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DYNAMIC MULTI-SPECIES ANIMAL HABITAT MODELING
WITH FOREST SUCCESSION MODELS

by

Stephen A. Compton

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Forest Ecology

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1992

ACKNOWLEDGEMENTS

I sincerely wish to thank Dr. David W. Roberts for guiding me through my Master of Science program. He has a tremendous sense of integrity, as well as a true sense of humor. It is easy to state that without his diligent effort and leadership, I would not have performed nearly as well in completing this project. Hopefully, without me around he will have a multitude of "abundant free time."

I also wish to thank Dr. James N. Long and Dr. Michael Wolfe, without whom my education at Utah State University would have been incomplete. I appreciate Dr. Charles Grier's acceptance to perform as a proxy at my defense. I wish to thank Dr. James MacMahon and Dr. Charles Romesburg for very stimulating and challenging courses. I also owe thanks to Bill Ehmann for improving my overall graduate and political experience. I am indebted to Dana Brunvand for reviewing drafts of this document.

Most of all, I wish to dedicate this thesis to my late mother, Eunice M. Compton.

This research was supported in part by funds provided by the Intermountain Research Station, Forest Service, U. S. Department of Agriculture.

Stephen A. Compton

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ABSTRACT

Dynamic Multi-species Animal Habitat Modeling
with Forest Succession Models

by

Stephen A. Compton, Master of Science

Utah State University, 1992

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Department: Forest Resources

This research determines and demonstrates the ability to simulate dynamic multi-species animal habitat suitability with forest succession models. A literature review of dynamic animal habitat models is presented. The structure of an existing forest simulation model (MASS10) was modified from a basal area-based model to a volume-based model (DYNAM10). The forest model was calibrated using data from permanent-plot growth and vegetation samples collected by USDA Forest Service Forest Survey procedures. The theoretical growth parameters used to simulate stand development were validated. Predictions of DBH and height growth, as well as stand-level behavior, were verified. A subroutine, VEGDYN, was added to DYNAM10 to simulate 34 structural vegetation parameters required by animal Habitat Suitability Index (HSI) models. Predictions of the structural parameters were verified. Ten animal-species HSI models were linked to DYNAM10 via the program HSI.FOR, and predicted dynamic HSI values were verified by hand-calculation. Typical patterns of dynamic HSI predictions are presented and discussed.

(128 pages)

INTRODUCTION

Recently, simulation models of a variety of designs have proven useful in resource management. These models have been dedicated primarily to analysis of growth and yield for timber production (e.g., PROGNOISIS [Wykoff et al. 1982]), but have also proven useful in wildlife population modeling (Grant 1986).

Wildlife habitat managers have developed numerous models for the evaluation of habitat quality or suitability for certain species of wildlife. In particular, the Habitat Evaluation Procedures Group of the USDI Fish and Wildlife Service has published a series of models under the name of Habitat Suitability Index (HSI) models. In contrast to the resource simulation models, however, these models are static, and portray habitat suitability only at the time of application. Changes in habitat quality resulting from natural or managed changes in the environment are not typically considered.

Typical forest succession models (e.g., FORET [Shugart 1984] or JABOWA [Botkin et al. 1972]) generate predictions of forest stand composition and structure for simulated forest stands at specified time intervals. While these models are intended to portray successional dynamics of interest primarily to plant ecologists, the information provided by these models is useful in predicting habitat structure dynamics for specific animal species. Accordingly, if the forest succession models can be modified to produce predictions of the parameters required by the HSI models, then predictions of the dynamics of habitat quality can be produced.

Natural resource managers are faced with an increasing demand for objective, documented, resource management decisions based on formal decision criteria. These decision criteria depend on the ability to formulate alternatives and predict the consequences of each alternative. To formulate the alternatives, and to evaluate the consequences of each alternative on the resource base, some means of prediction is required.

To predict the characteristics of animal habitat in the future, a dynamic habitat suitability model is required. To be useful to managers, such a model should provide detail sufficient to determine appropriate management opportunities, but need not provide a wealth of detail which is unnecessary for habitat management. Second, such a model should require only data which are relatively easily obtained, and which are in current use by wildlife habitat managers. Third, the model should incorporate current wildlife habitat models, so as to avoid duplicating existing research, and to provide outputs which are readily interpretable by practicing wildlife managers.

OBJECTIVES

The general objective of this thesis is to evaluate and demonstrate the utility of forest succession models for providing information on changes in animal habitat quality over time, whether resulting from managed or natural changes in the environment. A literature review of currently published dynamic animal habitat simulation models is presented. Numerous dynamic forest simulators have been linked to a great variety of static animal habitat models. Although different dynamic animal habitat models apply to different scales of land management, all of the models assume animal habitat quality can be predicted from structural measures of vegetation, almost to the exclusion of any other type of parameter.

The research presented in this document is a melding of an individual-tree forest simulation model with multiple HSI models for management indicator species. A dynamic animal habitat suitability simulation model was produced by modifying and calibrating an existing forest succession model and linking the model with several animal habitat suitability models. The model incorporates current wildlife habitat models and provides outputs which are readily interpretable by practicing wildlife managers. The model was designed to apply at appropriate scales of land management for wildlife, and requires from land managers a minimum of empirical data for calibration. Additionally, the model was developed from a regional database, and is therefore applicable over a relatively large region.

LITERATURE REVIEW

Linking Animal Habitat Models with Vegetation Succession Models

Forest planners are faced with the complex task of assessing the effect of alternative management plans on future forest conditions. Planners today require efficient, objective, documented methods for assessing long-term change of forest stand composition and structure, and their relation to animal habitat suitability. Several attempts have been made at linking static, single-species animal habitat models with computer simulation models of vegetation succession to create dynamic animal habitat simulation models.

Single-species Animal Habitat Models

Five types of single-species animal habitat models have been used in such attempts, namely Bayesian conditional probability models, habitat suitability index (HSI) models, habitat capability (HC) models, habitat evaluation procedures (HEP), and successional age-response models. All five types are static, meaning they can calculate an index of current habitat conditions for a particular site, but cannot predict future habitat conditions. All require information about vegetation structure (i.e., percent cover or density of shrubs, herbaceous vegetation, downed wood, and live or standing-dead trees). Structural characteristics are measured on the spatial scale of the stand (Bayesian, HSI, and HC models, and HEP) or landscape (HEP, and Bayesian and successional age-response models) in order to calculate an index of habitat quality. A stand is defined as a contiguous area of land that supports a relatively homogenous vegetational composition and structure, whereas a landscape contains one or more contiguous stands.

Bayesian and Pattern Recognition Models

Bayesian conditional probability models are based on Bayes Theorem, and include pattern recognition (PATREC) models (Williams et al. 1978). Such models calculate the probability of mutually exclusive categories of a species' response, such as high and low population density (Williams et al. 1978), given the probabilities of various habitat

conditions being present (Mannan et al. in prep.). The general form of Bayes Theorem is:

$$[1] \quad P(S/E) = \frac{P(S)P(E/S)}{P(S)P(E/S) + P(U)P(E/U)}$$

where, P(S) equals the prior probability of suitable habitat, P(U) equals the prior probability of unsuitable habitat, P(E/S) equals the likelihood of sample result E given suitable habitat, and P(E/U) equals the likelihood of sample result E given unsuitable habitat. P(S/E) equals the revised or posterior probability of suitable habitat given sample result E, and is typically defined as the expected habitat suitability index, or EHS (Williams et al. 1978).

Development of a Bayesian conditional probability model for an animal species requires the investigator to determine 1) mutually exclusive probability values for P(S) and P(U) in the geographical region under consideration, 2) a number of statistically independent, typically structural parameters, on the spatial scale of the stand or landscape, that are judged to be consistent predictors of suitable habitat, 3) probability values for each chosen parameter [P(E/S) and P(E/U)] over a range of habitat quality, and 4) the presence or absence of each habitat parameter for each sample area (Williams et al. 1978). As a result of these requirements, Bayesian models are usually developed for specific management units and cannot be applied more generally to regional areas.

Since sample data are often unavailable for a management unit, values of prior probabilities may be difficult to determine (Williams et al. 1978). Hence, these values are often based on expert evaluation, which may be uncertain (Mannan et al. in prep.). Since posterior probabilities are at times very sensitive to values of prior probabilities, posterior probabilities may be subject to a large and unknown degree of error (Mannan et al. in prep.).

The primary advantage of Bayesian models over other single-species animal habitat models is that they may be used to identify courses of action to improve habitat conditions. The habitat condition most in need of improvement is indicated by the lowest value obtained by subtracting the value of P(E/U) from the value of P(E/S) for each variable (Williams et al. 1978). This is accurate if prior probabilities are calculated from empirical

data. However, the argument is circular, and posterior probabilities may again be subject to error, if estimates of prior probabilities are based upon expert opinion.

Habitat Suitability Index Models

Over one-hundred habitat suitability index (HSI) models have been published by the USDI Fish and Wildlife Service. HSI models typically calculate an index of habitat suitability as the geometric mean of two to seven habitat variables (U. S. Fish and Wildlife Service 1981). These variables are also typically based on vegetation structure. Chosen variables are those judged by a panel of professional wildlife biologists and ecologists to most affect a species' capacity to utilize an area. The numerical value of an HSI ranges between 0.0 and 1.0, as do the values of each variable, because the values represent the ratio of habitat conditions of the study area to theoretical optimum habitat conditions (U. S. Fish and Wildlife Service 1981). The models assume a direct linear relationship between the HSI value and carrying capacity (U. S. Fish and Wildlife Service 1981).

Published HSI models appear to be verified by a three-step procedure. First, a peer review of the model is performed to ensure that appropriate variables are used and the relationships between variables are accurately portrayed. Second, each variable's relationship to habitat suitability is compared to sample data sets, either real or theoretical, which mimic various habitat conditions to reveal how well the model reflects the habitat condition for each data set. Finally, species authorities review the model to increase its reliability (U. S. Fish and Wildlife Service 1981). Lancia et al. (1982) criticizes this approach as circular because the same species authority may be consulted for both original model formulation and final model verification.

There have been few attempts at HSI model validation, that is, testing model predictions of habitat quality against empirical field data of animal usage of habitat. These attempts have been variously successful. Cole and Smith (1983) determined that the original equations (geometric means) used to combine each variable's HSI value for the meadow vole (*Microtus pennsylvanicus*), white-footed mouse (*Peromyscus leucopus*), and cottontail (*Sylvilagus floridanus*) models were almost useless when tested. However, modification of the equations to weighted means or combinations of weighted means and

geometric means proved very useful (Cole and Smith 1983), apparently without the need to modify the choice of variables or their individual relation to habitat suitability. Lancia et al. (1982) developed an HSI model for the bobcat (*Lynx rufus*) and determined that the model needed refinement, but that there was a relatively high degree of correspondence between predicted habitat quality and animal usage of habitat. Thomasma (1988) validated the fisher (*Martes pennanti*) HSI model for use in the Upper Peninsula of Michigan using fine-grained field measurements of habitat variables.

Habitat Capability Models

The USDA Forest Service has developed habitat capability (HC) models which are based on theory similar to the HSI models. HC models determine a habitat capability index for a stand that ranges from 0.0 to 1.0. The index value indicates the relative capacity of the stand to support an animal species. Unlike HSI models, HC models do not necessarily assume a direct relationship between the index value and animal population density (Sheppard et al. 1982). Habitat capability indices for different species are not linearly related to one another (Sheppard et al. 1982).

HC models vary in their structure. Wisdom et al. (1986) calculated the habitat effectiveness (HE) of a site for Roosevelt elk (*Cervus elaphus roosevelti*) as the geometric mean of four structural habitat variables. Alternatively, Sheppard et al. (1982) used the Wildlife and Fish Habitat Relationships (WFHR) database to develop HC models of a different structure. A number of mutually exclusive successional age-classes are specified. Each age-class is assigned a habitat capability index (HCI) value of 1.0 (optimum), 0.50 (acceptable), or 0.20 (marginal) for each of three presumed behavioral requirements for feeding, resting (cover), and reproduction habitat. The habitat capability coefficient (HCC) of each age-class is simply the mean of the three HCI values (Sheppard et al. 1982).

Habitat Evaluation Procedures

Habitat evaluation procedures (HEP) were developed by the USDI Fish and Wildlife Service to evaluate project impacts at the animal-species level (Hawkes et al. 1983). HEP are

a simple extension of HSI models that may be used to simultaneously assess the quality and quantity of available habitat within a specified area of land (U. S. Fish and Wildlife Service 1981). Habitat assessments using HEP are based upon habitat units (HU's) which are computed by the formula:

$$[2] \quad \text{Habitat Units} = (\text{HSI}) * (\text{Area of Available Habitat})$$

where the area of available habitat is defined as the total area of each cover type used by the evaluation species (U. S. Fish and Wildlife Service 1981).

Since HSI models are used to assess the suitability of each contiguous area of habitat, the application of HEP is subject to the same limitations as HSI models, namely circular verification and limited validation.

The primary advantage of HEP over Bayesian, HC, and HSI models alone is their ability to assess habitat on the spatial scale of the landscape instead of on a stand level. HEP, like HSI models, require much field data on specific habitat attributes (Mannan et al. in prep.). Doering and Armijo (1986) determined that results of attribute assessment obtained through aerial photo interpretation were close to those obtained by measuring habitat variables directly, and required considerably less time. They warn that some habitat variables cannot be estimated at all, or only inaccurately, from aerial photographs, but suggest estimating variables as a function of structure. Once such relationships are developed, HEP would require little time to determine landscape-level habitat suitability.

Successional Age-Response Models

Successional age-response models are the most simplistic of those discussed, and are best applied to multiple adjacent stands over a given landscape. These models calculate a measure of animal response, such as a suitability index (Boyce 1977) or potential carrying capacity (PCC) (Raedeke and Lehmkuhl 1986), based solely on the proportion of different structural vegetation classes distributed over a given area of land.

Raedeke and Lehmkuhl (1986) assume that each vegetation or successional age-class has a static animal density potential for a given species. The total PCC of the landscape is simply

the product of the quantity (area) of each class and each class' density potential (animals/area). Alternatively, Boyce (1977) developed curvilinear relationships between the proportion of area in various successional age-classes and a number of chosen structural habitat-variable indices. A mathematical algorithm is then used to combine the individual variable indices into a single index of habitat suitability (Hawkes et al. 1983).

Types of Vegetation Succession Models

Static animal habitat models have been linked to three broad types of vegetation succession simulators, namely tree-, stand-, and stand-type-based models.

Tree models simulate the growth of several to numerous individual trees and then extrapolate that growth to the entire stand. Such models are best applied at the spatial scale of the forest stand, where simulated small-scale vegetation dynamics are used to predict structural characteristics that may be related to animal species habitat quality.

Stand models typically classify individual trees into groups, such as by species (Horn 1975a, Horn 1975b) or age-class (Raedeke and Lehmkuhl 1986), and use rates of change between classes to simulate vegetation succession on the spatial scale of the stand. The transitional probabilities between classes tend to be measurements of long-term change, and are not based on any particular environmental mechanism.

Stand-type models simulate landscape-level vegetation succession as the transition of individual stands between specified, broad classes of forest-community or structural types. Transition of a stand from one type to another is a time-dependent process, typically represented as simple conversion rates along a linear chain or as a set of transitional probabilities in a matrix. Stand-type models are the least mechanistic, and operate at the coarsest scale of those vegetation simulators discussed.

Tree Models

The Prognosis Model for Stand Development (Stage 1973) is extensively used by the USDA Forest Service, and has variants for portions of the Northern, Intermountain, and Pacific Northwest regions of the Forest Service (Moeur 1986). Prognosis simulates the

growth of individual trees using submodels for individual-tree diameter growth, height growth, mortality, and product volumes, and can incorporate impacts of silvicultural activities on tree growth. The program COVER was written as a supplement to Prognosis to predict shrub and cover statistics that may be important for various animal species (Moeur 1986). COVER does not explicitly predict changes in any particular animal species' habitat suitability or population density, but presumably could be linked to submodels which could do so if particular structural habitat requirements were specified. Since most animal habitat models require information on a variety of habitat variables beyond shrub and cover statistics to calculate measures of animal response, current application of the Prognosis-COVER model as a dynamic animal habitat model is quite limited.

Brand et al. (1986) linked TWIGS, an individual-tree-based, distance-independent forest projection model, to the gray squirrel (*Sciurus carolinensis*) HSI model, and simulated the impact of three management alternatives on dynamic squirrel habitat suitability and economic return. TWIGS simulates the growth and death of each tree using species-specific regression coefficients for important tree species indigenous to the Lake States and the Central States (Brand et al. 1986). The output of TWIGS provided most of the information on vegetation structure required by the HSI model. Hence, little modification of TWIGS was necessary for the linkage.

Smith (1986) developed FORHAB, a modified version of FORET (Shugart and West 1977), an Appalachian deciduous-forest-stand simulator. FORHAB simulates annual change of a forest stand by calculating the growth increment of each tree, and tabulating the addition of new saplings, and the death of trees present on the stand (Smith 1986). The subroutine HABIT then calculates foliage, branch, and bole biomass for each tree using site-specific biomass regression equations. These values are summed for the stand and input into the subroutine DISCRIM.

DISCRIM classifies simulated stands by their potential to provide habitat for a given animal species using Bayesian linear decision scales based on two-group discriminant function analysis of sample data. The linear decision scales were developed from plot

census data of vegetation biomass and presence or absence of red-eyed vireo (*Vireo olivaceus*) and downy woodpecker (*Picoides pubescens*) breeding territories (Smith 1986).

Stand Models

HABSIM (Raedeke and Lehmkuhl 1986) applies a simple algorithm to create an N by N time-interval matrix of forest age-class rows and year-interval columns. The time-interval length represented by columns and rows is identical (i.e., 5-year interval), with N increasing as the length of simulation increases. For a 100-year simulation, the matrix would be 20 by 20, the rows being stand age (0-5, 6-10, etc.), and the columns being time (1931-35, 1936-40, etc.). The matrix is constructed by successively transferring the area of forest input in the first cell diagonally to the adjacent lower-right cell, representing the next age and time cell, until the triangular matrix is filled (Raedeke and Lehmkuhl 1986).

HABSIM requires the user to provide a model of wildlife response to successional change in stand-level habitat. Successional age-response models would be appropriate for this link, as HABSIM predicts change of the area or proportion of specified, broad successional age-classes over a landscape in response to alternative silvicultural prescriptions. Raedeke and Lehmkuhl (1986) linked an elk response model, described above, to HABSIM to predict the total PCC of a given area of land.

Stand-Type Models

Jenkins and Wright (1987) developed a transitional probability matrix for six community-types along the North Fork of the Flathead River in western Montana to simulate landscape-level vegetation succession. Change in the proportion of the landscape occupied by each plant community was simulated iteratively by multiplying the matrix of transition probabilities by the vector containing present plant community composition, thereby treating the matrix as a first-order Markov chain (Jenkins and Wright 1987).

They estimated winter densities of white-tailed deer for each community-type to develop a dynamic animal habitat model. The model functions by tracking the total area of land in each community-type and multiplying each total by the appropriate deer density potential of each community-type, then summing the six density estimates for the

landscape. They predicted the impact of three management policies on the total potential deer population.

Boyce (1977) developed DYNAST, the Dynamic Analytic Silviculture Technique. DYNAST projects the changing proportion of user-specified forest age-classes resulting from multiple patterns of harvest, or modes of management. The model has a cybernetic structure; it uses a set of negative feedback loops to maintain a given distribution of age-classes in a steady state (Boyce 1977). The original version of DYNAST specified five habitat or age-classes, namely seedling, sapling, pole, mature timber, and old-growth. The feedback mechanisms control the removal of timber to create a steady flow of acreage into seedling habitat, thus regulating the proportions of different habitats in the future landscape. The primary advantage of DYNAST lies in its ability to display trade-offs between timber, wildlife, and other forest benefit production for multiple management scenarios (Kirkman et al. 1986).

DYNAST was originally linked to successional age-response models (Boyce 1977) described above. Kirkman et al. (1986) used DYNAST outputs of areas cut, volumes, and percentage of forest land as regeneration, pole, sawlog, old-growth, and non-forested habitats to estimate measures of habitat parameters required by 13 PATREC models. They developed the PATREC models to predict total potential animal populations and density for 4000-8000 ha management areas after 50 years of change in forest structure.

Holthausen (1986) linked a modified version of DYNAST to 12 PATREC models developed specifically for use in the Mark Twain National Forest. Nine structural stages were defined for each cover-type, with age-classes ranging from 9 to 161 years in length. Habitat components required by the PATREC models were essentially identical to the structural stages used as habitat objectives, (i.e., old-growth, hard mast, and openings). The habitat components were modeled by using their relationship to vegetation age.

Benson and Laudenslayer (1986) developed HC models for the band-tailed pigeon (*Columba fasciata*), pileated woodpecker (*Dryocopus pileatus*), and mule deer (*Odocoileus hemionus*), and linked the wildlife models to DYNAST to evaluate effects of

three timber-management alternatives on the habitat capability of a 2700-ha study area. They specified seven successional age-classes for 10 land types.

FORPLAN is a large-scale linear optimization program commonly used in the USDA Forest Service forest planning process (Davis and DeLain 1986, Holthausen 1986). Most contemporary forest planning strives to optimally match land strata with prescriptions (Davis and DeLain 1986). FORPLAN finds a mathematically optimum solution to such problems defined in terms of desired resource outputs and constraints (Holthausen 1986).

Davis and DeLain (1986) linked a spotted owl (*Strix occidentalis*) HSI model to FORPLAN II. They showed how a geographic information system (GIS) can be used to identify spotted owl habitat areas and prepare efficient prescriptions for management. Hence, the primary advantage of linking FORPLAN II to a GIS is the ability to find an optimal management prescription for distinct land types within a spatially-explicit landscape. However, the spatial analysis is static, and needs to be linked to a vegetation succession simulator in order to form a dynamic model.

Holthausen (1986) used the Direct-Entry version of FORPLAN because of its enhanced abilities to represent outputs that are dependent on the age of vegetation. Ten-year age-classes of vegetation were modeled. Vegetation growth was simulated once in each decade by simply transferring the area in each age-class forward to the next age-class. Habitat components required by 13 PATREC models were simulated by using their relationship to vegetation age.

Conclusions

A set of common assumptions underlie all of the published dynamic animal habitat simulation models. The animal habitat models, with the exception of Jenkins and Wright's (1987) potential carrying capacity (PCC) and the PATREC models used by Kirkman et al. (1986), assume that potential population density cannot be predicted directly. In lieu of animal density, these models calculate some type of index of habitat quality, such as a habitat suitability index (HSI), habitat capability coefficient (HCC), habitat effectiveness (HE), or non-density based expected habitat suitability index (EHS).

The method of using indices of quality, however, is an attempt at resolving a paucity of available information necessary for adequate wildlife population and habitat management. Van Horne (1983) reviewed literature and stated that, under certain sets of circumstances, wildlife population density and habitat quality are not positively correlated. She defined habitat quality in terms of population demographics as a measure of the importance of a habitat type in maintaining a particular species. In particular, it is the survival and production characteristics, as well as density, of the animal species occupying a particular habitat type that should define the quality of that habitat (Van Horne 1983). In essence, the total fecundity and survival of a population realized on a particular habitat type is the most fundamental and revealing measure of habitat quality.

The habitat quality indices developed for a variety of animal habitat models depend on the assumption that the relationships between vegetative habitat structure and animal population fecundity and survival are known. This, however, is very often not the case. The models primarily depend on expert opinion, as opposed to direct, long-term evaluation of animal population fecundity and survival over a variety of habitat types, to determine these relationships. The result is that the animal habitat quality models are empirically weak, implying that resulting predictions of habitat quality are nothing more than a formal expression of expert intuition.

PATREC models are an exception to this rule, but only if anterior and posterior probabilities used to calculate EHS are developed from multi-annual empirical measures of animal species production on a variety of habitat types. However, if PATREC models are developed from expert opinion, they fall into the same category of formal measures of expert intuition. Additionally, if any type of habitat simulation model uses density alone as a measure of habitat quality, the resulting model will likely lead to incorrect assessments of habitat quality under certain sets of circumstances (Van Horne 1983).

As a result, wildlife and habitat managers should be aware of the severe limitations of dynamic animal habitat simulation models that are based on indices of habitat quality developed from expert opinion. These models are not empirically-based, and resulting

predictions are unsubstantiated at quantitatively measuring animal species fecundity and survival. Hence, using such indices to judge the relative abilities of different habitat types to maintain a species may be counter-productive as often as productive, potentially endangering survival of the species the model is designed to manage.

METHODS

Choosing the Set of Forest Types

Data were collected in western Montana in cooperation with the USDA Forest Service Intermountain Forest and Range Experimental Research Station, Forest Survey Unit, Ogden, Utah to calibrate the forest succession model for two habitat types. The *Pseudotsuga menziesii/Calamagrostis rubescens* (PSME/CARU) and *Abies grandis/Clintonia uniflora* (ABGR/CLUN) habitat types (Pfister et al. 1977) were chosen for simulation by examining the Forest Survey database of permanent-plot samples collected in previous years. The forest types had sufficient tree-species diversity to permit complex successional trends and were sufficiently widespread that sufficient numbers of sample plots could be obtained. The total number of types was minimized to maximize the number of samples collected for each type. Additionally, the two types differ sufficiently from each other to provide a range of habitats and plant community diversity.

The dominant overstory species in the ABGR/CLUN habitat type are quaking aspen (*Populus tremuloides* Michx.), western larch (*Larix occidentalis* Nutt.), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), lodgepole pine (*Pinus contorta* Dougl. ex Loud.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), and grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.). For the PSME/CARU habitat type, the dominant species are western larch, ponderosa pine, lodgepole pine, and Douglas-fir. By definition, grand fir and Douglas-fir are the climax species for ABGR/CLUN and PSME/CARU habitat types, respectively (Pfister et al. 1977). Quaking aspen dynamics were not simulated, as there were no aspens in the database from which to calibrate the model.

Successional pyramids for the PSME/CARU (Figure 1) and ABGR/CLUN (Figure 2) habitat types represent all potential community-types a forest stand may reach during its development (Steele 1984). The row in the pyramid that best represents a particular stand is determined by the indicator, or least shade-tolerant species, whereas the column is determined by the most abundant (dominant) species occurring on the stand (Steele 1984).

ABLA = *Abies lasiocarpa*
 ABGR = *Abies grandis*
 PIEN = *Picea engelmannii*
 PSME = *Pseudotsuga menziesii*
 PICO = *Pinus contorta*
 PIPO = *Pinus ponderosa*
 LAOC = *Larix occidentalis*

				PSME/ PSME	I N D I C A T O R
			PICO/ PICO	PICO/ PSME	
		PIPO/ PIPO	PIPO/ PICO	PIPO/ PSME	
LAOC/ LAOC	LAOC/ PIPO	LAOC/ PICO	LAOC/ PSME		
DOMINANT					

Figure 1. Successional pyramid for the PSME/CARU habitat type. To determine the cell in the pyramid that best represents a particular stand, the row of the cell is determined by the indicator, or least shade-tolerant species; the column is determined by the most abundant species occurring on the stand.

						ABLA/ ABLA	I N D I C A T O R
					ABGR/ ABGR	ABGR/ ABLA	
				PIEN/ PIEN	PIEN/ ABGR	PIEN/ ABLA	
			PSME/ PSME	PSME/ PIEN	PSME/ ABGR	PSME/ ABLA	
		PICO/ PICO	PICO/ PSME	PICO/ PIEN	PICO/ ABGR	PICO/ ABLA	
	PIPO/ PIPO	PIPO/ PICO	PIPO/ PSME	PIPO/ PIEN	PIPO/ ABGR	PIPO/ ABLA	
LAOC/ LAOC	LAOC/ PIPO	LAOC/ PICO	LAOC/ PSME	LAOC/ PIEN	LAOC/ ABGR	LAOC/ ABLA	
DOMINANT							

Figure 2. Successional pyramid for the ABGR/CLUN habitat type. To determine the cell in the pyramid that best represents a particular stand, the row of the cell is determined by the indicator, or least shade-tolerant species; the column is determined by the most abundant species occurring on the stand.

Choosing the Set of Animal Species

The list of animal species was chosen by a three-step procedure. First, all published HSI models were scanned to determine those species which have extant ranges western Montana. Second, animal species characteristic of forest habitats were selected. Finally, forest species were analyzed for suitable habitat parameters which could be measured in sample plots and successfully simulated by a forest succession model. Unfortunately, the required habitat parameters of these models have been determined in an *ad hoc* manner for each species, and the number of parameters in common among models is very low compared to the total number of parameters required. One species (snowshoe hare) was omitted for reasons of unreasonable data requirements; 10 species were retained (Table 1).

