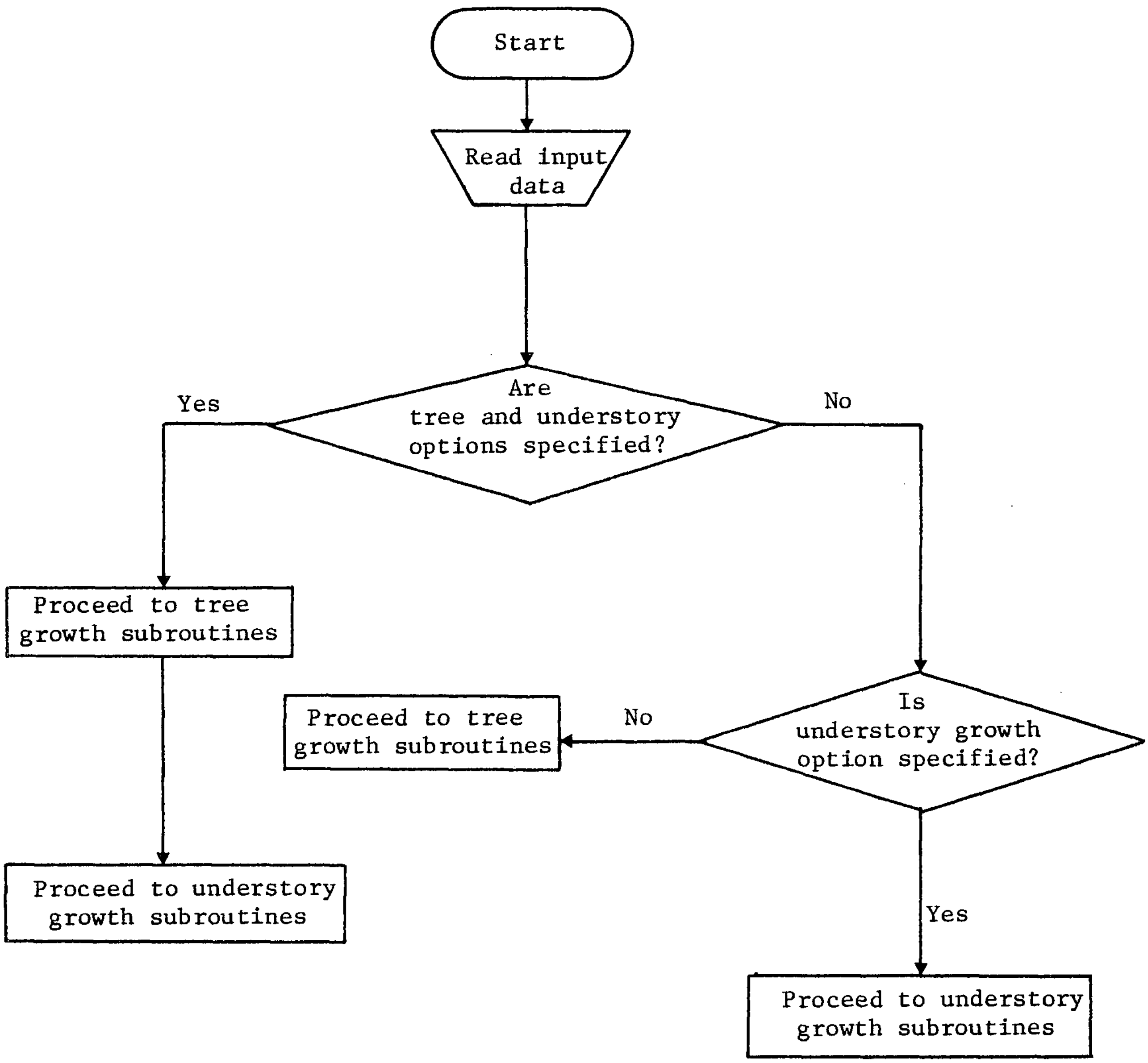


Figure 33. Simplified flow chart of the main program showing its control over optional pathways through the model.

(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.

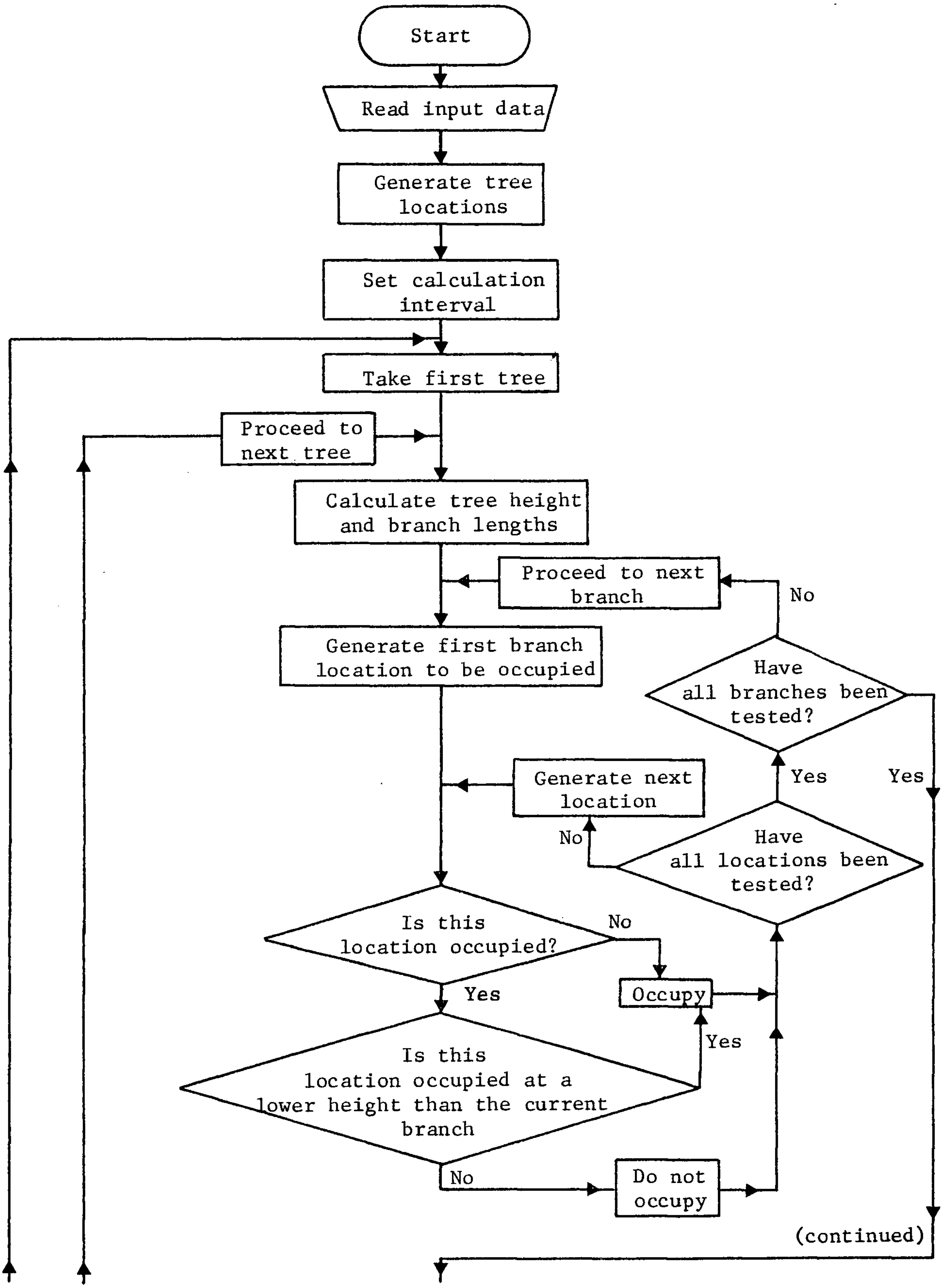
(3) Computation - Differential mortality and crown diameter growth for small shrub species.

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
No
Generate first branch location to be occupied
Have all branches been tested?
Yes
Yes
Generate next location
No
Have all locations been tested?
Is this location occupied?
No
Yes
Occupy
Yes
Is this location occupied at a lower height than the current branch
No
Do not occupy
(continued)

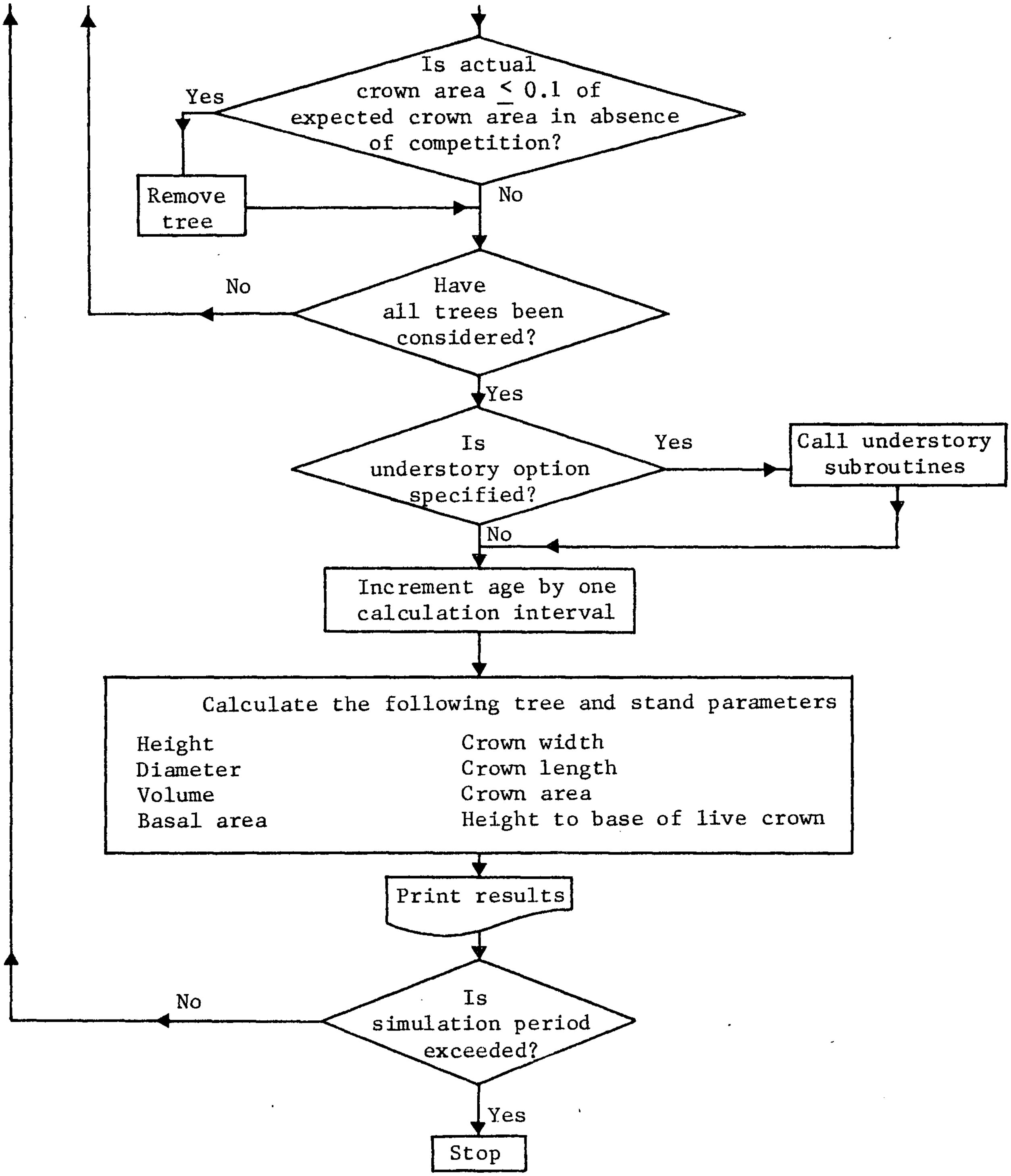


Figure 34. Simplified flow chart of tree-growth subroutines.

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 → 10

Height of occupancy in hundredths of feet → 0000

Individual plant, species and stem position (99 in this location indicates the location of the tree bole) → 00

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 (CAact) to expected crown area in the absence of competition (CAexp). If the ratio of CAact to CAexp 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

10000000	10000000	10000000	10000000	10000000	10000000	10000000
10000000	b 10000111	10000118	10000118	10000118	10000000	10000000
t 10000111	th 10008499 s	10013418	10013418	10013418	10000118	10000000
10000000	10000111	10013418	th 10044299 s	t 10013418	b 10000118	10000000
10000000	10000118	10013418	10013418	10013418	10000118	10000000
10000000	10000000	10000118	10000118	10000118	10000000	10000000
10000000	10000000	10000000	10000000	10000000	10000000	10000000

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

```
***********************************************************
*                                                         *
* B 1 1 1    2 2 2 B 2 2 2                           1 1 1*
* 1 1 1 1    2 2 2 2 2 2 2                           1 1 1*
* 1 1 1        2 2 2 2 2                               1 1*
* 1 1            2 2 2                                   1*
*                                    4 4 4                *
*                                4 4 4 4 4 4 4            *
*                                4 4 4 4 4 4 4            *
*                              4 4 4 4 4 4 4 4 4          *
*                              4 4 4 4 B 4 4 4 4          *
*                              4 4 4 4 4 4 4 4 4          *
*                                4 4 4 4 4 4 4            *
*                                4 4 4 4 4 4 4            *
*                                  5 5 B 5 5              *
*                                    5 5 5                *
*                                      5                  *
*                                                         *
*                                                         *
*                                                         *
*                                3 3 3                    *
*                                3 B 3                    *
*                                3 3 3                    *
*                                                         *
*                                                         *
*                                                         *
* 1 1            2 2 2                                   1*
* 1 1 1        2 2 2 2 2                               1 1*
* 1 1 1 1    2 2 2 2 2 2 2                           1 1 1*
*                                                         *
***********************************************************
```

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.

(7) Crown closure for entire plot.

(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

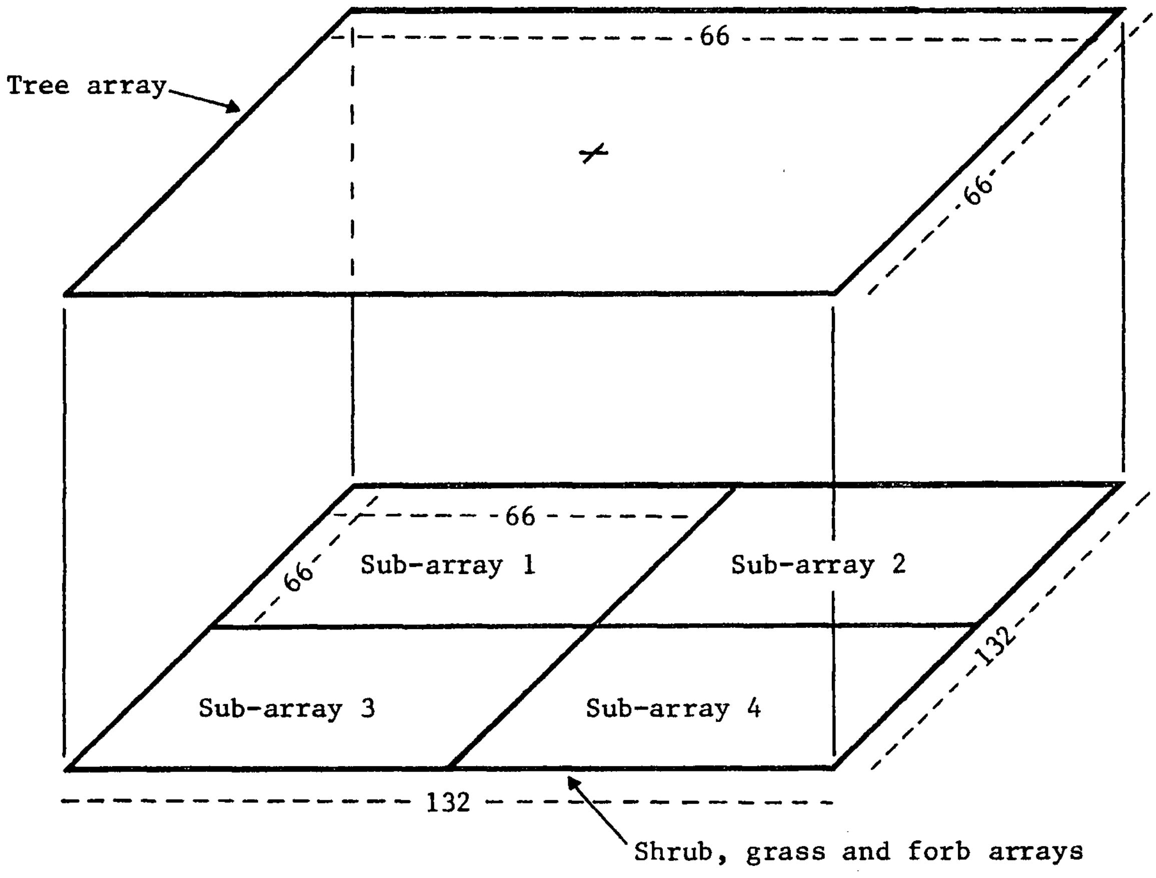


Figure 37. Arrangement of arrays showing relationship between tree and shrub, grass and forb arrays.

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.

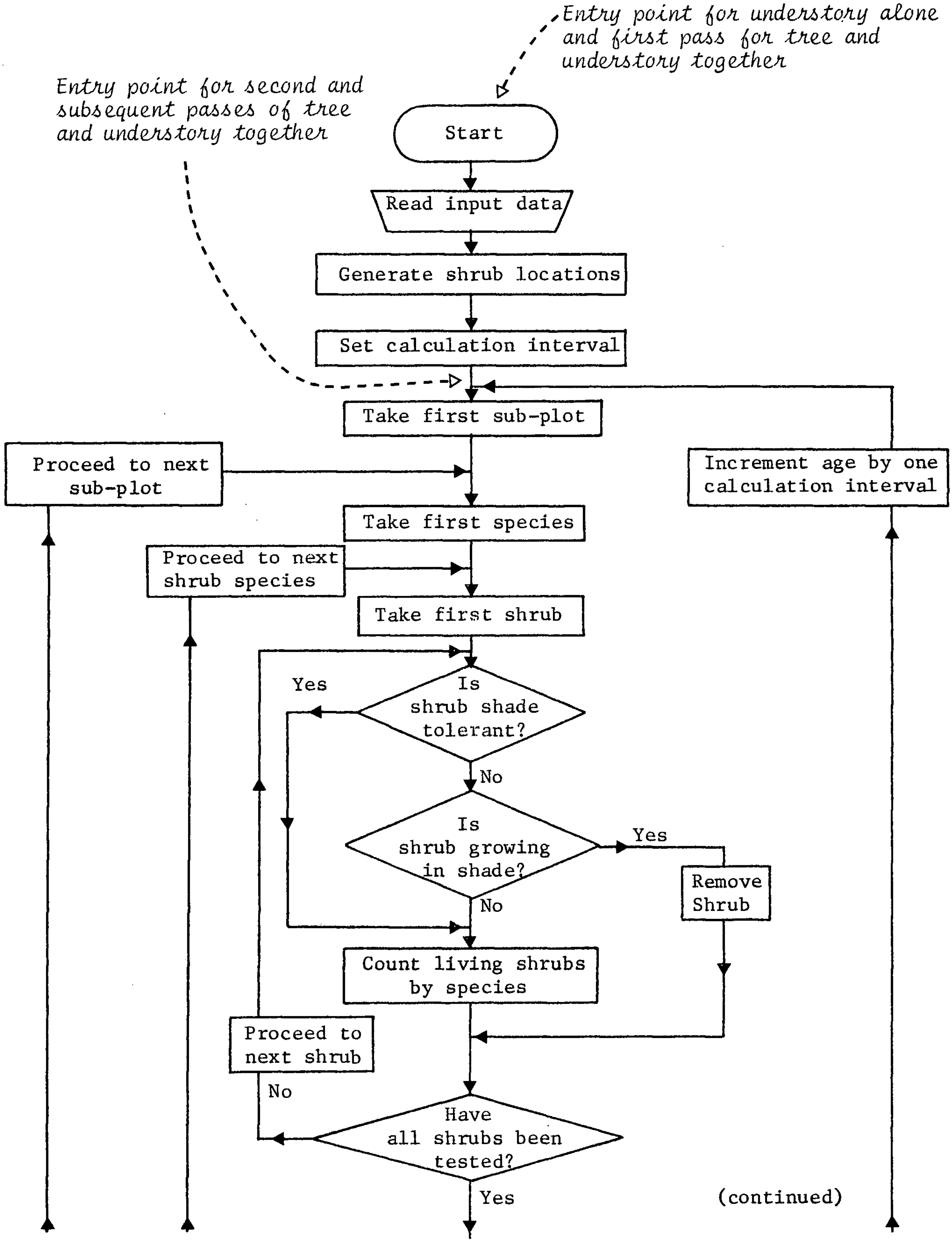
(5) Crown diameter of large shrub species is incremented and crowns are allowed to compete for aerial growing space.

(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.

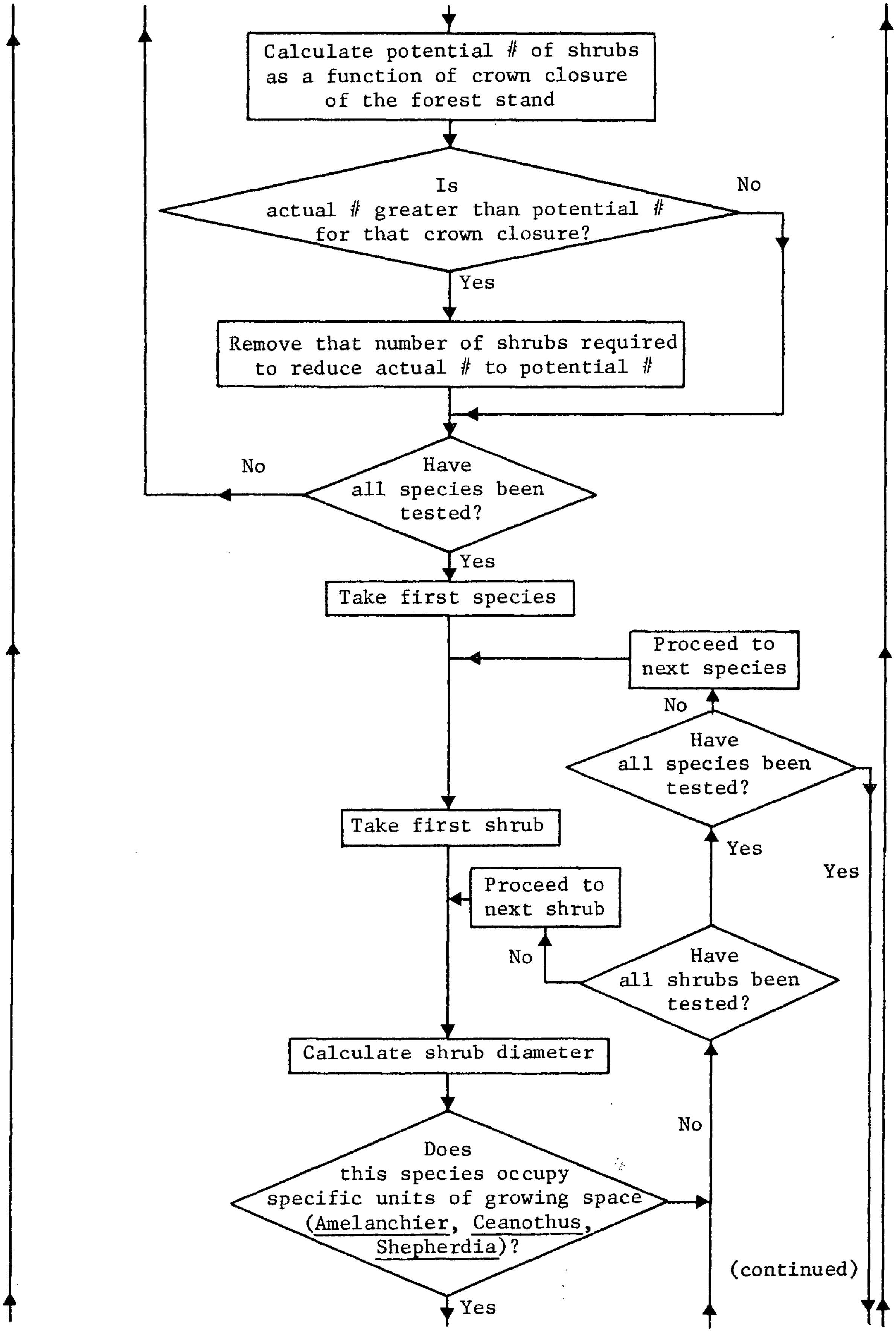
(7) Diameter, area and production are calculated for individual shrubs, and mortality by species, total number and production by species and the area occupied by trees, and large and small shrub species are summarized.

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

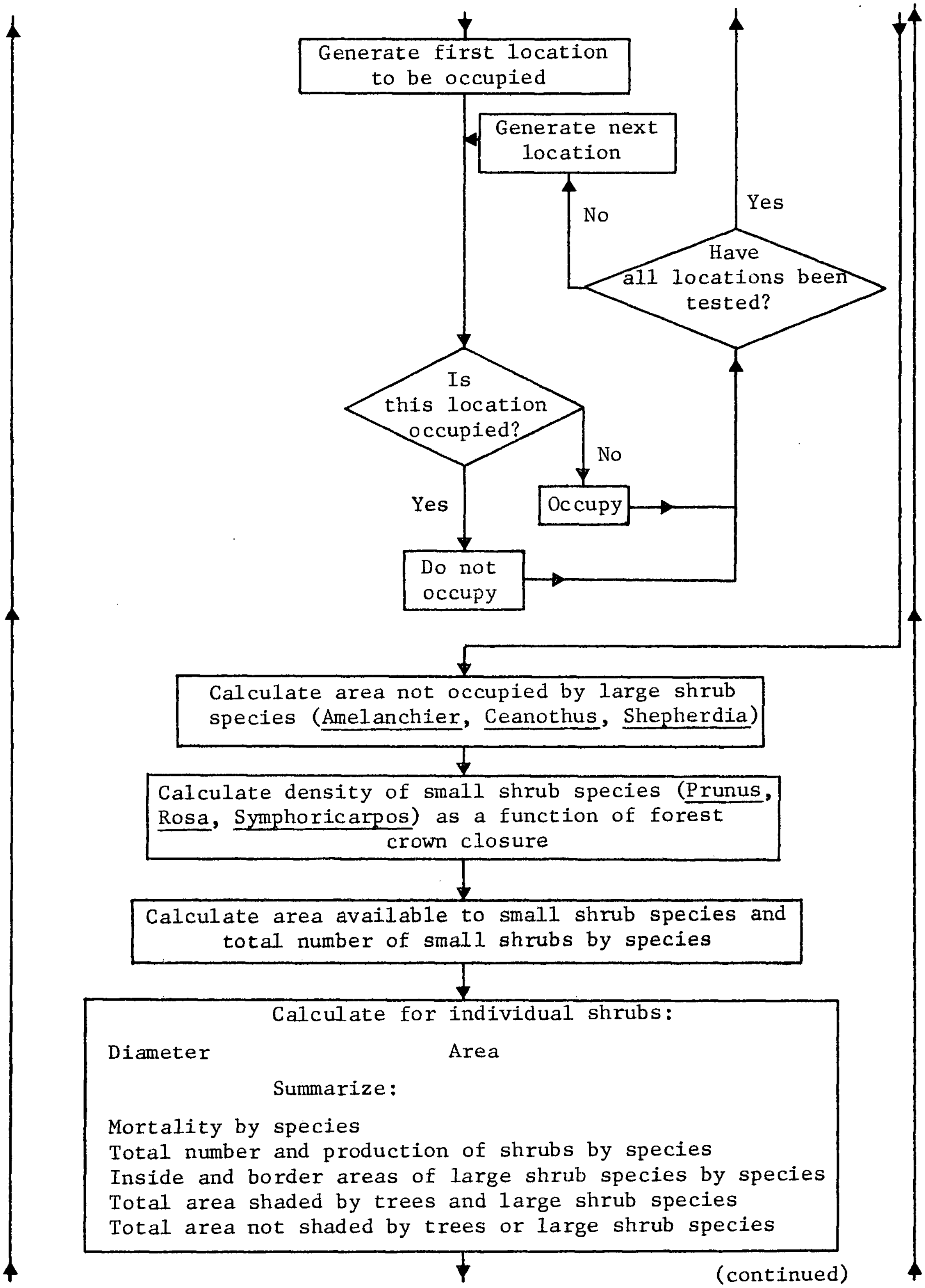
(9) Their production is then readjusted as a function of tree shading, location beneath large shrub species (i.e. border and inside areas) and density and age of small shrub species.


Entry point for understory alone and first pass for tree and understory together
Entry point for second and subsequent passes of tree and understory together
Start
Read input data
Generate shrub locations
Set calculation interval
Take first sub-plot
Proceed to next sub-plot
Increment age by one calculation interval
Take first species
Proceed to next shrub species
Take first shrub
Yes
Is shrub shade tolerant?
No
Is shrub growing in shade?
Yes
Remove Shrub
No
Count living shrubs by species
Proceed to next shrub
No
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?
No
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
Have all species been tested?
Take first shrub
Yes
Yes
Proceed to next shrub
No
Have all shrubs been tested?
Calculate shrub diameter
No
Does this species occupy specific units of growing space (Amelanchier, Ceanothus, Shepherdia)?
Yes

(continued)



Generate first location to be occupied
Generate next location
No
Yes
Have all locations been tested?
Is this location occupied?
No
Yes
Occupy
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)

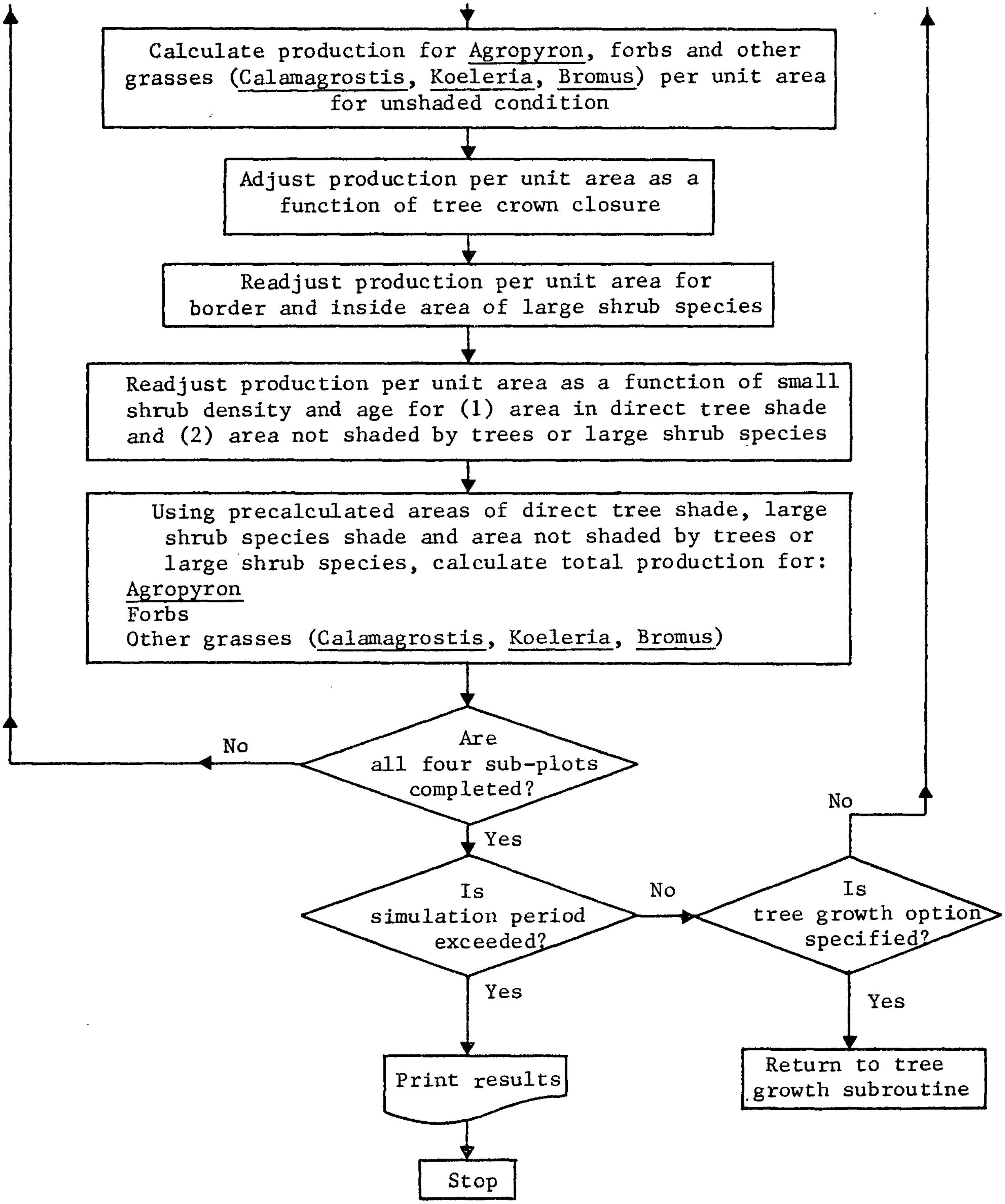


Figure 38. Simplified flow chart of shrub, grass and forb growth (understory subroutines).

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.

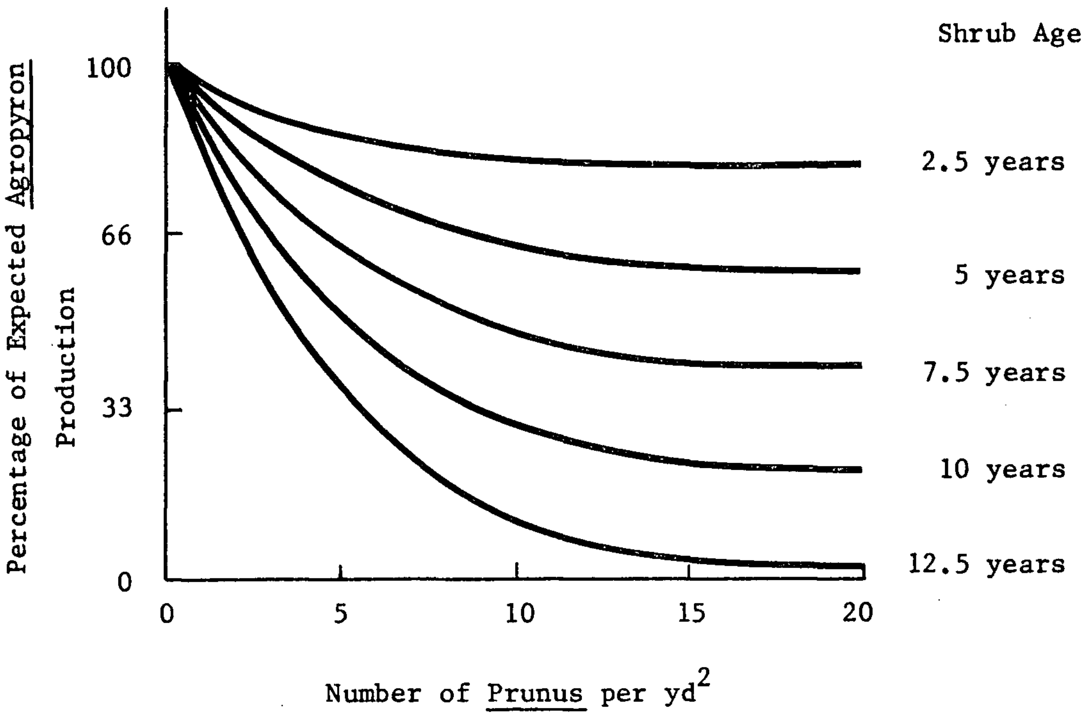


Figure 39. Relationship between *Agropyron* production and *Prunus* density by shrub age.

(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.

Parameter	Age					
	0	10	20	30	40	50
Crown closure - %	0	8.6	37.0	64.1	73.9	77.7
Agropyron production - kg/ha	475	223	180	156	10.7	3.6
Forb production - kg/ha	13.8	57.3	45.0	5.7	3.1	4.1
Calamagrostis and *Koeleria* production - kg/ha	0	1.6	7.2	16.5	19.1	20.0
No. of *Shepherdia* per ha	988	889	593	98	0	0
Shepherdia production - kg/ha	0	10.3	45.2	17.7	0	0
No. of *Prunus* per ha	95638	85363	28849	0	0	0
Prunus production - kg/ha	0	82.0	38.9	0	0	0

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).

2) Empirical testing (Naylor and Finger, 1967).

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 Windemere 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.

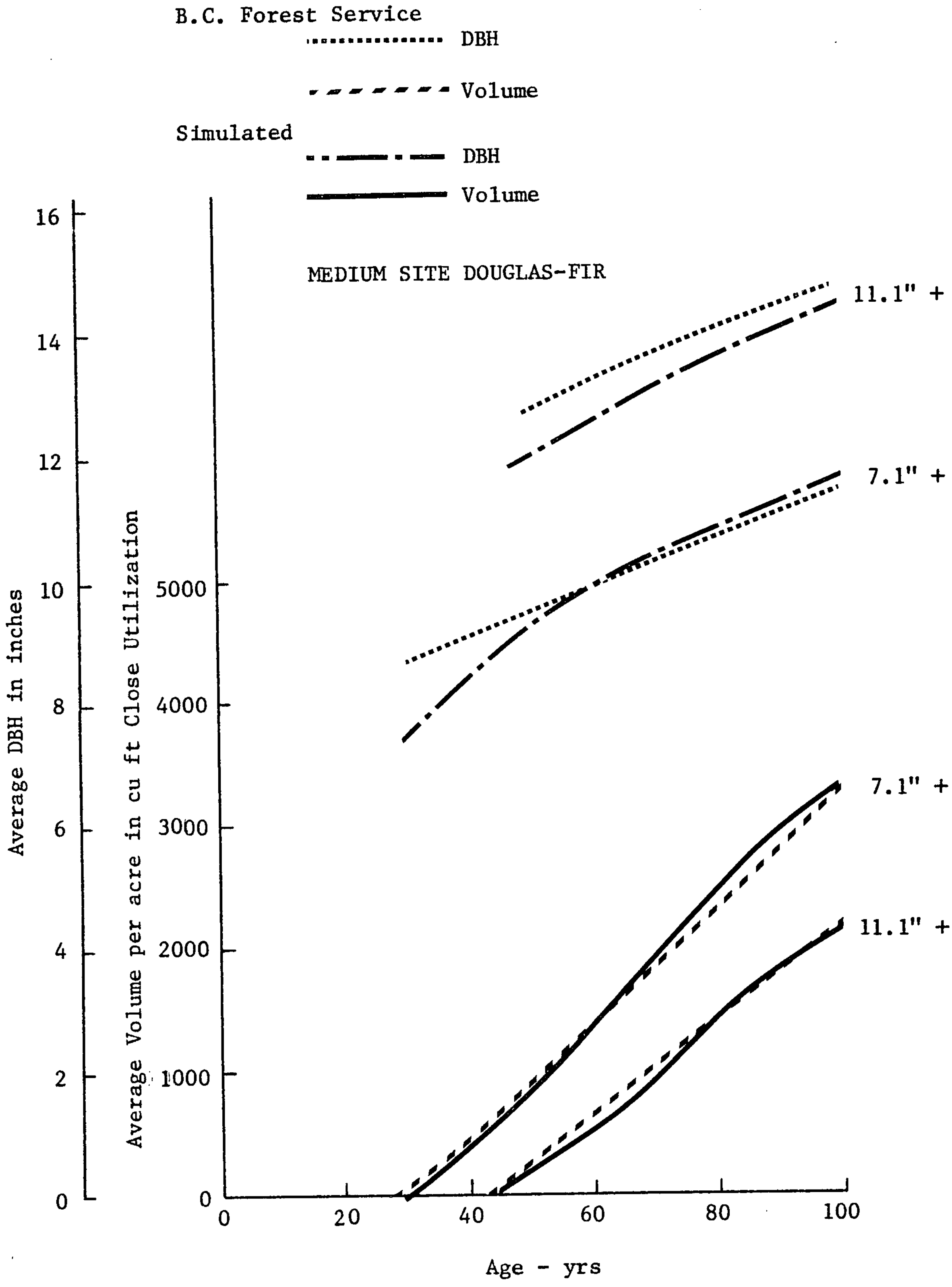


Figure 40. Comparison between simulated volume and DBH and B.C. Forest Service volume and DBH taken from V.A.C. 1012, medium site.