Although many of the 34 habitat parameters required by the 10 HSI models varied only slightly in data requirements, all were measured and simulated to avoid modifying the HSI models. A cross-reference table is provided (Table 2).

TABLE 1

Animal Species List and Acronyms

SPECIES	ACRONYM	COMMON NAME	REFERENCE
<i>Clethrionomys gapperi</i>	CLGA	southern red-backed vole	Allen 1983a
<i>Martes pennanti</i>	MAPE	fisher	Allen 1983b
<i>Martes americana</i>	MAAM	marten	Allen 1984
<i>Bonasa umbellus</i>	BOUM	ruffed grouse	Cade and Sousa 1985
<i>Dendragapus obscurus</i>	DEOB	blue grouse	Schroeder 1984
<i>Catharus fuscescens</i>	CAFU	veery	Sousa 1982a
<i>Sphyrapicus thyroideus</i>	SPTH	Williamson's sapsucker	Sousa 1983
<i>Picoides pubescens</i>	PIPU	downy woodpecker	Schroeder 1982a
<i>Melanerpes lewis</i>	MELE	Lewis' woodpecker	Sousa 1982b
<i>Drycopus pileatus</i>	DRPI	pileated woodpecker	Schroeder 1982b

TABLE 2

Cross-reference of Habitat Parameters by Animal Species

<u>HABITAT PARAMETER</u>	<u>ANIMAL SPECIES</u>									
	C L G A	M A P E	M A A M	B O U M	D E O B	C A F U	S P T H	P I P U	M E L E	D R P I
1) Average DBH of overstory trees (inches)	X	X	.	.	.	.	.	.	.	.
2) Average DBH of overstory aspen (inches)	X	.	.	.
3) Soft snags (stems/ac)	X	.	.	.
4) Snags > 6" DBH (stems/ac)	X	.	.
5) Snags > 12" DBH (stems/ac)	X	.
6) Snags > 20" DBH (stems/ac)	X
7) Average DBH snags > 20" DBH (stems/ac)	X
8) Trees > 20" DBH (stems/ac)	X
9) 7" diameter stumps/down logs (stems/ac)	X
10) Percent canopy closure coniferous trees	X	.	.	.	.	.	.	.	.	.
11) Percent canopy closure all trees	.	X	X	.	X	.	X	.	X	X
12) Percent shrub crown cover	X	.	.	.	X	.
13) Percent deciduous shrub crown cover	X	.	.	.	.
14) Percent overstory deciduous trees	.	X	.	.	.	.	.	.	.	.
15) Percent overstory spruce/fir trees	.	.	X	.	.	.	.	.	.	.
16) Percent grass canopy cover	X	.	.	.	.	.	.	.	.	.
17) Percent herbaceous canopy cover	X	.	.	.	.	.
18) Percent herbaceous cover in late spring	X	.	.	.	.
19) Percent cover 3" diameter downfall	X	.	X	.	.	.	.	.	.	.
20) Tree canopy diversity of stand (class)	.	X	.	.	.	.	.	.	.	.
21) Successional stage of stand (class)	.	.	X	.	.	.	.	.	.	.
22) Radius for twenty mature male aspen (ft)	.	.	.	X	.	.	.	.	.	.
23) Density deciduous shrubs (stems/ha)	.	.	.	X	.	.	.	.	.	.
24) Density deciduous trees (stems/ha)	.	.	.	X	.	.	.	.	.	.
25) Density coniferous trees (stems/ha)	.	.	.	X	.	.	.	.	.	.
26) Percent area dominated by aspen	X	.	.	.
27) Average lowest branch height (ft)	.	.	.	X	.	.	.	.	.	.
28) Average height woody stems (ft)	.	.	.	X	.	.	.	.	.	.
29) Average height shrubs (ft)	X	.	.	.	.	.
30) Average height deciduous shrubs (ft)	X	.	.	.	.
31) Average height herbaceous stems (ft)	X	X	.	.	.	.
32) Diversity herbaceous plant species (number)	X	.	.	.	.	.
33) Soil moisture regime (class)	X	.	.	.	.
34) Stand basal area (square ft/ac)	X	.

Animal species acronyms are provided in Table 1.

Designing an Efficient Sampling Scheme

Forest Survey procedures were examined to determine the habitat parameters that could be estimated from the Forest Survey database. Sampling procedures for all parameters are given in Appendix A. First, the parameter definition as given by the HSI models is presented. Second, a more operational definition of the required parameter is given. Third, an explanation of how datum for the required parameter was collected is given. Finally, simulation methods for each parameter are provided.

In the absence of a better explanation of "deciduous" and "evergreen" in the HSI models, it was assumed that deciduous means angiosperm and evergreen means conifer or evergreen angiosperm. Accordingly, western larch is regarded as an evergreen.

Collecting Field Data

The Forest Survey Work Unit surveyed permanent plots, located on non-USDA Forest Service lands, during the summers of 1978 and 1979, and remeasured the plots from May to October 1989. Data gathered in this effort included measurements of many of the structural habitat parameters, as well as measurements of individual-tree and stand growth necessary to calibrate the forest succession model. Data for the remaining habitat parameters were collected from mid-June to mid-September 1989, and from mid-July to mid-August 1990.

Seventy-five stands were available in the database to calibrate model growth parameters. The stands met two minimum requirements for inclusion. They had no live tallied trees harvested over the remeasurement period, and were identified as one of the two selected habitat types.

Twenty-five PSME/CARU and 20 ABGR/CLUN stands were chosen from the database for supplemental data collection. Stands were ordered by community-type distribution to determine the most desirable stands to sample. A sufficient data set, representing as complete a successional sequence as possible, was collected for each habitat type.

Choosing an Appropriate Forest Succession Simulator

Poole (1989) developed and implemented a forest succession model, MASS10 (Multiple

Age-class Stand Simulator using a 10-year time step), suitable for central and northern Rocky Mountain forests. The model simulates successional development in the absence of disturbance and predicts forest composition and structure for multi-species, all-aged stands, as well as for simpler stand types. MASS10 has modest data requirements, allowing easy calibration for new habitat types, but produces few of the structural habitat data required by the suitability models.

MASS10 Structure

MASS10 is an individual-tree simulator that uses a 10-year time step. The modeled stand size is 0.10 acre. Individual-tree growth is based upon "stand level resource allocation" (Poole 1989), which eliminates the calculation of a competitive index. Rather than assume each tree has a maximum potential for growth which is decremented by environment and competition, the model assumes each stands' environment has a maximum potential to support tree growth. Light, water, and nutrients are grouped into a "growth resource pool" and are not modeled explicitly. To allocate the growth-resource pool to individual trees, a "resource demand" is calculated for each tree based on its size and species. These demands are summed and each tree is allocated resources based on the fraction its demand comprises of the stand total (Poole 1989).

Species are defined by four general characteristics: understory tolerance, maximum size, maximum growth rate, and minimum growth rate. The site is defined by potential annual growth resources on the plot determined from habitat type and phase, and the stand may be defined by an initial stand table, by species and size class (Poole 1989).

Modification of MASS10

In order to be useful for predicting certain structural HSI parameters, MASS10 had to be modified to function using volume, rather than basal area, as its primary unit of measurement. Stand size was increased to 1.0 acre to be compatible with HSI-parameter requirements. The new model will be referred to as DYNAM10.

DYNAM10 produces a stand table of the number of trees per acre by species by 10 logarithmic volume classes, rather than by two-inch diameter classes as in the original

model. The first size class ranges from 0 to 1.25 cubic feet, with each of the other nine classes doubling in size. The model also produces a table of the fraction of total stand volume, rather than basal area, comprised by each of the tree species modeled. DYNAM10 is initialized by reading a stand table for a simulated stand from a user-supplied input file. Input and output stand tables also include the number of standing-dead trees, which are used to predict certain HSI parameters. The model keeps a list of individual-tree species, DBH, height, and volume for live trees, and species, DBH, and number of trees per age-class for standing-dead trees.

The species-specific input variables retain their original simplicity, but are calibrated to cubic-foot volume. Maximum cubic-foot volumes are estimates of how large a species typically grows in the habitat type modeled. Maximum volumes (Table 4) were calculated using DBH and height estimates from Burns and Honkala (1990) in the volume equations presented in Table 3. The species-specific maximum growth rates (Table 4) are 10-year cubic-foot volume increments, and were chosen from actual calculated volume increments for all trees in the database following the guidelines in Poole (1989). The species-specific minimum growth rates (Table 4) are represented by maximum ring-per-inch increments. Reasonable values were chosen from actual ring-per-inch increments for all trees in the database, biasing the estimates according to shade-tolerance. The chosen theoretical species-specific understory-tolerance ranks (Table 4) are based on a scale from 0 for extremely shade-intolerant species to 10 for extremely shade-tolerant species (Poole 1989).

The available stand growth resources are estimates of 10-year cubic-foot-volume increment per acre typically observed for the habitat type of the simulated stand. Available resources were calculated by calibrating annual growth-per-acre estimates by habitat type from Pfister et. al. (1977) to a 10-year increment and adding 100% more to this estimate to account for the resources used in respiration. Estimates for PSME/CARU and ABGR/CLUN habitat types are 1800 and 2200 ft³/acre/10-years, respectively.

Theoretical- and empirical-based changes in the equations used to calculate growth and resource distribution were necessary to maintain analogous functioning between MASS10

TABLE 3

Volume Equations by Tree Species

Equation	1	$V = a + b(\text{DBH})^2 * \text{HT} + c * \text{DBH} * \text{HT}$
	2	$V = a + b(\text{DBH}^2 * \text{HT}) / 100$

where V = Estimated total cubic foot volume
 DBH = Diameter at breast height in inches
 HT = Tree height in feet

SPECIES	EQUATION NUMBER	COEFFICIENTS		
		a	b	c
Western larch	1	0.0	0.00184	0.0
Douglas-fir	1	0.0	0.00184	0.0
Grand fir	1	0.0	0.00234	0.0
Engelmann spruce	1	0.0	0.00171	0.00386
Subalpine fir	1	0.0	0.00171	0.00386
Ponderosa pine				
(DBH ² * HT) < 6000 ft ³	1	0.03029	0.00221	0.0
(DBH ² * HT) > 6000 ft ³	1	- 1.55710	0.00247	0.0
Lodgepole pine				
DBH < 21.0"	2	1.652	0.221	-
DBH > 21.0"	2	5.369	0.197	-

Equations, except lodgepole pine (U.S.D.A. Forest Service 1984), are from Wykoff et al. (1982).

TABLE 4

Species-specific Growth Parameters

SPECIES	UT _s	MaxVol _s	MinG _s	MaxG _s
Grand fir	9	350.0	80.0	35.0
Subalpine fir	9	100.0	80.0	10.0
Engelmann spruce	8	600.0	70.0	25.0
Douglas fir	5	350.0	60.0	35.0
Lodgepole pine	4	100.0	60.0	15.0
Ponderosa pine	3	700.0	50.0	35.0
Western larch	2	1100.0	50.0	35.0

UT_s is the understory tolerance rank of the species.

MaxVol_s is the typical maximum cubic-foot volume of the species.

MinG_s is the maximum ten-year ring-per-inch increment of the species.

MaxG_s is the maximum ten-year cubic-foot-volume increment of the species.

and DYNAM10. Descriptions of the variable codes used in the modified model equations are provided in Table 5.

Growth equations were modified by maintaining Poole's (1989) general theory and applying it to a volume-based model. Growth of individual trees is a function of the growth resources on the site and the individual's species and size (Poole 1989). The maximum fraction of resources potentially allocated to a tree is termed the "individual resource demand" (Poole 1989, p. 11). The theoretical relationship is applied here using individual volume as a measure of tree size:

$$[3] \quad RD_i = (VOL_i)^{RCC_s}$$

Total resource demand is the sum of individual resource demands and is the measure of competition on the site. Each tree captures a fraction of the available resources equal to the fraction its demand comprises of the total (Poole 1989).

Each tree allocates its growth resources to either growth or respiration. As the tree size increases, the fraction of resources allocated to respiration also increases (Poole 1989). The respiration fraction is represented here using volume as the measure of size:

$$[4] \quad FR_i = RspA_s * (VOL_i)^{RspB_s}$$

Volume growth is equal to that fraction of the captured resources not used for respiration:

$$[5] \quad \Delta VOL_i = RC_i * (1 - FR_i)$$

As suggested by Poole (1989), if predicted growth exceeds a species-specific maximum, growth is set to that maximum to prevent unrealistic growth in poorly stocked stands.

Trees are considered stressed and may be subject to mortality if their growth is less than the specified minimum. This minimum is calculated from the maximum ring-per-inch estimates. Stress is calculated by the ratio of predicted and theoretical minimum volume:

$$[6] \quad Str_i = (VOL_i + \Delta VOL_i) / (VOL_i + \Delta VOL_{min})$$

TABLE 5
Description of Variable Codes

<u>Symbol</u>	<u>Definition</u>	<u>Units</u>
<u>Tree-level</u>		
DBH _i	Individual DBH	inches
VOL _i	Individual volume	ft ³
ΔVOL _i	Individual growth	ft ³
ΔVOL _{min}	Minimum unstressed growth	ft ³
RD _i	Individual resource demand	ft ³
RC _i	Individual resource capture	ft ³
FR _i	Fraction of resources allocated to respiration	ft ³
Str _i	Stress rating	
FR _{0.5}	Fraction of resources allocated to respiration at HafVol _s	ft ³
<u>Species-level</u>		
RCC _s	Resource capture coefficient for species s	
RspA _s	Respiration coefficient A for species s	
RspB _s	Respiration coefficient B for species s	
RVOL _s	Volume regenerated for species s	ft ³
UA _s	Understory abundance of species s	% cover
#Reg _s	Number of regeneration trees for species s	
Rmnd _s	Remaining regeneration after integer division	ft ³
UT _s	Understory-tolerance rank for species s	
MaxVol _s	Maximum volume of typical tree for species s	ft ³
HafVol _s	Half of maximum volume for species s	ft ³
DBHExp _s	Linear regression DBH parameter estimate for species s	inches
Y-Int _s	Linear regression Y-intercept estimate for species s	inches
<u>Standing dead trees</u>		
Age	Individual age since mortality	years
Prob _{Age}	Age-specific probability of falling	percent
Num _{Age}	Number of trees in an age class	
Fall _{Age}	Number of trees that fall in an age class	
<u>Stand-level</u>		
RA	Resources available to the stand	ft ³
RVOL	Regeneration volume on plot	ft ³

The number of mortality trees is determined from a ranked list of the stressed trees. Trees are removed from the live tree list one at a time, in order of stress, until either all of the stressed trees are removed or 15% of the total volume has been removed. This limit prevents excessive fractions of the stand from being classified as stressed (Poole 1989).

Mortality trees are moved from the live-tree list to a standing-dead-tree list, maintaining species and DBH. Dead-tree fall is simulated as a deterministic function of time and size. The probability of falling increases with age according to a negative-logistic, or Gompertz curve (Batschelet 1979):

$$[7] \quad \text{Prob}_{\text{Age}} = 1.05 * \exp^{(-0.05 * \exp^{[0.05 * \text{Age}]})}$$

The curve is calibrated such that the probability increases to 1.0 at age 100-years since mortality, which is consistent with dead-tree fall data for lodgepole pine and Engelmann spruce in the Southern Canadian Rocky Mountains (Johnson and Greene 1991).

At each iteration, the age-specific probability value is used to calculate the number of trees in each cohort that will fall:

$$[8] \quad \text{Fall}_{\text{Age}} = \text{Prob}_{\text{Age}} * \text{Num}_{\text{Age}}$$

Individual trees in each cohort are sorted from largest to smallest DBH. The smallest tree in each cohort is the first to fall, followed in ascending order to the number of trees to fall. The remaining standing-dead trees are moved to the next age-class.

Regeneration is simulated by inserting trees into the smallest logarithmic volume class. The amount of regeneration occurring, calculated in cubic-foot volume, is determined by comparing total resource demand to the resources available:

$$[9] \quad \text{RVOL} = \text{RA} * (1 - [\sum (\text{RD}_i) / \text{RA}]^{0.01})$$

Regeneration decreases over the development of the stand, reaching zero when resource demand is twice the available resources (Poole 1989). The regeneration volume is divided

among the species according to their understory abundance:

$$[10] \quad \text{RVOL}_s = \text{RVOL} * (\text{UA}_s / \Sigma (\text{UA}_s))$$

Understory abundance, the fraction of regeneration volume allocated to each species, was modeled empirically in MASS10. However, the original scheme was admittedly poor due to a paucity of tangible data (Poole 1989). Empirical data were also insufficient to simulate regeneration for western Montana. Instead, understory abundance is modeled theoretically using fuzzy set theory (Roberts 1989) and the successional pyramids by habitat type (Steele 1984). The least shade-tolerant species present on a stand determines the row of the successional pyramid, while each species' proportion of the total volume determines the community-type distribution of the stand (Poole 1989). Understory abundance is allocated by species based on the ratio of each species' understory-tolerance ranking to the sum of understory-tolerance rankings for all species in that row of the successional pyramid.

The species-specific number of regeneration trees is determined by dividing the regeneration volume for each species by the mean volume of a 2.0" DBH tree. Since volume equations do not apply below 5.0" DBH, volumes should not be calculated directly. However, for the purpose of simulating regeneration, the mean volume of a 2.0" DBH tree was estimated using the volume equations to be 0.1026 cubic feet:

$$[11] \quad \# \text{Reg}_s = \text{INT} [(\text{RVOL}_s + \text{Rmnd}_s) / 0.1026]$$

Species-specific growth parameters were obtained using the silvics-based method of Poole (1989) applied to a volume-based model. The resource-capture coefficients used in MASS10 were spread evenly about the value 0.8, plus or minus 12%, by species. This value represents the theoretical exponent of basal area along which thinning occurs (Long and Smith 1984). For volume, the value is 0.667, adapted from the -1.5 thinning law (Long and Smith 1984). The corresponding range of values for DYNAM10 is 0.58 to 0.75. The resource-capture coefficient is calculated from the understory-tolerance ranking of the species:

$$[12] \quad \text{RCC}_s = 0.75 - (\text{UT}_s * 0.0167)$$

MASS10 used a fractional respiration coefficient based on a tree with 0.5 ft² of basal area. The half-size coefficient takes on a different meaning and set of values in the volume model. For DYNAM10, the coefficient is defined as the fraction of resources allocated to respiration at one-half the theoretical maximum volume of the species. Since 0.5 ft² basal area represents a relatively small tree, the fraction of resources allocated to respiration at this size ranged from a low of 0.2 to a high of only 0.7. Theoretically, because trees at one-half their maximum size are relatively large, they should allocate more resources to respiration than relatively small trees. Hence, the range of fractional resources is set higher from 0.45 to 0.95. Fractional respiration is calculated based solely upon understory-tolerance ranking:

$$[13] \quad \text{FR}_{0.5} = 0.95 - (\text{UT}_s * 0.5)$$

The respiration coefficients can be calculated by solving simultaneous equations. The resulting equations are:

$$[14] \quad \text{RspB}_s = -\log(\text{FR}_{0.5}) / (\log(\text{MaxVol}_s) - \log(\text{HafVol}_s))$$

$$[15] \quad \text{RspA}_s = \text{FR}_{0.5} / (\text{HafVol}_s)^{\text{RspB}_s}$$

Measuring Accuracy of Growth Equations

The theoretically-derived growth parameters were used to predict 10-year volume increments for each live tallied tree in the database using initial individual-tree volumes. Predictions were compared to corresponding actual volumes calibrated to a 10-year growth period. Species-specific, habitat type-specific, and stand-level bias errors were calculated as the sum of individual-tree prediction error (predicted volume minus actual volume) divided by the number of trees in that class. Class-specific precision errors were calculated as the sum of the absolute values of individual-tree prediction error divided by the total

number of trees in that class. Bias and precision errors were divided by 10 to calculate mean annual per-tree errors. Mean annual individual-tree percent bias and precision errors were calculated by class as the sum of individual-tree bias and precision prediction errors divided by initial individual-tree volumes, all divided by the number of trees in that class.

Prediction of Individual-tree DBH

DYNAM10 calculates individual-tree DBH from predicted volume at each time-step. DBH is required to calculate values for certain HSI parameters. Long and Smith (1984) state that DBH is generally proportional to volume raised to the 2.4 power. White (1981) provides values for a number of species which vary near this value. Logarithmic transformations of DBH and volume were performed for all trees in the database. Linear regressions were performed on the transformed data by species. Hence, DBH is calculated in DYNAM10 given the volume and species of the tree by the equation:

$$[16] \quad \text{DBH}_i = 10^{((\log(\text{VOL}_i) - Y\text{-Int}_s) / \text{DBHExp}_s)}$$

Species-specific bias and precision errors were calculated by subtracting predicted individual-tree DBH, given initial tree volume, from actual DBH and dividing the sum of the differences, and sum of the absolute differences, by the number of trees for that species, respectively. Species-specific mean individual-tree percent DBH bias errors were calculated as the sum of individual-tree DBH bias errors divided by corresponding initial DBH, all divided by the number of trees for that species.

Prediction of Individual-tree Heights

Heights were calculated using known initial individual-tree volumes and predicted DBH in simple transformations of the species-specific volume equations (Table 3). Species-specific, habitat-type-specific, and stand-level bias and precision errors were calculated by subtracting predicted individual-tree heights from actual heights and dividing the sum of the differences, and sum of the absolute differences, by the number of trees for that class, respectively. Class-specific mean annual individual-tree percent height bias and precision errors were calculated as the sum of individual-tree height bias and precision errors

divided by corresponding initial heights, all divided by the number of trees in that class.

Stand-level Behavior Predictions

Predictions of stand-level behavior were compared to theoretical constraints. Successional behavior was determined by plotting individual-species volumes in mixed stands over time and comparing changes in volume to theoretical patterns. Each species was simulated to grow in an even-aged monoculture and the natural logarithm of density was plotted against the natural logarithm of mean individual-tree volume over time. The plots were compared to the theoretical -1.5 thinning rule of Yoda et al. (1963).

Finally, the species-specific monoculture simulations were analyzed to determine stand volumes at 100 years of age. Comparisons of stand volumes to empirical information were made when possible.

Dynamic HSI Parameter Simulation

A vegetation dynamics subroutine (VEGDYN) was added to DYNAM10. The subroutine uses the live and standing-dead tree arrays and species composition to predict 16 continuous-value and 2 categorical parameters directly, as specified in Appendix A. Seventeen continuous-value HSI parameters were simulated using the community-type distribution of the stand and individual weighted HSI-parameter tables by habitat type (Appendix A). One categorical parameter, soil moisture regime, is assigned in the growth-parameter initialization file, and is a constant habitat-type-specific value.

Habitat-type-specific pyramids of weighted HSI-parameter values were produced for 17 of the HSI parameters. Figures 3 and 4 show the weighted HSI-parameter values in pyramidal form for deciduous-shrub density and percent tree canopy cover, respectively, for the PSME/CARU habitat type. If a particular community-type was sparse in the database, then empty cells in the pyramid were interpolated from adjacent cells. During simulation, weighted mean values for each of the parameters are calculated by multiplying the current community-type abundance of each cell by the corresponding weighted average HSI-parameter value, and summing the products by parameter.

Stand-level bias and precision errors were calculated for the 31 continuous-value HSI parameters by subtracting actual initial HSI-parameter values from predicted time-zero values produced by DYNAM10 for each of the 45 supplemental stands, and dividing the sum of the differences by the number of stands. Categorical parameters (e.g., codes for soil moisture regime, stand canopy structure class, and successional stage) were not conducive to error analysis.

Dynamic HSI Model Program

At each 10-year time step of the simulation, the values of each of the 34 habitat parameters required by the static HSI models are stored in a file. After the simulation is completed, the file is used by an HSI program (HSI.FOR) to simultaneously predict species-specific dynamic habitat suitability for the 10 animal species modeled. The program achieves this by calling a unique subroutine for each animal species and using the appropriate HSI parameters required by the species-specific HSI models. The values are then written to a file by species and time-step.

Calculated dynamic HSI values produced by HSI.FOR were compared to corresponding hand-calculations for three reference stands, given specified HSI-parameter values for the reference stands produced by DYNAM10. FORTRAN source codes for DYNAM10.FOR and HSI.FOR are provided in Appendices B and C, respectively.

PSME = *Pseudotsuga menziesii*
 PICO = *Pinus contorta*
 PIPO = *Pinus ponderosa*
 LAOC = *Larix occidentalis*

			PSME/PSME	
			[675.4]	
		PICO/PICO	PICO/PSME	I N D I C A T O R
		[418.4]	[418.4]	
	PIPO/PIPO	PIPO/PICO	PIPO/PSME	
	[161.4]	[111.4]	[61.4]	
LAOC/LAOC	LAOC/PIPO	LAOC/PICO	LAOC/PSME	
[9.2]	[49.9]	[90.5]	[151.8]	

DOMINANT

Figure 3. Weighted HSI-parameter value pyramid for deciduous-shrub density (stems/ha). Each weighted value corresponds to a community-type cell represented in the PSME/CARU successional pyramid.

			PSME/PSME	
			[27.5]	
		PICO/PICO	PICO/PSME	I N D I C A T O R
		[25.8]	[34.7]	
	PIPO/PIPO	PIPO/PICO	PIPO/PSME	
	[50.1]	[59.6]	[56.8]	
LAOC/LAOC	LAOC/PIPO	LAOC/PICO	LAOC/PSME	
[73.4]	[72.7]	[83.9]	[65.6]	

DOMINANT

Figure 4. Weighted HSI-parameter value pyramid for percent tree canopy cover. Each weighted value corresponds to a community-type cell represented in the PSME/CARU successional pyramid.

RESULTS

The bias and precision, and percent bias and precision errors of predicted volume are presented in Table 6. The log-DBH versus log-volume linear regression parameter estimates and correlation coefficients are presented by species in Table 7, along with the species-specific bias and precision error estimates, and percent bias errors. Bias and precision, and percent bias and precision height growth prediction errors are presented by species, habitat type, and stand in Table 8.

Graphs are presented of changes in species-specific volumes over time for stands initialized with an even species mix, and a 50/50 mix of ponderosa pine and western larch

TABLE 6

Bias and Precision of Predicted Volume

SPECIES	%BIAS	BIAS	%PRECISION	PRECISION	N=
Grand fir	1.89	- 0.079	2.25	0.178	927.4
Subalpine fir	0.09	0.061	1.46	0.098	197.3
Engelmann spruce	0.51	- 0.001	1.59	0.167	392.3
Douglas-fir	1.66	0.089	2.11	0.178	5951.1
Lodgepole pine	0.91	0.045	1.53	0.138	1390.7
Ponderosa pine	- 0.72	- 0.108	2.34	0.276	736.0
Western larch	0.69	- 0.029	1.42	0.201	935.7
HABITAT TYPE					
PSME/CARU	1.54	0.093	2.19	0.178	7003.0
ABGR/CLUN	0.29	- 0.049	1.37	0.184	3527.5
STAND TOTALS	1.12	0.045	1.91	0.180	10530.5

%BIAS is equal to the sum of the individual-tree biases divided by corresponding initial individual-tree volumes, all divided by the number of trees in that class ($\text{ft}^3/\text{tree}/\text{year}$).

BIAS is equal to the sum of predicted volume minus actual volume divided by the number of trees in that class ($\text{ft}^3/\text{tree}/\text{year}$).

%PRECISION is equal to the sum of the individual-tree precisions divided by corresponding initial individual-tree volumes, all divided by the number of trees in that class ($\text{ft}^3/\text{tree}/\text{year}$).

PRECISION is equal to the sum of the absolute values of predicted volume minus actual volume divided by the number of trees in that class ($\text{ft}^3/\text{tree}/\text{year}$).

N is the number of trees on a per acre basis used to determine the bias and precision estimates.

TABLE 7
Log-DBH versus Log-volume Linear Regression Analysis

SPECIES	DBHExp _s	Y-Int _s	r ²	%BIAS	BIAS	PRECISION
Grand fir	2.3465	-1.2165	0.98	0.13	0.02	0.30
Subalpine fir	2.7545	-1.5946	0.97	0.06	0.02	0.40
Engelmann spruce	2.7533	-1.6151	0.97	0.08	0.02	0.43
Douglas-fir	2.4369	-1.3853	0.97	0.02	0.01	0.49
Lodgepole pine	2.0819	-0.8946	0.96	0.35	0.02	0.37
Ponderosa pine	2.8926	-1.8601	0.98	- 0.72	- 0.01	0.64
Western larch	2.5385	-1.4347	0.98	- 0.28	0.01	0.46
HABITAT TYPE						
PSME/CARU				- 0.77	- 0.06	0.48
ABGR/CLUN				1.50	0.17	0.45
ALL STANDS				- 0.01	0.01	0.47

DBHExp_s is the parameter estimate of the linear regression by species.

Y-Int_s is the y-intercept estimate of the linear regression by species.

r² is the regression correlation coefficient.

%BIAS is the sum of the individual-tree DBH biases divided by corresponding initial individual-tree DBH, all divided by the number of trees in that class (inches).

BIAS is the sum of predicted minus actual DBH by class (inches).

PRECISION is the sum of the absolute values of predicted minus actual DBH by class (inches).

for both habitat types (Figures 5, 6, 7, and 8). Simulations of species-specific even-aged monocultures are presented for Douglas-fir and grand fir as plots of the natural logarithms of density and mean individual-tree volume in Figures 9 and 10, respectively. Simulated stand volumes of even-aged monocultures at 100 years of age are compared to empirical values available from Burns and Honkala (1990) in Table 9. The bias and precision errors calculated for the 31 continuous-value HSI parameters are presented in Table 10.

Predicted dynamic HSI values were produced and graphed against time for all 45 supplemental stands. Species-specific patterns of predicted dynamic HSI values are presented for simulations of early-successional stands for Williamson's sapsucker, and downy, Lewis', and pileated woodpeckers (Figure 11), southern red-backed vole, marten, and fisher (Figure 12), and veery and blue grouse (Figure 13).

TABLE 8

Bias and Precision of Predicted Height

SPECIES	%BIAS	BIAS	%PRECISION	PRECISION	N=
Grand fir	- 0.04	- 0.027	0.79	0.027	927.4
Subalpine fir	- 0.04	- 0.049	1.01	0.049	197.3
Engelmann spruce	- 0.001	- 0.036	0.99	0.036	392.3
Douglas-fir	- 0.01	- 0.044	1.03	0.044	5951.1
Lodgepole pine	- 0.04	- 0.043	1.01	0.043	1390.7
Ponderosa pine	- 0.24	- 0.048	1.44	0.048	736.0
Western larch	- 0.08	- 0.042	1.05	0.042	935.7
HABITAT TYPE					
PSME/CARU	0.18	- 0.045	1.09	0.045	7003.0
ABGR/CLUN	- 0.27	- 0.043	0.97	0.043	3527.5
STAND TOTALS	0.03	- 0.044	1.05	0.044	10530.5

%BIAS is equal to the sum of the individual-tree height biases divided by corresponding initial individual-tree heights, all divided by the number of trees in that class (ft/year).

BIAS is equal to the sum of predicted height minus actual height divided by the number of trees in that class (ft/year).

%PRECISION is equal to the sum of the individual-tree height precisions divided by corresponding initial individual-tree heights, all divided by the number of trees in that class (ft/year).

PRECISION is equal to the sum of the absolute values of predicted height minus actual height divided by the number of trees in that class (ft/year).

N is the number of trees per acre used to determine the bias and precision estimates.

TABLE 9

Comparison of Simulated and Empirical Stand Volume Growth

SPECIES	EMPIRICAL VOLUMES AT AGE 100	SIMULATED VOLUMES AT AGE 100
Grand fir	6,720 - 15,400	22,104
Subalpine fir	N/A	20,382
Engelmann spruce	N/A	22,064
Douglas-fir	4,442 - 21,759	15,579
Lodgepole pine	N/A	10,239
Ponderosa pine	3,900 - 17,200	10,173
Western larch	4,407 - 11,608	8,536

EMPIRICAL VOLUMES are empirical species-specific volume ranges at age 100 years (ft³/acre) from Burns and Honkala (1990).

SIMULATED VOLUMES are simulated species-specific volumes at age 100 years (ft³/acre).

N/A means empirical data not available in Burns and Honkala (1990).

PSME/CARU STAND WITH SHADE-INTOLERANT SPECIES BEGINNING MIX

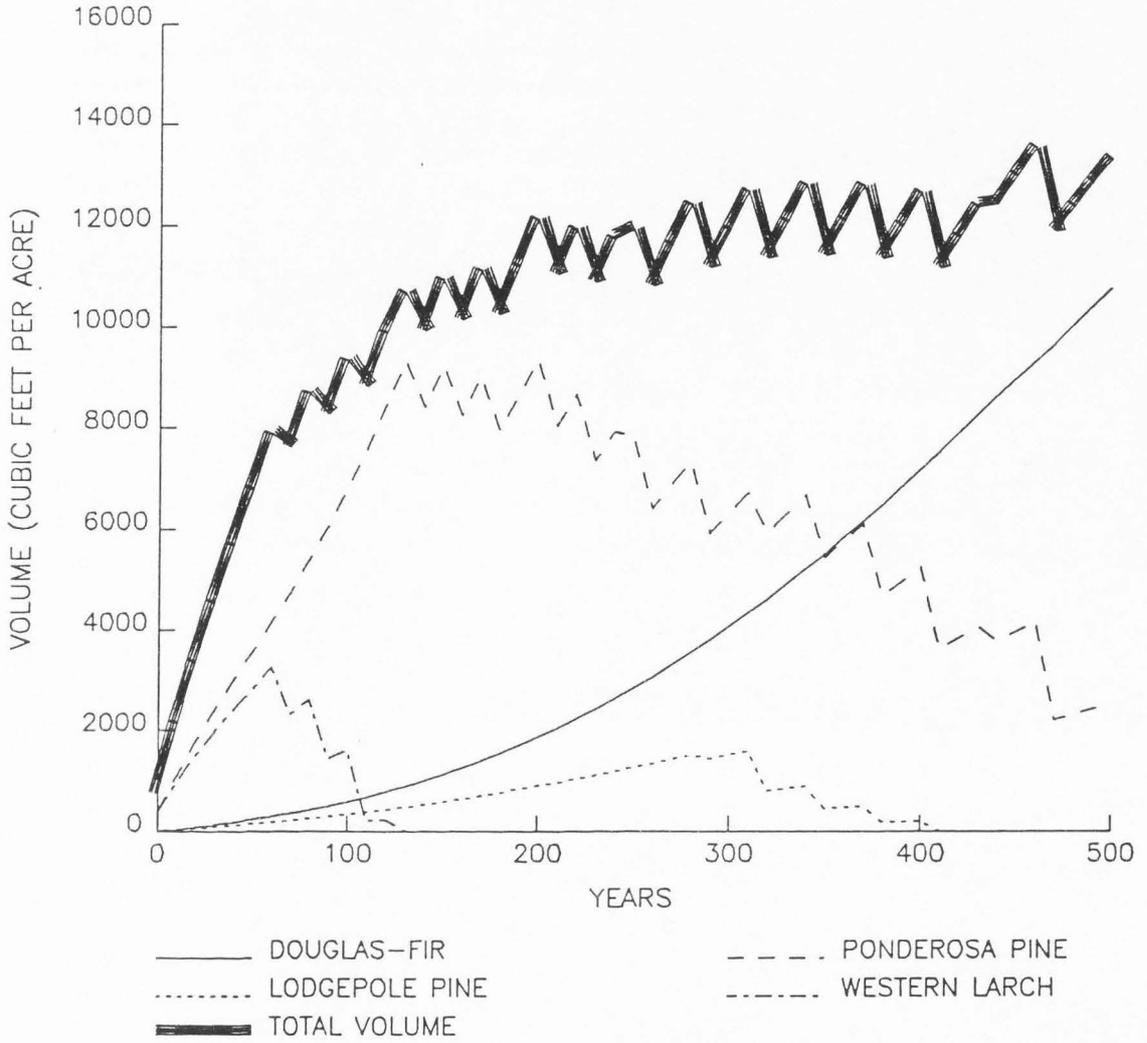


Figure 5. Plot of species-specific change in volume over 500 years of simulation for a PSME/CARU stand initialized with a 50/50 mix of ponderosa pine and western larch.

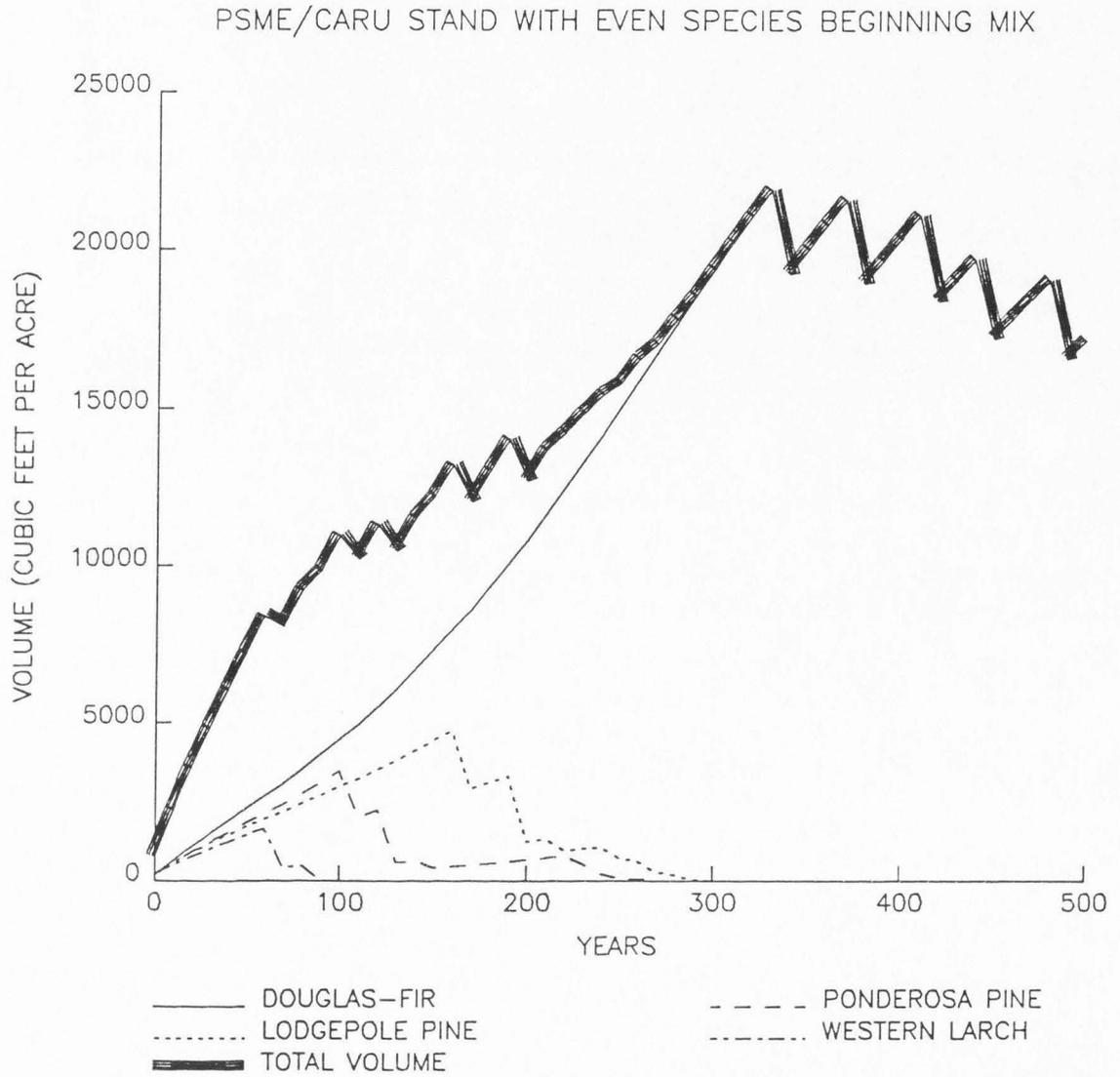


Figure 6. Plot of species-specific change in volume over 500 years of simulation for a PSME/CARU stand initialized with an even mix of all species.

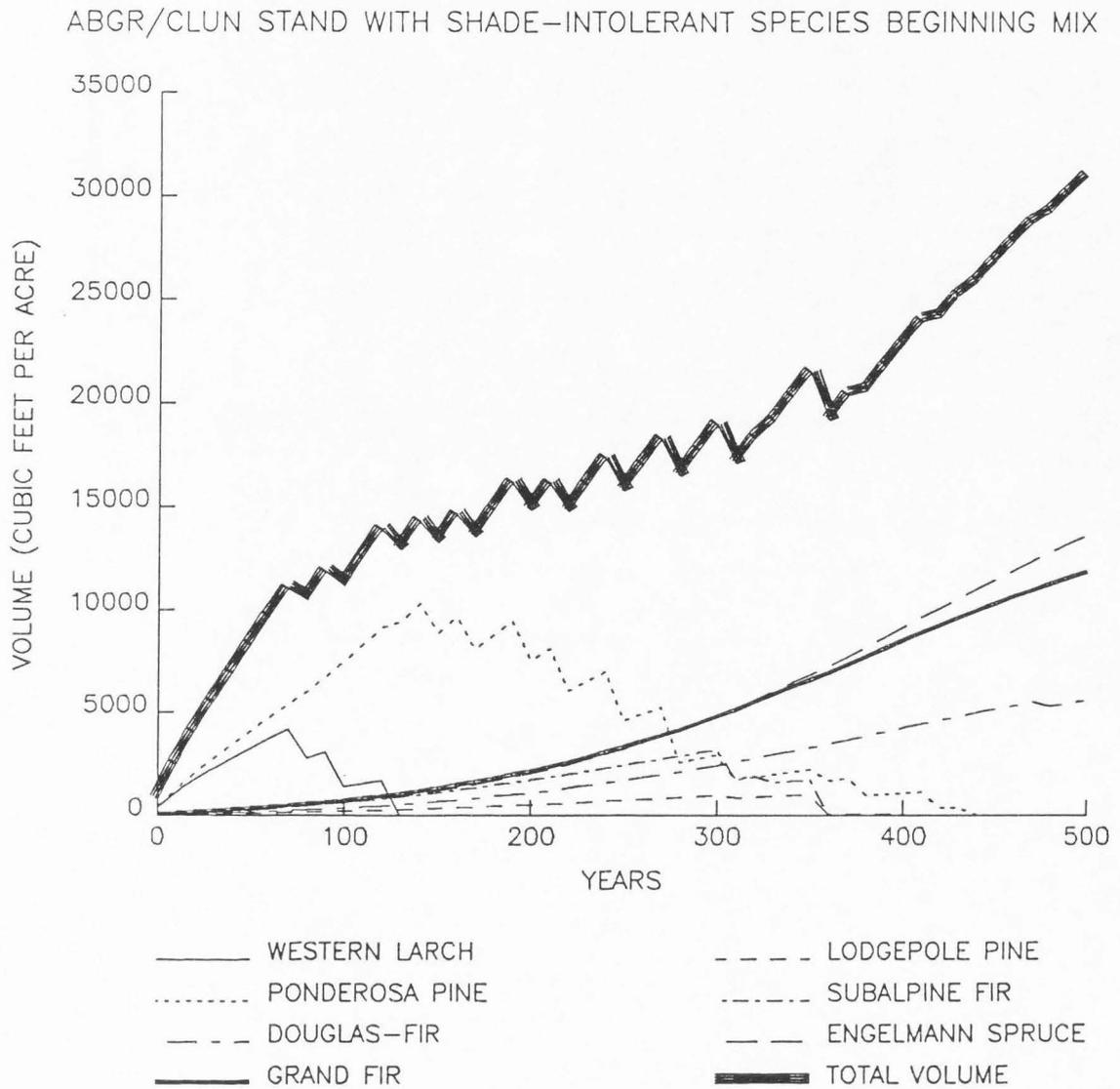


Figure 7. Plot of species-specific change in volume over 500 years of simulation for an ABGR/CLUN stand initialized with a 50/50 mix of ponderosa pine and western larch.

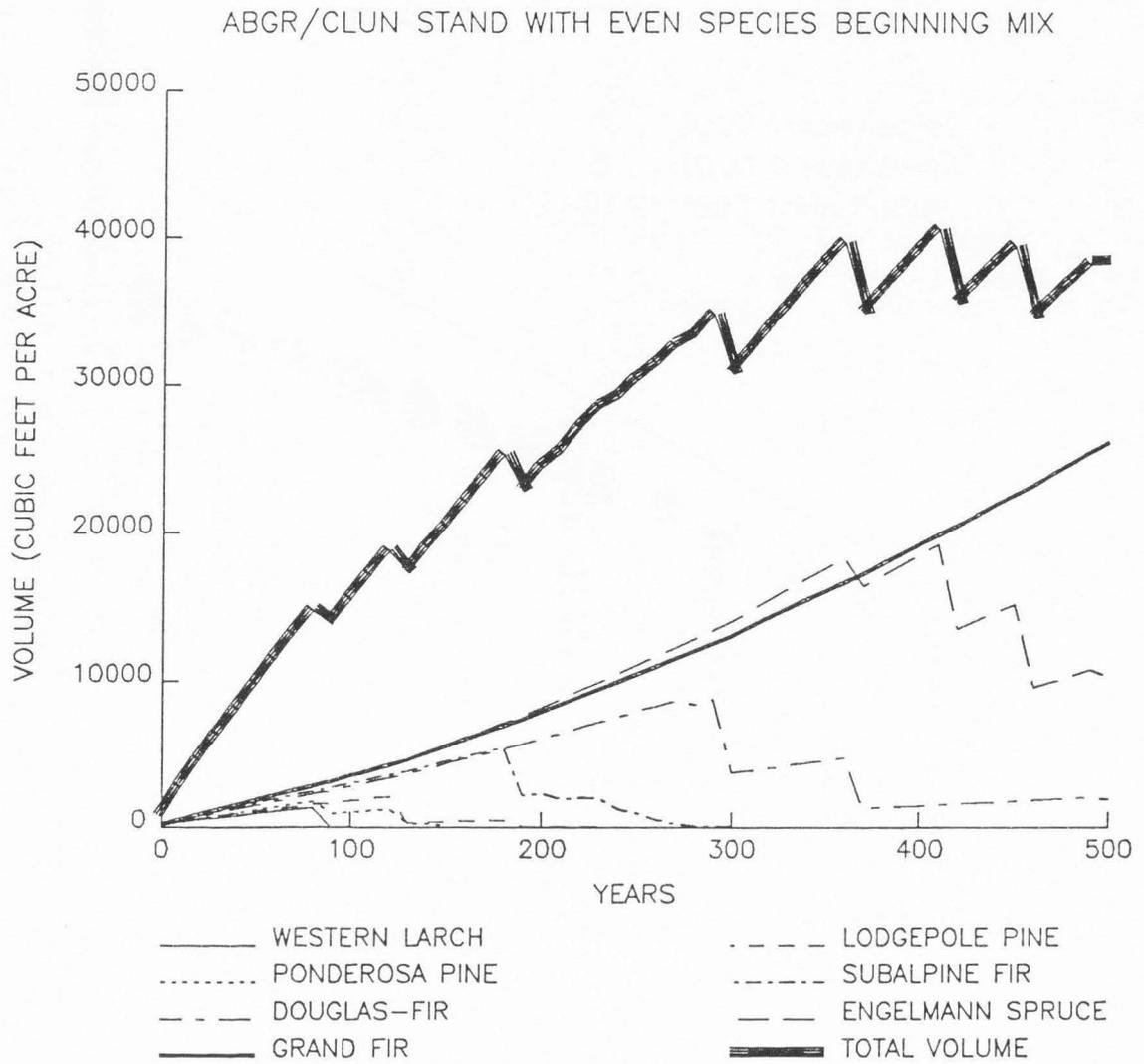


Figure 8. Plot of species-specific change in volume over 500 years of simulation for an ABGR/CLUN stand initialized with an even mix of all species.

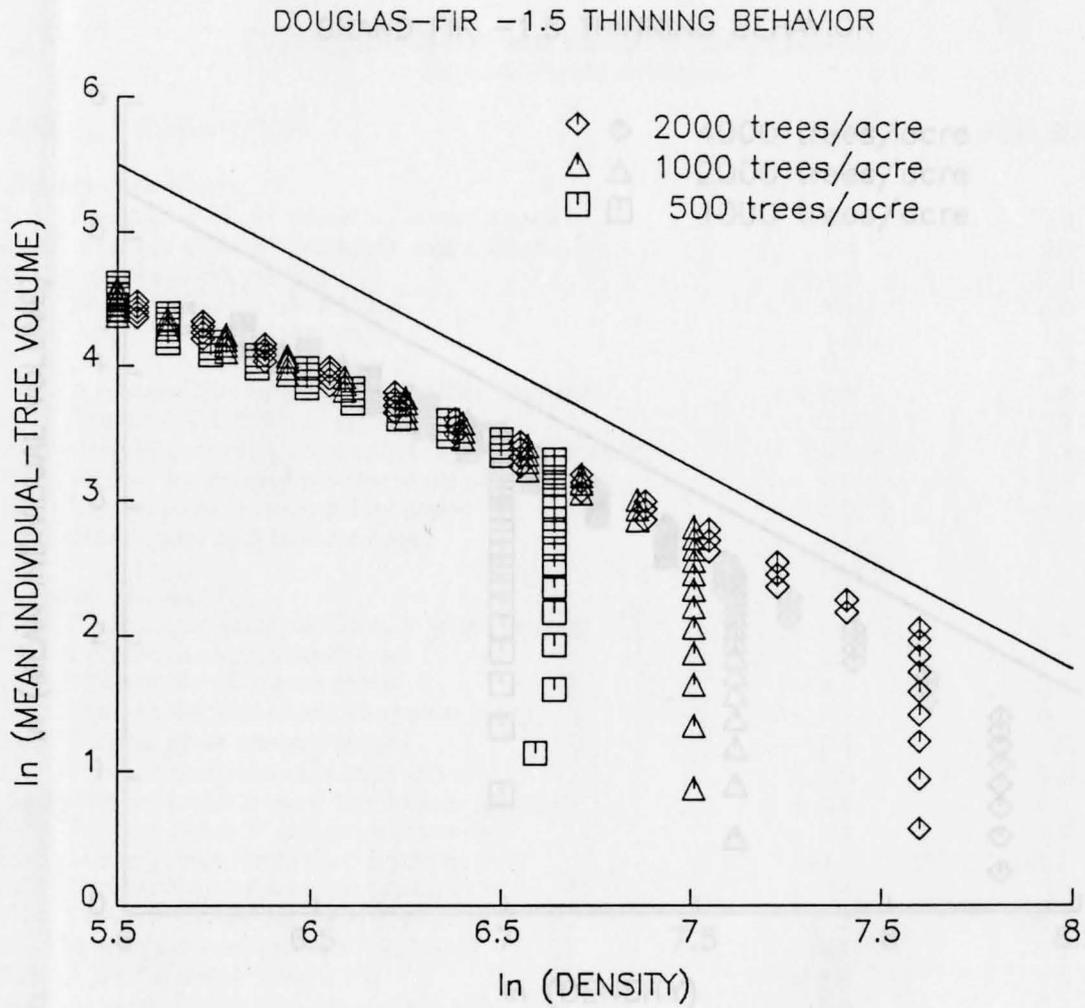


Figure 9. Plot of the natural logarithms of density (stems/acre) against mean individual-tree volume (ft^3/acre) for an even-aged monoculture of Douglas-fir.

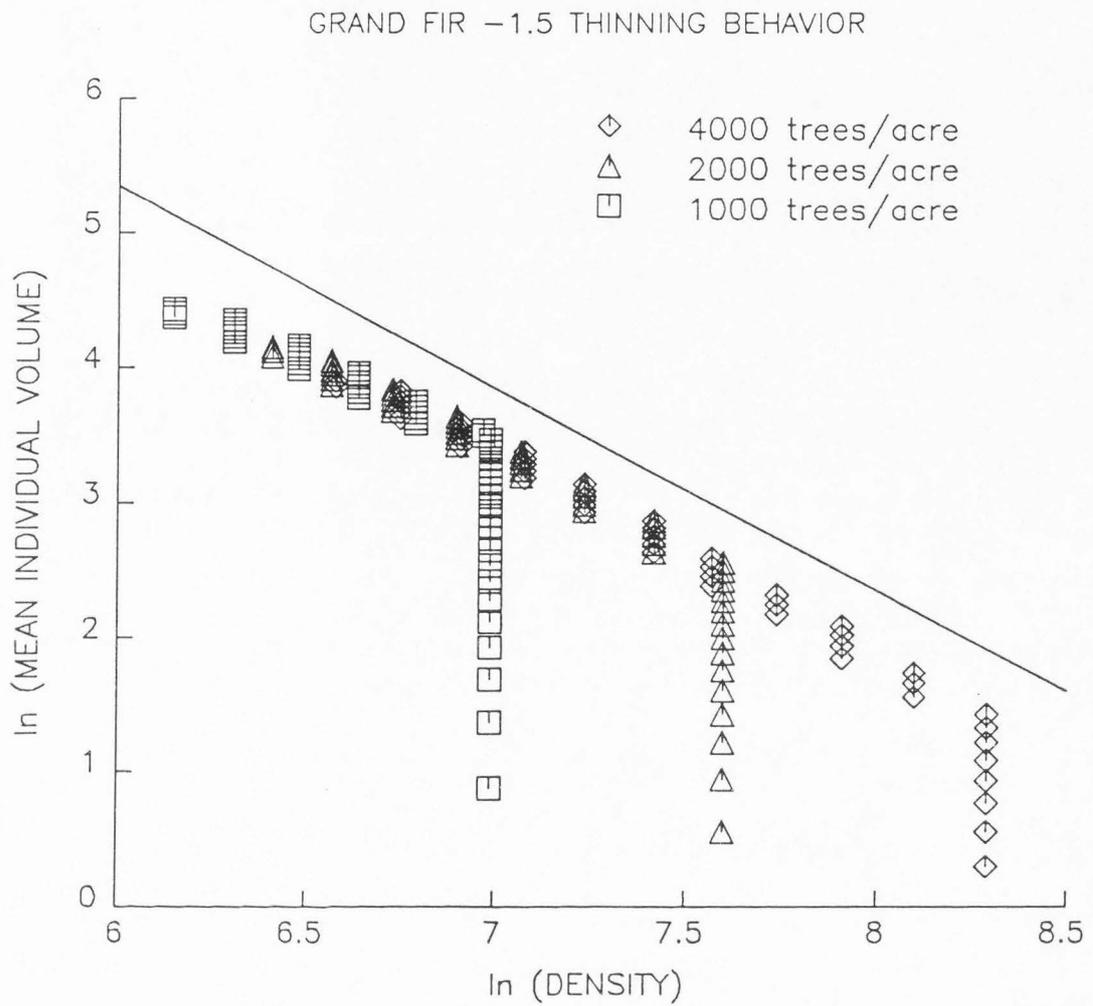


Figure 10. Plot of the natural logarithms of density (stems/acre) against mean individual-tree volume (ft^3/acre) for an even-aged monoculture of grand fir.

TABLE 10

Continuous-value Habitat Suitability Index Parameter
Bias and Precision Errors

HABITAT PARAMETER	BIAS	PRECISION
Directly-calculated:		
1) Average DBH of overstory trees (inches)	- 1.4	3.6
2) Average DBH of overstory aspen (inches)	0.0	0.0
3) Soft snags (stems/ac)	- 1.8	2.0
4) Snags > 6" DBH (stems/ac)	- 4.1	6.0
5) Snags > 12" DBH (stems/ac)	- 1.0	1.5
6) Snags > 20" DBH (stems/ac)	- 0.7	0.8
7) Average DBH of snags > 20" DBH (inches)	- 2.9	4.4
8) Trees > 20" DBH (stems/ac)	1.2	2.1
15) Percent overstory composed of spruce/fir trees	0.0	1.3
22) Radius for twenty mature male aspen (ft)	0.0	0.0
26) Percent area dominated by aspen	0.0	0.0
34) Stand basal area (square ft/ac)	4.5	8.3
Pyramid-calculated:		
9) 7" diameter stumps/down logs (stems/ac)	- 0.8	22.2
11) Percent canopy closure trees	2.0	11.3
12) Percent shrub crown cover	- 1.6	12.4
13) Percent deciduous shrub crown cover	- 0.7	8.9
16) Percent grass canopy cover	- 0.2	6.6
17) Percent herbaceous canopy cover	- 0.8	9.5
18) Percent herbaceous cover in late spring	- 0.8	9.5
19) Percent cover 3" diameter downfall	- 0.1	0.5
23) Density deciduous shrubs (stems/ha)	-85.5	348.8
24) Density deciduous trees (stems/ha)	- 0.2	3.0
25) Density coniferous trees (stems/ha)	-97.5	584.1
27) Average lowest branch height (ft)	- 0.1	0.5
28I) Average shrub height (ft)	- 1.4	2.0
28II) Average deciduous tree height (ft)	0.0	0.0
28III) Average coniferous tree height (ft)	0.0	2.8
29) Average height shrubs (ft)	- 1.4	2.0
30) Average height deciduous shrubs (ft)	- 1.4	2.0
31) Average height herbaceous stems (ft)	0.0	0.2
32) Diversity of herbaceous plant species (number)	0.0	0.8

BIAS is equal to the sum of the individual-stand differences between actual and predicted HSI-parameter values, all divided by the number of stands.