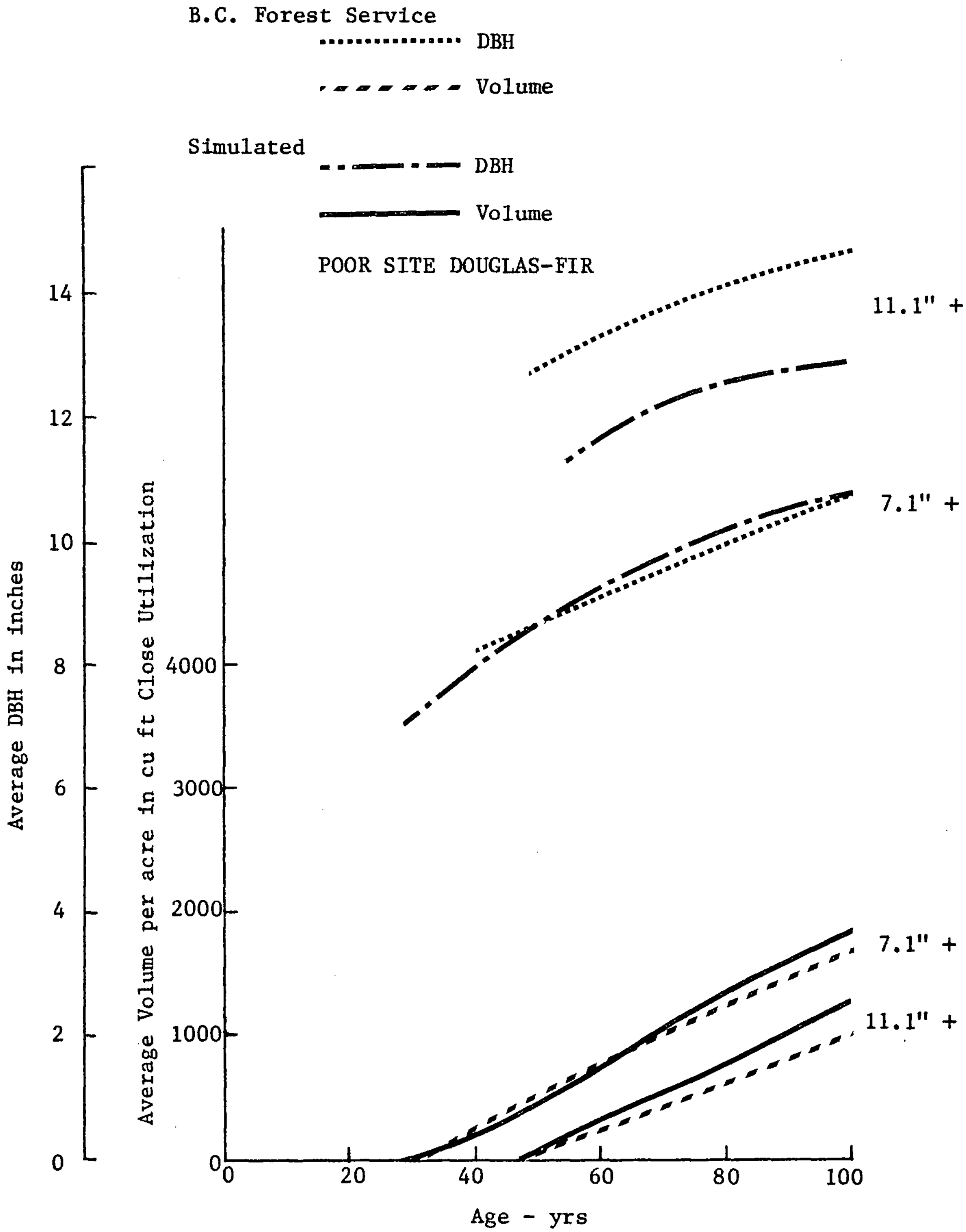


Figure 41. Comparison between simulated volume and DBH and B.C. Forest Service volume and DBH taken from V.A.C. 1013, poor site.

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.

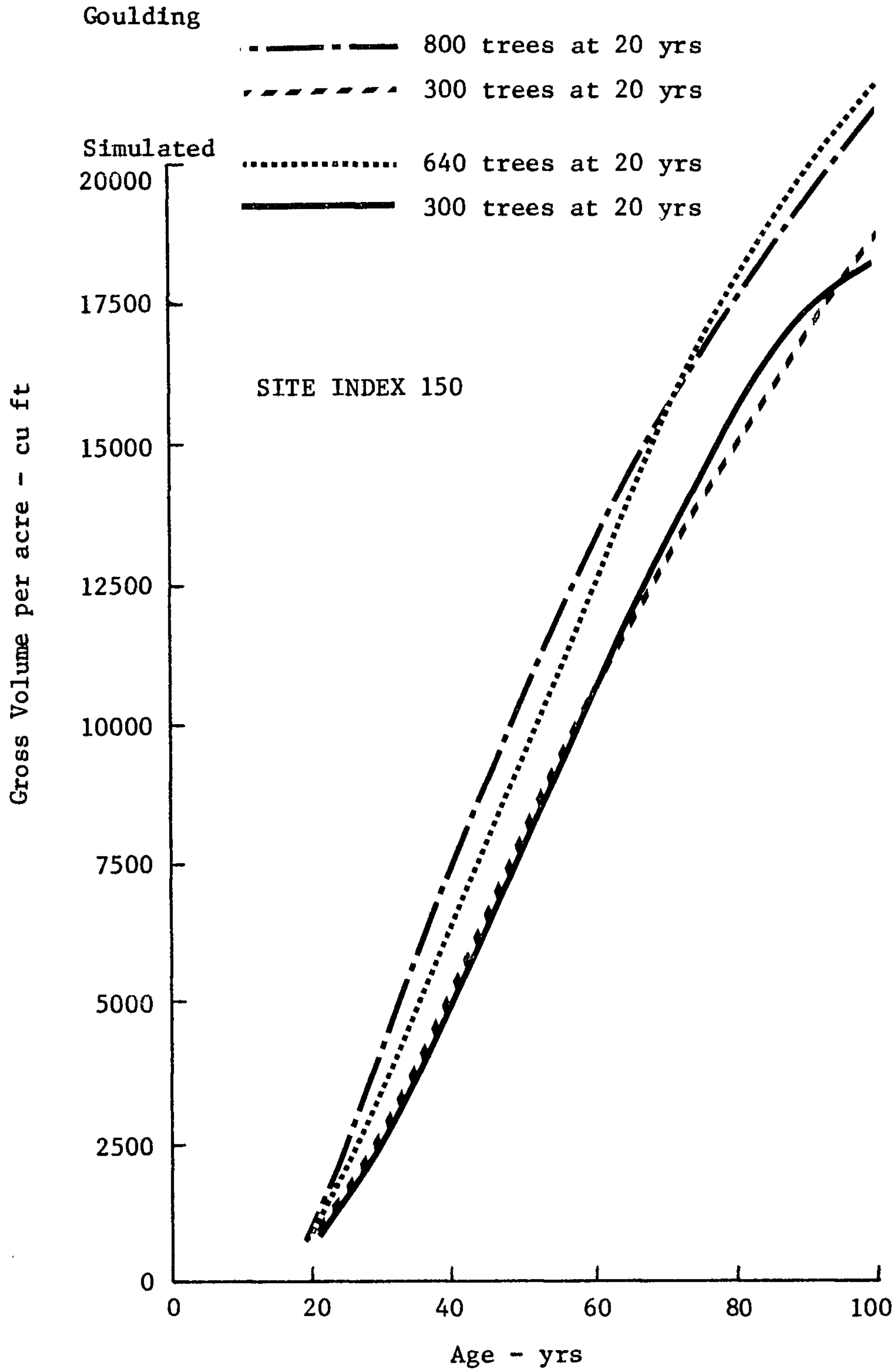


Figure 42. Comparison of Goulding's and my simulated gross cubic foot volume per acre for site index 150.

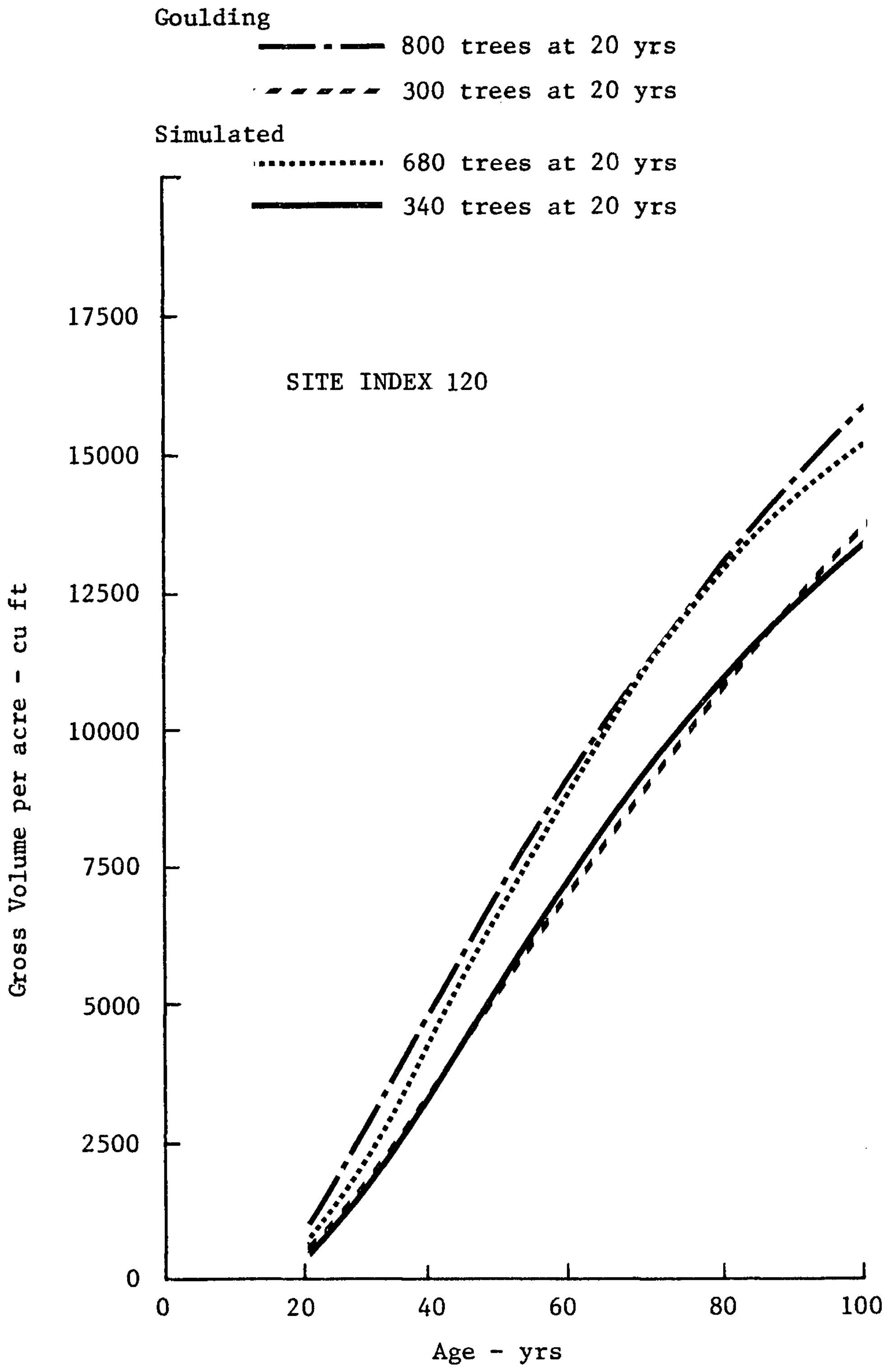


Figure 43. Comparison of Goulding's and my simulated gross cubic foot volume per acre for site index 120.

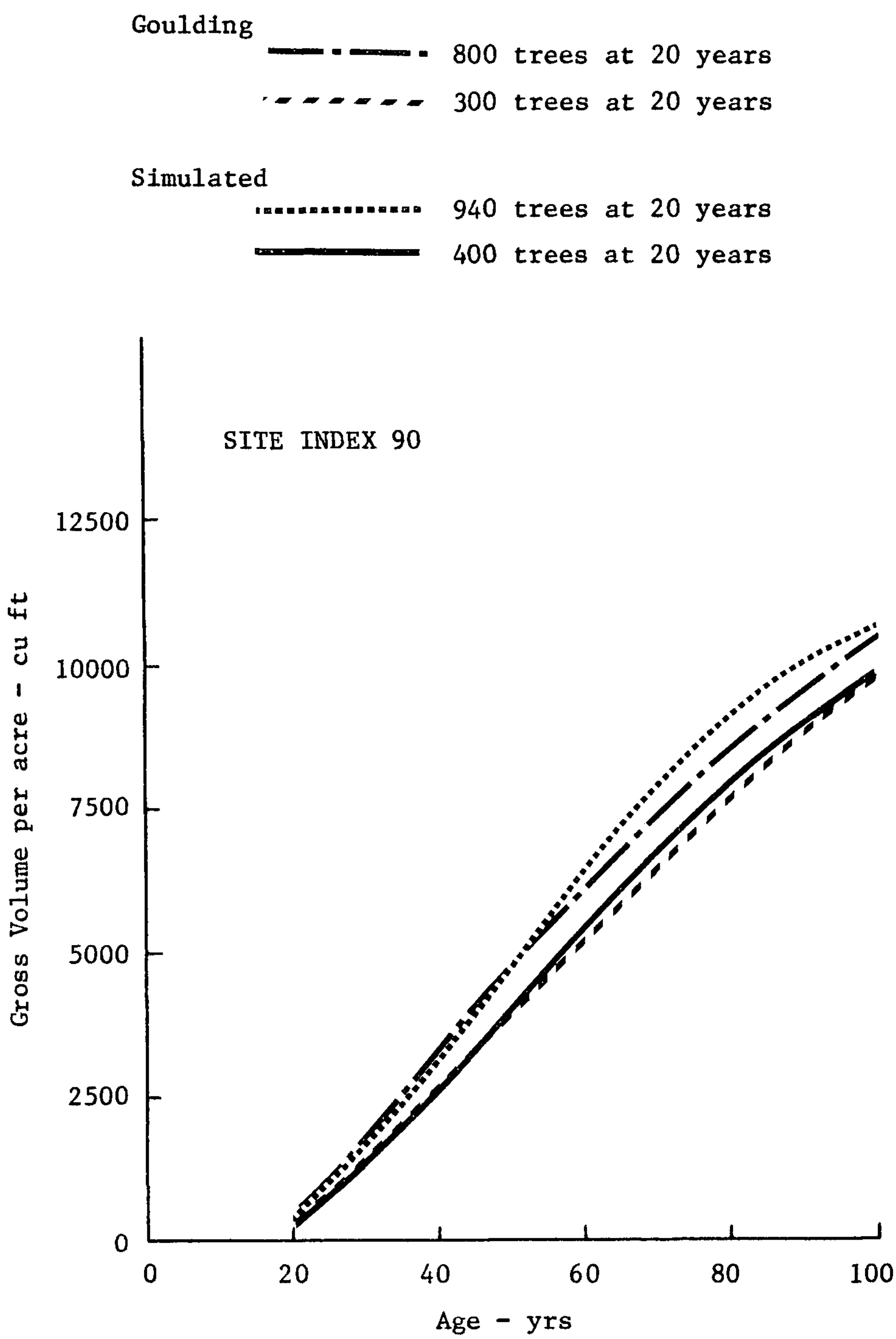


Figure 44. Comparison of Goulding's and my simulated gross cubic foot volume per acre for site index 90.

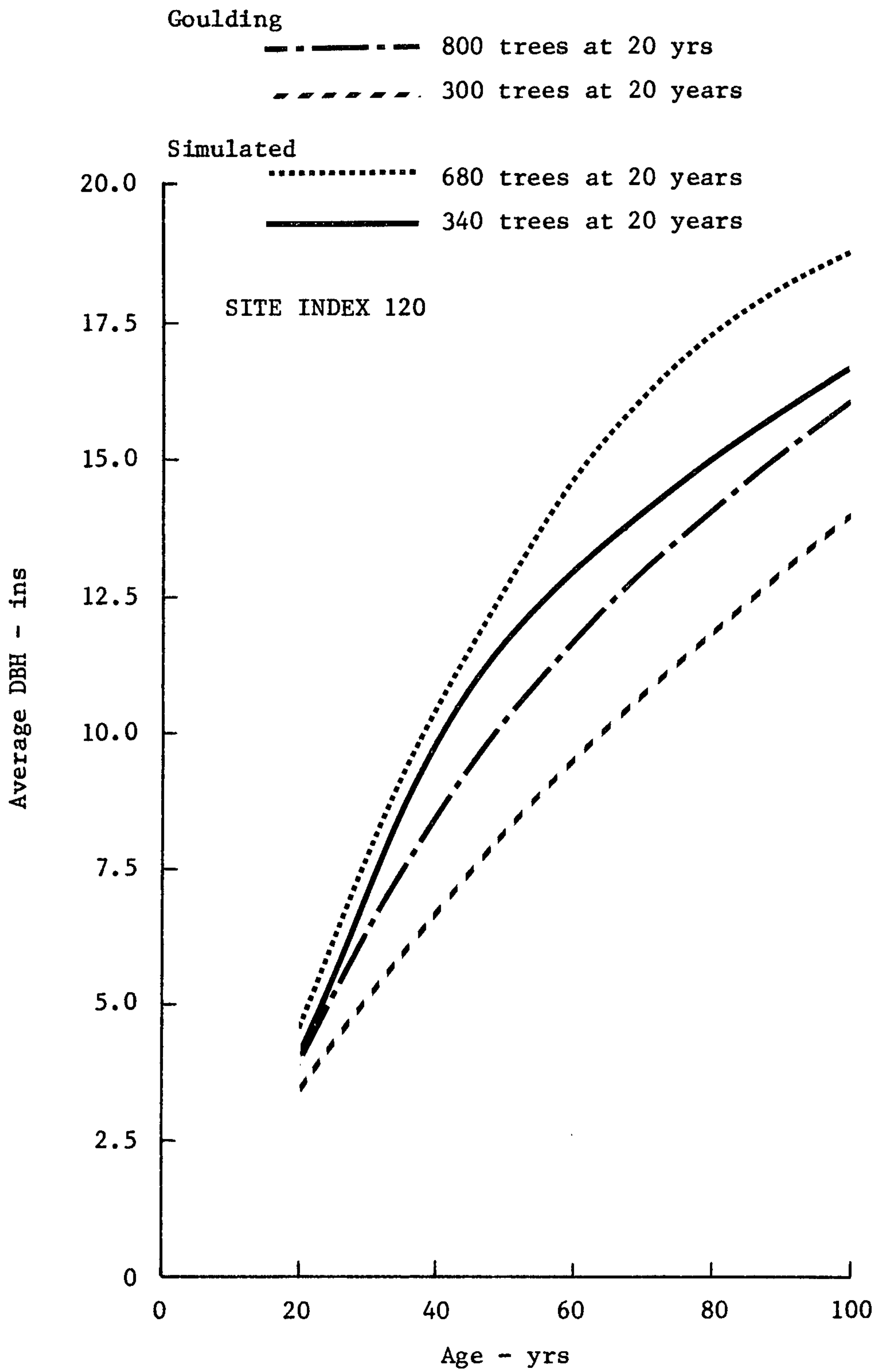


Figure 45. Comparison of Goulding's and my simulated mean DBH for site index 120.

Table 7. Comparison of simulated and actual stand volumes measured on the study area.

Stand	Actual Total Volume 1" + DBH cu ft/acre	Simulated Total Volume 1" + DBH cu ft/acre	Simulated as % of Actual
1	1710	1510	88.3
2	2001	1991	99.5
3	1832	2031	110.9
4	2131	2339	109.8
5	780	1000	128.2
6	857	777	90.7

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.