PRECISION is equal to the sum of individual-stand absolute differences between actual and predicted HSI-parameter values, all divided by the number of stands.

Calculated dynamic HSI values produced by HSI.FOR agreed with corresponding hand-calculations for three reference stands, given specified HSI-parameter values for the reference stands produced by DYNAM10.

HSI VALUES FOR AN EARLY-SUCCESSIONAL PSME/CARU STAND

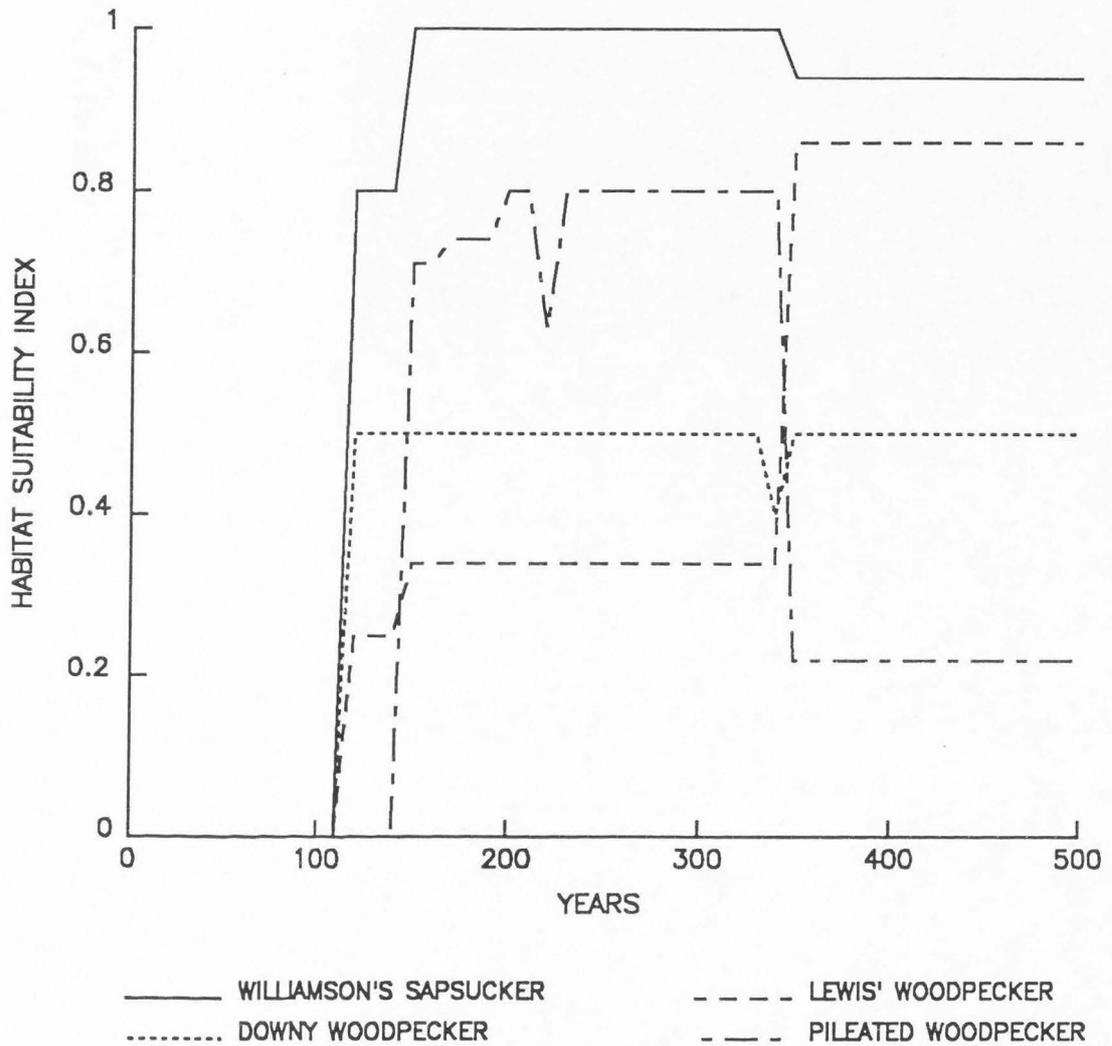


Figure 11. Plots of Habitat Suitability Index values for Williamson's sapsucker, and downy, Lewis', and pileated woodpeckers for an early-successional PSME/CARU stand over a 500-year simulation.

HSI VALUES FOR AN EARLY-SUCCESSIONAL ABGR/CLUN STAND

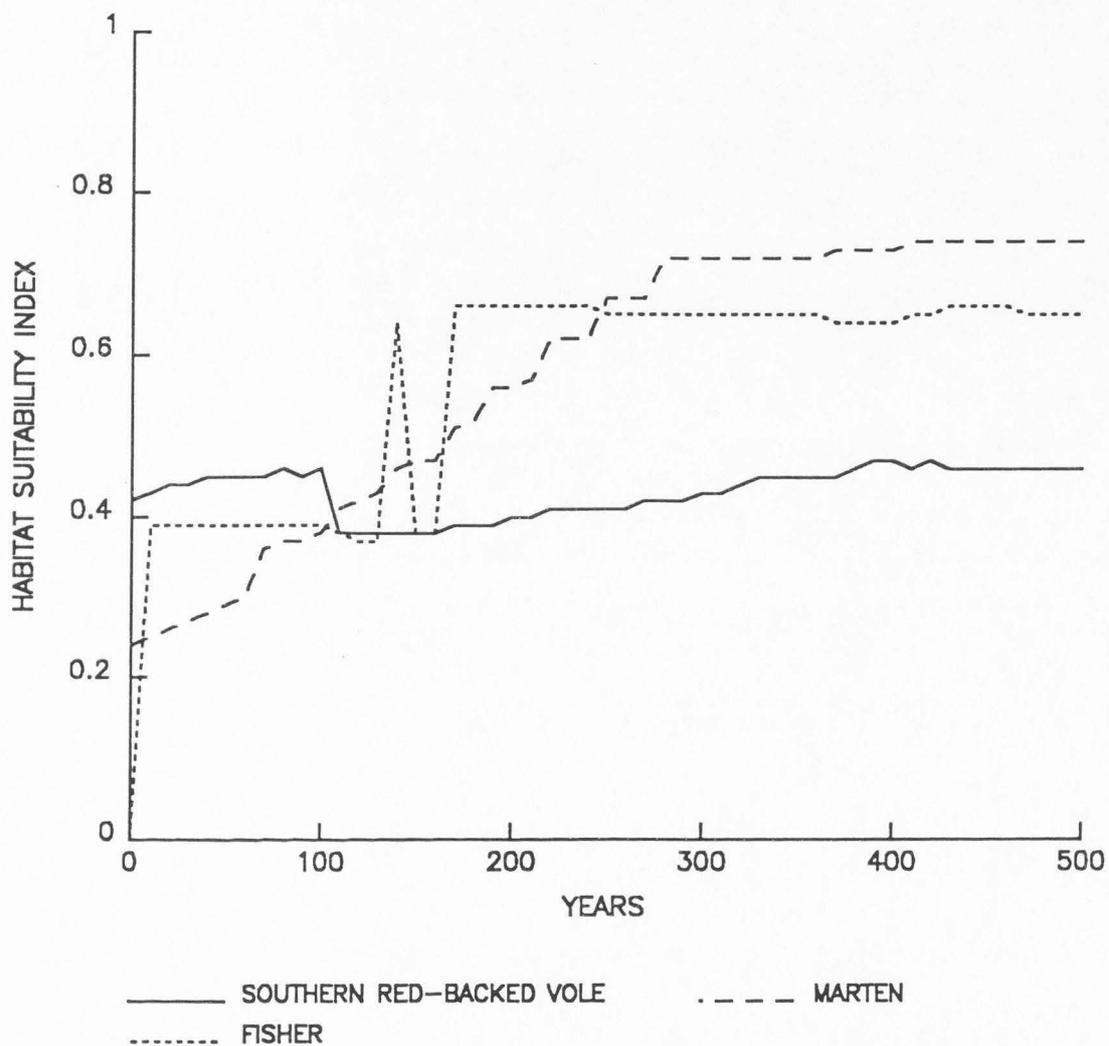


Figure 12. Plots of Habitat Suitability Index values for southern red-backed vole, marten, and fisher for an early-successional ABGR/CLUN stand over a 500-year simulation.

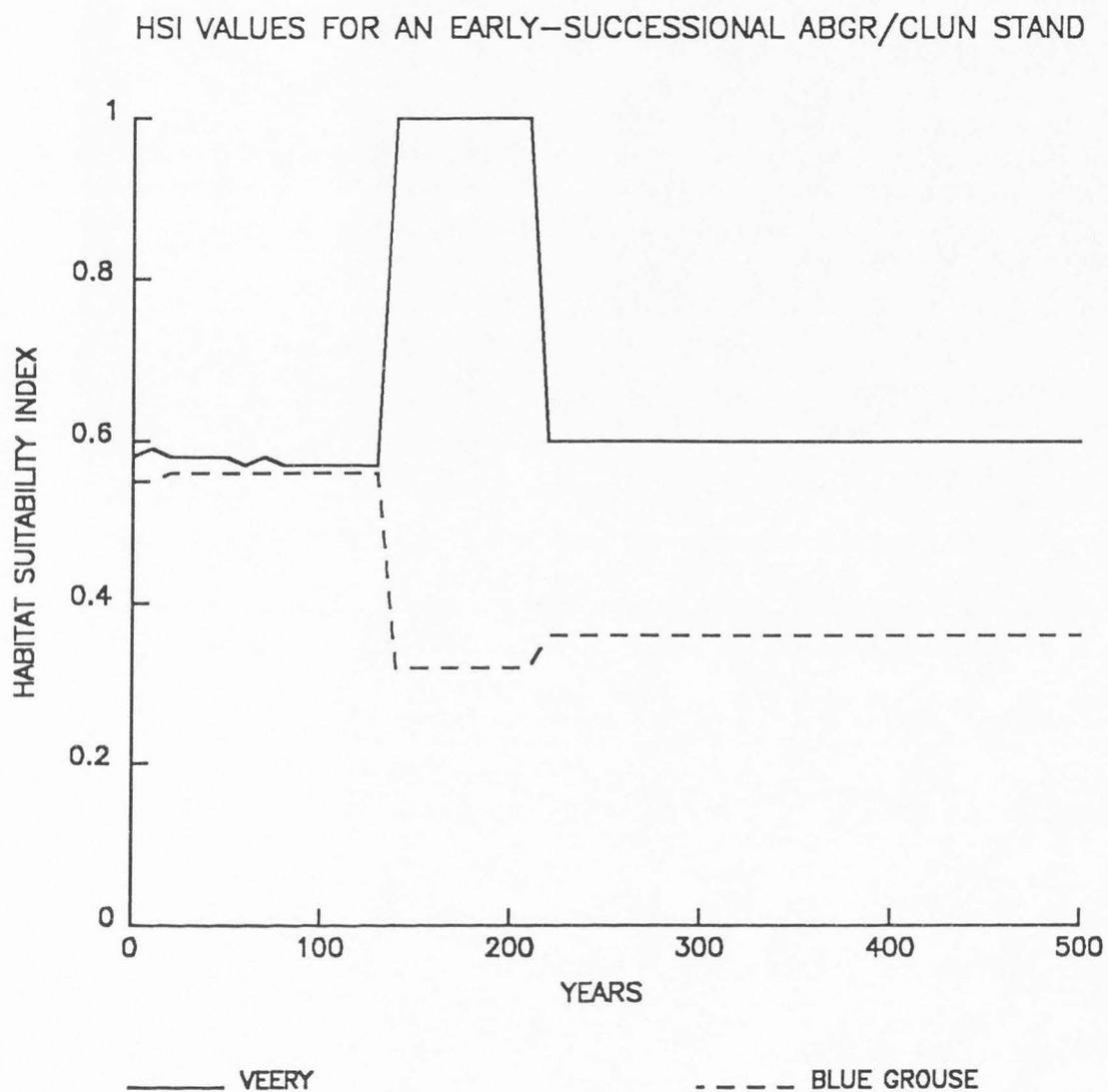


Figure 13. Plots of Habitat Suitability Index values for veery and blue grouse for an early-successional ABGR/CLUN stand over a 500-year simulation.

DISCUSSION

Validation of the Forest Simulation Model

Mean annual per-tree volume bias errors (Table 6), whether by species, habitat-type, or stand had absolute values near or less than $0.1 \text{ ft}^3/\text{tree}/\text{year}$. The stand-level, or total mean bias was $0.045 \text{ ft}^3/\text{tree}/\text{year}$. The mean annual percent individual-tree biases ranged from 0.09 to 1.89% by species, with a stand mean annual bias of 1.12%. A negative bias represents underestimation, while a positive bias represents overestimation. The species-specific precisions varied from 0.098 to $0.276 \text{ ft}^3/\text{tree}/\text{year}$ by species, corresponding to a range of 1.46 to 2.34% annual precision errors. The total mean stand precision is $0.18 \text{ ft}^3/\text{tree}/\text{year}$, a percent precision error of 1.91%.

The total mean bias of $0.045 \text{ ft}^3/\text{tree}/\text{year}$ is relatively small if one considers that a tree growing 100 years could have a total volume of 100 ft^3 or more, and the corresponding error over that time would be 4.5 ft^3 , or 4.5% error of estimate. The positive bias is negligible given the minimal size of the error. In addition, the species-specific biases, all with absolute values near or less than $0.10 \text{ ft}^3/\text{tree}/\text{year}$, are acceptably small, representing approximately 10.0% or less error of estimate. In fact, all mean annual species-specific individual-tree bias errors were less than 2.0%.

The precision errors may be interpreted as measures of the relative variance of volume growth for a class. In general, the lower the value, the better the growth parameters will be at predicting volume with precision. The species-specific precision errors may be related to absolute maximum size of the trees. That is, ponderosa pine has a larger potential maximum volume than subalpine fir. Hence, although the predicted precision of ponderosa pine growth is not as good as for subalpine fir growth in absolute terms, in relative terms all mean annual species-specific errors were less than 2.5% error of estimate. The total mean stand precision of $0.18 \text{ ft}^3/\text{tree}/\text{year}$ is somewhat difficult to interpret, given that individual-tree volumes in the database vary from 0.5 to 350 ft^3 . However, the stand-level percent precision error was 1.91%, and seems reasonably small enough to assert that the calculated, theoretically-based growth equations perform very well predicting volume.

Since the growth parameters were determined by purely theoretical means, the relatively small bias and precision errors are considered as positive evidence of validation of DYNAM10.

Verification of DBH Parameters

The log-DBH versus log-volume correlation coefficients were very high for all species ($r^2 = 0.96$ to 0.99). The y-intercepts are reasonable since, theoretically, they should be less than log 5.0 ($=0.699$), as a tree less than 5.0" DBH has no calculated volume.

The species-specific bias error estimates were less than or equal to 0.02 inches, with an absolute percent bias error of 0.72% or less. The stand-level mean per-tree bias was nearly zero (-0.01 inches), as was the mean percent bias error (0.01%). The per-tree precision errors were also quite negligible considering the large range of sampled DBH. Therefore, the DBH routine is verified.

Verification of Height Predictions

The species-specific mean annual height growth prediction bias errors were all less than 0.05 ft, with corresponding absolute percent biases being all less than 0.25%, or 2.5% over 10 years. For comparison, the Forest Survey measurement errors for trees 100 ft or taller is 5 ft, or a 5% 10-year error. Hence, the bias and precision height growth prediction error estimates were all quite reasonable, thereby verifying acceptable functioning of the height prediction routine.

Verification of Stand-level Behavior

DYNAM10 produces different pathways of succession dependent upon initial stand conditions, as evidenced by the graphs of changes in individual species volumes over time for stands initialized with an even species mix, and a 50/50 mix of ponderosa pine and western larch for both habitat types (Figures 5, 6, 7, and 8). In all cases, shade-intolerant species eventually drop out of the stands, generally in order of shade-tolerance. Also, the shade-tolerant species increase in volume over time. These general patterns are consistent

with theoretical patterns.

The graphs of the natural logarithm of density against the natural logarithm of mean individual-tree volume for simulated even-aged monocultures of Douglas-fir and grand fir (Figures 9 and 10, respectively) are generally consistent with the theoretical -1.5 thinning rule of Yoda et al. (1963), as are graphs for all other species. Stand volumes of simulated even-aged monocultures at 100 years of age (Table 9) tend to be in range with empirical information from Burns and Honkala (1990).

Hence, simulated stand-level behavior of successional dynamics, thinning, and volume growth over time were consistent with theoretical and empirical information, thereby verifying the overall behavior of the model.

Verification of Predicted Habitat Suitability Index Model Parameters

The bias and precision errors calculated for the 31 continuous-value HSI parameters (Table 10) are relatively small when compared to the parameter units of each measure, with two exceptions. The deciduous shrub and understory coniferous tree density bias errors are large when compared to low actual stand densities. At low densities, however, large bias errors do not affect predictions of HSI values. A minimum combined density of 4287.5 understory stems/ha is necessary to calculate an HSI value for the ruffed grouse. Bias errors are acceptably small, less than 5% errors of estimate, when actual densities approach 5,000 stems/ha.

The small HSI-parameter bias and precision prediction errors are not surprising for the 17 parameters calculated from the weighted community-type pyramid tables, since the actual initial values calculated from the supplemental stands were used to calibrate the tables. The 16 directly-calculated parameters have slightly higher bias and precision errors, caused by assuming trees in the stand table to be spread evenly within a volume class during model initialization, instead of reading tree volumes into the model directly. This operation is necessary to create an average stand distribution table. Therefore, because the actual values for each stand are calculated directly from the Forest Survey database, the

small difference between predicted and actual values is an artifact of model initialization.

In order to validate this portion of the model, an independent data set is required against which to test the pyramid and direct-calculation schemes. The subroutine VEGDYN is sufficiently verified, however, as evidenced by the minimal bias and precision errors.

Verification of HSI.FOR

Calculated dynamic HSI values were verified by hand-calculation, agreeing with expected results given specified HSI-parameter values. Hence, HSI.FOR produces dynamic HSI values indicative of simulated stand vegetation dynamics. This is certainly not surprising, but is indeed essential to verify the linkage between the two programs. Analysis of the relative weighting of different HSI variables may reveal limitations to the reliability of HSI models. However, HSI models are the only current wildlife habitat models readily available for large numbers of species.

Analysis of HSI Value Dynamics

Predictions of species-specific dynamic HSI values for Williamson's sapsucker, and downy and Lewis' woodpeckers (Figure 11) shows that the first 110 years of simulated forest structure provide a habitat quality of 0.0, while the following years provide good to excellent habitat. Similarly, the pileated woodpecker (Figure 11) has a predicted suitability of 0.0 for the first 140 years, and good to excellent suitability thereafter. This pattern is typical for most of the simulations of the 45 supplemental stands.

Analysis of the corresponding predicted HSI parameters shows that during periods of zero habitat quality the number of standing-dead trees is also 0.0 for the snag measures used to predict habitat quality for the four species above. During periods of non-zero habitat quality, the snag densities are above threshold values. This reveals that simulated standing-dead tree density is a primary factor determining predicted habitat quality for these wildlife species. This is not surprising, considering the high weighting these variables receive in the HSI models for each species.

Dynamic HSI values of the 45 simulated stands reveal a consistent, general nested pattern of predicted suitability indices by species. Williamson's sapsucker has the highest

HSI rating, followed in order by Lewis', downy, and pileated woodpeckers. This ranking is caused by a variety of factors which are analyzed by species in the following text.

Predicted suitability for the Williamson's sapsucker during non-zero periods switches from 0.80 to 1.0, and 1.0 to 0.94. These discrete changes are controlled by corresponding changes in tree canopy cover. The other three model variables are percent deciduous tree canopy cover and DBH of overstory aspen, both of which are always zero, and number of 6.0" DBH snags per acre, which has a suitability value of 1.0 if the number of snags is greater than 1.5/acre. Since the number of snags is always greater than the threshold value during periods of non-zero suitability, tree canopy cover determines the HSI value. Tree canopy cover shifts from 70 to 57%, and 57 to 28% at years 150 and 350, respectively, of the simulation. This shift is in turn caused by discrete changes in community-type distribution of the stand. This general pattern of discrete changes in sapsucker suitability is typical for most of the 45 simulated stands.

Predicted suitability for Lewis' woodpecker increases discretely at years 150 and 350 from 0.25 to 0.34, and 0.34 to 0.86, respectively. Again, the discrete changes are due to corresponding discrete changes in parameters calculated via the community-type pyramid scheme. Two variables, tree canopy cover and shrub density, determine the HSI values during periods of non-zero suitability when the number of 12.0" DBH snags is above the threshold value of 1.0/acre. Tree canopy cover shifts as described above, while shrub density changes at years 150 and 350 of the simulation from 28 to 14, and 14 to 37stems/acre, respectively.

The downy woodpecker model has only two variables, namely stand basal area and number of snags greater than 12.0" DBH, or 18.0" DBH for ponderosa pine, per acre. The threshold value for the snag measure is 5.0 stems/acre, which is achieved every time step during non-zero suitability except years 330 and 340 of the simulation. The suitability value of the snag measure is 1.0, except for years 330 and 340, which correspond to values of 0.80 and 0.40 respectively. Stand basal area is also above the threshold value of 131 cubic-feet per acre during the period of non-zero suitability, which translates to a variable suitability of

0.50. The HSI value is the minimum of the two variable suitability values, and is 0.50 throughout the simulation, except for being 0.40 at year 340.

Predicted pileated woodpecker suitability is determined by five variables. Three directly-calculated variables are number of snags, and number of live trees greater than 20.0" DBH per acre, and average DBH of snags greater than 20.0" DBH. The two pyramid-calculated variables are tree canopy cover and average number of downed logs and stumps greater than 7.0" diameter per acre. The limiting factor determining the HSI value changes over time. From years 0 to 140, the number of 20.0" DBH snags is below threshold value, and the HSI value is 0.0. From years 150 to 190, the average DBH of large snags is the limiting factor, with values of 18.0" and 22.0" causing corresponding HSI values of 0.71 and 0.74, respectively. From years 200 to 340, tree canopy cover is 57%, causing an HSI value of 0.80. Finally, from year 350 on, tree canopy cover is 28%, causing an HSI value of 0.22. One exception occurs at year 220, when the number of large live trees drops below the threshold value of 30 stems/acre, and the resulting HSI value is 0.63.

The plotted dynamic HSI values for the southern red-backed vole remain fairly stable over the 500-year simulation, while the values increase over time for the fisher and marten (Figure 12).

The southern red-backed vole HSI values begin at 0.42 and end at 0.46. The HSI value is calculated as the cube root of the product of three variable indices, all multiplied by a fourth variable index value. Hence, if any of the variable index values equals 0.0 the final HSI value will also be 0.0.

The initial three indices represent average overstory DBH, percent down wood ground cover, and percent graminoid ground cover. For most simulations, these variables remained relatively stable over time. The combined index of these three stable HSI variable values are then multiplied by an index for the percent conifer canopy cover. Conifer canopy cover also remains relatively stable over most simulations, explaining the stability of the plotted dynamic HSI values.

The fisher HSI values are calculated similarly as the vole index. The cube root of three

variable indices are multiplied by an index for the percent deciduous canopy cover. This percentage is 0.0 for the entire simulation, which translates positively to an index value of 0.8 for the variable. The three combined variable indices of the fisher HSI model represent total canopy crown cover, average overstory DBH, and canopy-structure class. The total canopy cover is equal to the coniferous crown cover, and is stable for most simulations. Average overstory DBH increases over time, but has little effect on the resulting HSI value as the threshold value of 15.0" is reached throughout the simulation. The abrupt changes in HSI values from 0.39 to 0.65 (Figure 12) is caused by the discrete change in canopy-structure class from "1" meaning single-storied, to "3" meaning multi-storied.

The plot of predicted dynamic marten HSI values increases from 0.24 to 0.74 over the 500-year simulation (Figure 12). The marten HSI value is calculated as the square root of the product of four variable indices. Total crown cover and percent down wood ground cover represent two of the indices, and are stable over most simulations. The successional stage of the stand represents a third index, which shifted abruptly from a "4," meaning "young," to a "5," meaning "mature," at year 70 of the simulation, causing a slight increase in the HSI value from 0.30 to 0.36. The fourth variable index is representative of the percent canopy coverage of spruce and true fir species combined. This index value increased significantly over the simulation from 1.5 to 40.4%. The percent spruce and fir index value contributes most to the increase in predicted fisher suitability.

Dynamic HSI values for the veery shifted abruptly from 0.58 to 1.0, and 1.0 to 0.60 at years 140 and 220, respectively, of the simulation of an early-successional ABGR/CLUN stand (Figure 13). The veery HSI value is calculated as the minimum value of a combination of four indices and a single index representing soil moisture content class. The soil moisture class is always constant, based on the habitat type of the stand. For the ABGR/CLUN habitat type, the variable value is 1.0. The four combined variable indices represent total deciduous shrub cover, average shrub height, total herbaceous plant cover, and average herbaceous plant height. The first two and second two indices are multiplied separately, then the two products are multiplied for the final HSI value. All four variables are pyramid-calculated, and values shift abruptly at years 140 and 220 due to corresponding

changes in community-type distribution. The combined index shifts from 0.58 to 1.15, and 1.15 to 0.60 at years 140 and 220, respectively. Hence, the limiting factor determining the HSI value is the combined index from years 0 to 130, soil moisture class from years 140 to 210, and the combined index again from year 220 to 500. Slight variation in deciduous shrub cover and average herbaceous height causes slight variation in the HSI value from years 0 to 140 between 0.57 and 0.59.

The blue grouse HSI value is calculated as the minimum of three indices representing total crown cover, the square root of the total shrub cover and average shrub height indices, and the square root of the total herbaceous cover and average herbaceous height indices multiplied by an index representing herbaceous plant diversity. All the variables are pyramid-calculated, and help determine final HSI values on different stands.

For the simulated early-successional ABGR/CLUN stand, blue grouse HSI values shifted abruptly from 0.56 to 0.32, and 0.32 to 0.36 at the same years (140 and 220, respectively) of the simulation as shifts in veery HSI values occurred. All five model variables shifted abruptly at years 140 and 220 of the simulation, but the limiting factor changed over time. From years 0 to 130, and from years 220 to 500, the combined index representing herbaceous cover, height, and diversity was the limiting factor, while the combined index representing shrub cover and height was the limiting factor from years 140 to 210.

Ruffed grouse HSI values were equal to 0.0 for all stands in the Forest Survey database. The predicted value of 0.0 is caused by a two factors. First, the average radius of a circle containing 20k mature male aspens is always indeterminate, given that no aspens occurred on the stands. Second, the total shrub and understory deciduous- and coniferous-tree densities were below threshold values used in the HSI model, causing that combined index to always be 0.0.

Model Evaluation

The primary objective of the model has been accomplished by calibrating a forest succession model and linking the model directly with several animal HSI models to

produce dynamic estimates of habitat suitability. The model is designed to be applied at appropriate scales of land management, namely for contiguous stands 1.0 acre in size or larger. DYNAM10 requires a minimum of empirical information for stand-specific calibration. The manager is required to enter only a stand table of average composition and structure representative of the stand to be simulated. Additionally, the model is developed from a regional database allowing extrapolation across a large area, namely the northern Rocky Mountain region. Simultaneous predictions of dynamic HSI values for the 10 modeled animal species are a convenience to allow land managers to assess the effects of natural forest development on a variety of indicator wildlife species, aiding the creation of viable management alternatives.

The growth parameters in DYNAM10 have very low bias and precision errors, thereby revealing the strength of the stand resource allocation theory. The forest simulation portion of the model is very strong, allowing high precision and low bias of predictions over a variety of forest stand structures. This portion of the model is considered to be validated.

Calibration of the VEGDYN subroutine of DYNAM10 to predict the 34 HSI parameters by habitat type required a fair amount of empirical data. Creation of successional pyramids of weighted mean habitat-parameter values is a theoretically simplistic approach with potentially high prediction precision. Unfortunately, the reliability of the pyramids is dependant upon the quality and quantity of the data. Necessary interpolation of empty cells in the successional pyramid potentially causes bias in predictions. Additionally, high variation in parameter values across stands is not completely accounted for by community type. However, comparison between predicted and actual structural habitat parameter values showed low bias and precision errors, leading to verification of the VEGDYN subroutine of DYNAM10.

Analysis of predicted HSI values proved to verify the proper functioning of the program HSI.FOR. However, the reliability of the HSI models to portray actual habitat quality is under some question. In general, animal habitat models require theoretical

improvement and empirical validation over a wide range of conditions. The assumption that habitat quality is correlated to vegetation structure is rather intuitive, but has not been established in the literature (Van Horne 1983). Hence, the HSI models represent the weak link in the DYNAM10 chain.

Development of DYNAM10 is very compatible with the Forest Survey database and current wildlife habitat management methods. The database represents a potentially powerful predictive tool when applied to simulation models. Addition of new animal species and habitat parameters to DYNAM10 would require a minimum of effort, with the difficulty of addition depending upon the data requirements of the particular HSI model. Certain species may be very easily added if they require a subset of the vegetational variables already simulated. Addition may also be relatively difficult if the required data for calibration of a new parameter to DYNAM10 are not available in the database.

Moreover, the process for producing dynamic multi-species habitat models has been tested and found to be viable. The production of new models, using the DYNAM10 format, for different habitat types in the Intermountain region is certainly possible. In time, as a larger portion of the Forest Survey database contains remeasurement data over a larger region, model performance may be enhanced and the process of creating new models streamlined.

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APPENDIX A

Description of Sample Methods for Animal Habitat Parameters

1) Average DBH of overstory trees

The average diameter at breast height of those trees at least 80% of the height of the tallest tree.

Field Method: I chose the tallest tree in the stand from Forest Survey measurements of live tallied trees, and compared all tallied tree heights and their corresponding DBH to this tree. I then calculated the mean DBH of all sample trees at least 80% the height of the tallest tree.

Simulation Method: This value is calculated by searching the live individual-tree array for the tallest tree in the stand, counting all trees at least 80% of the height of this tree, summing the DBH of each counted tree, and dividing the sum of counted-tree DBH by the number of counted trees.

2) Average DBH of overstory aspen

The average diameter at breast height of those aspen at least 80% of the height of the tallest tree.

Field Method: I chose the tallest tree in the stand from Forest Survey measurements of live tallied trees, and compared all tallied aspen heights and their corresponding DBH to this tree. I then calculated the mean DBH of all sample aspen at least 80% the height of the tallest tree.

Simulation Method: This value is calculated by searching the live tree array for the tallest tree in the stand, counting all aspens at least 80% of the height of this tree, summing the DBH of counted trees, and dividing the sum of counted-tree DBH by the number of counted trees.

3) Number of suitable soft snags per acre

The number of standing dead or partly dead ponderosa pine at least 18 inches DBH or other dead or partly dead trees at least 12 inches DBH per acre.

4) Number of snags at least 6 inches DBH per acre

The number of standing dead or partly dead trees, at least 6 inches DBH that are at least 6 feet tall.

5) Number of snags at least 12 inches DBH per acre

The number of standing dead or partly dead trees at least 12 inches DBH and 30 feet tall.

6) Number of snags greater than 20 inches DBH per acre

The number of standing dead or partly dead trees that are greater than 20 inches DBH and at least 6 feet tall.

Field Method for Numbers 3-6: Forest Survey crews collect species, DBH, and height (if at least eight feet tall) for all tallied snags at each sample point. I changed the height criterion for numbers 4 and 6 to eight feet rather than six. This will introduce a negligible bias, and minimize additional data requirements. However, the Forest Survey height data is based on an estimated height of the tree before death. Since the HSI requirement is for actual height, I collected information on each tallied snag and placed the snag in one of two height classes, 1) greater than 8 feet and less than 30 feet, or 2) greater than or equal to 30 feet. From this data I simply calculated snags/acre in each of the categories.

Simulation Method: The number of snags greater than 6", 12", 20" DBH, and soft snags greater than 12" (or 18" if ponderosa pine) are calculated by counting appropriate trees from the standing dead tree arrays.

7) Average DBH of snags which exceed 20 inches DBH

The average DBH of snags which exceed 20 inches DBH.

Field Method: I simply calculated a weighted average of the DBH for trees counted in number 6.

Simulation Method: This value is calculated by summing the DBH of appropriate counted standing dead trees from the standing dead tree array and dividing by the number of counted trees.

8) Number of trees greater than 20 inches DBH per acre

Actual or estimated number of trees that are greater than 20 inches DBH per acre.

Field Method: Forest Survey crews collect DBH on all sample trees. I simply calculated the number per acre from these data.

Simulation Method: This value is calculated by summing the number of trees in the appropriate size range in the live individual-tree array.

9) Number of tree stumps greater than 1.0 foot in height and 7 inches in diameter and/or logs greater than 7 inches in diameter per acre

The actual or estimated number of stumps greater than 1.0 foot in height and 7 inches in diameter measured at 1.0 foot height, and/or the number of logs greater than 7 inches diameter measured at the largest point.

Field Method: One 0.05 acre circular plot was centered on each of the ten sample points used by the Forest Survey crews. On each sample plot, all suitable stumps and logs were tallied. Stumps included all dead trees less than 8 feet tall, since taller dead trees were considered snags.

Simulation Method: This value is calculated by the successional pyramid method.

10) Percent canopy closure of evergreen trees

The percent of the ground surface that is shaded by a vertical projection of the canopies of all coniferous woody vegetation taller than 16.5 feet.

Field Method: Forest Survey crews measure the total canopy closure of all trees. Assuming all trees are evergreen except for aspen, I determined the fraction of total basal area composed of all species except aspen. This fraction was multiplied by the total canopy coverage to determine evergreen canopy coverage.

Simulation Method: This value is calculated by summing the proportion of the total stand volume composed of coniferous trees and multiplying by the total stand canopy crown cover.

11) Percent tree canopy closure

The percent of the ground surface that is shaded by a vertical projection of the canopies of all woody vegetation taller than 16.5 feet.

Field Method: The Forest Survey crews estimate total canopy closure.

Simulation Method: This value is calculated by the successional pyramid method.

12) Percent deciduous shrub crown cover

The percent of the ground surface that is shaded by a vertical projection of the canopies of woody vegetation less than 16.5 feet tall.

13) Percent deciduous shrub crown cover

The percent of the ground surface that is shaded by a vertical projection of the canopies of deciduous shrubs.

Field Method for 12 and 13: I estimated the total shrub cover and deciduous shrub cover for each of three 0.05 acre sample plots centered on Forest Survey sample points and calculated an average.

Simulation Method for 12 and 13: This value is calculated by the successional pyramid method.

14) Percent of overstory composed of deciduous species

The percent canopy closure of deciduous trees in the overstory divided by the total overstory trees.

Field Method: The fraction of the total stand basal area composed of deciduous species (aspen only) was calculated from the Forest Survey sample data, and this fraction was multiplied by the total canopy coverage.

Simulation Method: This value is calculated by summing the proportion of the total stand volume composed of deciduous trees (aspen only) and multiplying by the total stand canopy crown cover.

15) Percent of overstory composed of fir or spruce

The percent of the overstory canopy closure of fir or spruce trees divided by the total overstory canopy closure.

Field Method: Considering "fir" to mean true fir, I calculated the fraction of the basal area made up of fir and spruce species. This fraction was multiplied by total canopy closure.

Simulation Method: This value is calculated by summing the proportion of the total stand volume composed of spruce and fir and multiplying by the total stand canopy crown cover.

16) Percent grass canopy cover

The percent of the ground surface covered by a vertical projection of grasses or sedges.

Field Method: Forest Survey crews estimate total coverage for grasses and sedges combined for each of three height classes, on each of the first three sample points, using eight cover classes (Pfister and Arno 1980). I averaged the midpoints of the cover classes for the three

sample points for the lowest height class, assuming that grasses with cover above the first height class also have cover in the lowest height class.

Simulation Method: This value is calculated by the successional pyramid method.

17) Percent herbaceous canopy cover

The percent of the ground surface that is shaded by a vertical projection of all non-woody vegetation.

18) percent herbaceous canopy cover in late-spring/early-summer condition

The percent of the ground surface that is shaded by a vertical projection of all non-woody vegetation.

Field Method for 17 and 18: Forest Survey crews estimate total coverage for grasses and sedges combined and for forbs for each of three height classes, on each of the first three sample points, using eight cover classes (Pfister and Arno 1980). For each height class, I chose the higher coverage class for either grass and sedges combined or forbs. I then averaged the cover-class midpoints for the three points. For 18, no significant curing of vegetation was observed over the field season of 1989 to place Forest Survey estimates in different classes, hence the original estimates are adequate.

Simulation Method for 17 and 18: This value is calculated by the successional pyramid method.

19) Percent of the ground surface covered by downfall at least 3 inches in diameter

The percent of the ground surface covered by dead woody material, including tree boles, stumps, limbs, or root wads at least 3 inches in diameter.

Field Method: I ocularly estimated the percent of the ground surface covered by all dead woody material at least 3 inches in diameter by estimating the number of square feet of down pieces and summing the estimates on each of ten 0.05 acre sample points. The square foot estimates were then summed and divided by the number of sample points for a stand average square foot estimate. The average square foot coverage estimate was then divided by the number of square feet per 0.05 acre to determine a percent coverage estimate.

Simulation Method: This value is calculated by the successional pyramid method.

20) Tree canopy diversity

An evaluation of the tree structural diversity within a forest stand classed as follows: 1) single-storied, 2) two-storied, 3) multi-storied.

Field Method: The Forest Survey crews estimate canopy structure according to four classes: 1) even-aged, 2) two-storied, 3) uneven-aged, 4) even-aged clumped. I cross-classified type 1 as single-storied, type 2 as two-storied, and types 3 and 4 as multi-storied.

Simulation Method: Tree canopy diversity is calculated by reading the list of all live tree heights and placing each tree in one of 20 ten-foot height classes. Each consecutive set of three contiguous classes is summed. If the class composes 50% or more of the total number of trees, then it is assigned a value of 2. If the class composes 10 to 49% of the total number of trees, then it is assigned a value of 1. Small classes are assigned a value of 0. The resulting string of integer values is then read to determine height class distribution. If five or more consecutive values are 1s or 2s, then the stand is declared multi-aged. If there are any set of 2s separated by a lower value, then the stand is declared two storied. If there are fewer than

five, but more than one consecutive 1s or 2s, then the stand is declared one-storied. If one or fewer values are 1 or 2 the stand is declared non-stocked.

21) Successional stage of stand

The structural condition of a forest community which occurs during its development. Five stages are recognized: 1) grass-forb, 2) shrub-seedling, 3) pole-sapling, 4) young, 5) mature or old-growth.

Field Method: Visually assess the condition of the stand and record as one of the five classes.

Simulation Method: The successional stage of the stand is determined by calculating the quadratic mean diameter of the stand from the list of individual-tree DBH. If the quadratic mean diameter is greater than 12.0" the stand is mature/old-growth. If the stand diameter is greater than 5.0" but less than 12.0", the stand is young. If the stand diameter is between 2.0" and 5.0" the stand is classified as a pole-sapling stand. A stand with a quadratic mean diameter less than 2.0 is classified as shrub-seedling/grass-forb.

22) The average radius of a circle encompassing 20 mature male aspen

The radius of a circle containing staminate flower producing aspen typically at least 25 years of age and 6 inches DBH.

Field Method: I used the Forest Survey data on aspen size class distribution to estimate aspen density per acre for aspen at least 6 inches DBH. I assumed a 50/50 sex ratio for aspen, assuming that half of the aspen clones were male. Finally from this number, I calculated the radius of a circle which would hold 20 male aspen given the calculated density.

Simulation Method: This value is calculated by summing the number of aspen per acre greater than 6.0" in the live individual-tree array, dividing by 2 for a 50/50 sex ratio, and using a transformation of the equation for the radius of a circle.

23) Density of deciduous shrub stems

The number of deciduous woody stems per hectare at least 3 feet tall growing with multiple, clumped, erect stems emanating from a common base on the ground.

Field Method: I counted or estimated the number of deciduous woody stems at least 3 feet tall and less than 16.5 feet tall on each of the first three 0.05 acre plots. I calculated the average of the three points, and multiplied by 2.417 to convert from acres to hectares.

Simulation Method: This value is calculated by the successional pyramid method.

24) Density of deciduous trees

Number of deciduous trees per hectare at least three feet tall and less than 16.5 feet tall growing from a single erect stem.

Field Method: I counted the number of deciduous tree stems at least 3 feet tall and less than 16.5 feet tall on each of the first three 0.05 acre sample plots, and calculated the average.

Simulation Method: This value is calculated by the successional pyramid method.

25) Density of coniferous stems

Number of coniferous stems per hectare at least 3 feet tall and less than 16.5 feet tall growing with a single erect stem.

Field Method: I counted the number of coniferous tree stems at least 3 feet tall and less than 16.5 feet tall on each of the first three 0.05 acre sample plots, and calculated the average.

Simulation Method: This value is calculated by the successional pyramid method.

26) Percent of the area dominated by aspen

The proportion of the total area being evaluated where aspen comprises at least 50% of the overstory tree canopy.

Field Method: I used Forest Survey live tallied tree data to check whether aspen made up at least 50% of the basal area on each of the ten variable-plot points. I summed the number of points where aspen comprised at least 50% of the basal area, and multiplied by 10 to convert to percent of total area dominated by aspen.

Simulation Method: This value is calculated by summing the proportion of the total stand volume composed of deciduous trees (aspen only) and multiplying by the total stand canopy crown cover.

27) Average lowest branch height of conifers

Average height of lowest conifer branches measured from the ground to the lowest point on the branch.

Field Method: The Forest Survey crews collect uncompact live crown ratios of all tallied trees, as well as the height of the tree. From these data, I calculated the lowest branch height for each tallied tree. I then averaged the sum of lowest branch heights by dividing by 10 for the ten variable-point plots to determine the stand average.

Simulation Method: This value is calculated by the successional pyramid method.

28) Average height of woody stems

The average vertical distance from the ground to the top of woody stems, measured separately for deciduous shrubs, deciduous trees, and conifers.

Field Method: The Forest Survey crews estimate the percent canopy coverage of understory trees and shrubs which comprise at least five percent cover, as well as total coverage for understory species at each of three height classes for each of the first three 0.05 acre sample points. Crews also measure height of tallied trees for each sample point. Using the midpoint of the coverage classes and the midpoints of the height classes, I calculated a weighted mean height for shrubs. Using the heights of the tallied trees, I calculated a weighted average height for the trees by converting to trees per acre.

Simulation Method: This value is calculated by the successional pyramid method.

29) Average height of shrub canopy

The average vertical distance from the ground to the highest point of all woody plants less than 16.5 feet tall.

30) Average height of deciduous shrubs

The average vertical distance from the ground to the highest point of all deciduous woody plants less than 16.5 feet tall.

Field Method for 29 and 30: Assuming that non-deciduous shrubs in the northern Rocky Mountain region are few, then all woody vegetation less than 16.5 feet equals all deciduous woody vegetation less than 16.5 feet tall. I used the midpoint of the coverage classes and the midpoint of the height classes to calculate a weighted average as for 28.

Simulation Method: This value is calculated by the successional pyramid method.

31) Average height of herbaceous canopy

The average vertical distance from the ground surface to the dominant height stratum of the herbaceous vegetative canopy.

Field Method: The Forest Survey crews collect estimates for the canopy coverage of grasses and sedges combined and for forbs in each of three height classes. Only the first two of these classes ever contained non-woody vegetation. For the second height class, I estimated the average height of herbaceous vegetation as the class interval is relatively wide. From the data for the first three 0.05 acre sample plots, I calculated the weighted average of the height of the dominant stratum.

Simulation Method: This value is calculated by the successional pyramid method.

32) Diversity of herbaceous vegetation per cover type

The number of plant species comprising 1% or more of the total herbaceous canopy coverage.

Field Method: For each of the first three 0.05 acre sample plots, I recorded the number of species in the plot that comprised 1% canopy coverage. From the three plots, I calculated an average value.

Simulation Method: This value is calculated by the successional pyramid method.

33) Soil moisture regime

The moisture condition of the soil at the ground surface during average spring/early summer conditions, classified as: 1) moist to saturated, 2) moderately dry to moist, 3) dry.

Method: We simply assumed that all ABGR/CLUN plots were soil moisture class 1, and that all PSME/CARU plots were moisture class 2.

Simulation Method: This parameter is assigned a value in the growth-parameter initialization file based on the habitat type of the stand, and is therefore not simulated.

34) Stand basal area

The cross-sectional area of all trees measured at 4.5 feet height per acre.

Field Method: The Forest Survey crews collect the data necessary on each of ten variable-point plots, namely individual tree diameters at breast height. I simply calculated the average basal area over the ten points to determine stand average basal area.

Simulation Method: This value is calculated by summing the basal area of each tree in the live individual-tree array.

APPENDIX B

FORTRAN Source Code for DYNAM10.FOR

```
PROGRAM DYNAM10
C
  IMPLICIT NONE
C
C* DEFINING PARAMETERS
C
  INTEGER*2 MAXSPC
  INTEGER*2 MAXCLA
  INTEGER*2 MAXTRE
  INTEGER*2 SUCPYR
C
  PARAMETER (MAXSPC=10)
  PARAMETER (SUCPYR=(MAXSPC**2+MAXSPC)/2)
  PARAMETER (MAXCLA=10)
  PARAMETER (MAXTRE=10000)
C
C* COMMON STAND
C
  INTEGER*2 STDTBL(MAXSPC,MAXCLA)
  INTEGER*2 NUMPERSPC(MAXSPC)
  REAL*4 VOLPERSPC(MAXSPC)
  REAL*4 TOTVOL
  REAL*4 DEADVL(MAXSPC)
  INTEGER*2 DTBL(MAXSPC,MAXCLA)
  INTEGER*2 NEWTREES(MAXSPC)
  REAL*4 NEWVOL(MAXSPC)
C
  COMMON / STAND / STDTBL,NUMPERSPC,VOLPERSPC,TOTVOL,
+           DEADVL,DTBL,NEWTREES,NEWVOL
C
C* COMMON FIXPAR
C
  CHARACTER*20 SPNAME(MAXSPC)
  INTEGER*2 UTRNK(MAXSPC)
  REAL*4 MING(MAXSPC)
  REAL*4 MAXG(MAXSPC)
  REAL*4 MAXT(MAXSPC)
  REAL*4 RES
  INTEGER*2 NUMSPC
C
  COMMON / FIXPAR / SPNAME,UTRNK,MING,MAXG,MAXT,RES,NUMSPC
```

```
C
C* COMMON VOLUME
C
    INTEGER*2 VOLEQN(MAXSPC)
    REAL*4 DBHEXP(MAXSPC)
    REAL*4 INTCPT(MAXSPC)
    REAL*4 VOLA(MAXSPC)
    REAL*4 VOLB(MAXSPC)
    REAL*4 VOLC(MAXSPC)
    REAL*4 VOLD(MAXSPC)
    REAL*4 VOLE(MAXSPC)
    REAL*4 VOLF(MAXSPC)
    CHARACTER*10 BRKTYP(MAXSPC)
    REAL*4 BRKVAL(MAXSPC)

C
    COMMON / VOLUME / VOLEQN, DBHEXP, INTCPT, VOLA, VOLB, VOLC,
+           VOLD, VOLE, VOLF, BRKTYP, BRKVAL

C
C* COMMON EXP
C
    REAL*4 RCEXP(MAXSPC)
    REAL*4 RSPA(MAXSPC)
    REAL*4 RSPB(MAXSPC)

C
    COMMON / EXP / RCEXP, RSPA, RSPB

C
C* COMMON VAR
C
    REAL*4 VAR9(SUCPYR)
    REAL*4 VAR11(SUCPYR)
    REAL*4 VAR12(SUCPYR)
    REAL*4 VAR13(SUCPYR)
    REAL*4 VAR16(SUCPYR)
    REAL*4 VAR17(SUCPYR)
    REAL*4 VAR19(SUCPYR)
    REAL*4 VAR23(SUCPYR)
    REAL*4 VAR24(SUCPYR)
    REAL*4 VAR25(SUCPYR)
    REAL*4 VAR27(SUCPYR)
    REAL*4 VAR281(SUCPYR)
    REAL*4 VAR282(SUCPYR)
    REAL*4 VAR283(SUCPYR)
    REAL*4 VAR31(SUCPYR)
    REAL*4 VAR32(SUCPYR)

C
    COMMON / VAR / VAR9, VAR11, VAR12, VAR13, VAR16, VAR17, VAR19, VAR23,
+           VAR24, VAR25, VAR27, VAR281, VAR282, VAR283, VAR31, VAR32
```

```

C
C* COMMON SNAG
C
      INTEGER*2 DEADSP(100,10)
      INTEGER*2 NMDEAD(10)
      REAL*4 DEADBH(100,10)
      REAL*4 PROB(10)

C
      COMMON / SNAG / DEADSP,DEADBH,NMDEAD,PROB

C
C* COMMON SPP
C
      INTEGER*2 ASPEN
      INTEGER*2 DECID(MAXSPC)
      INTEGER*2 CONIF(MAXSPC)
      INTEGER*2 SPRFIR(MAXSPC)
      INTEGER*2 PIPO
      INTEGER*2 SOIL

C
      COMMON / SPP / ASPEN,DECID,CONIF,SPRFIR,PIPO,SOIL

C
C* PASSED OR LOCAL
C
      INTEGER*2 NUMTRE
      INTEGER*2 SPE(MAXTRE)
      INTEGER*2 YEARS
      INTEGER*2 AGE
      INTEGER*2 IND
      INTEGER*2 INDEX
      INTEGER*2 SUM

C
      REAL*4 SPREAD
      REAL*4 TREEVL(MAXTRE)
      REAL*4 DBH(MAXTRE)
      REAL*4 HEIGHT(MAXTRE)
      REAL*4 TREEBA(MAXTRE)
      REAL*4 TOTBA
      REAL*4 UDRSTR(MAXSPC,SUCPYR)
      REAL*4 LOREG(MAXSPC)
      REAL*4 CLASIZ(MAXCLA)
      REAL*4 ABUNDA(SUCPYR)

C
      CHARACTER*30 OUTFL

C
      INTEGER*2 I,J,K,L

C
      DATA NUMPERSPC / MAXSPC*0 /
      DATA VOLPERSPC / MAXSPC*0 /
      DATA LOREG      / MAXSPC*0 /

```

```

C* DYNAM10 ***** ONE *****
C      Initialize stand table and call proper subroutines
C* DYNAM10 ***** ONE *****
C
      WRITE(*,(' ***** Welcome to DYNAM-10 *****',//))
C
      CALL SETUP(YEARS,UDRSTR)
C
10  WRITE(*,(
+      ' Initializing the stand is performed by',/,
+      ' reading a stand table of logarithmic volume',/,
+      ' classes from a file',// ))
C
      CALL GETINP(STDTBL,NUMSPC,NUMTRE,TREEVL,SPE,CLASIZ)
C
C* DYNAM10 ***** TWO *****
C      Main simulation loop
C* DYNAM10 ***** TWO *****
C
      AGE=0
C
20  TOTVOL=0.0
      TOTBA=0.0
      DO 21 I=1,NUMSPC
          NUMPERSPC(I)=0
          VOLPERSPC(I)=0.0
21  CONTINUE
C
      DO 22 I=1,NUMTRE          ! for all trees in stand
          TOTVOL = TOTVOL + TREEVL(I)          ! sum up volume
          DBH(I) = 10.0**((LOG10(TREEVL(I))-INTCPT(SPE(I)))
+          /DBHEXP(SPE(I)))          ! calc indiv DBH
          IF (((BRKTYP(SPE(I)) .EQ. 'DBH') .AND.
+          (DBH(I) .LT. BRKVAL(SPE(I)))) .OR.
+          ((BRKTYP(SPE(I)) .EQ. 'D2H') .AND.
+          (DBH(I)**2*HEIGHT(I) .LT. BRKVAL(SPE(I))))
+          .OR. (BRKTYP(SPE(I)) .EQ. 'NONE')) THEN
          IF (VOLEQN(SPE(I)) .EQ. 1) THEN
              HEIGHT(I)= (TREEVL(I)-VOLA(SPE(I))) / (VOLB(SPE(I))*
+              DBH(I)**2 + VOLC(SPE(I))*DBH(I))
          ELSE IF (VOLEQN(SPE(I)) .EQ. 2) THEN
              HEIGHT(I) = 100.0 * (TREEVL(I)-VOLA(SPE(I))) /
+              (VOLB(SPE(I))*DBH(I)**2)
          END IF

```

```

ELSE IF (((BRKTYP(SPE(I)) .EQ. 'DBH') .AND.
+ (DBH(I) .GE. BRKVAL(SPE(I)))) .OR.
+ ((BRKTYP(SPE(I)) .EQ. 'D2H') .AND.
+ (DBH(I)**2*HEIGHT(I) .GE. BRKVAL(SPE(I)))))) THEN
  IF (VOLEQN(SPE(I)) .EQ. 1) THEN
    HEIGHT(I)= (TREEVL(I)-VOLD(SPE(I))) / (VOLE(SPE(I))*
+ DBH(I)**2 + VOLF(SPE(I))*DBH(I))
  ELSE IF (VOLEQN(SPE(I)) .EQ. 2) THEN
    HEIGHT(I)= 100.0 * (TREEVL(I)-VOLD(SPE(I))) /
+ (VOLE(SPE(I))*DBH(I)**2)
  END IF
END IF
TREEBA(I) = DBH(I)**2 * 0.005454      ! calc indiv BA
TOTBA = TOTBA + TREEBA(I)           ! sum total stand BA
NUMPERSPC(SPE(I))=NUMPERSPC(SPE(I))+1 ! sum num trees by spp
VOLPERSPC(SPE(I))=VOLPERSPC(SPE(I))+TREEVL(I) ! sum vol by spp
22 CONTINUE
C
IF (AGE .EQ. 0) THEN !for first iteration calc C-T abundances
  SUM=0
  DO 23 I=1,SUCPYR
    ABUNDA(I)=0.0
23 CONTINUE
  DO 24 I=NUMSPC,1,-1
    IF (VOLPERSPC(I) .NE. 0) THEN
      IND=I
      GOTO 25
    END IF
24 CONTINUE
25 DO 26 I=1,IND
    SUM=SUM+I
26 CONTINUE
  DO 27 I=1,NUMSPC
    IF (VOLPERSPC(I) .GT. 0) THEN
      INDEX=SUM-(I-1)
      ABUNDA(INDEX)=VOLPERSPC(I)/TOTVOL
    END IF
27 CONTINUE
  WRITE(10,'(55F5.2)') (ABUNDA(I),I=1,(NUMSPC**2+NUMSPC)/2)
END IF
C

```

```

C      CALL REPORT(AGE,NUMTRE,NUMSPC,SPNAME) !write stand table to file
C
C      CALL VEGDYN(ABUNDA,DBH,HEIGHT,SPE,TOTBA,NUMTRE,NUMSPC)
C              ! calc veget dynamics and output HSI variables
C
C      WRITE(*,'('' Calculating year: '' ,I7)')AGE
C
C      AGE=AGE+10
C      IF(AGE.GT.YEARS)GOTO 28          ! check for end of simulations
C
C      CALL GROWTH (NUMTRE,TREEVL,SPE,UDRSTR,LOREG,CLASIZ,HEIGHT,
+              ABUNDA,DBH)
C      ! simulate growth for 10 years
C
C      GOTO 20
C
C 28   CLOSE(3)
C
C      END
C
C* DYNAM10/SETUP ***** SUBROUTINE SETUP *****
C
C      SUBROUTINE SETUP(YEARS,UDRSTR)
C
C      IMPLICIT NONE
C
C      INTEGER*2 MAXSPC
C      INTEGER*2 SUCPYR
C
C      PARAMETER (MAXSPC=10)
C      PARAMETER (SUCPYR=(MAXSPC**2+MAXSPC)/2)
C
C      INTEGER*2 YEARS
C      INTEGER*2 PSIZE
C      INTEGER*2 NUMPYR
C      INTEGER*2 ROWS
C      INTEGER*2 BEGIN
C      INTEGER*2 END
C
C      INTEGER*2 I,J
C
C      REAL*4 HAFVOL(MAXSPC)
C      REAL*4 UDRSTR(MAXSPC,SUCPYR)
C      REAL*4 UNDTOL(MAXSPC)
C      REAL*4 RSP5
C
C      CHARACTER*30 FLNM
C      CHARACTER*20 VFMT1
C      CHARACTER*20 VFMT2