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

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

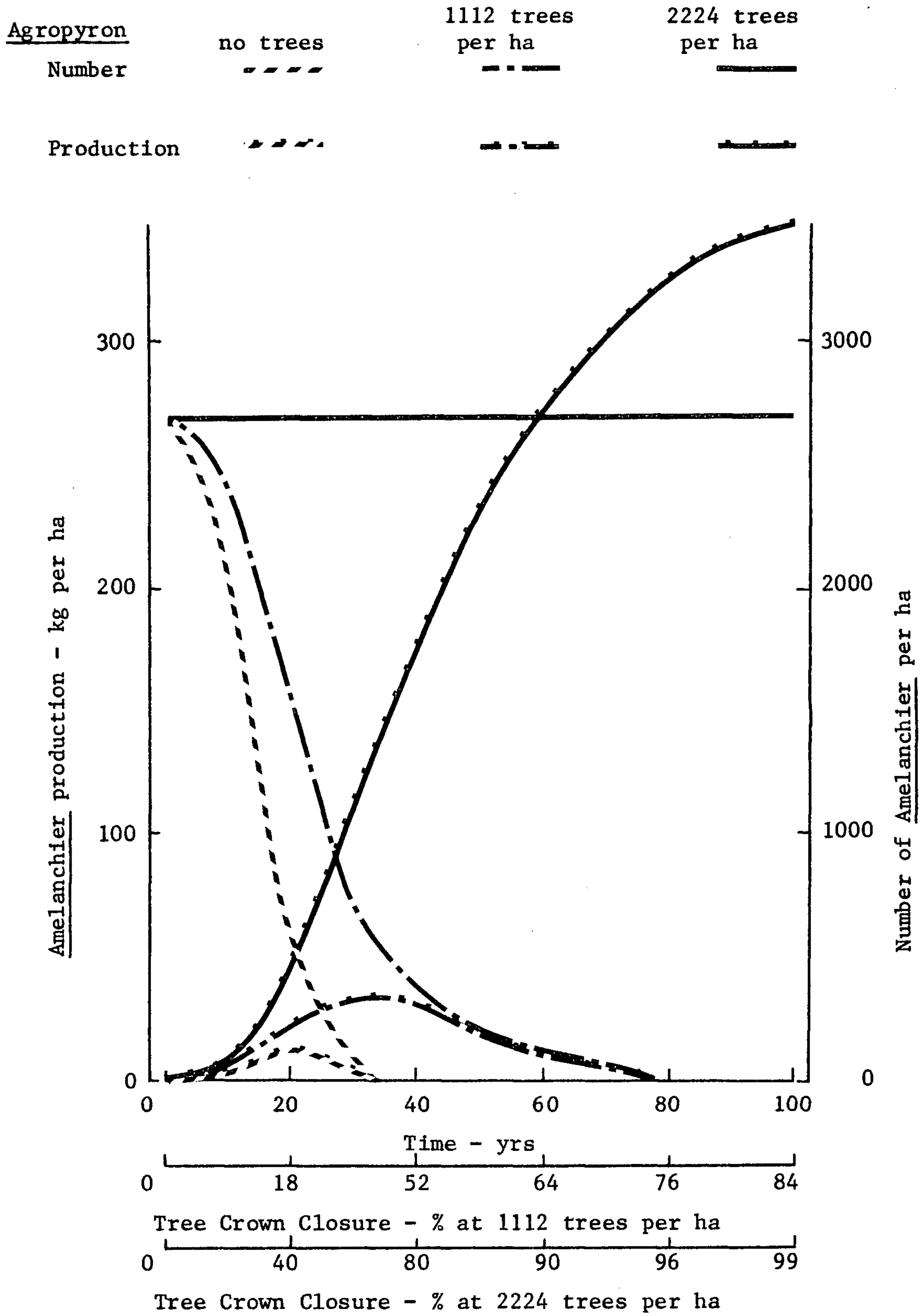


Figure 46. Simulated effect of tree crown closure on Amelanchier numbers and production.

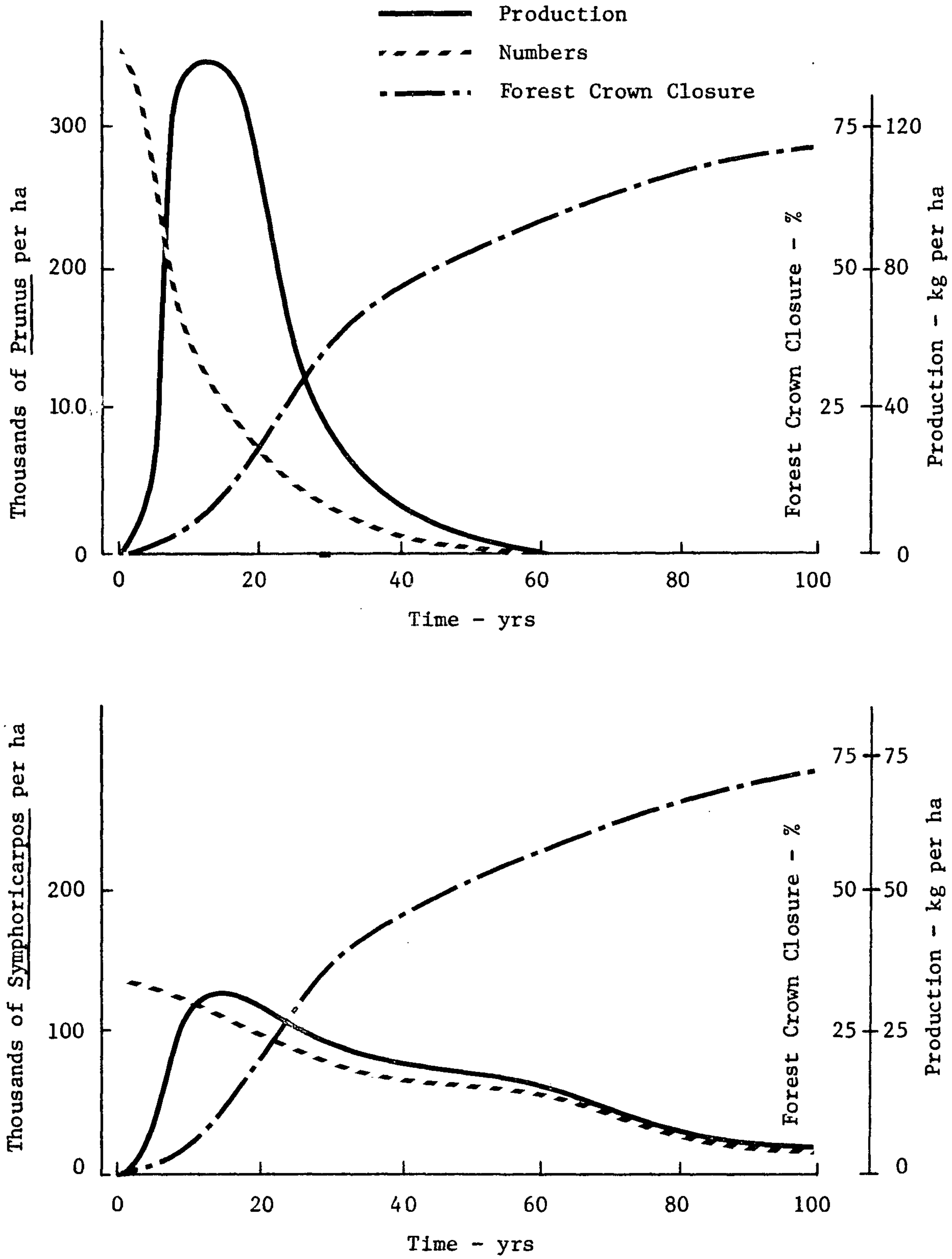


Figure 47. Simulated shrub mortality and production response to changing crown closure for a shade intolerant and an intermediate shade tolerant species. A: Prunus B: Symphoricarpos

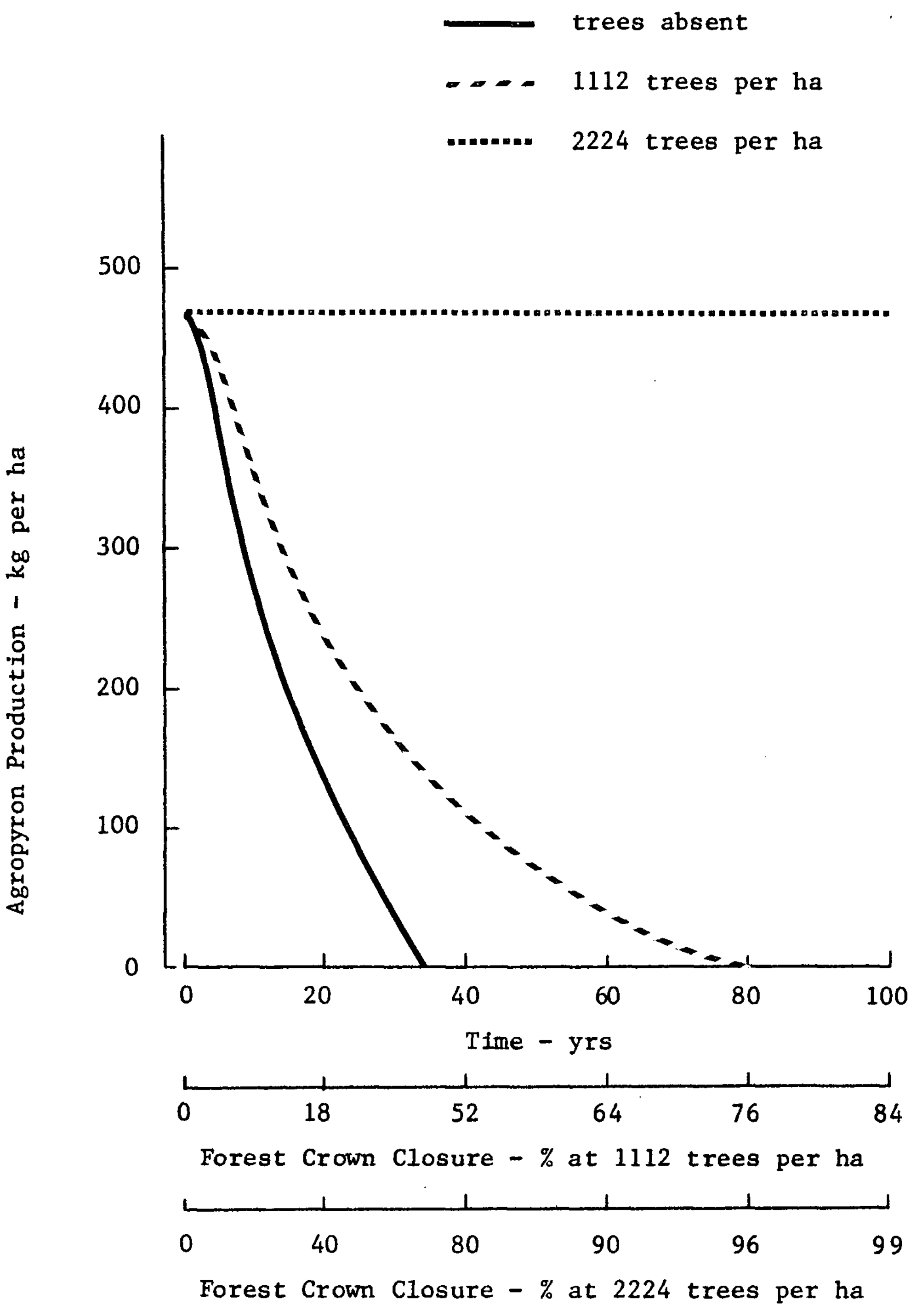


Figure 48. Comparison of simulated Agropyron production for site index 60 with 2224, 1112 and zero trees per hectare.

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*.

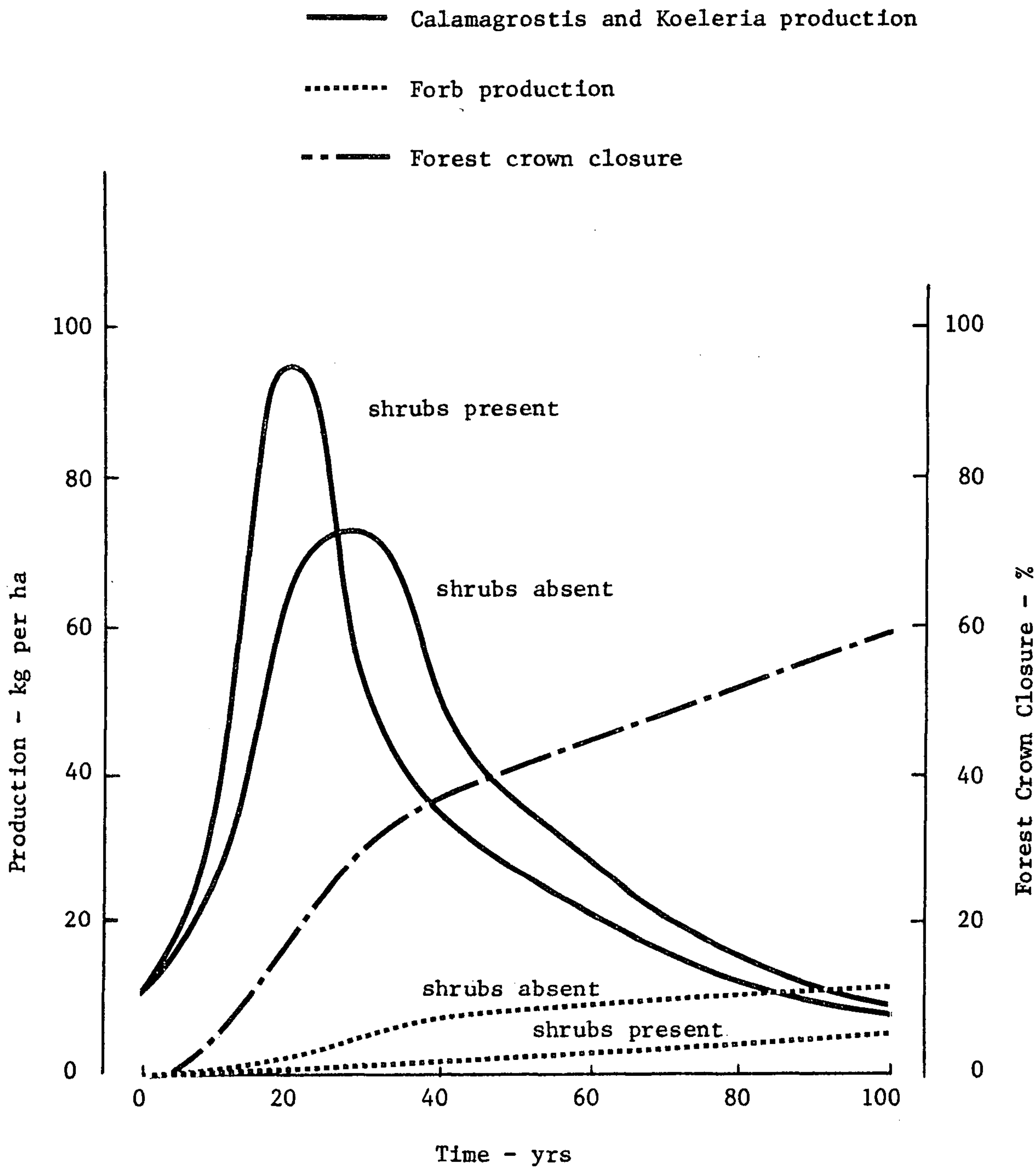


Figure 49. Comparison of simulated forb and Calamagrostis and Koeleria production response to tree crown closure in the presence and absence of shrubs.

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.

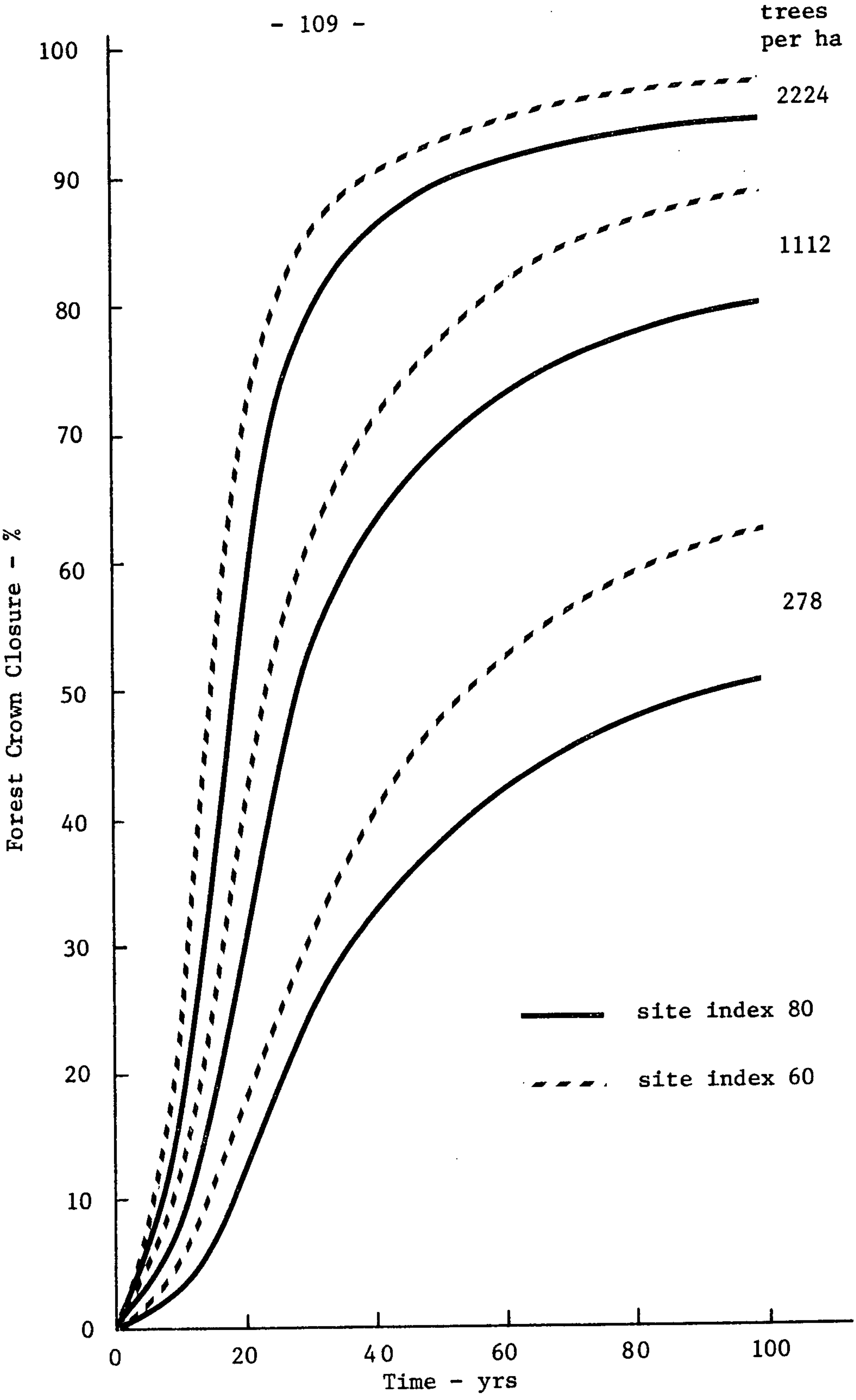


Figure 50. Effect of forest stand density and site index on forest crown closure.

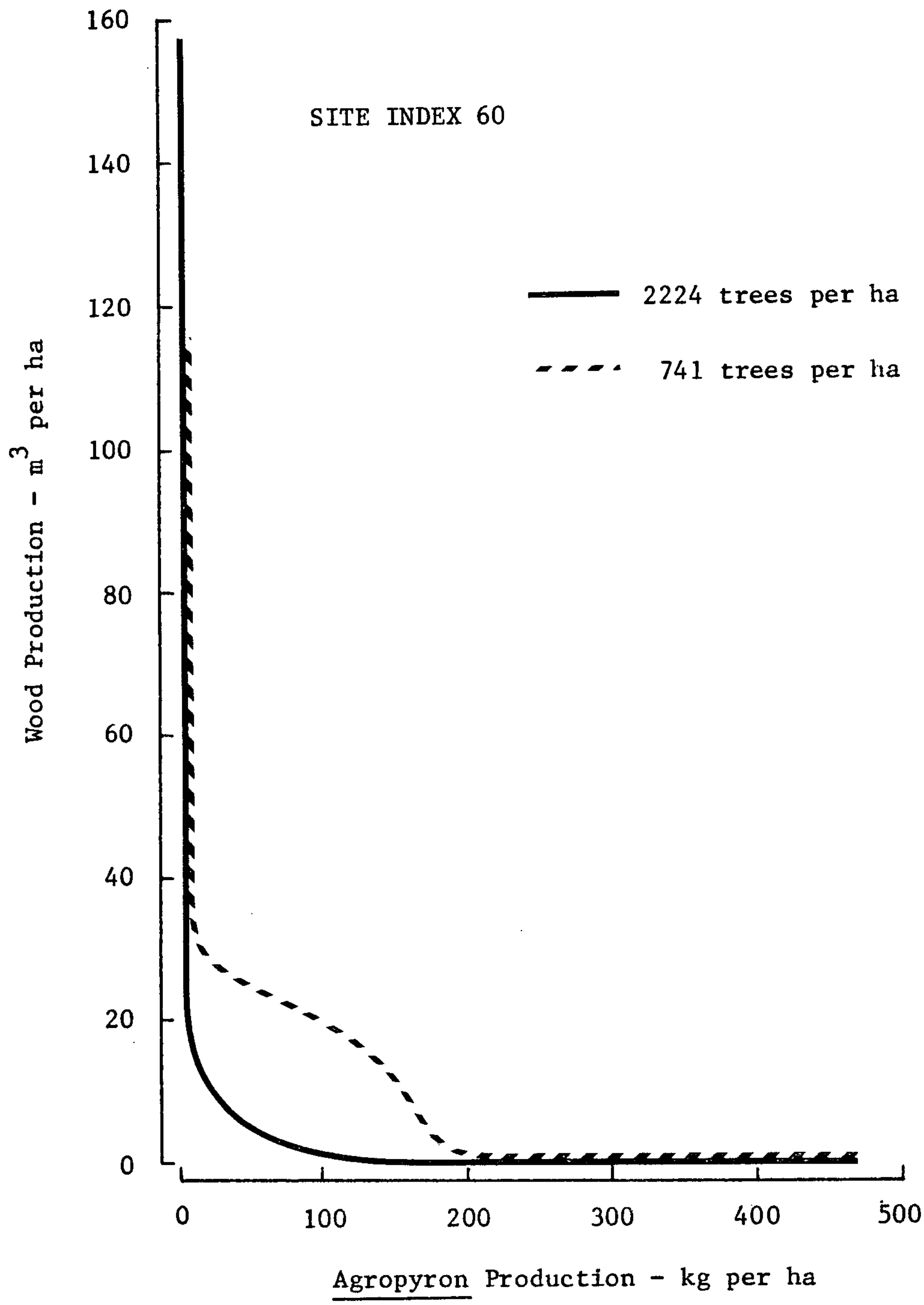


Figure 51. Trade-off between wood and Agropyron production.

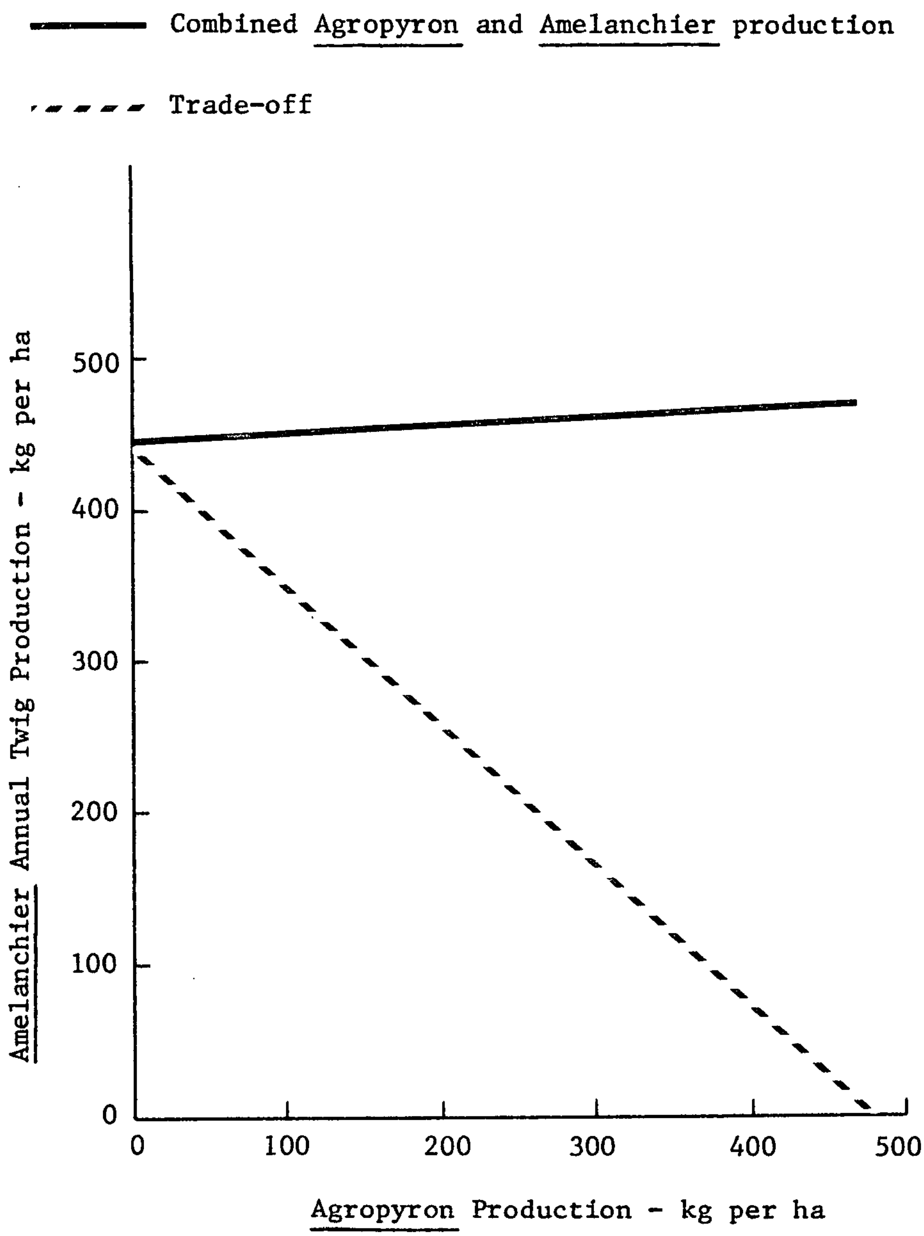


Figure 52. Trade-off between Agropyron production and annual twig production of Amelanchier.

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.

SITE INDEX 60

	2224 trees per ha				247 trees per ha			
Age	Wood cu ft/ha	Amel. kg/ha	Agrop. kg/ha	Forbs kg/ha	Wood cu ft/ha	Amel. kg/ha	Agrop. kg/ha	Forbs kg/ha
0	0	0	0	0	0	0	0	0
10	0	12	210	55	0	11	400	40
20	0	25	60	25	0	25	390	45
30	250	3	10	12	8	31	375	50
40	1200	0	0	10	125	37	340	55
50	2500	0	0	10	250	38	310	60
60	3500	0	0	10	820	39	280	59
70	5000	0	0	10	1250	39	250	58
80	6300	0	0	10	1750	40	230	55
90	7500	0	0	10	2000	40	215	52
100	8000	0	0	10	2200	41	200	50

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.

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APPENDIX I. COMMON AND SCIENTIFIC NAMES

PLANTS

Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco[1]
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.

---

[1] Hitchcock, C. L., Cronquist, A., Ownby, M. and J. W. Thompson. 1969. Vascular plants of the Pacific Northwest. University of Washington Press. Seattle and London. 5 Vols.

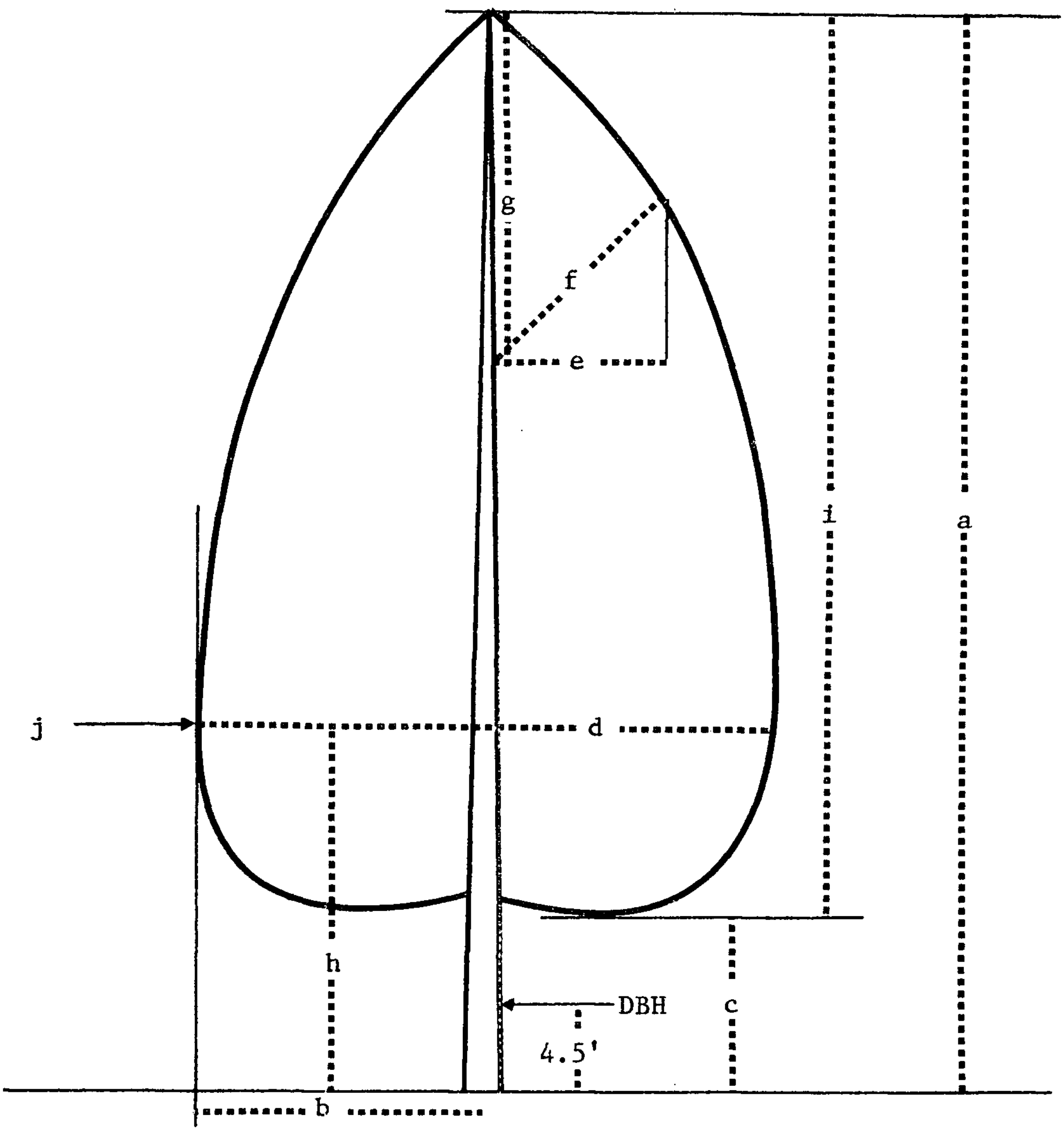
Large purple aster	*Aster conspicuus* Lindl.
Pasture wormwood	*Artemesia frigida* Willd.
Spring sunflower	*Balsamorhiza sagittata* (Pursh.) Nutt.
	Monarda fistulosa L.
Beardtongue	*Penstemon* spp.
Tuffted phlox	*Phlox caespitosa* Nutt.

UNGULATES

Elk	*Cervus canadensis nelsoni*, Bailey[2]
Mule deer	*Odocoileus hemionus hemionus* (Rafinsque)
Rocky mountain big-horn sheep	*Ovis canadensis canadensis* Shaw

2 McTaggart Cowan, I. and C. J. Guiget. 1965. The mammals of British Columbia, A. Sutton, Queen's Printer (B. C. Provincial Museum, Handbook No. 9).