```

```
C
C* COMMON FIXPAR
C
    CHARACTER*20 SPNAME(MAXSPC)
    INTEGER*2 UTRNK(MAXSPC)
    REAL*4 MING(MAXSPC)
    REAL*4 MAXG(MAXSPC)
    REAL*4 MAXT(MAXSPC)
    REAL*4 RES
    INTEGER*2 NUMSPC
C
    COMMON / FIXPAR / SPNAME,UTRNK,MING,MAXG,MAXT,RES,NUMSPC
C
C* COMMON VOLUME
C
    INTEGER*2 VOLEQN(MAXSPC)
    REAL*4 DBHEXP(MAXSPC)
    REAL*4 INTCPT(MAXSPC)
    REAL*4 VOLA(MAXSPC)
    REAL*4 VOLB(MAXSPC)
    REAL*4 VOLC(MAXSPC)
    REAL*4 VOLD(MAXSPC)
    REAL*4 VOLE(MAXSPC)
    REAL*4 VOLF(MAXSPC)
    CHARACTER*10 BRKTYP(MAXSPC)
    REAL*4 BRKVAL(MAXSPC)
C
    COMMON / VOLUME / VOLEQN,DBHEXP,INTCPT,VOLA,VOLB,VOLC,
+           VOLD,VOLE,VOLF,BRKTYP,BRKVAL
C
C* COMMON EXP
C
    REAL*4 RCEXP(MAXSPC)
    REAL*4 RSPA(MAXSPC)
    REAL*4 RSPB(MAXSPC)
C
    COMMON / EXP / RCEXP,RSPA,RSPB
```

```

C
C* COMMON VAR
C
    REAL*4 VAR9(SUCPYR)
    REAL*4 VAR11(SUCPYR)
    REAL*4 VAR12(SUCPYR)
    REAL*4 VAR13(SUCPYR)
    REAL*4 VAR16(SUCPYR)
    REAL*4 VAR17(SUCPYR)
    REAL*4 VAR19(SUCPYR)
    REAL*4 VAR23(SUCPYR)
    REAL*4 VAR24(SUCPYR)
    REAL*4 VAR25(SUCPYR)
    REAL*4 VAR27(SUCPYR)
    REAL*4 VAR281(SUCPYR)
    REAL*4 VAR282(SUCPYR)
    REAL*4 VAR283(SUCPYR)
    REAL*4 VAR31(SUCPYR)
    REAL*4 VAR32(SUCPYR)
C
    COMMON / VAR / VAR9,VAR11,VAR12,VAR13,VAR16,VAR17,VAR19,VAR23,
+          VAR24,VAR25,VAR27,VAR281,VAR282,VAR283,VAR31,VAR32
C
C* COMMON SPP
C
    INTEGER*2 ASPEN
    INTEGER*2 DECID(MAXSPC)
    INTEGER*2 CONIF(MAXSPC)
    INTEGER*2 SPRFIR(MAXSPC)
    INTEGER*2 PIPO
    INTEGER*2 SOIL
C
    COMMON / SPP / ASPEN,DECID,CONIF,SPRFIR,PIPO,SOIL
C
C* COMMON SNAG
C
    INTEGER*2 DEADSP(100,10)
    INTEGER*2 NMDEAD(10)
    REAL*4 DEADBH(100,10)
    REAL*4 PROB(10)
C
    COMMON / SNAG / DEADSP,DEADBH,NMDEAD,PROB
C
C
    WRITE(*,('( Enter the stand parameter file name      '''))
    WRITE(*,('( (DYNAM10.PRM): ',,$)')
    READ(*, '(A30)')FLNM
    IF (FLNM.EQ.' ')FLNM='DYNAM10.PRM'
    OPEN (UNIT=1,FILE=FLNM,STATUS='OLD')

```

```

WRITE(*, '( ' Enter the stand output file name      ' )')
WRITE(*, '( ' (DYNAM10.OUT): ' , $ )')
READ(*, '(A30)') FLNM
IF (FLNM.EQ. ' ') FLNM='DYNAM10.OUT'
OPEN (UNIT=3, FILE=FLNM, STATUS='NEW')
C
WRITE(*, '( ' Enter the HSI parameter file name      ' )')
WRITE(*, '( ' (HSIVAR.PRM): ' , $ )')
READ(*, '(A30)') FLNM
IF (FLNM.EQ. ' ') FLNM='HSIVAR.PRM'
OPEN (UNIT=4, FILE=FLNM, STATUS='OLD')
C
WRITE(*, '( ' Enter the HSI variable output file name ' )')
WRITE(*, '( ' (HSIVAR.OUT): ' , $ )')
READ(*, '(A30)') FLNM
IF (FLNM.EQ. ' ') FLNM='HSIVAR.OUT'
OPEN (UNIT=6, FILE=FLNM, STATUS='NEW' ,
+     CARRIAGECONTROL='FORTRAN')
C
OPEN (UNIT=10, FILE='COMMTYPE.OUT', STATUS='NEW' ,
+     CARRIAGECONTROL='LIST', RECL=180)
C
READ(1,120) NUMSPC
DO 10 I=1, NUMSPC
  READ(1,110) SPNAME(I)
10 CONTINUE
READ(1,100) (UNDTOL(I), I=1, NUMSPC)
READ(1,100) (MING(I), I=1, NUMSPC)
READ(1,100) (MAXG(I), I=1, NUMSPC)
READ(1,100) (MAXT(I), I=1, NUMSPC)
READ(1,190) (DBHEXP(I), I=1, NUMSPC)
READ(1,190) (INTCPT(I), I=1, NUMSPC)
READ(1,140) (VOLEQN(I), I=1, NUMSPC)
READ(1,150) (BRKTYP(I), I=1, NUMSPC)
READ(1,100) (BRKVAL(I), I=1, NUMSPC)
READ(1,100) (VOLA(I), I=1, NUMSPC)
READ(1,100) (VOLB(I), I=1, NUMSPC)
READ(1,100) (VOLC(I), I=1, NUMSPC)
READ(1,100) (VOLD(I), I=1, NUMSPC)
READ(1,100) (VOLE(I), I=1, NUMSPC)
READ(1,100) (VOLF(I), I=1, NUMSPC)
READ(1,100) RES
READ(1,120) YEARS
READ(1,170) SOIL
READ(1,170) ASPEN
READ(1,170) PIPO
READ(1,180) (DECID(I), I=1, NUMSPC)
READ(1,180) (CONIF(I), I=1, NUMSPC)
READ(1,180) (SPRFIR(I), I=1, NUMSPC)

```

```

DO 11 I=1,NUMSPC
  READ(1,130)(UDRSTR(I,J),J=1,(NUMSPC**2+NUMSPC)/2)
11 CONTINUE
C
  READ(1,130) (PROB(I),I=1,10)
C
  CLOSE(1)
C
  NUMPYR=(NUMSPC**2+NUMSPC)/2
  ROWS=((NUMPYR/15.0)+0.99)
  DO 12 I=1,ROWS
    BEGIN=15*(I-1)+1
    END=MIN(15*I,NUMPYR)
    READ(4,160) (VAR9(J),J=BEGIN,END)
    READ(4,160) (VAR11(J),J=BEGIN,END)
    READ(4,160) (VAR12(J),J=BEGIN,END)
    READ(4,160) (VAR13(J),J=BEGIN,END)
    READ(4,160) (VAR16(J),J=BEGIN,END)
    READ(4,160) (VAR17(J),J=BEGIN,END)
    READ(4,160) (VAR19(J),J=BEGIN,END)
    READ(4,160) (VAR23(J),J=BEGIN,END)
    READ(4,160) (VAR24(J),J=BEGIN,END)
    READ(4,160) (VAR25(J),J=BEGIN,END)
    READ(4,160) (VAR27(J),J=BEGIN,END)
    READ(4,160) (VAR281(J),J=BEGIN,END)
    READ(4,160) (VAR282(J),J=BEGIN,END)
    READ(4,160) (VAR283(J),J=BEGIN,END)
    READ(4,160) (VAR31(J),J=BEGIN,END)
    READ(4,160) (VAR32(J),J=BEGIN,END)
12 CONTINUE
C
  CLOSE(4)
C
100 FORMAT (12F10.4)
110 FORMAT (A20,I6)
120 FORMAT (I6)
130 FORMAT (55F4.2)
140 FORMAT (10I2)
150 FORMAT (10A4)
160 FORMAT (15F6.1)
170 FORMAT (I2)
180 FORMAT (10I2)
190 FORMAT (10F10.7)

```

```

C** DYNAM10/SETUP ***** TWO *****
C
C*****
C
  DO 20 I=1,NUMSPC
    HAFVOL(I)=MAXT(I)*0.5
    RSP5=1.0-(UNDTOL(I)*.05)
    RCEXP(I)=0.75-(UNDTOL(I)*.0167)
    RSPB(I)=-LOG10(RSP5)/(LOG10(MAXT(I))-LOG10(HAFVOL(I)))
    RSPA(I)=RSP5/HAFVOL(I)**RSPB(I)
20  CONTINUE
C
  PSIZE=MIN(15,(110/NUMSPC))
  WRITE(VFMT1,200)MAXSPC,PSIZE-1
  WRITE(VFMT2,210)MAXSPC,PSIZE-1
C
200  FORMAT(' (A20,' ,I2,' (A' ,I2,' ,A1)')' )
210  FORMAT(' (A20,' ,I2,' (F' ,I2,' .3,A1)')' )
C
C* DYNAM10/SETUP ***** THREE *****
C
C*****
C
  WRITE(3,*)' DYNAM10:  Multiple Age-class Stand Simulator'
  WRITE(3,*)' '
  WRITE(3,*)'      SITE SPECIFIC PARAMETERS:'
  WRITE(3,300)RES
  WRITE(3,*)' '
  WRITE(3,*)'      SPECIES SPECIFIC PARAMETERS:'
  WRITE(3,VFMT1)'      PARAMETER      ',(SPNAME(I),':',I=1,NUMSPC)
  WRITE(3,VFMT2)'      Undrsty Tol: ',(UNDTOL(I),':',I=1,NUMSPC)
  WRITE(3,VFMT2)'      Min Growth : ',(MING(I),':',I=1,NUMSPC)
  WRITE(3,VFMT2)'      Max Growth : ',(MAXG(I),':',I=1,NUMSPC)
  WRITE(3,VFMT2)'      Max Ind Vol: ',(MAXT(I),':',I=1,NUMSPC)
  WRITE(3,*)' '
  WRITE(3,*)'      CALCULATED PARAMETERS:'
  WRITE(3,VFMT2)'      Res Cap Exp: ',(RCEXP(I),':',I=1,NUMSPC)
  WRITE(3,VFMT2)'      Respiratn A: ',(RSPA(I),':',I=1,NUMSPC)
  WRITE(3,VFMT2)'      Respiratn B: ',(RSPB(I),':',I=1,NUMSPC)
  WRITE(3,*)' '
C
300  FORMAT('      Potential Growth Resources:',F8.2)

```

```
C* DYNAM10/SETUP ***** FOUR *****
C
C*****
C
    DO 40 I=1,NUMSPC
        UTRNK(I)=I
40    CONTINUE
C
    RETURN
C
    END
C
C* DYNAM10/INPUT ***** SUBROUTINE GETINP *****
C
    SUBROUTINE GETINP(STDTBL,NUMSPC,NUMTRE,TREEVL,SPE,CLASIZ)
C
    IMPLICIT NONE
C
    INTEGER*2 MAXSPC
    INTEGER*2 MAXCLA
    INTEGER*2 MAXTRE
C
    PARAMETER (MAXSPC=10)
    PARAMETER (MAXCLA=10)
    PARAMETER (MAXTRE=10000)
C
    INTEGER*2 I,J,L
C
    INTEGER*2 STDTBL(MAXSPC,MAXCLA)
    INTEGER*2 DEDTBL(MAXSPC,MAXCLA)
    INTEGER*2 SPE(MAXTRE)
    INTEGER*2 NUMTRE
    INTEGER*2 NUMSPC
C
    REAL*4 VOL
    REAL*4 SPREAD
    REAL*4 TREEVL(MAXTRE)
    REAL*4 CLASIZ(MAXCLA)
C
    CHARACTER*30 FLNM
```

```

C
C* COMMON VOLUME
C
      INTEGER*2 VOLEQN(MAXSPC)
      REAL*4 DBHEXP(MAXSPC)
      REAL*4 INTCPT(MAXSPC)
      REAL*4 VOLA(MAXSPC)
      REAL*4 VOLB(MAXSPC)
      REAL*4 VOLC(MAXSPC)
      REAL*4 VOLD(MAXSPC)
      REAL*4 VOLE(MAXSPC)
      REAL*4 VOLF(MAXSPC)
      CHARACTER*10 BRKTYP(MAXSPC)
      REAL*4 BRKVAL(MAXSPC)
C
      COMMON / VOLUME / VOLEQN, DBHEXP, INTCPT, VOLA, VOLB, VOLC,
+           VOLD, VOLE, VOLF, BRKTYP, BRKVAL
C
C* COMMON SNAG
C
      INTEGER*2 DEADSP(100,10)
      INTEGER*2 NMDEAD(10)
      REAL*4 DEADBH(100,10)
      REAL*4 PROB(10)
C
      COMMON / SNAG / DEADSP, DEADBH, NMDEAD, PROB
C
      WRITE(*,100)
100  FORMAT(/, ' Enter the stand table file name (STAND.TBL): ', $)
      READ(*, '(A20)') FLNM
      WRITE(*,*) ' '
      IF(FLNM.EQ.' ') FLNM='STAND.TBL'
C
      OPEN (UNIT=2, FILE=FLNM, STATUS='OLD')
C
      DO 10 I=1, NUMSPC
          READ(2,110) (STDTBL(I,J), J=1, MAXCLA)
10   CONTINUE
C
      DO 11 I=1, NUMSPC
          READ(2,110) (DEDTBL(I,J), J=1, MAXCLA)
11  CONTINUE
C
110  FORMAT (20I4)
C
      CLOSE(2)

```

```

C* DYNAM10 ***** TWO *****
C   Convert stand table into 1D array of individual trees
C* DYNAM10 ***** TWO *****
C
      CLASIZ(1)=1.25           ! set class size upper boundaries
      DO 20 I=2,MAXCLA
        CLASIZ(I)=CLASIZ(I-1)*2.00
20    CONTINUE
C
      DO 21 I=1,NUMSPC           ! for all species
        DO 22 J=1,MAXCLA         ! for all size classes
          IF (STDTBL(I,J) .GT. 0) THEN ! check for stems
            SPREAD = (CLASIZ(J)*0.5)/(STDTBL(I,J)+1) ! calc spread
            DO 23 L=1,STDTBL(I,J) ! for all stems
              NUMTRE = NUMTRE + 1 ! increment tree count
              TREEVL(NUMTRE) = (CLASIZ(J)*0.5) + (L*SPREAD) ! calc vol
              SPE(NUMTRE) = I ! store species ID
23          CONTINUE
            ENDIF
22          CONTINUE
21        CONTINUE
C
      DO 24 I=1,10
        NMDEAD(I)=0
24      CONTINUE
C
      DO 25 I=1,NUMSPC
        DO 26 J=1,MAXCLA
          IF (DEDTBL(I,J) .GT. 0) THEN
            SPREAD = (CLASIZ(J)*0.5)/(DEDTBL(I,J)+1)
            DO 27 L=1,DEDTBL(I,J)
              NMDEAD(1)=NMDEAD(1)+1
              VOL=(CLASIZ(J)*0.5) + (L*SPREAD)
              DEADSP(NMDEAD(1),1)=I
              DEADBH(NMDEAD(1),1)=10.0**((LOG10(VOL)-INTCPT(SPE(I)))/
+                DBHEXP(SPE(I)))
27          CONTINUE
            END IF
26          CONTINUE
25        CONTINUE

      RETURN
C
      END

```

```

C* DYNAM10/GROWTH ***** SUBROUTINE GROWTH *****
C
  SUBROUTINE GROWTH(NUMTRE, TREEVL, SPE, UDRSTR, LOREG, CLASIZ, HEIGHT,
+                ABUNDA, DBH)
C
  IMPLICIT NONE
C
  INTEGER*2 MAXSPC
  INTEGER*2 MAXCLA
  INTEGER*2 MAXTRE
  INTEGER*2 SUCPYR
C
  PARAMETER (MAXSPC=10)
  PARAMETER (SUCPYR=(MAXSPC**2+MAXSPC)/2)
  PARAMETER (MAXCLA=10)
  PARAMETER (MAXTRE=10000)
C
  INTEGER*2 I, J, K, L
C
  INTEGER*2 NUMPYR
  INTEGER*2 STRTRE(MAXTRE)
  INTEGER*2 SPE(MAXTRE)
  INTEGER*2 NUMSTR
  INTEGER*2 NUMTRE
  INTEGER*2 KILL
  INTEGER*2 INDEX
  INTEGER*2 PASTNT
  INTEGER*2 NREG
  INTEGER*2 REGSPC(MAXSPC)
  INTEGER*2 IND
  INTEGER*2 SZCL
  INTEGER*2 FALL
  INTEGER*2 SAVSPP
C
  REAL*4 DEMAND
  REAL*4 RD(MAXTRE)
  REAL*4 TREEVL(MAXTRE)
  REAL*4 HEIGHT(MAXTRE)
  REAL*4 DBH(MAXTRE)
  REAL*4 RSP
  REAL*4 GROW
  REAL*4 SHAR
  REAL*4 MAXSIZE
  REAL*4 NEXTVL
  REAL*4 STRESS(MAXTRE)
  REAL*4 STRVOL
  REAL*4 REGRES
  REAL*4 TOTWT
  REAL*4 REGWT(MAXSPC)
  REAL*4 SPREAD

```

```

REAL*4 TOTRW
REAL*4 UDRSTR(MAXSPC, SUCPYR)
REAL*4 ABUNDA(SUCPYR)
REAL*4 SUM
REAL*4 LOREG(MAXSPC)
REAL*4 REGVOL
REAL*4 CLASIZ(MAXSPC)
REAL*4 SAVDBH
REAL*4 NXTDBH
REAL*4 DBHINC
REAL*4 ACTRPI
C
C* COMMON VOLUME
C
INTEGER*2 VOLEQN(MAXSPC)
REAL*4 DBHEXP(MAXSPC)
REAL*4 INTCPT(MAXSPC)
REAL*4 VOLA(MAXSPC)
REAL*4 VOLB(MAXSPC)
REAL*4 VOLC(MAXSPC)
REAL*4 VOLD(MAXSPC)
REAL*4 VOLE(MAXSPC)
REAL*4 VOLF(MAXSPC)
CHARACTER*10 BRKTYP(MAXSPC)
REAL*4 BRKVAL(MAXSPC)
C
COMMON / VOLUME / VOLEQN, DBHEXP, INTCPT, VOLA, VOLB, VOLC,
+ VOLD, VOLE, VOLF, BRKTYP, BRKVAL
C
C* COMMON STAND
C
INTEGER*2 STDTBL(MAXSPC, MAXCLA)
INTEGER*2 NUMPERSPC(MAXSPC)
REAL*4 VOLPERSPC(MAXSPC)
REAL*4 TOTVOL
REAL*4 DEADVL(MAXSPC)
INTEGER*2 DTBL(MAXSPC, MAXCLA)
INTEGER*2 NEWTREES(MAXSPC)
REAL*4 NEWVOL(MAXSPC)
C
COMMON / STAND / STDTBL, NUMPERSPC, VOLPERSPC, TOTVOL,
+ DEADVL, DTBL, NEWTREES, NEWVOL

```

```

C
C* COMMON FIXPAR
C
      CHARACTER*20 SPNAME(MAXSPC)
      INTEGER*2   UTRNK(MAXSPC)
      REAL*4      MING(MAXSPC)
      REAL*4      MAXG(MAXSPC)
      REAL*4      MAXT(MAXSPC)
      REAL*4      RES
      INTEGER*2   NUMSPC

C
      COMMON / FIXPAR / SPNAME,UTRNK,MING,MAXG,MAXT,RES,NUMSPC
C
C* COMMON EXP
C
      REAL*4 RCEXP(MAXSPC)
      REAL*4 RSPA(MAXSPC)
      REAL*4 RSPB(MAXSPC)

C
      COMMON / EXP / RCEXP,RSPA,RSPB
C
C* COMMON SNAG
C
      INTEGER*2 DEADSP(100,10)
      INTEGER*2 NMDEAD(10)
      REAL*4   DEADBH(100,10)
      REAL*4   PROB(10)

C
      COMMON / SNAG / DEADSP,DEADBH,NMDEAD,PROB
C
C
      DATA DEADSP /1000*0/
      DATA DEADBH /1000*0.0/
      DATA NMDEAD /10*0/
C
C* DYNAM10/GROWTH ***** ONE *****
C      Initialize stand variables
C* DYNAM10/GROWTH ***** ONE *****
C
      DEMAND = 0.0
      DO 10 I=1,NUMSPC
          DEADVL(I) = 0
          DO 11 J=1,MAXCLA
              DTBL(I,J) = 0
11      CONTINUE
10      CONTINUE

```

```

C* DYNAM10/GROWTH ***** TWO *****
C      Calculate individual growth and find stressed trees
C* DYNAM10/GROWTH ***** TWO *****
C
      DO 20 I=1,NUMTRE           ! for all trees in stand
          RD(I) = TREEVL(I)**RCEXP(SPE(I)) ! calculate resource demand
          DEMAND=DEMAND+RD(I)         ! sum stand resource demand
20    CONTINUE
C
      NUMSTR = 0                 ! init num stressed trees
      STRVOL = 0.0
C
      DO 21 I=1,NUMTRE           ! for all trees
          RSP = RSPA(SPE(I))*TREEVL(I)**RSPB(SPE(I)) ! calc respiration
          SHAR = (RD(I)/DEMAND)*RES           ! calc resource capture
          GROW = SHAR*(1-RSP)                 ! calc growth
C
          NEXTVL = TREEVL(I) + GROW
          TOTVOL = TOTVOL + GROW
C
          NXTDBH = 10.0**((LOG10(NEXTVL) - INTCP(SPE(I)))/DBHEXP(SPE(I)))
          DBHINC = NXTDBH - DBH(I)
          ACTRPI = 20.0/DBHINC
C
          MAXSIZE = TREEVL(I) + MAXG(SPE(I))
C
          IF (ACTRPI .GT. MING(SPE(I))) THEN ! test for stress
              NUMSTR = NUMSTR + 1           ! increment stress count
              STRTRE(NUMSTR) = I           ! memorize stressed tree
              STRESS(NUMSTR) = GROW         ! calc stress level
              STRVOL = STRVOL + TREEVL(I)   ! sum stressed volume
              TREEVL(I) = -1 * (TREEVL(I)+GROW)! flag stressed tree
          ELSE
              IF (NEXTVL.GT.MAXSIZE) THEN
                  TREEVL(I) = MAXSIZE
              ELSE
                  TREEVL(I)=TREEVL(I)+GROW
              ENDIF
          ENDIF
21 CONTINUE

```

```

C* DYNAM10/GROWTH ***** THREE *****
C   Kill off trees with most stress and fill holes in array by
C   taking live trees from bottom and moving them up into array
C   elements left open by dead trees.
C   Blowdown most susceptible snags and update snag arrays.
C* DYNAM10/GROWTH ***** THREE *****
C
  DO 30 I=1,10                ! remove blowdowns from all columns
    FALL=PROB(I)*NMDEAD(I)    ! from bottom up
    DO 31 J=NMDEAD(I)-FALL+1,NMDEAD(I)
      DEADSP(J,I)=0
      DEADBH(J,I)=0.0
31    CONTINUE
      NMDEAD(I)=NMDEAD(I)-FALL
30    CONTINUE
C
  DO 32 I=10,2,-1            ! move values forward one column
    NMDEAD(I)=NMDEAD(I-1)
    DO 33 J=1,NMDEAD(I)
      DEADSP(J,I)=DEADSP(J,I-1)
      DEADBH(J,I)=DEADBH(J,I-1)
33    CONTINUE
32    CONTINUE
C
  DO 34 I=1,100              ! clear first column of snag arrays
    DEADSP(I,1)=0
    DEADBH(I,1)=0.0
34    CONTINUE
    NMDEAD(1)=0
C
  IF (STRVOL .GT. TOTVOL*0.05) THEN ! test against number stressed
    CALL SORTSTR(NUMSTR,STRESS,STRTRE,TREEVL,KILL,TOTVOL)
C                                     ! sort by stress level
  ELSE
    KILL=NUMSTR
  ENDIF
C

```

```

PASTNT = NUMTRE
NUMTRE = NUMTRE - KILL
DO 35 I=1,KILL                                ! for all trees to be killed
  DEADVL(SPE(STRTRE(I))) = DEADVL(SPE(STRTRE(I))) +
+   TREEVL(STRTRE(I))
  DO 36 J=1,MAXCLA
    IF(TREEVL(STRTRE(I)) .LE. CLASIZ(J)) THEN
      INDEX=J
      GOTO 37
    END IF
36  CONTINUE
37  DTBL(SPE(STRTRE(I)),INDEX) =
+   DTBL(SPE(STRTRE(I)),INDEX) - 1
  IF (STRTRE(I) .GT. NUMTRE) GOTO 35 ! prevent overflow
38  IF (TREEVL(PASTNT) .LT. 0.0) THEN
    PASTNT = PASTNT - 1
    GOTO 38
  ENDIF
  IF (DBH(STRTRE(I)) .GT. 6.0) THEN
    NMDEAD(1)=NMDEAD(1)+1                ! increment new snags
    DEADSP(NMDEAD(1),1)=SPE(STRTRE(I))! and fill first column of
    DEADBH(NMDEAD(1),1)=DBH(STRTRE(I))! snag arrays.
  ENDIF
  TREEVL(STRTRE(I)) = TREEVL(PASTNT) ! swap dead tree with
  SPE(STRTRE(I)) = SPE(PASTNT)       ! last tree in list
  HEIGHT(STRTRE(I)) = HEIGHT(PASTNT) ! decrement num of trees
  PASTNT = PASTNT - 1
35  CONTINUE
C
DO 390 I=1,NMDEAD(1)
  DO 391 J=1,NMDEAD(1)-I
    IF (DEADBH(J,1) .LT. DEADBH(J+1,1)) THEN
      SAVDBH=DEADBH(J+1,1)
      SAVSPP=DEADSP(J+1,1)
      DEADBH(J+1,1)=DEADBH(J,1)
      DEADSP(J+1,1)=DEADSP(J,1)
      DEADBH(J,1)=SAVDBH
      DEADSP(J,1)=SAVSPP
    END IF
391  CONTINUE
390  CONTINUE

```

```

C* DYNAM10/GROWTH ***** FOUR *****
C   Calculate which species regenerate
C* DYNAM10/GROWTH ***** FOUR *****
C
  REGRES=0
  REGRES=MAX(0.0,RES*(1-(DEMAND/RES)**.01))
C
  TOTWT = 0.0
  NREG = 0
  DO 40 I=1,NUMSPC
    NEWTREES(I)=0
    VOLPERSPC(I)=0
    NEWVOL(I)=0
40  CONTINUE
C
  TOTVOL = 0.0
C
  DO 41 I=1,NUMTRE
    VOLPERSPC(SPE(I))=VOLPERSPC(SPE(I))+ABS(TREEVL(I))
    TOTVOL = TOTVOL + ABS(TREEVL(I))
41  CONTINUE
C
  IND=1
  DO 42 I=1,NUMSPC
    REGWT(I)=0
    IF(VOLPERSPC(I).NE.0)IND=MAX(IND,UTRNK(I))
42  CONTINUE
C
  DO 43 I=1,SUCPYR
    ABUNDA(I)=0
43  CONTINUE
C
  SUM=0
  DO 44 I=1,IND
    SUM=SUM+I
44  CONTINUE
C
  TOTRW=0
  DO 45 I=1,NUMSPC
    IF(VOLPERSPC(I).GT.0)THEN
      INDEX=SUM-(UTRNK(I)-1)
      ABUNDA(INDEX)=VOLPERSPC(I)/TOTVOL
      DO 46 J=1,NUMSPC
        REGWT(J)=REGWT(J)+(UDRSTR(J,INDEX)*ABUNDA(INDEX))
        TOTRW=TOTRW+(UDRSTR(J,INDEX)*ABUNDA(INDEX))
46      CONTINUE
      ENDIF
45  CONTINUE