APPENDIX II



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

```
C
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C                             APPENDIX III
C
C
C
C
C
C
C                         PROGRAM LISTING FOR
C
C                                 THE
C
C                         GROWTH SIMULATION OF
C
C                 TREES, SHRUBS, GRASSES AND FORBS
C
C                     ON A BIG-GAME WINTER RANGE
C
C
C
C         MAIN PROGRAM
C
C
C           TREE GROWTH SIMULATION
C
C                 TREE GROWTH AND COMPETITION    -   SUBROUTINE TREE
C                 STAND MAPS                     -   SUBROUTINE XSECT
C
C
C           VEGETATIVE COMMUNITY SIMULATION
C
C                 PROGRAM CONTROL AND SPECIFICATIONS - SUBROUTINE AGROP
C                 SHRUB GROWTH                       - SUBROUTINE BRANCH
C                 SHRUB MORTALITY                    - SUBROUTINE REM
C                 SHRUB AREA                         - SUBROUTINE AREA
C                 SHRUB PRODUCTION                   - SUBROUTINE SGPDN
C                 GRASS AND FORB PRODUCTION          - SUBROUTINE SUM
C
C
C           UTILITY PROGRAMS
C
C                         UNIFORM AND RANDOM NUMBER GENERATORS
C
C
C
C
```

```
C
C                            MAIN PROGRAM
C
C
C     SIMULATION OF THE GROWTH AND COMPETITIVE INTERACTIONS OF
C
C                       TREES, SHRUBS AND GRASSES
C
C     ON A BIG-GAME WINTER RANGE IN THE EAST KOOTENAY DISTRICT
C
C                         OF BRITISH COLUMBIA
C
C
C
C     DUMMY MAIN PROGRAM TO ALLOW BYPASS OF THE TREE GROWTH SIMULATION
C
C
      DIMENSION IARRA(66,66),BL2(96),ACC(4,21),ATA(4,21),ATG(4,21),ATF(4
     1,21),APONA(4,21),APDNC(4,21),APONS(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),NNCEON(4),NNSHEP(4),NNPRUN(4),NNROSE(4),NNSYMP(4),JRAND(50),K
     2RAND(50),LRAND(50),JJRAND(100),KKRAND(100),LLRAND(100),          J
     3AMEL(20),JCEON(20),JSHEP(20),JPRUN(20),JROSE(20),JSYMP(20),      I
     5COM(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
     7IAM1(150),IDIAM2(150),IDIAM3(150),IDIAM4(150),PER(153),EPER(16),KA
     8MEL(4,21),KCEON(4,21),KSHEP(4,21),KPRUN(4,21),KROSE(4,21),KSYMP(4,
     921),KCHAR(160),IHT(100,97),ICHAR(99),IBB(50,97),IRAND(97),IXX(97),
     1JXX(97),IVOL(97),IDBH(97),ICL(97),IAPER(97),ICW(97),ICB(97),IBA(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,XINA,UTILA,BORDC,XINC,UTIL
     2C,BORDS,XINS,UTILS,AGE,C,CC,TAUT,TAUTS,TAUTT,TAUD,UNOCC,YUNOCC,PDN
     1,ITHRU,M,ISTRT,IINT,IEND,IYUNOC,IAUTTY,IUNOCC,ILOOP,IX,ISUB,ICOUNT
     3,IHT,IBB,JARRA,LARR1,LARR2,LARR3,LARR4,IQQ,JQQ,IAREA,PER,KCHAR,ICO
     4M,JCOM,IDEAD1,IDEAD2,IDEAD3,IDEAD4,IDIAM1,IDIAM2,IDIAM3,IDIAM4,JJR
     5AND,KKRAND,LLRAND,ICHAR,IRAND,IXX,JXX,IVOL,IDBH,ICL,IAPER,ICW,ICB,
     6IBA,IDEAD,NSET,KAMEL,KCEON,KSHEP,KPRUN,KROSE,KSYMP,NAGE,JRAND,KRAN
     7D,LRAND,JAMEL,JCEON,JSHEP,JPRUN,JROSE,JSYMP,EPER,NNAMEL,NNCEON,NNS
     8HEP,NNPRUN,NNROSE,NNSYMP,JCHAR
      IRD=5
      IOUT=6
      ITHRU=0
      DO 2 I=1,66
      DO 2 J=1,66
      IARRA(I,J)=10000000
    2 JARRA(I,J)=0
C
C     READS BRANCH LENGTH-OCCUPANCY DATA DECK
C
```

```
      DO 3 I=1,96
      READ(IRD,5) BL2(I),NS,(IQQ(I,II),JQQ(I,II),II=1,NS)
 3    NSET(I)=NS
  5   FORMAT(F6.4,13I3)
C
C     DELOPT  ***  DELETE OPTION FOR TREE SUBROUTINE   ***
C     ******  IF    DELOPT .LE. 0  TREE SUB CALLED  ******
C
      READ(IRD,10) DELOPT
 10   FORMAT(I2)
C
C     READS STARTING AGE
C
      READ(IRD,15) ISTRT
 15   FORMAT(I3)
C
C     READS GROWTH INTERVAL
C
      READ(IRD,20) IINT
 20   FORMAT(I3)
C
C     READS UPPER AGE LIMIT
C
      READ(IRD,30) IEND
 30   FORMAT(I3)
      IF(DELOPT) 100,100,40
 40   J=0
      DO 50 I=ISTRT,IEND,IINT
      J=J+1
 50   NAGE(J)=I-1
      READ(IRD,55) IX
 55   FORMAT(I5)
      TINT=IINT
      NINT=IEND/IINT
C
C     INCREMENTS 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.
```

```
 65    M=0
C
C      CALLS UNDERSTORY ROUTINES
C
       CALL AGROP
       DO 70 I=1,NINT
       M=I
C
C      CALLS UNDERSTORY ROUTINES
C
 70    CALL AGROP
       IF(CSUB1.LT.10.) GO TO 60
       IF(CSUB1.LT.50.) GO TO 62
C      M = STAND AGE
C      ITREE = ITH TREE
C      IPOS = ITH BRANCH
C      HABM = HEIGHT TO MAXIMUM CROWN WIDTH
C      BL = BRANCH LENGTH
C      HBL = HORIZONTAL BRANCH LENGTH
C      IOCC = TEST VALUE FOR BRANCH OCCUPANCY
C      BB,IBB = HEIGHT TO BRANCH BASE
C      HT,IHT,HTA,HTS= TREE HEIGHTS
C      ICW,CWS,CW,ACW = MEASURES OF CROWN WIDTH
C      IVOL,VOL,VOLS,AVOL = MEASURES OF VOLUME
C      IDBH,DBHS,DBH,ADBH = MEASURES OF DIAMETER AT BREAST HEIGHT
C      IBA,BAS,BA,ABA = MEASURES OF BASAL AREA
C      ICL,CLS,CL,ACL = MEASURES OF CROWN LENGTH
C      IAPER = % CROWN CLOSURE
C
C
       IRD=5
       IOUT=6
C
C      IDELAG  *****  OPTION TO DELETE AGROPYRON SUBROUTINE CALL  *****
C      $$$$$  IF IDELAG .GT. 0  = CALL SUBROUTINE AGRO  $$$$$
C
       READ(IRD,3)IDELAG
 3     FORMAT(I2)
C
C      INTEGER TO START GAUSS
C
       READ(IRD,10)IX
  10   FORMAT(I5)
C
C      SI  *** READS SITE INDEX  ***
C
       READ(IRD,20)SI
  20   FORMAT(F5.2)
C
C      ALL TREES INITIALIZED AS BEING ALIVE   *** IDEAD ***
C      NUMTR  ***  OPTION TO CHANGE NUMBER OF TREES  ***
```

```
C
      READ(IRD,30)NUMTR
   30 FORMAT(I3)
C
C     MATRIX *** OPTION TO ALLOCATE TREE LOCATIONS RANDOMLY  ***
C
      READ(IRD,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 IX=IY
C
      DO 56 I=1,NUMTR
      CALL RANDU (IX,IY,YFL)
      JXX(I)=YFL*65.+1.
   56 IX=IY
   37 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
      LX=JXX(J)
   38 CALL RANDU (IX,IY,YFL)
      JXX(J)=YFL*65.+1.
      IX=IY
      IF(JXX(J).EQ.LX) GO TO 38
      ICHK=1
   39 CONTINUE
      IF(ICHK)59,59,37
   51 DO 40 I=1,NUMTR
      IDEAD(I)=0
   40 READ(IRD,50)IXX(I),JXX(I)
   50 FORMAT(2I3)
   59 READ(IRD,60) ICHAR
   60 FORMAT(40A2)
C
C     READS OPTIONS
C
C
C     IPRIN  ***  OPTION TO PRINT OUT STAND MAP  ***
C     ******  IF .LE. 1 = NO MAP  ***  IF .GT. 1  =  MAP  ******
C
      READ(IRD,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(IRD,80)NCODE
   80  FORMAT(I2)
C
C      NTREE  ***  OPTION TO PRINT INDIVIDUAL TREE PARAMETERS  ***
C      ******  IF .LE. 1  =  NO TREES  ***  IF .GT. 1  =  TREES  ******
C
       READ(IRD,90)NTREE
   90  FORMAT(I2)
C
C      ITRFN  ***  OPTION TO PRINT TREE FUNCTIONS AS GRAPHS  ***
C      ******  IF .LE. 1  =  NO FUNCTIONS ***  IF .GT. 1  =  FUNCTIONS  *
C
       READ(IRD,220)ITRFN
  220  FORMAT(I2)
       READ(IRD,230)JCHAR
  230  FORMAT(2A1)
C
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(IRD,240)LINPR
  240  FORMAT(I2)
C
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 I=1,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*1000.
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
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
      NAGE(J)=I-1
      X=I-1
      DO 350 K=1,NUMTR
      RAND1=IRAND(K)
      RAND=RAND1/1000.
      IF(X-45.)320,330,330
 320  HT=RAND*(SI/76.)*(18.05*(SIN(X*3.14159/50.-3.14159/2.)+1.)+.7-.038
     175*X)
      GO TO 340
 330  HT=RAND*(SI/76.)*(1.66222+.7044*X)
      IF(HT.LT..01) HT=.01
 340  HT2=HT*100.
 350  IHT(J,K)=HT2
C
C     CALCULATES HEIGHT AT AGE 1 *  REPRESENTS LOWEST BRANCH WHORL
C
      DO 360 J=1,1
C
      DO 360 K=1,NUMTR
      RAND1=IRAND(K)
      RAND=RAND1/1000.
      BB=RAND*1805.*(SIN(3.14159/50.-3.14159/2.)+1.)
       IF(BB.LT.1.) BB=1.
 360  IBB(J,K)=BB
C
C     PLACES HEIGHTS TO BRANCH BASE FROM AGE INTERVAL 2 TO IMAX IN ARRAY
C
      DO 370 J=2,ILOOP
      L=J-1
C
      DO 370 K=1,NUMTR
 370  IBB(J,K)=IHT(L,K)
C
C     PRINTS HEIGHT AND BRANCH BASE ARRAYS FOR TREES 1 TO 9
C
      WRITE(IOUT,380)
 380  FORMAT('1',5X,'TREE HEIGHTS STORED IN ARRAY',/)
C
      WRITE(IOUT,390)
 390  FORMAT(3X,'  TREE 1  TREE 2  TREE 3  TREE 4  TREE 5  TREE 6  TREE
     17  TREE 8  TREE 9')
C
      DO 400 I=1,ILOOP
C
 400  WRITE(IOUT,410)(IHT(I,J),J=1,9)
410   FORMAT(3X,12I3)
C
      WRITE(IOUT,420)
 420  FORMAT(////,5X,'HEIGHTS TO BRANCH BASE STORED IN ARRAY',/)
C
```

```
      WRITE(IOUT,390)
C
      DO 430 I=1,ILOOP
C
 430  WRITE(IOUT,410)(IBB(I,J),J=1,9)
C
C     SETS IARRA(I,J) = 10000000
C
      DO 440 I=1,66
C
      DO 440 J=1,66
 440  IARRA(I,J)=10000000
 450  M=0
C
      WRITE(IOUT,451)
 451  FORMAT(/,5X,'STAND AGE = 0 YRS.   **  TREES NOT YET ESTABLISHED')
      CSUB1=0
      CSUB2=0
      CSUB3=0
      CSUB4=0
      IF(IDELAG.LE.0) GO TO 460
C
      GO TO 130
C
C     CALLS TREE GROWTH ROUTINES
C
 100  CALL TREE
  130 CALL EXIT
      STOP
      END
C
C
C
      SUBROUTINE GAUSS(IX,S,AM,V)
C
C     RANDOM NUMBER GENERATOR FOR NORMAL DISTRIBUTION
C
      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
C
C
C
      SUBROUTINE RANDU(IX,IY,YFL)
C
C     RANDOM NUMBER GENERATOR
```

```
C
      IY=IX*65539
      IF(IY)5,6,6
  5   IY=IY+2147483647+1
 6    YFL=IY
      YFL=YFL*.4656613E-9
      RETURN
      END
```

```
      SUBROUTINE TREE
C
C     STAND GROWTH SIMULATION FOR INTERIOR DOUGLAS-FIR
C
      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),NNCEON(4),NNSHEP(4),NNPRUN(4),NNROSE(4),NNSYMP(4),JRAND(50),K
     2RAND(50),LRAND(50),JJRAND(100),KKRAND(100),LLRAND(100),          J
     3AMEL(20),JCEON(20),JSHEP(20),JPRUN(20),JROSE(20),JSYMP(20),      I
     5COM(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
     71AM1(150),IDIAM2(150),IDIAM3(150),IDIAM4(150),PER(153),EPER(16),KA
     8MEL(4,21),KCEON(4,21),KSHEP(4,21),KPRUN(4,21),KROSE(4,21),KSYMP(4,
     921),KCHAR(160),IHT(100,97),ICHAR(99),IBB(50,97),IRAND(97),IXX(97),
     1JXX(97),IVOL(97),IDBH(97),ICL(97),IAPER(97),ICW(97),ICB(97),IBA(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,XINA,UTILA,BORDC,XINC,UTIL
     2C,BORDS,XINS,UTILS,AGE,C,CC,TAUT,TAUTS,TAUTT,TAUO,UNOCC,YUNOCC,PON
     1,ITHRU,M,ISTRT,IINT,IEND,IYUNOC,IAUTTY,IUNOCC,ILOOP,IX,ISUB,ICOUNT
     3,IHT,IBB,JARRA,LARR1,LARR2,LARR3,LARR4,IQQ,JQQ,IAREA,PER,KCHAR,ICO
     4M,JCOM,IDEAD1,IDEAD2,IDEAD3,IDEAD4,IDIAM1,IDIAM2,IDIAM3,IDIAM4,JJR
     5AND,KKRAND,LLRAND,ICHAR,IRAND,IXX,JXX,IVOL,IDBH,ICL,IAPER,ICW,ICB,
     6IBA,IDEAD,NSET,KAMEL,KCEON,KSHEP,KPRUN,KROSE,KSYMP,NAGE,JRAND,KRAN
     7D,LRAND,JAMEL,JCEON,JSHEP,JPRUN,JROSE,JSYMP,EPER,NNAMEL,NNCEON,NNS
     8HEP,NNPRUN,NNROSE,NNSYMP,JCHAR
C
C
C     IARRA = ARRAY REPRESENTING 1/10 ACRE PLOT
C     JARRA = ARRAY FOR PLOTTING CROWN PROFILES
C     CSUB1,...4 = CROWN CLOSURE OF SUB-PLOTS
C     SUB1,...4 = CROWN AREAS FOR 1/40TH ACRE PLOTS
C     HTAB = HEIGHT ABOVE BRANCH
C     CAE = EXPECTED CROWN AREA
C     NUMTR = # OF TREES
C     ICHAR = TREE NUMBERS
C     IXX, JXX = I,J TREE LOCATIONS
C     IRAND = TREE GROWTH POTENTIAL
      CALL AGROP
C
C     INCREMENTS AGE INTERVAL
C
 460  M=M+1
C
      DO 500 I=1,66
C
      DO 500 J=1,66
 500  JARRA(I,J)=0
      IF(M-ILOOP)510,510,1470
```

```
 510   ITREE=0
C
C      STARTS NEW TREE
C
 520   ITREE=ITREE+1
       L2=1
       KTHBR=1
       IF(ITREE-NUMTR)530,530,790
 530   HT1=IHT(M,ITREE)
       IF(HT1.LE.0.)GO TO 520
C
C      GOES TO NEXT LOWER BRANCH AND CALCULATES BRANCH LENGTH
C
       DO 780 IBR=1,M
       IPOS=M+1-IBR
       BB1=IBB(IPOS,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
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
C      DESIGNATES POSITION OF TREE BOLE
C
       IARRA(IX,JX)= 97+IHT(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)
 640  IF(I)670,670,650
 650  IF(I-66)670,670,660
 660  I=I-66
 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=66+I
 720  IF(J)730,730,740
 730  J=66+J
C
C            TEST FOR OCCUPANCY
C
 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
C
C     GOES TO NEXT TREE
C
      GO TO 520
C
C     PRINTS MATRIX CODES IN IARRA (CROWN COMPETITION)
C
 790  IF(NCODE-1)880,880,800
C
 800  WRITE(IOUT,990)NAGE(M)
C
      WRITE(IOUT,810)
 810  FORMAT(2X,'CODES STORED IN IARRA MATRIX-LOCATIONS I=10 TO 40
     1 J=1 TO 14')
      DO 820 ICODE=40,50
C
 820  WRITE(IOUT,830)(IARRA(ICODE,JCODE),JCODE=1,14)
 830  FORMAT(2X,14I9)
```

```
C
      WRITE(IOUT,840)
  840 FORMAT('1',2X,'LOCATIONS J=15 TO 28')
C
      DO 850 ICODE=40,50
C
  850 WRITE(IOUT,830)(IARRA(ICODE,JCODE),JCODE=15,28)
C
      WRITE(IOUT,860)
  860 FORMAT('1',2X,'LOCATIONS J = 29 TO 42')
C
      DO 870 ICODE=40,50
C
  870 WRITE(IOUT,830)(IARRA(ICODE,JCODE),JCODE=29,42)
C
  880 DO 890 LL=1,NUMTR
      ICW(LL)=0
      IVOL(LL)=0
      IDBH(LL)=0
      IBA(LL)=0
      ICL(LL)=0
      IAPER(LL)=0
  890 IAREA(LL)=1
      DO 900 LL=1,NUMTR
  900 ICB(LL)=9999
      ICB(97)=0
      DO 980 I=1,66
C
C     DETERMINES HEIGHT TO CROWN WIDTH MAX
C
      DO 980 J=1,66
      NEW=IARRA(I,J)/100*100
      LTREE=IARRA(I,J)-NEW
      IF(LTREE)930,930,910
  910 IF((NEW/100-100000) -ICB(LTREE))920,930,930
  920 ICB(LTREE)=NEW/100-100000
  930 JARRA(I,J)=IARRA(I,J)-NEW
      NB=JARRA(I,J)
      IF(NB)960,960,940
  940 IF(NB-97)950,960,960
C
C     CALCULATION OF CROWN AREA
C
  950 IAREA(NB)=IAREA(NB)+1
  960 IF(NB)970,970,980
  970 NB=98
  980 JARRA(I,J)=ICHAR(NB)
C
      WRITE(IOUT,990)NAGE(M)
  990 FORMAT('1',2X,'STAND AGE=',2X,I3,//)
C
```

```
C      CALCULATES STAND PARAMETERS
C
1000   DO 1100 MM=1,NUMTR
       HT1=IHT(M,MM)
       HT=HT1/100.
1010   CRAR=IAREA(MM)
C
C               NATURAL MORTALITY
C
       HABM=-5.5+.425*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*(BL**3./20.**3.)
       IF(HBL.LE.0.) HBL=.1
       CAE=3.14159*HBL**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   ICL(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+(1.739416*ALOG(DBH)+1.166033*ALOG(HT))/2.302585
       VOL=10.**VOL
1100   IVOL(MM)=VOL*100.
C
C      PRINTS MAP OF CROWN OCCUPANCY
C
       IF(IPRIN-1)1150,1150,1110
C
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
      WRITE(IOUT,1120)
1150  HTS=0
      DBHS=0
      BAS=0
      CBS=0
      CLS=0
      CWS=0
      AREAS=0
      VOLS=0
      APERS=0
      IF(NTREE-1)1170,1170,1160
C
1160  WRITE(IOUT,1200)
 1170 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=IDBH(NB)
      DBH=DBHI/100.
      BAI=IBA(NB)
      BA=BAI/14400.
      CBI=ICB(NB)
      IF(CBI-9000)1190,1190,1180
1180  CBI=0.
1190  CB=CBI/100.
      CL=HT-CB
      CWI=ICW(NB)
      CW=CWI/100.
      AREA=IAREA(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
      IF(NTREE-1) 1240,1240,1210
 1200 FORMAT(///,1X,'    TREE #  I    J     HEIGHT       DBH         B.A
```

```
     1.   CR.BASE  CR.LENGTH          C.W.     C. AREA  C.A. AS %     VOLU
     2ME',/)
C
1210  WRITE(IOUT,1230)NB,IXX(NB),JXX(NB),HT,DBH,BA,CB,CL,CW,AREA,APER,
     1VOL
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
      WRITE(IOUT,1250)
1250  FORMAT(/////,5X,'STAND TOTALS',/)
C
      WRITE(IOUT,1260)
C
 1260 FORMAT(2X,'NUMBER OF TREES   HEIGHT        DBH        B.A.   CR. BAS
     1E   CR. LENGTH        CW    C. AREA                    VOLUME')
C
      WRITE(IOUT,1270)NEWTR,HTS,DBHS,BAS,CBS,CLS,CWS,AREAS,VOLS
1270  FORMAT(7X,I3,5X,7F11.2,F22.2)
      LOSTR=NUMTR-NEWTR
C
      WRITE(IOUT,1280)LOSTR
1280  FORMAT('0',2X,'NUMBER OF TREES HAVING DIED SINCE YEAR 1=',I5)
C
      WRITE(IOUT,1290)
1290  FORMAT(////,5X,'STAND AVERAGES',//,2X,'NUMBER OF TREES   HEIGHT
     1   DBH        B.A.     HT. CWM CR. LENGTH        C.W.     C. AREA C.
     2A. AS %      VOLUME',/)
C
      WRITE(IOUT,1300)NEWTR,AHT,ADBH,ABA,ACB,ACL,ACW,AAREA,AAPER,AVOL
1300  FORMAT(6X,I3,5X,9F11.2)
C
C     CALCULATES CROWN AREAS AND CROWN CLOSURES FOR SUBSETS
C     SUBSETS FORM BASIS FOR EVALUATION OF SHRUB AND GRASS RESPONSE TO
C     STAND CONDITIONS
C
C
```

```
1310  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
C     SUBSET # 1  **  I=1,33;  J=1,33  **
C
C
1350  DO 1360 I=1,33
C
      DO 1360 J=1,33