```

```

NUMPYR=(NUMSPC**2+NUMSPC)/2
WRITE(10,'(55F5.2)')(ABUNDA(I),I=1,NUMPYR)
C
NREG=0
DO 47 I=1,NUMSPC
  REGWT(I)=REGWT(I)/TOTRW
  IF(REGWT(I).GT.0)THEN
    NREG=NREG+1
    REGSPC(NREG)=I
  ENDIF
47 CONTINUE
C
DO 48 I=1,NREG
  REGVOL=REGWT(REGSPC(I))*REGRES + LOREG(REGSPC(I))
  NEWTREES(REGSPC(I)) = INT(REGVOL/.1026)
  LOREG(REGSPC(I))=REGVOL - NEWTREES(REGSPC(I))*0.1026
  DO 49 J=1,NEWTREES(REGSPC(I))      ! for all stems
    SPREAD = 1.25 / (NEWTREES(REGSPC(I))+1) ! calculate spread
    NUMTRE = NUMTRE + 1                ! increment tree count
    TREEVL(NUMTRE) = J*SPREAD          ! calculate volume
    SPE(NUMTRE) = REGSPC(I)           ! store species ID
    NEWVOL(REGSPC(I))=NEWVOL(REGSPC(I)) + TREEVL(NUMTRE)
    VOLPERSPC(REGSPC(I))=VOLPERSPC(REGSPC(I))+TREEVL(NUMTRE)
49 CONTINUE
48 CONTINUE
C
C* DYNAM10/GROWTH ***** FIVE *****
C
50 DO 51 I=1,NUMSPC
  DO 52 J=1,MAXCLA
    STDTBL(I,J) = 0
52 CONTINUE
51 CONTINUE
C
DO 53 I=1,NUMTRE      ! for all trees still alive
  DO 54 J=1,MAXCLA    ! calc new stand table
    IF (TREEVL(I) .LE. CLASIZ(J)) THEN
      SZCL=J
      GOTO 55
    END IF
54 CONTINUE
55 SZCL = MIN(SZCL,MAXCLA)
  STDTBL(SPE(I),SZCL)=STDTBL(SPE(I),SZCL)+1
53 CONTINUE
C
RETURN
END

```

```

C* DYNAM10/SORTSTR ***** SUBROUTINE SORTSTR *****
C
  SUBROUTINE SORTSTR(NUMSTR, STRESS, STRTRE, TREEVL, KILL, TOTVOL)
C
  IMPLICIT NONE
C
  INTEGER*2 MAXTRE
C
  PARAMETER (MAXTRE=10000)
C
  INTEGER*2 KILL
  INTEGER*2 NUMSTR
  INTEGER*2 STRTRE(MAXTRE)
C
  INTEGER*2 I, J
C
  REAL*4 STRESS(MAXTRE)
  REAL*4 TREEVL(MAXTRE)
  REAL*4 TEMSTR
  REAL*4 TEMTRE
  REAL*4 VLLOST
  REAL*4 TOTVOL
C
  VLLOST=0.0
  KILL=0
C
  DO 10 I=1, NUMSTR-1
    DO 11 J=I+1, NUMSTR
      IF (STRESS(J) .LT. STRESS(I)) THEN
        TEMSTR = STRESS(I)
        TEMTRE = STRTRE(I)
        STRESS(I) = STRESS(J)
        STRTRE(I) = STRTRE(J)
        STRESS(J) = TEMSTR
        STRTRE(J) = TEMTRE
      ENDIF
    11 CONTINUE
  10 CONTINUE
C
  DO 13 I=1, NUMSTR
    VLLOST=VLLOST+(-1*TREEVL(STRTRE(I)))
    IF((VLLOST.GT.TOTVOL*.15).AND.(KILL.EQ.0))THEN
      KILL=I
      GOTO 14
    ENDIF
  13 CONTINUE
C

```

```

14 DO 12 I=KILL+1,NUMSTR
    TREEVL(STRTRE(I)) = -1 * TREEVL(STRTRE(I))
12 CONTINUE
C
    RETURN
C
    END
C
C* DYNAM10/VEGDYN ***** SUBROUTINE VEGDYN *****
C
    SUBROUTINE VEGDYN(ABUNDA,DBH,HEIGHT,SPE,TOTBA,NUMTRE,NUMSPC)
C
    IMPLICIT NONE
C
    INTEGER*2 MAXSPC
    INTEGER*2 MAXTRE
    INTEGER*2 SUCPYR
    INTEGER*2 MAXCLA
C
    PARAMETER (MAXSPC=10)
    PARAMETER (MAXTRE=10000)
    PARAMETER (SUCPYR=(MAXSPC**2+MAXSPC)/2)
    PARAMETER (MAXCLA=10)
C
    INTEGER*2 NUMSPC
    INTEGER*2 SPE(MAXTRE)
    INTEGER*2 STAGE
    INTEGER*2 CANOPY
    INTEGER*2 NUMTRE
    INTEGER*2 SUMASP
    INTEGER*2 OVRSUM
    INTEGER*2 OVRASP
    INTEGER*2 CN2MRK
    INTEGER*2 CONMRK
    INTEGER*2 NMMARK
    INTEGER*2 CODE(20)
    INTEGER*2 NUMPYR
C
    INTEGER*2 I,J
C
    REAL*4 ABUNDA(SUCPYR)
    REAL*4 DBH(MAXTRE)
    REAL*4 HEIGHT(MAXTRE)
    REAL*4 TOTBA
    REAL*4 SUMVOL
    REAL*4 SUMHT(20)
    REAL*4 SUMTPA(20)
    REAL*4 CLASS
    REAL*4 QUADBH

```

```

REAL*4 SUMDBH
REAL*4 HIGHHT
REAL*4 AVELOG
REAL*4 CROWN
REAL*4 TTLSHB
REAL*4 TTLDSB
REAL*4 GRAMCV
REAL*4 TTLHRB
REAL*4 PERWOD
REAL*4 SHBDEN
REAL*4 DTREES
REAL*4 CTREES
REAL*4 AVBRNC
REAL*4 AVSBHT
REAL*4 AVDCHT
REAL*4 AVCNHT
REAL*4 AVHBHT
REAL*4 DVRSTY
REAL*4 PERCON
REAL*4 PERDEC
REAL*4 PERSF
REAL*4 OVRDBH
REAL*4 ASPDBH
REAL*4 TPA20
REAL*4 RADIUS
REAL*4 SNAGS3
REAL*4 SNAGS4
REAL*4 SNAGS5
REAL*4 SNAGS6
REAL*4 SNAGS7

```

C

C* COMMON STAND

C

```

INTEGER*2 STDTBL(MAXSPC,MAXCLA)
INTEGER*2 NUMPERSPC(MAXSPC)
REAL*4 VOLPERSPC(MAXSPC)
REAL*4 TOTVOL
REAL*4 DEADVL(MAXSPC)
INTEGER*2 DTBL(MAXSPC,MAXCLA)
INTEGER*2 NEWTREES(MAXSPC)
REAL*4 NEWVOL(MAXSPC)

```

C

```

COMMON / STAND / STDTBL,NUMPERSPC,VOLPERSPC,TOTVOL,
+ DEADVL,DTBL,NEWTREES,NEWVOL

```

```
C
C* COMMON SPP
C
      INTEGER*2 ASPEN
      INTEGER*2 DECID(MAXSPC)
      INTEGER*2 CONIF(MAXSPC)
      INTEGER*2 SPRFIR(MAXSPC)
      INTEGER*2 PIPO
      INTEGER*2 SOIL

C
      COMMON / SPP / ASPEN,DECID,CONIF,SPRFIR,PIPO,SOIL

C
C* COMMON VAR
C
      REAL*4 VAR9(SUCPYR)
      REAL*4 VAR11(SUCPYR)
      REAL*4 VAR12(SUCPYR)
      REAL*4 VAR13(SUCPYR)
      REAL*4 VAR16(SUCPYR)
      REAL*4 VAR17(SUCPYR)
      REAL*4 VAR19(SUCPYR)
      REAL*4 VAR23(SUCPYR)
      REAL*4 VAR24(SUCPYR)
      REAL*4 VAR25(SUCPYR)
      REAL*4 VAR27(SUCPYR)
      REAL*4 VAR281(SUCPYR)
      REAL*4 VAR282(SUCPYR)
      REAL*4 VAR283(SUCPYR)
      REAL*4 VAR31(SUCPYR)
      REAL*4 VAR32(SUCPYR)

C
      COMMON / VAR / VAR9,VAR11,VAR12,VAR13,VAR16,VAR17,VAR19,VAR23,
+          VAR24,VAR25,VAR27,VAR281,VAR282,VAR283,VAR31,VAR32

C
C* COMMON SNAG
C
      INTEGER*2 DEADSP(100,10)
      INTEGER*2 NMDEAD(10)
      REAL*4 DEADBH(100,10)
      REAL*4 PROB(10)

C
      COMMON / SNAG / DEADSP,DEADBH,NMDEAD,PROB
```

```

C* DYNAM10/VEGDYN ***** ONE *****
C   Calculate HSI variables by multiplying community-type
C   abundances and corresponding HSI variable successional
C   pyramid table cells.
C* DYNAM10/VEGDYN ***** ONE *****
C
AVELOG=0.0
CROWN=0.0
TTLSHB=0.0
TTLDSB=0.0
GRAMCV=0.0
TTLHRB=0.0
PERWOD=0.0
SHBDEN=0.0
DTREES=0.0
CTREES=0.0
AVBRNC=0.0
AVSBHT=0.0
AVDCHT=0.0
AVCNHT=0.0
AVHBHT=0.0
DVRSTY=0.0
C
NUMPYR=(NUMSPC**2+NUMSPC)/2
C
DO 10 I=1,NUMPYR
AVELOG=AVELOG+VAR9(I)*ABUNDA(I)
CROWN=CROWN+VAR11(I)*ABUNDA(I)
TTLSHB=TTLSHB+VAR12(I)*ABUNDA(I)
TTLDSB=TTLDSB+VAR13(I)*ABUNDA(I)
GRAMCV=GRAMCV+VAR16(I)*ABUNDA(I)
TTLHRB=TTLHRB+VAR17(I)*ABUNDA(I)
PERWOD=PERWOD+VAR19(I)*ABUNDA(I)
SHBDEN=SHBDEN+VAR23(I)*ABUNDA(I)
DTREES=DTREES+VAR24(I)*ABUNDA(I)
CTREES=CTREES+VAR25(I)*ABUNDA(I)
AVBRNC=AVBRNC+VAR27(I)*ABUNDA(I)
AVSBHT=AVSBHT+VAR281(I)*ABUNDA(I)
AVDCHT=AVDCHT+VAR282(I)*ABUNDA(I)
AVCNHT=AVCNHT+VAR283(I)*ABUNDA(I)
AVHBHT=AVHBHT+VAR31(I)*ABUNDA(I)
DVRSTY=DVRSTY+VAR32(I)*ABUNDA(I)
10 CONTINUE

```

```

C* DYNAM10/VEGDYN ***** TWO *****
C   Calculate percent crown cover by coniferous, deciduous
C   and spruce/fir categories.
C* DYNAM10/VEGDYN ***** TWO *****
C
      SUMVOL=0.0
      DO 20 I=1,MAXSPC
        IF (CONIF(I) .EQ. 0) GOTO 21
        SUMVOL=SUMVOL+VOLPERSPC(CONIF(I))
20    CONTINUE
21    PERCON=(SUMVOL/TOTVOL)*CROWN
C
      SUMVOL=0.0
      DO 22 I=1,MAXSPC
        IF (DECID(I) .EQ. 0) GOTO 23
        SUMVOL=SUMVOL+VOLPERSPC(DECID(I))
22    CONTINUE
23    PERDEC=(SUMVOL/TOTVOL)*CROWN
C
      SUMVOL=0.0
      DO 24 I=1,MAXSPC
        IF (SPRFIR(I) .EQ. 0) GOTO 25
        SUMVOL=SUMVOL+VOLPERSPC(SPRFIR(I))
24    CONTINUE
25    PERSF=(SUMVOL/TOTVOL)*CROWN
C
C* DYNAM10/VEGDYN ***** THREE *****
C   Calculate remaining HSI variables
C* DYNAM10/VEGDYN ***** THREE *****
C
      SUMASP=0
      TPA20=0.0
      HIGHHT=0.0
      OVRDBH=0.0
      OVRSUM=0
      ASPDBH=0.0
      OVRASP=0
      DO 30 I=1,20
        SUMHT(I)=0.0
        SUMTPA(I)=0.0
30    CONTINUE

```

```

DO 31 I=1,NUMTRE
  IF ((SPE(I) .EQ. ASPEN) .AND. (DBH(I) .GT. 6.0)) THEN
    SUMASP=SUMASP+1
  END IF
  IF (DBH(I) .GE. 20.0) TPA20=TPA20+1.0
  IF (HEIGHT(I) .GT. HIGHHT) HIGHHT=HEIGHT(I)
  DO 32 J=1,20
    CLASS=10.0*J
    IF (HEIGHT(I) .LE. CLASS) THEN
      SUMHT(J)=SUMHT(J)+1.0
      GOTO 31
    END IF
  CONTINUE
32 CONTINUE
31 CONTINUE
C
DO 33 I=1,NUMTRE
  IF (HEIGHT(I) .GE. 0.80*HIGHHT) THEN
    OVRDBH=OVRDBH+DBH(I)
    OVRSUM=OVRSUM+1
    IF (SPE(I) .EQ. ASPEN) THEN
      ASPDBH=ASPDBH+DBH(I)
      OVRASP=OVRASP+1
    END IF
  END IF
  CONTINUE
33 CONTINUE
C
OVRDBH=OVRDBH/OVRSUM
IF (OVRASP .EQ. 0) THEN
  ASPDBH=0.0
ELSE IF (OVRASP .NE. 0) THEN
  ASPDBH=ASPDBH/OVRASP
END IF
C
QUADBH=((TOTBA/NUMTRE)/0.005454)**0.5
IF (QUADBH .LE. 2.0) THEN
  STAGE=2
ELSE IF (QUADBH .LE. 5.0) THEN
  STAGE=3
ELSE IF (QUADBH .LE. 12.0) THEN
  STAGE=4
ELSE IF (QUADBH .GT. 12.0) THEN
  STAGE=5
END IF
C
IF (SUMASP .NE. 0) THEN
  RADIUS=((20.0/(SUMASP/2.0))/3.1415)*0.5
ELSE IF (SUMASP .EQ. 0) THEN
  RADIUS=999.9
END IF

```

```

CN2MRK=1
CONMRK=1
NMMARK=0
CODE(1)=0

```

C

```

DO 34 I=2,18
  SUMTPA(I)=(SUMHT(I)+SUMHT(I+1)+SUMHT(I+2))/NUMTRE
  IF (SUMTPA(I) .GE. 0.50) THEN
    CODE(I)=2
    IF (CODE(I-1) .NE. 0) THEN
      CONMRK=CONMRK+1
    END IF
    IF ((CODE(I-1) .LE. 1) .AND. (CN2MRK .LE. 2)) THEN
      CN2MRK=CN2MRK+1
    END IF
    NMMARK=NMMARK+1
  ELSE IF ((SUMTPA(I) .LT. 0.50) .AND. (SUMTPA(I) .GT. 0.10)) THEN
    CODE(I)=1
    IF (CODE(I-1) .NE. 0) THEN
      CONMRK=CONMRK+1
    END IF
    NMMARK=NMMARK+1
  ELSE IF (SUMTPA(I) .LE. 0.10) THEN
    CODE(I)=0
  END IF
34 CONTINUE

```

C

```

IF (CN2MRK .GT. 2) THEN
  CANOPY=2
ELSE IF (CONMRK .GE. 5) THEN
  CANOPY=3
ELSE IF ((CONMRK .LT. 5) .AND. (NMMARK .GE. 1)) THEN
  CANOPY=1
ELSE IF (NMMARK .EQ. 0) THEN
  CANOPY=0
END IF

```

```
C
SNAGS3=0
SNAGS4=0
SNAGS5=0
SNAGS6=0
SUMDBH=0.0
C
DO 35 I=1,10
  DO 36 J=1,NMDEAD(I)
    IF (DEADBH(J,I) .GT. 20.0) THEN
      SNAGS6=SNAGS6+1
      SUMDBH=SUMDBH+DEADBH(J,I)
    END IF
    IF (DEADBH(J,I) .GT. 12.0) THEN
      SNAGS5=SNAGS5+1
    END IF
    IF (DEADBH(J,I) .GT. 6.0) THEN
      SNAGS4=SNAGS4+1
    END IF
36  CONTINUE
35  CONTINUE
C
IF (SNAGS6 .NE. 0) THEN
  SNAGS7=SUMDBH/SNAGS6
ELSE IF (SNAGS6 .EQ. 0) THEN
  SNAGS7=0.0
END IF
C
DO 37 I=1,10
  DO 38 J=1,NMDEAD(I)
    IF (((SPE(J) .NE. PIPO).AND.(DEADBH(J,I) .GT. 12.0)) .OR.
+      ((SPE(J) .EQ. PIPO).AND.(DEADBH(J,I) .GT. 18.0))) THEN
      SNAGS3=SNAGS3+1
    END IF
38  CONTINUE
37  CONTINUE
```

```

C* DYNAM10/VEGDYN ***** FOUR *****
C   Write HSI variables to output file HSIVAR.OUT
C* DYNAM10/VEGDYN ***** FOUR *****
C
      WRITE(6,400) OVRDBH,ASPD BH,SNAGS3,SNAGS4,SNAGS5,SNAGS6,SNAGS7,
+      TPA20,AVELOG,PERCON,CROWN,TTL SHB,TTLDSB,PERDEC,PERSF
      WRITE(6,410) GRAMCV,TTLHRB,PERWOD,RADIUS,SHBDEN,DTREES,CTREES,
+      AVBRNC,AVSBHT,AVDCHT,AVCNHT,AVHBHT,DVRSTY,TOTBA,
+      CANOPY,STAGE,SOIL
C
400  FORMAT(' ',15F6.1)
410  FORMAT(' ',14F6.1,3I2)
C
      RETURN
C
      END
C
C* DYNAM10/REPORT ***** SUBROUTINE REPORT *****
C
      SUBROUTINE REPORT(AGE,NTREES,NUMSPC,SPNAME)
C
      IMPLICIT NONE
C
      INTEGER*2 MAXCLA
      INTEGER*2 MAXSPC
C
      PARAMETER (MAXCLA=10)
      PARAMETER (MAXSPC=10)
C
      INTEGER*2 NUMSPC
      INTEGER*2 NTREES
      INTEGER*2 TABS
      INTEGER*2 AGE
      INTEGER*2 DEAD(MAXSPC)
      INTEGER*2 LENLINE
      INTEGER*2 I,J
C
      CHARACTER*30 VFMT1,VFMT2,VFMT3,VFMT4,LFMT
      CHARACTER*130 DLINE
      CHARACTER*20 SPNAME(MAXSPC)

```

```

C
C* COMMON STAND
C
      INTEGER*2 STDTBL(MAXSPC,MAXCLA)
      INTEGER*2 NUMPERSPC(MAXSPC)
      REAL*4 VOLPERSPC(MAXSPC)
      REAL*4 TOTVOL
      REAL*4 DEADVL(MAXSPC)
      INTEGER*2 DTBL(MAXSPC,MAXCLA)
      INTEGER*2 NEWTREES(MAXSPC)
      REAL*4 NEWVOL(MAXSPC)

C
      COMMON / STAND / STDTBL,NUMPERSPC,VOLPERSPC,TOTVOL,
+          DEADVL,DTBL,NEWTREES,NEWVOL

C
C
      TABS=(MAXCLA*4)+25          ! COMPUTE FORMAT FOR PRINTOUT.
      WRITE(VFMT1,100)TABS        ! FORMAT DIFFERS BY NUMBER OF
      WRITE(VFMT2,110)MAXCLA      !   SIZE CLASSES PRESENT.
      WRITE(VFMT3,120)MAXCLA
      WRITE(VFMT4,130)(MAXCLA-1)*4

C
      WRITE(3,VFMT3)(I,I=1,MAXCLA),'+',NTREES,TOTVOL
      WRITE(3,*)' '
      WRITE(3,VFMT1)' YEAR =',AGE,' NUMBER VOL'

C
      DO 10 I=1,NUMSPC
        DEAD(I)=0
        DLINE='
        LENLINE=24
        DO 11 J=1,MAXCLA
          DEAD(I)=DEAD(I)+DTBL(I,J)
          WRITE(LFMT,150)LENLINE
          WRITE(DLINE,LFMT)DLINE,DTBL(I,J)
          LENLINE=LENLINE+4
11      CONTINUE
C
        WRITE(LFMT,160)LENLINE
        WRITE(DLINE,LFMT)DLINE,DEAD(I),DEADVL(I)
C
        IF((NUMPERSPC(I).GT.0).OR.(DEADVL(I).NE.0)) THEN
          WRITE(3,VFMT4)NEWTREES(I),NEWTREES(I),NEWVOL(I)
          WRITE(3,VFMT2)SPNAME(I),(STDTBL(I,J),J=1,MAXCLA),
+          NUMPERSPC(I),VOLPERSPC(I)
          WRITE(3,'(A130)')DLINE
          WRITE(3,*)' '
        ENDIF
10      CONTINUE

```

```
100  FORMAT(' (A8,I4,T',I3,',A13)')
110  FORMAT(' (4X,A20,',I2,',I4,I7,F9.2)')
120  FORMAT(' (24X,',I2,',I4,A1,I6,F9.2)')
130  FORMAT(' (24X,I4,',I3,',X,I7,F9.2)')
140  FORMAT(' (A',I3,',A4)')
150  FORMAT(' (A',I3,',I4)')
160  FORMAT(' (A',I3,',I7,F9.2)')
C
      RETURN
C
      END
```

APPENDIX C

FORTRAN Source Code for HSI.FOR

```

C*****
C
C DYNAMIC WILDLIFE HABITAT SUITABILTY INDEX CALCULATOR (HSI.FOR)
C
C This program calculates dynamic HSI values for ten wildlife species
C based upon USFWS HSI models. The program uses final values for
C 34 HSI variables from an input file produced by the program MASS10.
C
C* HSI/MAIN *****
C
C DECLARE AND DESCRIBE VARIABLES
C
C* HSI/MAIN *****
C
C PROGRAM HSI
C
C IMPLICIT NONE
C
C INTEGER*2 CANOPY ! HSI VAR 20 : Total tree canopy closure
C INTEGER*2 STAGE ! HSI VAR 21 : Successional stage
C INTEGER*2 SOIL ! HSI VAR 33 : Soil moisture content
C INTEGER*2 YEAR ! Year of simulation
C
C REAL*4 OVRDBH ! HSI VAR 1
C REAL*4 ASPDBH ! HSI VAR 2
C REAL*4 SNAGS3 ! HSI VAR 3
C REAL*4 SNAGS4 ! HSI VAR 4
C REAL*4 SNAGS5 ! HSI VAR 5
C REAL*4 SNAGS6 ! HSI VAR 6
C REAL*4 SNAGS7 ! HSI VAR 7
C REAL*4 TPA20 ! HSI VAR 8
C REAL*4 AVELOG ! HSI VAR 9
C REAL*4 PERCON ! HSI VAR 10
C REAL*4 CROWN ! HSI VAR 11
C REAL*4 TTLSHB ! HSI VAR 12
C REAL*4 TTLDSB ! HSI VAR 13
C REAL*4 PERDEC ! HSI VAR 14 AND 26
C REAL*4 PERSF ! HSI VAR 15
C REAL*4 GRAMCV ! HSI VAR 16
C REAL*4 TTLHRB ! HSI VAR 17 AND 18
C REAL*4 PERWOD ! HSI VAR 19
C REAL*4 RADIUS ! HSI VAR 22
C REAL*4 SHBDEN ! HSI VAR 23
C REAL*4 DTREES ! HSI VAR 24
C REAL*4 CTREES ! HSI VAR 25
C REAL*4 AVBRNC ! HSI VAR 27
C REAL*4 AVSBHT ! HSI VAR 28 IN PART, 29 AND 30
C REAL*4 AVDCHT ! HSI VAR 28 IN PART
C REAL*4 AVCNHT ! HSI VAR 28 IN PART
C REAL*4 AVHBHT ! HSI VAR 31
C REAL*4 DVRSTY ! HSI VAR 32
C REAL*4 STNDBA ! HSI VAR 34

```

```

REAL*4 VOLE      ! Final HSI values for Southern red-backed vole
REAL*4 FISHER   ! Final HSI values for fisher
REAL*4 MARTEN  ! Final HSI values for marten
REAL*4 RUFFGR  ! Final HSI values for ruffed grouse
REAL*4 BLUEGR  ! Final HSI values for blue grouse
REAL*4 VEERY   ! Final HSI values for veery
REAL*4 SAPSKR  ! Final HSI values for Williamson's sapsucker
REAL*4 DOWNY   ! Final HSI values for downy woodpecker
REAL*4 LEWIS   ! Final HSI values for Lewis' woodpecker
REAL*4 PILEAT  ! Final HSI values for pileated woodpecker
C
CHARACTER*40 INFILE ! User-supplied input file name
CHARACTER*40 OUTFIL ! User-supplied output file name
C
C* HSI/MAIN ***** ONE *****
C
C OPEN USER-SUPPLIED INPUT AND OUTPUT FILE NAMES AND ERROR CHECK
C
C* HSI/MAIN ***** ONE *****
C
C
WRITE(*,('' Enter the input file name (HSIVAR.OUT): ', $))
READ(5,100) INFILE
IF (INFILE .EQ. ' ') INFILE='HSIVAR.OUT'
OPEN(UNIT=1, FILE=INFILE, STATUS='OLD', ERR=10)
C
WRITE(*,('' Enter the output file name (HSI.OUT): ', $))
READ(5,100) OUTFIL
IF (OUTFIL .EQ. ' ') OUTFIL='HSI.OUT'
OPEN(UNIT=2, FILE=OUTFIL, STATUS='NEW', ERR=11,
+ CARRIAGECONTROL='LIST')
C
GOTO 12
C
10 WRITE(5,*) 'An error has occurred in opening', INFILE
WRITE(5,*) 'Program stops'
STOP
C
11 WRITE(5,*) 'An error has occurred in opening', OUTFIL
WRITE(5,*) 'Program stops'
STOP
C
12 CONTINUE
C
100 FORMAT (A40)

```

```

C* HSI/MAIN ***** TWO *****
C
C READ FINAL HSI VARIABLE VALUES FROM THE DATA FILE PRODUCED BY
C THE PROGRAM MASS10.FOR. READ AS MANY LINES AS 10-YEAR ITERATIONS
C WERE PRODUCED FROM MASS10.FOR.
C CALL INDIVIDUAL SUBROUTINES FOR EACH OF TEN ANIMAL SPECIES TO
C CALCULATE FINAL HSI VALUES FOR THE SIMULATED STAND.
C WRITE FINAL DYNAMIC HSI VALUES TO USER-SUPPLIED OUTPUT FILE NAME.
C* HSI/MAIN ***** TWO *****
C
      YEAR=0
C
20  READ(1,200,ERR=21,END=23) OVRDBH,ASPDBH,SNAGS3,SNAGS4,SNAGS5,
    +SNAGS6,SNAGS7,TPA20,AVELOG,PERCON,CROWN,TTLSHB,TTLDSB,PERDEC
    +,PERSF
C
      READ(1,210,ERR=22) GRAMCV,TTLHRB,PERWOD,RADIUS,SHBDEN,DTREES,
    +CTREES,AVBRNC,AVSBHT,AVDCHT,AVCNHT,AVHBHT,DVRSTY,STNDBA,
    +CANOPY,STAGE,SOIL
C
      CALL CALC1(OVRDBH,PERCON,GRAMCV,PERWOD,VOLE)
      CALL CALC2(OVRDBH,CROWN,PERDEC,CANOPY,FISHER)
      CALL CALC3(CROWN,PERSF,PERWOD,STAGE,MARTEN)
      CALL CALC4(RADIUS,SHBDEN,DTREES,CTREES,AVBRNC,AVSBHT,AVDCHT,
    +
      +AVCNHT,RUFFGR)
      CALL CALC5(CROWN,TTLSHB,TTLHRB,AVSBHT,AVHBHT,DVRSTY,BLUEGR)
      CALL CALC6(TTLDSB,TTLHRB,AVSBHT,AVHBHT,SOIL,VEERY)
      CALL CALC7(ASPDBH,SNAGS3,CROWN,PERDEC,SAPSKR)
      CALL CALC8(SNAGS4,STNDBA,DOWNY)
      CALL CALC9(SNAGS5,CROWN,TTLSHB,LEWIS)
      CALL CALC10(SNAGS6,SNAGS7,TPA20,AVELOG,CROWN,PILEAT)
C
      WRITE(2,220) YEAR,VOLE,FISHER,MARTEN,RUFFGR,BLUEGR,VEERY,
    +
      +SAPSKR,DOWNY,LEWIS,PILEAT
C
      YEAR=YEAR+10
      GOTO 20
C
21  WRITE(5,*) 'Error reading first line of pair, program stops'
      STOP
C
22  WRITE(5,*) 'Error reading second line of pair, program stops'
      STOP
C
23  CONTINUE
C
200  FORMAT(1X,15F6.1)
210  FORMAT(1X,14F6.1,3I2)
220  FORMAT(' ',I4,10(2X,F4.2))
C
      END