      NB=JARRA(I,J)
      IF(NB.GE.1) SUB1=SUB1+1
1360  CONTINUE
      GO TO 1340
C
C     SUBSET # 2  **  I = 1,33;  J = 34,66  **
C
C
1370  DO 1380 I=1,33
C
      DO 1380 J=34,66
      NB=JARRA(I,J)
      IF(NB.GE.1) SUB2=SUB2+1
1380  CONTINUE
      GO TO 1340
C
C     SUBSET # 3  **  I = 34,66;  J = 1,33  **
C
1390  DO 1400 I=34,66
C
      DO 1400 J=1,33
      NB=JARRA(I,J)
      IF(NB.GE.1) SUB3=SUB3+1
1400  CONTINUE
      GO TO 1340
C
C     SUBSET # 4  **  I = 34,66;  J = 34,66  **
```

```
C
1410  DO 1420 I=34,66
C
      DO 1420 J=34,66
      NB=JARRA(I,J)
      IF(NB.GE.1) SUB4=SUB4+1
1420  CONTINUE
      CSUB1=SUB1/1089.*100.
      CSUB2=SUB2/1089.*100.
      CSUB3=SUB3/1089.  *100.
      CSUB4=SUB4/1089. *100.
C
      WRITE(IOUT,1430)
1430  FORMAT(////,5X,'CROWN AREA AND CROWN CLOSURES FOR SUBSETS',///)
C
      WRITE(IOUT,1440)
1440  FORMAT(12X,'SUB-PLOT 1 - I=1,33  J=1,33',2X,'SUB-PLOT 2 - I=1,33
     1J=34,66',2X,'SUB-PLOT 3 - I=34,66 J=1,33',2X,'SUB-PLOT 4 - I=34,66
     2 J=34,66',//)
C
      WRITE(IOUT,1450)SUB1,SUB2,SUB3,SUB4
1450  FORMAT(1X,'CROWN AREA =',F15.2,3F29.2,//)
C
      WRITE(IOUT,1460)CSUB1,CSUB2,CSUB3,CSUB4
1460  FORMAT(1X,'CROWN CLOSURE =',F12.2,3F29.2)
       IF(LINPR.LE.0) GO TO 1463
C
      CALL XSECT (LINPR)
 1463 IF(IDELAG.LE.0) GO TO 460
C
      CALL AGROP
      GO TO 460
1470  IF(ITRFN-1)1490,1490,1480
C
 1480 CALL TRFUN
 1490 RETURN
      END
```

```
      SUBROUTINE XSECT (LINPR)
C
C     PRINTS VERTICAL X SECTION THROUGH STAND
C
      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),NNCEON(4),NNSHEP(4),NNPRUN(4),NNROSE(4),NNSYMP(4),JRAND(50),K
     2RAND(50),LRAND(50),JJRAND(100),KKRAND(100),LLRAND(100),          J
     3AMEL(20),JCEON(20),JSHEP(20),JPRUN(20),JROSE(20),JSYMP(20),      I
     5COM(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
     7IAM1(150),IDIAM2(150),IDIAM3(150),IDIAM4(150),PER(153),EPER(16),KA
     8MEL(4,21),KCEON(4,21),KSHEP(4,21),KPRUN(4,21),KROSE(4,21),KSYMP(4,
     921),KCHAR(160),IHT(100,97),ICHAR(99),IBB(50,97),IRAND(97),IXX(97),
     1JXX(97),IVOL(97),IDBH(97),ICL(97),IAPER(97),ICW(97),ICB(97),IBA(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,XINA,UTILA,BORDC,XINC,UTIL
     2C,BORDS,XINS,UTILS,AGE,C,CC,TAUT,TAUTS,TAUTT,TAUO,UNOCC,YUNOCC,PDN
     1,ITHRU,M,ISTRT,IINT,IEND,IYUNOC,IAUTTY,IUNOCC,ILOOP,IX,ISUB,ICOUNT
     3,IHT,IBB,JARRA,LARR1,LARR2,LARR3,LARR4,IQQ,JQQ,IAREA,PER,KCHAR,ICO
     4M,JCOM,IDEAD1,IDEAD2,IDEAD3,IDEAD4,IDIAM1,IDIAM2,IDIAM3,IDIAM4,JJR
     5AND,KKRAND,LLRAND,ICHAR,IRAND,IXX,JXX,IVOL,IDBH,ICL,IAPER,ICW,ICB,
     6IBA,IDEAD,NSET,KAMEL,KCEON,KSHEP,KPRUN,KROSE,KSYMP,NAGE,JRAND,KRAN
     7D,LRAND,JAMEL,JCEON,JSHEP,JPRUN,JROSE,JSYMP,EPER,NNAMEL,NNCEON,NNS
     8HEP,NNPRUN,NNROSE,NNSYMP,JCHAR
C
C
C     JLOC = LOCATION ON LINE
C     ILINE = LINE
C     ISCLE = SCALING FACTOR
C     NB = CHARACTER TO BE PRINTED
C
C
      IOUT=6
      ISCLE=0
C
 991  DO 992 KCL=1,66
C
      DO 992 JCL=1,66
 992  JARRA(KCL,JCL)=0
      DO 993 JLOC=1,66
      ILINE=IARRA(LINPR,JLOC)
      N=ILINE-ILINE/100*100
      ILOC=(ILINE+5000/10000*10000-10000000)/10000
      IF(ILOC.LT.1) ILOC=1
      IF(ISCLE.GT.0) GO TO 995
      IF(ILOC.GT.66) ISCLE=2
      IF(ISCLE-1)994,994,991
```

```
 994   JARRA(ILOC,JLOC)=N
       GO TO 993
 995   ILOC=(ILOC+1)/2
       IF(ILOC.LT.1) ILOC=1
       JARRA(ILOC,JLOC)=N
 993   CONTINUE
C
       DO 998 J=1,66
C
       DO 998 I=1,66
 996   NB=JARRA(I,J)
       IF(NB)997,997,998
 997   NB=99
 998   JARRA(I,J)=ICHAR(NB)
C
       WRITE(IOUT,981)LINPR
 981   FORMAT('1',////,20X,'CROSS-SECTIONAL PROFILE OF STAND -  SECTION T
      1HROUGH LINE ',I2,///)
       IF(ISCLE.GT.1) GO TO 987
C
       WRITE(IOUT,982)
 982   FORMAT(60X,'VERTICAL SCALE =  1FT. = 1 LINE',//,58X,'HORIZONTAL SC
      1ALE - 1FT. = 2 SPACES',///)
       GO TO 988
C
 987   WRITE(IOUT,983)
 983   FORMAT(60X,'VERTICAL SCALE - 2FT. = 1 LINE',//,58X,'HORIZONTAL SCA
      1LE - 1FT. = 2 SPACES',///)
C
 988   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
C
 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
     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),NNCEON(4),NNSHEP(4),NNPRUN(4),NNROSE(4),NNSYMP(4),JRAND(50),K
     2RAND(50),LRAND(50),JJRAND(100),KKRAND(100),LLRAND(100),           J
     3AMEL(20),JCEON(20),JSHEP(20),JPRUN(20),JROSE(20),JSYMP(20),       I
     5COM(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
     7IAM1(150),IDIAM2(150),IDIAM3(150),IDIAM4(150),PER(153),EPER(16),KA
     8MEL(4,21),KCEON(4,21),KSHEP(4,21),KPRUN(4,21),KROSE(4,21),KSYMP(4,
     921),KCHAR(160),IHT(100,97),ICHAR(99),IBB(50,97),IRAND(97),IXX(97),
     1JXX(97),IVOL(97),IDBH(97),ICL(97),IAPER(97),ICW(97),ICB(97),IBA(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,XINA,UTILA,BORDC,XINC,UTIL
     2C,BORDS,XINS,UTILS,AGE,C,CC,TAUT,TAUTS,TAUTT,TAUO,UNOCC,YUNOCC,PDN
     1,ITHRU,M,ISTRT,IINT,IEND,IYUNOC,IAUTTY,IUNOCC,ILOOP,IX,ISUB,ICOUNT
     3,IHT,IBB,JARRA,LARR1,LARR2,LARR3,LARR4,IQQ,JQQ,IAREA,PER,KCHAR,ICO
     4M,JCOM,IDEAD1,IDEAD2,IDEAD3,IDEAD4,IDIAM1,IDIAM2,IDIAM3,IDIAM4,JJR
     5AND,KKRAND,LLRAND,ICHAR,IRAND,IXX,JXX,IVOL,IDBH,ICL,IAPER,ICW,ICB,
     6IBA,IDEAD,NSET,KAMEL,KCEON,KSHEP,KPRUN,KROSE,KSYMP,NAGE,JRAND,KRAN
     7D,LRAND,JAMEL,JCEON,JSHEP,JPRUN,JROSE,JSYMP,EPER,NNAMEL,NNCEON,NNS
     8HEP,NNPRUN,NNROSE,NNSYMP,JCHAR
C
C
C     LARR1,..4 = SHRUB,GRASS & FORB GROWTH ARRAYS
C     ITHRU = COUNTER
C     KCHAR = SHRUB NUMBER
C     EPER = EXPECTED PERIMETER OF SHRUBS
C     IDIAM1,..4 = SHRUB DIAMETER
C     IDEAD1,..4 = DEAD SHRUBS
C     LAMEL,..,LSYMP = VARIABILITY IN SIZE OF SHRUB SPECIES
C     NNAMEL,..,NNSYMP = NUMBER OF SHRUBS BY SPECIES / SUB-PLOT
C     ZERO ARRAYS FOR PRINTING # SHRUBS AND PRODUCTION, AGE, CROWN
C      CLOSURE
C     JRAND,..,LLRAND = SHRUB SPECIES GROWTH POTENTIAL
C     IAREA,AREAS,AAREAS = CROWN AREA MEASUREMENTS
C
      IRD=5
      IOUT=6
C
      DO 3 I=1,66
      DO 3 J=1,66
 3    JARRA(I,J)=0
C
      IF(ITHRU.GT.0) GO TO 150
      IF(M.GT.0) GO TO 150
C
      READ(IRD,2)EPER
```

```
 2    FORMAT(16I3)
C
      READ(IRD,4)KCHAR
 4    FORMAT(40A2)
C
      DO 5 I=1,150
      IDIAM1(I)=0
      IDIAM2(I)=0
      IDIAM3(I)=0
      IDIAM4(I)=0
      IDEAD1(I)=0
      IDEAD2(I)=0
      IDEAD3(I)=0
 5    IDEAD4(I)=0
C
      DO 7 I=1,66
C
      DO 7 J=1,66
      LARR1(I,J)=0
      LARR2(I,J)=0
      LARR3(I,J)=0
 7    LARR4(I,J)=0
C
      READ(IRD,10) LAMEL,LCEON,LSHEP,LPRUN,LROSE,LSYMP
 10   FORMAT(6I5)
C
      READ(IRD,15) ISHRUB,INDISH
 15   FORMAT(2I3)
C
      READ(IRD,20)IDD
 20   FORMAT(I3)
C
      DO 30 I=1,4
C
 30   READ(IRD,40) NNAMEL(I),NNCEON(I),NNSHEP(I),NNPRUN(I),NNROSE(I),NNS
     1YMP(I)
 40   FORMAT(6I4)
C
      DO 45 I=1,4
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.
      APDNPR(I,J)=0.
      APDNRO(I,J)=0.
      APDNSY(I,J)=0.
```

```
      KAMEL(I,J)=0
      KCEON(I,J)=0
      KSHEP(I,J)=0
      KPRUN(I,J)=0
      KROSE(I,J)=0
 45   KSYMP(I,J)=0
C
C     CALCULATE SHRUB SPECIES GROWTH POTENTIAL
C
      VAMEL=LAMEL
      VAMEL=VAMEL/10000.
      VCEON=LCEON
      VCEON=VCEON/10000.
      VSHEP=LSHEP
      VSHEP=VSHEP/10000.
      VPRUN=LPRUN
      VPRUN=VPRUN/10000.
      VROSE=LROSE
      VROSE=VROSE/10000.
      VSYMP=LSYMP
      VSYMP=VSYMP/10000.
C
      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.
C
      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.
C
      DO 80 I=1,50
      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.
C
      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   JJRAND(I)=V*1000.
C
      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.
```

```
C
      DO 110 I=1,100
      CALL GAUSS (IX,VSYMP,1.0000,V)
      IF(V.LT..1) V=.1
      IF(V.GT.1.6) V=1.6
 110  LLRAND(I)=V*1000.
C
C
 130  READ(IRD,140)PDN
 140  FORMAT(F6.2)
C
 150  WRITE(IOUT,160)
 160  FORMAT(2X,'NUMBER OF SHRUBS BY SPECIES AT AGE 1',//,T24,'AMEL',T34
     1,'CEON',T44,'SHEP',T54,'PRUN',T64,'ROSE',T74,'SYMP',//)
C
      DO 170 I=1,4
C
 170  WRITE(IOUT,180)I,NNAMEL(I),NNCEON(I),NNSHEP(I),NNPRUN(I),NNROSE(I)
     1,NNSYMP(I)
 180  FORMAT(2X,'SUB-PLOT=',I2,5X,6I10)
C
C
      ISUB=0
C
C     INCREMENTS SUB-SETS
C
 190  ISUB=ISUB+1
      IF(ISUB.GT.4) GO TO 4000
      NAMEL=NNAMEL(ISUB)
      NCEON=NNCEON(ISUB)
      NSHEP=NNSHEP(ISUB)
      NPRUN=NNPRUN(ISUB)
      NROSE=NNROSE(ISUB)
      NSYMP=NNSYMP(ISUB)
C
      ITA=NAMEL
      IF(M.GT.0) GO TO 199
      WRITE(IOUT,200)ISUB,M
      GO TO 210
C
 199  WRITE(IOUT,200) ISUB,NAGE(M)
 200  FORMAT('1',2X,128('*'),//,5X,'SUB-PLOT =',I5,10X,15('*'),10X,'AGE
     1=',I5)
 210  CONTINUE
C
      DO 220 I=1,66
C
      DO 220 J=1,66
 220  JARRA(I,J)=0
      IF(ITHRU.GT.0) GO TO 430
      IF(ISUB.GT.1) GO TO 430
```

```
C
C     ASSIGNS SHRUB LOCATIONS
C
 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)-10000000).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 480
 465  IDEAD2(I)=1
      LARR2(K,L)=0
      GO TO 480
 470  IDEAD3(I)=1
      LARR3(K,L)=0
      GO TO 480
 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=50+NCEON
      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(II,JJ)-10000000).EQ.0) GO TO 540
      INUM=INUM-1
C
      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-IKILLC
      WRITE(IOUT,2060)ISUB,IKILLC,NCEON
 2060 FORMAT(2X,'SUB-PLOT =',I2,5X,'NO. CEON. DEAD =',I2,5X,'NO. CEON. =
     1',I2)
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
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
C
      GO TO (580,585,590,595),ISUB
 580  IDEAD1(I)=1
      LARR1(K,L)=0
      GO TO 600
 585  IDEAD2(I)=1
      LARR2(K,L)=0
      GO TO 600
 590  IDEAD3(I)=1
      LARR3(K,L)=0
      GO TO 600
 595  IDEAD4(I)=1
      LARR4(K,L)=0
 600  CONTINUE
C
      IKILLS=NSHEP-INUM
      NSHEP=NSHEP-IKILLS
C
      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
      C=CC
      WRITE(IOUT,635) CC
 635  FORMAT(//,10('*'),5X,'CROWN CLOSURE =',F6.2,5X,10('*'))
 670  IF(CC.GT.74.5) CC=74.5
      IF(CC.LE.0) CC=.01
      IF(M.EQ.0) GO TO 695
C
C     DETERMINES NO. OF CEONOTHUS AS A FUNCTION OF CROWN CLOSURE
C
      IF(NAMEL.EQ.0) GO TO 675
      MAMEL=8.-.10606*CC+19.*((75.-CC)**2.5/75.**2.5)+.5
      IF(NAMEL.GT.MAMEL) NAMEL=MAMEL
      ITA=NAMEL+IKILLA
C
```

```
C       DETERMINES NO. OF AMELANCHIER AS A FUNCTION OF CROWN CLOSURE
C
 675    IF(NCEON.EQ.0) GO TO 680
        MCEON=8.-.10606*CC+19.*((75.-CC)**2.5/75.**2.5)+.5
        IF(NCEON.GT.MCEON) NCEON=MCEON
        ITC=NCEON+IKILLC +50
C
C       DETERMINES NO. OF SHEPHERDIA AS A FUNCTION OF CROWN CLOSURE
C
 680    IF(NSHEP.EQ.0) GO TO 685
        MSHEP=8.-.10606*CC+19.*((75.-CC)**2.5/75.**2.5)+.5
        IF(NSHEP.GT.MSHEP) NSHEP=MSHEP
        ITS=NSHEP+IKILLS + 100
C
C       DETERMINES NO. OF PRUNUS AS A FUNCTION OF CROWN CLOSURE
C
 685    IF(CC.GT.65.) NPRUN=0
        IF(NPRUN.EQ.0) GO TO 688
        MPRUN=7.-.1167*CC+9.*((65.-CC)**2./65.**2.)+.5
        IF(NPRUN.GT.MPRUN) NPRUN=MPRUN
C
C
C       DETERMINES NO. OF ROSES AS A FUNCTION OF CROWN CLOSURE
C
 688    IF(CC.GT.65.) NROSE=0
        IF(NROSE.EQ.0) GO TO 690
        MROSE=7.-.1167*CC+9.*((65.-CC)**2./65.**2.)+.5
        IF(NROSE.GT.MROSE) NROSE=MROSE
C
C
C       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.-.38889*C+.5
        IF(NSYMP.GT.MSYMP) NSYMP=MSYMP
C
C       SETS BORDER, INSIDE AND TOTAL AREA OF AMELANCHIER TO ZERO
C
 695    BORDA=0.
        XINA=0.
        UTILA=0.
C
C       SETS BORDER, INSIDE AND TOTAL AREA OF CEONOTHUS TO ZERO
C
        BORDC=0.
        XINC=0.
        UTILC=0.
C
C       SETS BORDER, INSIDE AND TOTAL AREA OF SHEPHERDIA TO ZERO
C
        BORDS=0.
```

```
      XINS=0.
      UTILS=0.
C
C     SETS PRODUCTION OF AMELANCHIER, CEONOTHUS, SHEPHERDIA, PRUNUS,
C         ROSE AND SYMPHORICARPOS TO ZERO
C
      PDNA=0.
      PDNC=0.
      PDNS=0.
      PDNPR=0.
      PDNRO=0.
      PDNSY=0.
      IF(M.EQ.0) GO TO 2000
      AGE=NAGE(M)
      XDIAM=0.
C
      WRITE(IOUT,699)ISUB,NAMEL,NCEON,NSHEP,NPRUN,NROSE,NSYMP
 699  FORMAT(//,5X,'SHRUB #.S SURVIVING IN UNSHADED AREA',//,5X,'SUB-PLO
     1T =',I5,2X,'# AMEL =',I5,2X,'# CEON =',I5,2X,'# SHEP =',I5,2X,'# P
     2RUN =',I5,2X,'# ROSE =',I5,2X,'# SYMP =',I5,///)
C
C
C
C     IDIAM1(I),..4(I) = DIAMETER OF INDIVIDUAL SHRUBS
C
C
C     AMELANCHIER CALCULATIONS
C
      NCOUN1=0
C
      DO 745 I=1,50
C
      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
```

```
 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
C        CALCULATES DIAMETER OF CEONOTHUS
C
 755   NCOUN2=0
C
       DO 805 I=51,100
C
       GO TO (760,763,769,772),ISUB
 760   IF(NCOUN2.GE.NCEON) IDEAD1(I)=1
       IF(IDEAD1(I).EQ.1) GO TO 805
       GO TO 775
 763   IF(NCOUN2.GE.NCEON) IDEAD2(I)=1
       IF(IDEAD2(I).EQ.1) GO TO 805
       GO TO 775
 769   IF(NCOUN2.GE.NCEON) IDEAD3(I)=1
       IF(IDEAD3(I).EQ.1) GO TO 805
       GO TO 775
 772   IF(NCOUN2.GE.NCEON) IDEAD4(I)=1
       IF(IDEAD4(I).EQ.1) GO TO 805
 775   NCOUN2=NCOUN2+1
       RANDK=KRAND(I-50)
       RANDK=RANDK/1000.
       DIAM=RANDK*(5.5*TANH(AGE*.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
C      SHEPHERDIA CALCULATIONS
C
 810   NCOUN3=0
C
       DO 865 I=101,150
       GO TO (815,820,825,830),ISUB
```

```
 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=LRAND(I-100)
       RANDL=RANDL/1000.
       IF(AGE.LT.28.) DIAM=RANDL*(.18*AGE)
       IF(AGE.GE.28.) DIAM=RANDL*(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
C      STARTS NEW SHRUB
       IF(ICOUNT.GT.ITS) GO TO 997
C
C      CALCULATES SHRUB RADIUS
C      RAD= RADIUS
C
       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(IDEAD3(ICOUNT).EQ.1) GO TO 880
      IF(IDIAM3(ICOUNT).EQ.0) GO TO 880
      RAD=IDIAM3(ICOUNT)
      RAD=RAD/200.
      IIX=ICOM(ICOUNT)
      JJX=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)
      JJX=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,'RADIUS IN FT. =',F8.2,5X,'ILOC =',I5,5
     1X,'J LOC =',I5)
      GO TO 995
C
 910  WRITE(IOUT,915)ICOUNT,RAD,ICOM(ICOUNT),JCOM(ICOUNT)
 915  FORMAT(2X,'CEON # =',I4,5X,'RADIUS IN FT. =',F8.2,5X,'ILOC =',I5,5
     1X,'J LOC =',I5)
      GO TO 995
C
 920  WRITE(IOUT,925)ICOUNT,RAD,ICOM(ICOUNT),JCOM(ICOUNT)
 925  FORMAT(2X,'SHEP # =',I4,5X,'RADIUS IN FT. =',F8.2,5X,'ILOC =',I5,5
     1X,'J LOC =',I5)
C
C     SHRUB GROWTH
 995  CALL BRANCH
      GO TO 880
C
 997  DO 998 I=1,153
      IAREA(I)=1
 998  PER(I)=0
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
     1NC,PDNPR,PDNRO,PDNSY,INDISH)
C
C     PRODUCTION CALC FOR SHRUBS, GRASSES & FORBS
      CALL SGPDN       (NAMEL,NCEON,NSHEP,NPRUN,NROSE,NSYMP,PDNS,PDNA,PD
     1NC,PDNPR,PDNRO,PDNSY,INDISH)
```

```
C
 2000 CALL SUM          (NAMEL,NCEON,NSHEP,NPRUN,NROSE,NSYMP,PDNS,PDNA,PD
     1NC,PDNPR,PDNRO,PDNSY,INDISH)
C
      IF(ISUB.LE.3) GO TO 190
      IF(IDD.LE.0) GO TO 3900
C
C     PRINTS SHRUB MAPS
C
      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)
C
      WRITE(IOUT,3700)
 3700 FORMAT('1',2X,'SUB-PLOT # 1',//,2X,'SHRUB MAP',//,1X,130('*'))
C
      DO 3800 I=1,66
C
 3800 WRITE(IOUT,3850)(JARRA(I,J),J=1,64)
C
      WRITE(IOUT,3889)
      IF(IDD.LE.1) GO TO 3900
C
      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)
C
      WRITE(IOUT,3701)
 3701 FORMAT('1',2X,'SUB-PLOT # 2',//,2X,'SHRUB MAP',//,1X,130('*'))
C
      DO 3801 I=1,66
C
 3801 WRITE(IOUT,3850)(JARRA(I,J),J=1,64)
C
      WRITE(IOUT,3889)
      IF(IDD.LE.2) GO TO 3900
C
      DO 3602 I=1,66
C
      DO 3602 J=1,66
      NB=LARR3(I,J)
      IF(NB.EQ.0) NB=154
 3602 JARRA(I,J)=KCHAR(NB)
C
      WRITE(IOUT,3702)
 3702 FORMAT('1',2X,'SUB-PLOT # 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,NCEON,NSHEP,NPRUN,NROSE,NSYMP,PDNS,PDNA,PD
     1NC,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),NNCEON(4),NNSHEP(4),NNPRUN(4),NNROSE(4),NNSYMP(4),JRAND(50),K
     2RAND(50),LRAND(50),JJRAND(100),KKRAND(100),LLRAND(100),          J
     3AMEL(20),JCEON(20),JSHEP(20),JPRUN(20),JROSE(20),JSYMP(20),      I
     5COM(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
     7IAM1(150),IDIAM2(150),IDIAM3(150),IDIAM4(150),PER(153),EPER(16),KA
     8MEL(4,21),KCEON(4,21),KSHEP(4,21),KPRUN(4,21),KROSE(4,21),KSYMP(4,
     921),KCHAR(160),IHT(100,97),ICHAR(99),IBB(50,97),IRAND(97),IXX(97),
     1JXX(97),IVOL(97),IDBH(97),ICL(97),IAPER(97),ICW(97),ICB(97),IBA(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,XINA,UTILA,BORDC,XINC,UTIL
     2C,BORDS,XINS,UTILS,AGE,C,CC,TAUT,TAUTS,TAUTT,TAUO,UNOCC,YUNOCC,PDN
     1,ITHRU,M,ISTRT,IINT,IEND,IYUNOC,IAUTTY,IUNOCC,ILOOP,IX,ISUB,ICOUNT
     3,IHT,IBB,JARRA,LARR1,LARR2,LARR3,LARR4,IQQ,JQQ,IAREA,PER,KCHAR,ICO
     4M,JCOM,IDEAD1,IDEAD2,IDEAD3,IDEAD4,IDIAM1,IDIAM2,IDIAM3,IDIAM4,JJR
     5AND,KKRAND,LLRAND,ICHAR,IRAND,IXX,JXX,IVOL,IDBH,ICL,IAPER,ICW,ICB,
     6IBA,IDEAD,NSET,KAMEL,KCEON,KSHEP,KPRUN,KROSE,KSYMP,NAGE,JRAND,KRAN
     7D,LRAND,JAMEL,JCEON,JSHEP,JPRUN,JROSE,JSYMP,EPER,NNAMEL,NNCEON,NNS
     8HEP,NNPRUN,NNROSE,NNSYMP,JCHAR
      IOUT=6
      IF(AGE.EQ.0) GO TO 2000
C
C     OCCUPATION OF AREA BY SHRUBS
C
      DO 1041 I=1,66
C
      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).NE.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),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),NNCEON(4),NNSHEP(4),NNPRUN(4),NNROSE(4),NNSYMP(4),JRAND(50),K
     2RAND(50),LRAND(50),JJRAND(100),KKRAND(100),LLRAND(100),          J
     3AMEL(20),JCEON(20),JSHEP(20),JPRUN(20),JROSE(20),JSYMP(20),      I
     5COM(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
     7IAM1(150),IDIAM2(150),IDIAM3(150),IDIAM4(150),PER(153),EPER(16),KA
     8MEL(4,21),KCEON(4,21),KSHEP(4,21),KPRUN(4,21),KROSE(4,21),KSYMP(4,
     921),KCHAR(160),IHT(100,97),ICHAR(99),IBB(50,97),IRAND(97),IXX(97),
     1JXX(97),IVOL(97),IDBH(97),ICL(97),IAPER(97),ICW(97),ICB(97),IBA(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,XINA,UTILA,BORDC,XINC,UTIL
     2C,BORDS,XINS,UTILS,AGE,C,CC,TAUT,TAUTS,TAUTT,TAUO,UNOCC,YUNOCC,PDN
     1,ITHRU,M,ISTRT,IINT,IEND,IYUNOC,IAUTTY,IUNOCC,ILOOP,IX,ISUB,ICOUNT
     3,IHT,IBB,JARRA,LARR1,LARR2,LARR3,LARR4,IQQ,JQQ,IAREA,PER,KCHAR,ICO
     4M,JCOM,IDEAD1,IDEAD2,IDEAD3,IDEAD4,IDIAM1,IDIAM2,IDIAM3,IDIAM4,JJR
     5AND,KKRAND,LLRAND,ICHAR,IRAND,IXX,JXX,IVOL,IDBH,ICL,IAPER,ICW,ICB,
     6IBA,IDEAD,NSET,KAMEL,KCEON,KSHEP,KPRUN,KROSE,KSYMP,NAGE,JRAND,KRAN
     7D,LRAND,JAMEL,JCEON,JSHEP,JPRUN,JROSE,JSYMP,EPER,NNAMEL,NNCEON,NNS
     8HEP,NNPRUN,NNROSE,NNSYMP,JCHAR
C
C     DETERMINES SHRUB SPECIES
C     IIX,JJX = LOCATIONS OCCUPIED
C
      IIX=ICOM(ICOUNT)
      JJX=JCOM(ICOUNT)
      GO TO (800,810,820,830),ISUB
  800 IF(ICOUNT.LE.50.) LARR1(IIX,JJX)=151
      IF(ICOUNT.GT.50.AND.ICOUNT.LE.100) LARR1(IIX,JJX)=152
      IF(ICOUNT.GT.100) LARR1(IIX,JJX)=153
      GO TO 900
  810 IF(ICOUNT.LE.50.) LARR2(IIX,JJX)=151
      IF(ICOUNT.GT.50.AND.ICOUNT.LE.100) LARR2(IIX,JJX)=152
      IF(ICOUNT.GT.100) LARR2(IIX,JJX)=153
      GO TO 900
  820 IF(ICOUNT.LE.50.) LARR3(IIX,JJX)=151
      IF(ICOUNT.GT.50.AND.ICOUNT.LE.100) LARR3(IIX,JJX)=152
      IF(ICOUNT.GT.100) LARR3(IIX,JJX)=153
      GO TO 900
  830 IF(ICOUNT.LE.50.) LARR4(IIX,JJX)=151
      IF(ICOUNT.GT.50.AND.ICOUNT.LE.100) LARR4(IIX,JJX)=152
      IF(ICOUNT.GT.100) LARR4(IIX,JJX)=153
  900 DO 1000 L=1,96
      NS=NSET(L)
      DO 1000 K=1,NS
      IF(RAD*2.-BL2(L))996,910,910
```

```
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)955,955,945
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
     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),NNCEON(4),NNSHEP(4),NNPRUN(4),NNROSE(4),NNSYMP(4),JRAND(50),K
     2RAND(50),LRAND(50),JJRAND(100),KKRAND(100),LLRAND(100),          J
     3AMEL(20),JCEON(20),JSHEP(20),JPRUN(20),JROSE(20),JSYMP(20),      I
     5COM(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
     7IAM1(150),IDIAM2(150),IDIAM3(150),IDIAM4(150),PER(153),EPER(16),KA
     8MEL(4,21),KCEON(4,21),KSHEP(4,21),KPRUN(4,21),KROSE(4,21),KSYMP(4,
     921),KCHAR(160),IHT(100,97),ICHAR(99),IBB(50,97),IRAND(97),IXX(97),
     1JXX(97),IVOL(97),IDBH(97),ICL(97),IAPER(97),ICW(97),ICB(97),IBA(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,XINA,UTILA,BORDC,XINC,UTIL
     2C,BORDS,XINS,UTILS,AGE,C,CC,TAUT,TAUTS,TAUTT,TAUO,UNOCC,YUNOCC,PDN
     1,ITHRU,M,ISTRT,IINT,IEND,IYUNOC,IAUTTY,IUNOCC,ILOOP,IX,ISUB,ICOUNT
     3,IHT,IBB,JARRA,LARR1,LARR2,LARR3,LARR4,IQQ,JQQ,IAREA,PER,KCHAR,ICO
     4M,JCOM,IDEAD1,IDEAD2,IDEAD3,IDEAD4,IDIAM1,IDIAM2,IDIAM3,IDIAM4,JJR
     5AND,KKRAND,LLRAND,ICHAR,IRAND,IXX,JXX,IVOL,IDBH,ICL,IAPER,ICW,ICB,
     6IBA,IDEAD,NSET,KAMEL,KCEON,KSHEP,KPRUN,KROSE,KSYMP,NAGE,JRAND,KRAN
     7D,LRAND,JAMEL,JCEON,JSHEP,JPRUN,JROSE,JSYMP,EPER,NNAMEL,NNCEON,NNS
     8HEP,NNPRUN,NNROSE,NNSYMP,JCHAR
C
C     REMOVES DEAD SHRUBS AND CALCULATES DEGREE OF INTERSHRUB
C       COMPETITION
C
      DO 60 I=1,66
C
      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
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```
      SUBROUTINE SGPON (NAMEL,NCEON,NSHEP,NPRUN,NROSE,NSYMP,PDNS,PDNA,PD
     1NC,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),NNCEON(4),NNSHEP(4),NNPRUN(4),NNROSE(4),NNSYMP(4),JRAND(50),K
     2RAND(50),LRAND(50),JJRAND(100),KKRAND(100),LLRAND(100),          J
     3AMEL(20),JCEON(20),JSHEP(20),JPRUN(20),JROSE(20),JSYMP(20),       I
     5COM(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
     7IAM1(150),IDIAM2(150),IDIAM3(150),IDIAM4(150),PER(153),EPER(16),KA
     8MEL(4,21),KCEON(4,21),KSHEP(4,21),KPRUN(4,21),KROSE(4,21),KSYMP(4,
     921),KCHAR(160),IHT(100,97),ICHAR(99),IBB(50,97),IRAND(97),IXX(97),
     1JXX(97),IVOL(97),IDBH(97),ICL(97),IAPER(97),ICW(97),ICB(97),IBA(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,XINA,UTILA,BORDC,XINC,UTIL
     2C,BORDS,XINS,UTILS,AGE,C,CC,TAUT,TAUTS,TAUTT,TAUO,UNOCC,YUNOCC,PDN
     1,ITHRU,M,ISTRT,IINT,IEND,IYUNOC,IAUTTY,IUNOCC,ILOOP,IX,ISUB,ICOUNT
     3,IHT,IBB,JARRA,LARR1,LARR2,LARR3,LARR4,IQQ,JQQ,IAREA,PER,KCHAR,ICO
     4M,JCOM,IDEAD1,IDEAD2,IDEAD3,IDEAD4,IDIAM1,IDIAM2,IDIAM3,IDIAM4,JJR
     5AND,KKRAND,LLRAND,ICHAR,IRAND,IXX,JXX,IVOL,IDBH,ICL,IAPER,ICW,ICB,
     6IBA,IDEAD,NSET,KAMEL,KCEON,KSHEP,KPRUN,KROSE,KSYMP,NAGE,JRAND,KRAN
     7D,LRAND,JAMEL,JCEON,JSHEP,JPRUN,JROSE,JSYMP,EPER,NNAMEL,NNCEON,NNS
     8HEP,NNPRUN,NNROSE,NNSYMP,JCHAR
      IOUT=6
C
C     CALCULATES NUMBER AND PRODUCTIVITY OF SHRUBS
C
C     SETS PRODUCTION TO 0.
      PDNA=0.
      PDNC=0.
      PDNS=0.
      PDNPR=0.
      PDNRO=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(IMORT.EQ.1) GO TO 1200
C
C      CALCULATES BORDER AND INSIDE AREA OF SHRUBS AND PRODUCTION
C      XINS= INSIDE AREA
C      BORDS = BORDER AREA
C
       IF(DIAM.EQ.0) GO TO 1200
       RAD=DIAM/100.
       DIAM=RAD
       RDS=RAD/2.
       IRAD=RAD
       K=IRAD+1
       IF(PER(I).LT.EPER(K))  GO TO 1090
       IF(RDS.LT..82) GO TO 1070
       BORD=(RDS+.82)**2.*3.14159-(RDS-.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.
C
 1075 IF(I.GT.50) GO TO 1076
       BORDA=BORDA+BORD
       XINA=XINA+XIN
       XAREA=RDS**2.*3.14159
       AMELP=4.1*XAREA
       GO TO 1130
C
 1076 IF(I.GT.100) GO TO 1079
       BORDC=BORDC+BORD
       XINC=XINC+XIN
       XAREA=RDS**2.*3.14159
       IF(XAREA.LE.6.) CEONP=60./6.**1.7*XAREA**1.7
       IF(XAREA.GT.6.)  CEONP=810.-1.45454*(110.-XAREA)-700.*(110.-XAREA)
      1**2.7/110.**2.7
       GO TO 1130
C
 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=IAREA(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.LE..82) GO TO 1095
      EXPINS=(RDS-.82)**2.*3.14159
      BORD=DIF*((RDS+.82)**2.*3.14159-EXPINS)
      EXPAR=3.14159*RDS**2.
      ACTINS=ACTAR*EXPINS/EXPAR
      BORDIN=DIF*(EXPAR-EXPINS)
      IF((BORDIN+ACTINS).NE.ACTAR) ACTINS=ACTAR-BORDIN
      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
      BORDA=BORDA+BORD
      XINA=XINA+XIN
      AMELP=4.1*XAREA
      GO TO 1130
 1105 IF(I.GT.100) GO TO 1120
      BORDC=BORDC+BORD
      XINC=XINC+XIN
      IF(XAREA.LE.6.) CEONP=60./6.**1.7*XAREA**1.7
      IF(XAREA.GT.6.)  CEONP=810.-1.45454*(110.-XAREA)-700.*(110.-XAREA)
     1**2.7/110.**2.7
 1115 GO TO 1130
 1120 BORDS=BORDS+BORD
      XINS=XINS+XIN
      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
 1130 IF(I.LE.50) PDNA=PDNA+AMELP
      IF(I.GT.50) GO TO 1140
      IF(INDISH.EQ.0)  GO TO 1200
C
      WRITE(IOUT,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+CEONP
      IF(I.GT.100) GO TO 1150
      IF(INDISH.EQ.0)  GO TO 1200
C
      WRITE(IOUT,1180) I,PER(I),EPER(K),DIAM,XIN,BORD,CEONP,IAREA(I)
      GO TO 1200
 1150 IF(I.GT.100) PDNS=PDNS+SHEPP
      IF(INDISH.EQ.0)  GO TO 1200
C
      WRITE(IOUT,1180) I,PER(I),EPER(K),DIAM,XIN,BORD,SHEPP,IAREA(I)
 1180 FORMAT(2X,'# ='I3,3X,'PER=',I5,3X,'EPER=',I5,3X,'DIAM=',F6.2,3X,'X
```

```
     1IN=',F6.2,3X,'BORD=',F6.2,3X,'PDN=',F8.2,3X,'AREA=',I9)
 1200 CONTINUE
C
C
C
C
      PDNA=PDNA/25.
      PDNS=PDNS/25.
      PDNC=PDNC/25.
      WRITE(IOUT,1201) PDNA,PDNC,PDNS
 1201 FORMAT(//,2X,'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=1089.*C/100.
C     TAUT  =  AREA OCCUPIED BY TREES AND SHRUBS
      TAUT=TAUTS+TAUTT
C     TAUO  =  AREA NOT OCCUPIED BY TREES AND SHRUBS
      TAUO=1089.-TAUT
      IF(TAUO.LT.0) TAUO=0
C     IAUTTY  =  AREA IN SHADE IN SQ. YDS.
      UNOCC=1089.-TAUT
C     IUNOCC  =  OPEN AREA (AREA NOT OCC. BY TREES AND SHRUBS) IN SQ.FT.
      YUNOCC=UNOCC/9.
C     IYUNOC  =  OPEN AREA IN SQ. YDS.
      IYUNOC=YUNOCC
      IAUTTY=TAUTT/9.
      IUNOCC=UNOCC
C
      WRITE(IOUT,1202) TAUTS,TAUTT,TAUT,IYUNOC
 1202 FORMAT(///,2X,'TAUTS='F9.2,3X,'TAUTT='F9.2,3X,'TAUT=',F9.2,3X,'IYU
     1NOC=',I9)
      IF(NPRUN.LT.1) GO TO 1225
      J=100
      IF((NPRUN*IYUNOC).LT.100) J=NPRUN*IYUNOC
      ITH=0
C
      DO 1220 I=1,J
      ITH=ITH+1
```

```
      RANDJJ=JJRAND(I)
      RANDJJ=RANDJJ/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=RANDJJ*(-.2+.178*AGE+.2*(X1/X2))
      GO TO 1215
 1212 DPRUN=RANDJJ*2.14
 1215 IF(DIAM.LT.1.37) PDNP=.04+.6*DPRUN
      IF(DIAM.GE.1.37) PDNP=-8.8+7.1*DPRUN
 1220 PDNPR=PDNPR+PDNP
      PRUN=NPRUN
      IF(ITH.LT.100) GO TO 1225
      BLOCK=100./PRUN
      XBLK=YUNOCC/BLOCK
      PDNPR=XBLK*PDNPR
C
 1225 IF(NROSE.LT.1) GO TO 1240
      J=100
      IF((NROSE*IYUNOC).LT.100) J=NROSE*IYUNOC
      ITH=0
      DO 1230 I=1,J
      ITH=ITH+1
      RANDKK=KKRAND(I)
      RANDKK=RANDKK/1000.
      DROSE=RANDKK*(2.3*TANH(AGE*.1776))
      PDNR=.1+1.4*DROSE**1.5
 1230 PDNRO=PDNRO+PDNR
      ROSE=NROSE
      IF(ITH.LT.100) GO TO 1240
      BLOCK=100./ROSE
      XBLK=YUNOCC/BLOCK
      PDNRO=XBLK*PDNRO
 1240 IF(NSYMP.LT.1) GO TO 1260
      J=100
      IF((NSYMP*IYUNOC).LT.100) J=NSYMP*IYUNOC
      ITH=0
C
      DO 1255 I=1,J
      ITH=ITH+1
      RANDLL=LLRAND(I)
      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 PDNSY=PDNSY+PDNSM
      SYMP=NSYMP
      IF(ITH.LT.100) GO TO 1260
```

```
      BLOCK=100./SYMP
      XBLK=YUNOCC/BLOCK
      PDNSY=XBLK*PDNSY
 1258 FORMAT(//,2X,'PDNRO =',F10.4,5X,'PDNSY =',F10.4,5X,'PDNPR =',F9.4)
C
 1260 WRITE(IOUT,1258) PDNRO,PDNSY,PDNPR
 1280 RETURN
      END
```

```
      SUBROUTINE SUM    (NAMEL,NCEON,NSHEP,NPRUN,NROSE,NSYMP,PDNS,PDNA,PD
     1NC,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),NNCEON(4),NNSHEP(4),NNPRUN(4),NNROSE(4),NNSYMP(4),JRAND(50),K
     2RAND(50),LRAND(50),JJRAND(100),KKRAND(100),LLRAND(100),           J
     3AMEL(20),JCEON(20),JSHEP(20),JPRUN(20),JROSE(20),JSYMP(20),       I
     5COM(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
     7IAM1(150),IDIAM2(150),IDIAM3(150),IDIAM4(150),PER(153),EPER(16),KA
     8MEL(4,21),KCEON(4,21),KSHEP(4,21),KPRUN(4,21),KROSE(4,21),KSYMP(4,
     921),KCHAR(160),IHT(100,97),ICHAR(99),IBB(50,97),IRAND(97),IXX(97),
     1JXX(97),IVOL(97),IDBH(97),ICL(97),IAPER(97),ICW(97),ICB(97),IBA(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,XINA,UTILA,BORDC,XINC,UTIL
     2C,BORDS,XINS,UTILS,AGE,C,CC,TAUT,TAUTS,TAUTT,TAUO,UNOCC,YUNOCC,PDN
     1,ITHRU,M,ISTRT,IINT,IEND,IYUNOC,IAUTTY,IUNOCC,ILOOP,IX,ISUB,ICOUNT
     3,IHT,IBB,JARRA,LARR1,LARR2,LARR3,LARR4,IQQ,JQQ,IAREA,PER,KCHAR,ICO
     4M,JCOM,IDEAD1,IDEAD2,IDEAD3,IDEAD4,IDIAM1,IDIAM2,IDIAM3,IDIAM4,JJR
     5AND,KKRAND,LLRAND,ICHAR,IRAND,IXX,JXX,IVOL,IDBH,ICL,IAPER,ICW,ICB,
     6IBA,IDEAD,NSET,KAMEL,KCEON,KSHEP,KPRUN,KROSE,KSYMP,NAGE,JRAND,KRAN
     7D,LRAND,JAMEL,JCEON,JSHEP,JPRUN,JROSE,JSYMP,EPER,NNAMEL,NNCEON,NNS
     8HEP,NNPRUN,NNROSE,NNSYMP,JCHAR
C
C     CALCULATES GRASS AND FORB PRODUCTION
C     CHECKS CROWN CLOSURE OF TREES AND ADJUSTS GRASS PRODUCTION
C     ADJUSTS GRASS AND FORB PRODUCTION TO SHRUB INSIDE AND BORDER AREA
C       AND SHRUB NUMBER
       IOUT=6
      IF(C.LT.68.) PDNAG=PDN/83.3/9.*(27.+.085294*(68.-C)+50.5/68.**6.*(
     168.-C)**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+.87*C)
      IF(C.GT.18..AND.C.LT.80.) FORB=PDN/83.3/9.*(.5+18./60.**2.7*(80.-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*1.365/25.
      GRASB=GRAS*UBORD*1.365/25.
      FORBB=FORB*UBORD*1.365/25.
      AGROI=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.
      GRTO=GRAS*(1089.-TAUTS)/25.
      GO TO 2000
 1270 AGTO=PDNAG*TAUTT/25.
      FOTO=FORB*TAUTT/25.
      GRTO=GRAS*TAUTT/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) 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*NSYMP)/3.76
      AGTO=PDNAG*REDUCA*TAUTT/25.
      GRTO=GRAS*REDUCA*TAUTT/25.
      FOTO=FORB*TAUTT/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+GRTO+GRASI+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
```

```
C     SUMMARY OF PRODUCTION OF SHRUBS,GRASSES AND FORBS
C
 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
      KCEON(ISUB,L)=NCEON
      APDNC(ISUB,L)=PDNC
      KSHEP(ISUB,L)=NSHEP
      APDNS(ISUB,L)=PDNS
      KPRUN(ISUB,L)=NPRUN*IYUNOC
      APDNPR(ISUB,L)=PDNPR
      KROSE(ISUB,L)=NROSE*IYUNOC
      APDNRO(ISUB,L)=PDNRO
      KSYMP(ISUB,L)=NSYMP*((1089-TAUTS)/9.)
      APDNSY(ISUB,L)=PDNSY
      IPRUN=NPRUN*IYUNOC
      IROSE=NROSE*IYUNOC
      ISYMP=NSYMP*IYUNOC
C
C     PRINT PRODUCTION SUMMARIES
C
      WRITE(IOUT,2)
 2    FORMAT(2X,T10,'CC',T13,'AGROP PDN',T23,'GRASS PDN',T34,'FORB PDN',
     1T47,'# AMEL',T55,'AMEL PDN',T67,'# CEON',T75,'CEON PDN',T87,'# SHE
     2P',T95,'SHEP PDN')
C
      WRITE(IOUT,5)C,TA,TG,TF,NAMEL,PDNA,NCEON,PDNC,NSHEP,PDNS
 5    FORMAT(2X,4F10.4,I10,F10.4,I10,F10.4,I10,F10.4)
C
      WRITE(IOUT,7)
 7    FORMAT(2X,T7,'# PRUN',T15,'PRUN PDN',T27,'# ROSA',T35,'ROSA PDN',T
     147,'# SYMP',T55,'SYMP PDN')
C
      WRITE(IOUT,10)IPRUN,PDNPR,IROSE,PDNRO,ISYMP,PDNSY
 10   FORMAT(2X,I10,F10.4,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 IDO=0
C
 2022 DO 2027 I=1,4
      IF(IDO.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
C
C
      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)(APDNA(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)(APDNPR(I,K),K=N,J)
      WRITE(IOUT,2043)(KROSE(I,K),K=N,J)
      WRITE(IOUT,2044)(APDNRO(I,K),K=N,J)
      WRITE(IOUT,2045)(KSYMP(I,K),K=N,J)
 2027 WRITE(IOUT,2046)(APDNSY(I,K),K=N,J)
C
      IF(ILOOP.LE.10) GO TO 3000
      IDO=IDO+1
      GO TO 2022
C
C
 2030 FORMAT(2X,'AGE', 6X,11I10)
 2031 FORMAT(2X,'CR. CLOSE.',1X,11F10.1)
 2032 FORMAT(2X,'AGROP. PDN.',11F10.3)
 2033 FORMAT(2X,'FORB PDN.',2X,11F10.3)
 2034 FORMAT(2X,'GRASS 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)
C
C
```

```
3000 RETURN
     END
```