```

```

C* HSI/CALC1 ***** SUBROUTINE CALC1 *****
C
C  CALCULATES FINAL HSI VALUES FOR SOUTHERN RED-BACKED VOLE
C      (Clethrionomys gapperi)
C
C* HSI/CALC1 *****
C
C      SUBROUTINE CALC1(OVRDBH, PERCON, GRAMCV, PERWOD, VOLE)
C
C      REAL*4 OVRDBH, PERCON, GRAMCV, PERWOD, VOLE, VAR1, VAR2, VAR3, VAR4
C
C      IF (OVRDBH .LT. 30.0) THEN
C          VAR1= OVRDBH * (1.0/30.0)
C      ELSE IF (OVRDBH .GE. 30.0) THEN
C          VAR1= 1.0
C      END IF
C
C      IF (PERWOD .LT. 20.0) THEN
C          VAR2= PERWOD * (1.0/20.0)
C      ELSE IF (PERWOD .GE. 20.0) THEN
C          VAR2= 1.0
C      END IF
C
C      IF (GRAMCV .LE. 10.0) THEN
C          VAR3= 1.0
C      ELSE IF ((GRAMCV .GT. 10.0) .AND. (GRAMCV .LT. 80.0)) THEN
C          VAR3= 1.0 - ((GRAMCV - 10.0)/70.0)
C      ELSE IF (GRAMCV .GE. 80.0) THEN
C          VAR3= 0.0
C      END IF
C
C      IF (PERCON .LE. 20.0) THEN
C          VAR4= 0.05 + ((PERCON/20.0) * 0.05)
C      ELSE IF ((PERCON .GT. 20.0) .AND. (PERCON .LT. 50.0)) THEN
C          VAR4= 0.1 + (((PERCON - 20.0)/50.0) * 0.9)
C      ELSE IF (PERCON .GE. 50.0) THEN
C          VAR4= 1.0
C      END IF
C
C      IF (VAR1*VAR2*VAR3 .LE. 0.0000) THEN
C          VOLE=0.0
C      ELSE IF (VAR1*VAR2*VAR3 .GT. 0.0000) THEN
C          VOLE= ((VAR1 * VAR2 * VAR3) ** (1.0/3.0)) * VAR4
C      END IF
C
C      RETURN
C      END

```

```

C* HSI/CALC2 ***** SUBROUTINE CALC2 *****
C
C CALCULATES FINAL HSI VALUES FOR FISHER (Martes pennanti)
C
C* HSI/CALC2 *****
C
C SUBROUTINE CALC2(OVRDBH, CROWN, PERDEC, CANOPY, FISHER)
C
C REAL*4 OVRDBH, CROWN, PERDEC, FISHER, VAR1, VAR2, VAR3, VAR4
C INTEGER*2 CANOPY
C
C IF (CROWN .LE. 20.0) THEN
C   VAR1= 0.0
C ELSE IF ((CROWN .GT. 20.0) .AND. (CROWN .LE. 40.0)) THEN
C   VAR1= ((CROWN - 20.0)/20.0) * 0.1
C ELSE IF ((CROWN .GT. 40.0) .AND. (CROWN .LT. 80.0)) THEN
C   VAR1= 0.1 + (((CROWN - 40.0)/40.0) * 0.9)
C ELSE IF (CROWN .GE. 80.0) THEN
C   VAR1= 1.0
C END IF
C
C IF (OVRDBH .LE. 2.5) THEN
C   VAR2= 0.0
C ELSE IF ((OVRDBH .GT. 2.5) .AND. (OVRDBH .LT. 15.0)) THEN
C   VAR2= (OVRDBH - 2.5)/12.5
C ELSE IF (OVRDBH .GE. 15.0) THEN
C   VAR2= 1.0
C END IF
C
C IF (CANOPY .EQ. 1) THEN
C   VAR3= 0.2
C ELSE IF (CANOPY .EQ. 2) THEN
C   VAR3= 0.75
C ELSE IF (CANOPY .EQ. 3) THEN
C   VAR3= 1.0
C END IF
C
C IF (PERDEC .LT. 10.0) THEN
C   VAR4= 0.80 + ((PERDEC/10.0) * 0.2)
C ELSE IF ((PERDEC .GE. 10.0) .AND. (PERDEC .LE. 50.0)) THEN
C   VAR4= 1.0
C ELSE IF ((PERDEC .GT. 50.0) .AND. (PERDEC .LE. 75.0)) THEN
C   VAR4= 1.0 - (((PERDEC - 50.0)/25.0) * 0.6)
C ELSE IF (PERDEC .GT. 75.0) THEN
C   VAR4= 0.4 - (((PERDEC - 75.0)/25.0) * 0.2)
C END IF

```

```

IF (VAR1*VAR2*VAR3 .LE. 0.0) THEN
  FISHER=0.0
ELSE
  FISHER= ((VAR1 * VAR2 * VAR3) ** (1.0/3.0)) * VAR4
END IF
C
RETURN
END
C
C* HSI/CALC3 ***** SUBROUTINE CALC3 *****
C
C CALCULATES FINAL HSI VALUES FOR MARTEN (Martes americanus)
C
C* HSI/CALC3 *****
C
SUBROUTINE CALC3(CROWN,PERSF,PERWOD,STAGE,MARTEN)
C
INTEGER*2 STAGE
REAL*4 CROWN,PERSF,PERWOD,MARTEN,VAR1,VAR2,VAR3,VAR4
C
IF (CROWN .LE. 25.0) THEN
  VAR1= 0.0
ELSE IF ((CROWN .GT. 25.0) .AND. (CROWN .LT. 50.0)) THEN
  VAR1= (CROWN -25.0)/25.0
ELSE IF (CROWN .GE. 50.0) THEN
  VAR1= 1.0
END IF
C
IF (PERSF .LT. 40.0) THEN
  VAR2= 0.1 + ((PERSF/40.0) * 0.9)
ELSE IF (PERSF .GE. 40.0) THEN
  VAR2= 1.0
END IF
C
IF ((STAGE .EQ. 1) .OR. (STAGE .EQ. 2)) THEN
  VAR3= 0.0
ELSE IF (STAGE .EQ. 3) THEN
  VAR3= 0.25
ELSE IF (STAGE .EQ. 4) THEN
  VAR3= 0.75
ELSE IF ((STAGE .EQ. 5) .OR. (STAGE .EQ. 6)) THEN
  VAR3= 1.0
END IF
C
IF (PERWOD .LT. 20.0) THEN
  VAR4= 0.5 + ((PERWOD/20.0) * 0.5)
ELSE IF ((PERWOD .GE. 20.0) .AND. (PERWOD .LE. 50.0)) THEN
  VAR4= 1.0
ELSE IF (PERWOD .GT. 50.0) THEN
  VAR4= 1.0 - (((PERWOD - 50.0)/50.0) * 0.5)
END IF

```

```

IF (VAR1*VAR2*VAR3*VAR4 .LE. 0.0)THEN
  MARTEN=0.0
ELSE
  MARTEN= (VAR1 * VAR2 * VAR3 * VAR4) ** 0.5
END IF
C
RETURN
END
C
C* HSI/CALC4 ***** SUBROUTINE CALC4 *****
C
C CALCULATES FINAL HSI VALUES FOR RUFFED GROUSE (Bonasa umbellus)
C
C* HSI/CALC4 *****
C
SUBROUTINE CALC4(RADIUS,SHBDEN,DTREES,CTREES,AVBRNC,AVSBHT,
+ AVDCHT,AVCNHT,RUFFGR)
C
INTEGER*2 I
INTEGER*2 NUMBR(3)
REAL*4 RADIUS,SHBDEN,DTREES,CTREES,AVBRNC,AVSBHT,AVDCHT,AVCNHT,
+ RUFFGR,VAR1,VAR2,VAR3,TESD,WTVAR4,WTDEQ,SUM,TMPTOT,STEMS,
+ VAR5,WINTER,FALL
REAL*4 AVHT(3),VAR4(3),ESD(3),RANK(3)
C
C !Convert acre measure to hectare
SBHDEN=SBHDEN*2.471
DTREES=DTREES*2.471
CTREES=CTRESS*2.471
C
IF ((RADIUS .GT. 0.0) .AND. (RADIUS .LE. 300.0)) THEN
  VAR1= 1.0
ELSE IF ((RADIUS .GT. 300.0) .AND. (RADIUS .LT. 600.0)) THEN
  VAR1= 1.0 - (((RADIUS - 300.0)/300.0) * 0.75)
ELSE IF (RADIUS .GE. 600.0) THEN
  VAR1= 0.25
END IF
C
IF (AVBRNC .LE. 3.0) THEN
  VAR2= 1.0
ELSE IF ((AVBRNC .GT. 3.0) .AND. (AVBRNC .LT. 15.0)) THEN
  VAR2= 1.0 - ((AVBRNC - 3.0)/ 12.0)
ELSE IF (AVBRNC .GE. 15.0) THEN
  VAR2= 0.0
END IF
C
ESD(1)=DTREES
ESD(2)=0.25 * SHBDEN
ESD(3)=VAR2 * CTREES
TESD=ESD(1) + ESD(2) + ESD(3)

```

```

IF (TESD .LE. 4287.5) THEN
  VAR3= 0.0
ELSE IF ((TESD .GT. 4287.5) .AND. (TESD .LT. 4900.0)) THEN
  VAR3= (TESD - 4287.5)/612.5
ELSE IF ((TESD .GE. 4900.0) .AND. (TESD .LE. 14800.0)) THEN
  VAR3= 1.0
ELSE IF ((TESD .GT. 14800.0) .AND. (TESD .LT. 21025.0)) THEN
  VAR3= 1.0 - ((TESD - 14800.0)/6225.0)
ELSE IF (TESD .GE. 21025.0) THEN
  VAR3= 0.0
END IF
C
AVHT(1)= AVDCHT
AVHT(2)= AVSBHT
AVHT(3)= AVCNHT
C
DO 10 I=1,3
  IF (AVHT(I) .LE. 5.0) THEN
    VAR4(I)= 0.0
  ELSE IF ((AVHT(I) .GT. 5.0) .AND. (AVHT(I) .LT. 15.0)) THEN
    VAR4(I)= (AVHT(I) - 5.0)/10.0
  ELSE IF (AVHT(I) .GE. 15.0) THEN
    VAR4(I)= 1.0
  END IF
10 CONTINUE
C
DO 15 I=1,3
  NUMBR(I)= 0.0
  RANK(I)= 0.0
15 CONTINUE
C
DO 20 I=1,3
  IF (VAR4(I) .GE. RANK(1)) THEN
    RANK(3)=RANK(2)
    RANK(2)=RANK(1)
    RANK(1)=VAR4(I)
    NUMBR(1)=I
  ELSE IF (VAR4(I) .GE. RANK(2)) THEN
    NUMBR(2)=I
    RANK(3)=RANK(2)
    RANK(2)=VAR4(I)
  ELSE IF (VAR4(I) .GE. RANK(3)) THEN
    NUMBR(3)=I
    RANK(3)=VAR4(I)
  END IF
20 CONTINUE

```

```
IF (ESD(NUMBR(1)) .GT. 4900.0) THEN
  WTVAR4=VAR4(NUMBR(1))
ELSE IF (TESD .LE. 4900.0) THEN
  WTVAR4=0.0
  DO 21 I=1,3
    WTDEQ= VAR4(I) * (ESD(I)/4900.0)
    WTVAR4=WTVAR4 + WTDEQ
21  CONTINUE
ELSE
  SUM= 0.0
  DO 22 I=1,3
    TMPTOT=SUM + ESD(NUMBR(I))
    IF (TMPTOT .GE. 4900.0) THEN
      STEMS= ESD(NUMBR(I)) - (TMPTOT - 4900.0)
    ELSE
      STEMS= ESD(NUMBR(I))
    END IF
    WTVAR4=WTVAR4 + (VAR4(NUMBR(I)) * STEMS)
    SUM=SUM + STEMS
22  CONTINUE
END IF
C
IF (CTREES .LE. 0.0) THEN
  VAR5=0.0
ELSE
  VAR5= ((3.0 * (CTREES/(CTREES + DTREES))) + 1.0) ** -1.0
END IF
C
FALL= VAR3 * WTVAR4 * VAR5
WINTER= VAR1
C
RUFFGR=MIN(WINTER, FALL)
C
RETURN
END
```

```

C* HSI/CALC5 ***** SUBROUTINE CALC5 *****
C
C CALCULATES FINAL HSI VALUES FOR BLUE GROUSE (Dendragopus obscurus)
C
C* HSI/CALC5 *****
C
      SUBROUTINE CALC5(CROWN, TTLSHB, TTLHRB, AVSBHT, AVHBHT, DVRSTY,
+                     BLUEGR)
C
      REAL*4 CROWN, TTLSHB, TTLHRB, AVSBHT, AVHBHT, DVRSTY, BLUEGR, VAR1,
+          VAR2, VAR3, VAR4, VAR5, VAR6, HSI1, HSI2, HSI3
C
      IF (CROWN .LT. 20.0) THEN
          VAR1= CROWN * (1.0/20.0)
      ELSE IF ((CROWN .GE. 20.0) .AND. (CROWN .LE. 50.0)) THEN
          VAR1= 1.0
      ELSE IF ((CROWN .GT. 50.0) .AND. (CROWN .LE. 75.0)) THEN
          VAR1= 1.0 - (((CROWN - 50.0)/25.0) * 0.9)
      ELSE IF (CROWN .GT. 75.0) THEN
          VAR1= 0.1 - (((CROWN - 75.0)/25.0) * 0.1)
      END IF
C
      IF (TTLSHB .LT. 10.0) THEN
          VAR2= TTLSHB * (1.0/10.0)
      ELSE IF ((TTLSHB .GE. 10.0) .AND. (TTLSHB .LE. 30.0)) THEN
          VAR2=1.0
      ELSE IF ((TTLSHB .GT. 30.0) .AND. (TTLSHB .LT. 75.0)) THEN
          VAR2= 1.0 - ((TTLSHB - 30.0)/45.0)
      ELSE IF (TTLSHB .GE. 75.0) THEN
          VAR2= 0.0
      END IF
C
      IF (AVSBHT .LE. 1.5) THEN
          VAR3= AVSBHT * (1.0/1.5)
      ELSE IF (AVSBHT .GT. 1.5) THEN
          VAR3= 1.0
      END IF
C
      IF (TTLHRB .LT. 40.0) THEN
          VAR4= TTLHRB * (1.0/40.0)
      ELSE IF ((TTLHRB .GE. 40.0) .AND. (TTLHRB .LE. 75.0)) THEN
          VAR4= 1.0
      ELSE IF (TTLHRB .GT. 75.0) THEN
          VAR4= 1.0 - (((TTLHRB - 75.0)/25.0) * 0.9)
      END IF

```

```
IF (AVHBHT .LT. 0.75) THEN
  VAR5= AVHBHT * (1.0/0.75)
ELSE IF ((AVHBHT .GE. 0.75) .AND. (AVHBHT .LE. 1.67)) THEN
  VAR5= 1.0
ELSE IF (AVHBHT .GT. 1.67) THEN
  VAR5= 1.0 - (((AVHBHT - 1.67)/3.33) * 0.9)
END IF
C
VAR6= 0.4 + ((DVRSTY/10.0) * 0.6)
C
HSI1=VAR1
C
IF (VAR2*VAR3 .LE. 0.0) THEN
  HSI2=0.0
ELSE
  HSI2=(VAR2*VAR3) ** 0.5
END IF
C
IF (VAR4*VAR5 .LE. 0.0) THEN
  HSI3=0.0
ELSE
  HSI3=((VAR4*VAR5) ** 0.5) * VAR6
END IF
C
BLUEGR = MIN(HSI1,HSI2,HSI3)
C
RETURN
END
```

```

C* HSI/CALC6 ***** SUBROUTINE CALC6 *****
C
C  CALCULATES FINAL HSI VALUES FOR VEERY (Catharus fuscescens)
C
C* HSI/CALC6 *****
C
C      SUBROUTINE CALC6(TTLDSB, TTLHRB, AVSBHT, AVHBHT, SOIL, VEERY)
C
C      INTEGER*2 SOIL
C      REAL*4  TTLDSB, TTLHRB, AVSBHT, AVHBHT, VEERY, VAR2, VAR3, VAR4, VAR5,
+          VAR6, HSI1, HSI2, TEMP1, TEMP2
C
C      IF (SOIL .EQ. 1) THEN
C          VAR2= 1.0
C      ELSE IF (SOIL .EQ. 2) THEN
C          VAR2= 0.5
C      END IF
C
C      IF (TTLDSB .LE. 20.0) THEN
C          VAR3= 0.0
C      ELSE IF ((TTLDSB .GT. 20.0) .AND. (TTLDSB .LT. 70.0)) THEN
C          VAR3= (TTLDSB - 20.0)/50.0
C      ELSE IF (TTLDSB .GE. 70.0) THEN
C          VAR3= 1.0
C      END IF
C
C      IF (AVSBHT .LE. 1.65) THEN
C          VAR4= 0.0
C      ELSE IF ((AVSBHT .GT. 1.65) .AND. (AVSBHT .LT. 4.95)) THEN
C          VAR4= (AVSBHT - 1.65)/3.3
C      ELSE IF ((AVSBHT .GE. 4.95) .AND. (AVSBHT .LE. 9.8)) THEN
C          VAR4= 1.0
C      ELSE IF (AVSBHT .GT. 9.8) THEN
C          VAR4= 1.0 - (((AVSBHT - 9.8)/6.6) * 0.5)
C      END IF
C
C      IF (TTLHRB .LE. 30.0) THEN
C          VAR5= 0.0
C      ELSE IF ((TTLHRB .GT. 30.0) .AND. (TTLHRB .LT. 90.0)) THEN
C          VAR5= (TTLHRB - 30.0)/60.0
C      ELSE IF (TTLHRB .GE. 90.0) THEN
C          VAR5= 1.0
C      END IF
C
C      IF (AVHBHT .LT. 1.0) THEN
C          VAR6= AVHBHT
C      ELSE IF (AVHBHT .GE. 1.0) THEN
C          VAR6= 1.0
C      END IF

```

```
TEMP1= VAR3*VAR4
TEMP2= VAR5*VAR6
C
HSI1= VAR2
IF ((TEMP1 .LE. 0.0).AND.(TEMP2 .LE. 0.0)) THEN
  HSI2=0.0
ELSE IF (TEMP1 .LE. 0.0) THEN
  HSI2= 0.5 * (TEMP2 ** 0.5)
ELSE IF (TEMP2 .LE. 0.0) THEN
  HSI2= TEMP1 ** 0.5
ELSE IF ((TEMP1 .GT. 0.0) .AND. (TEMP2 .GT. 0.0)) THEN
  HSI2= (TEMP1 ** 0.5) + (0.5 * (TEMP2 ** 0.5))
END IF
C
IF (HSI1 .LE. HSI2) THEN
  VEERY=HSI1
ELSE
  VEERY=HSI2
END IF
C
RETURN
END
```

```

C* HSI/CALC7 ***** SUBROUTINE CALC7 *****
C
C   CALCULATES FINAL HSI VALUES FOR WILLIAMSON'S SAPSUCKER
C           (Sphyrapicus thyroideus)
C
C* HSI/CALC7 *****
C
C   SUBROUTINE CALC7(ASPDBH,SNAGS3,CROWN,PERDEC,SAPSKR)
C
C   REAL*4 ASPDBH,SNAGS3,CROWN,PERDEC,SAPSKR,VAR1,VAR2,VAR3,VAR4
C
C   IF (CROWN .LT. 15.0) THEN
C     VAR1= 0.0
C   ELSE IF ((CROWN .GE. 15.0) .AND. (CROWN .LT. 30.0)) THEN
C     VAR1= (CROWN - 15.0)/15.0
C   ELSE IF ((CROWN .GE. 30.0) .AND. (CROWN .LE. 60.0)) THEN
C     VAR1= 1.0
C   ELSE IF ((CROWN .GT. 60.0) .AND. (CROWN .LT. 80.0)) THEN
C     VAR1= 1.0 - ((CROWN - 60.0)/20.0)
C   ELSE IF (CROWN .GE. 80.0) THEN
C     VAR1= 0.0
C   END IF
C
C   IF (PERDEC .LT. 5.0) THEN
C     VAR2= 0.1 + ((PERDEC/5.0) * 0.9)
C   ELSE IF ((PERDEC .GE. 5.0) .AND. (PERDEC .LE. 15.0)) THEN
C     VAR2= 1.0
C   ELSE IF (PERDEC .GT. 15.0) THEN
C     VAR2= 1.0 - (((PERDEC - 15.0)/35.0) * 0.9)
C   END IF
C
C   IF (ASPDBH .LE. 5.0) THEN
C     VAR3= 0.0
C   ELSE IF ((ASPDBH .GT. 5.0) .AND. (ASPDBH .LT. 10.0)) THEN
C     VAR3= (ASPDBH - 5.0)/5.0
C   ELSE IF (ASPDBH .GE. 10.0) THEN
C     VAR3= 1.0
C   END IF
C
C   IF (SNAGS3 .LT. 1.5) THEN
C     VAR4= SNAGS3 * (1.0/1.5)
C   ELSE IF (SNAGS3 .GE. 1.5) THEN
C     VAR4= 1.0
C   END IF
C
C   IF (((VAR2*VAR3 .LE. 0.0) .AND. (VAR4 .LE. 0.0)) .OR.
C + (VAR1 .LE. 0.0)) THEN
C     SAPSKR=0.0
C   ELSE
C     SAPSKR= (((VAR2*VAR3) + VAR4) ** 2.0) * VAR1 ** (1.0/3.0)
C   END IF

```

```

      RETURN
      END

C
C* HSI/CALC8 ***** SUBROUTINE CALC8 *****
C
C   CALCULATES FINAL HSI VALUES FOR DOWNY WOODPECKER
C           (Picoides pubescens)
C
C* HSI/CALC8 *****
C
C   SUBROUTINE CALC8(SNAGS4,STNDBA,DOWNY)
C
C   REAL*4 SNAGS4,STNDBA,DOWNY,VAR1,VAR2
C
C   IF (STNDBA .LT. 44.0) THEN
C     VAR1= STNDBA * (1.0/44.0)
C   ELSE IF ((STNDBA .GE. 44.0) .AND. (STNDBA .LE. 87.0)) THEN
C     VAR1= 1.0
C   ELSE IF ((STNDBA .GT. 87.0) .AND. (STNDBA .LE. 131.0)) THEN
C     VAR1= 1.0 - (((STNDBA - 87.0)/44.0) * 0.5)
C   ELSE IF (STNDBA .GT. 131.0) THEN
C     VAR1=0.5
C   END IF
C
C   IF (SNAGS4 .LT. 5.0) THEN
C     VAR2= SNAGS4 * (1.0/5.0)
C   ELSE IF (SNAGS4 .GE. 5.0) THEN
C     VAR2= 1.0
C   END IF
C
C   IF (VAR1 .LE. VAR2) THEN
C     DOWNY=VAR1
C   ELSE
C     DOWNY=VAR2
C   END IF
C
C   RETURN
C   END

```

```

C* HSI/CALC9 ***** SUBROUTINE CALC9 *****
C
C   CALCULATES FINAL HSI VALUES FOR LEWIS' WOODPECKER
C           (Melanerpes lewis)
C
C* HSI/CALC9 *****
C
C   SUBROUTINE CALC9(SNAGS5,CROWN,TTLSHB,LEWIS)
C
C   REAL*4 SNAGS5,CROWN,TTLSHB,LEWIS,VAR1,VAR2,VAR7,HSI1,HSI2
C
C   IF (CROWN .LE. 30.0) THEN
C       VAR1= 1.0
C   ELSE IF ((CROWN .GT. 30.0) .AND. (CROWN .LT. 75.0)) THEN
C       VAR1= 1.0 - ((CROWN - 30.0)/45.0)
C   ELSE IF (CROWN .GE. 75.0) THEN
C       VAR1=0.0
C   END IF
C
C   IF (TTLSHB .LT. 50.0) THEN
C       VAR2=TTLSHB * (1.0/50.0)
C   ELSE IF (TTLSHB .GE. 50.0) THEN
C       VAR2=1.0
C   END IF
C
C   IF (SNAGS5 .LT. 1.0) THEN
C       VAR7=SNAGS5
C   ELSE
C       VAR7=1.0
C   END IF
C
C   HSI1=VAR7
C   IF (VAR1*VAR2 .LE. 0) THEN
C       HSI2=0.0
C   ELSE
C       HSI2=(VAR1*VAR2) ** 0.5
C   END IF
C
C   IF (HSI1 .LE. HSI2) THEN
C       LEWIS=HSI1
C   ELSE
C       LEWIS=HSI2
C   END IF
C
C   RETURN
C   END

```

```

C* HSI/CALC10 ***** SUBROUTINE CALC10 *****
C
C CALCULATES FINAL HSI VALUES FOR PILEATED WOODPECKER
C (Dryocopus pileatus)
C
C* HSI/CALC10 *****
C
C SUBROUTINE CALC10(SNAGS6,SNAGS7,TPA20,AVELOG,CROWN,PILEAT)
C
C REAL*4 SNAGS6,SNAGS7,TPA20,AVELOG,CROWN,PILEAT,VAR1,VAR2,VAR3,
+ VAR6,VAR7,HSI1,HSI2
C
C IF (CROWN .LT. 25.0) THEN
C   VAR1=0.0
C ELSE IF ((CROWN .GE. 25.0) .AND. (CROWN .LE. 75.0)) THEN
C   VAR1= (CROWN - 25.0)/50.0
C ELSE IF (CROWN .GT. 75.0) THEN
C   VAR1=1.0
C END IF
C
C IF (TPA20 .LT. 3.8) THEN
C   VAR2=0.0
C ELSE IF ((TPA20 .GE. 3.8) .AND. (TPA20 .LT. 30.0)) THEN
C   VAR2=(TPA20 - 3.8)/26.2
C ELSE IF (TPA20 .GE. 30.0) THEN
C   VAR2=1.0
C END IF
C
C IF (AVELOG .LT. 10.0) THEN
C   VAR3= 0.3 + ((AVELOG/10.0) * 0.7)
C ELSE IF (AVELOG .GE. 10.0) THEN
C   VAR3=1.0
C END IF
C
C IF (SNAGS6 .LT. 0.17) THEN
C   VAR6= SNAGS6 * (1.0/0.17)
C ELSE IF (SNAGS6 .GE. 0.17) THEN
C   VAR6=1.0
C END IF
C
C IF (SNAGS7 .LT. 20.0) THEN
C   VAR7=0.25
C ELSE IF ((SNAGS7 .GE. 20.0) .AND. (SNAGS7 .LT. 30.0)) THEN
C   VAR7= 0.25 + (((SNAGS7 - 20.0)/10.0) * 0.75)
C ELSE IF (SNAGS7 .GE. 30.0) THEN
C   VAR7=1.0
C END IF

```

```
IF (VAR1*VAR2*VAR3 .LE. 0.0) THEN
  HSI1=0.0
ELSE
  HSI1= (VAR1 * VAR2 * VAR3) ** 0.5
END IF
C
IF (VAR6*VAR7 .LE. 0.0) THEN
  HSI2=0.0
ELSE
  HSI2= (VAR6 * VAR7) ** 0.5
END IF
C
IF (HSI1 .LE. HSI2) THEN
  PILEAT=HSI1
ELSE
  PILEAT=HSI2
END IF
C
RETURN
END
```