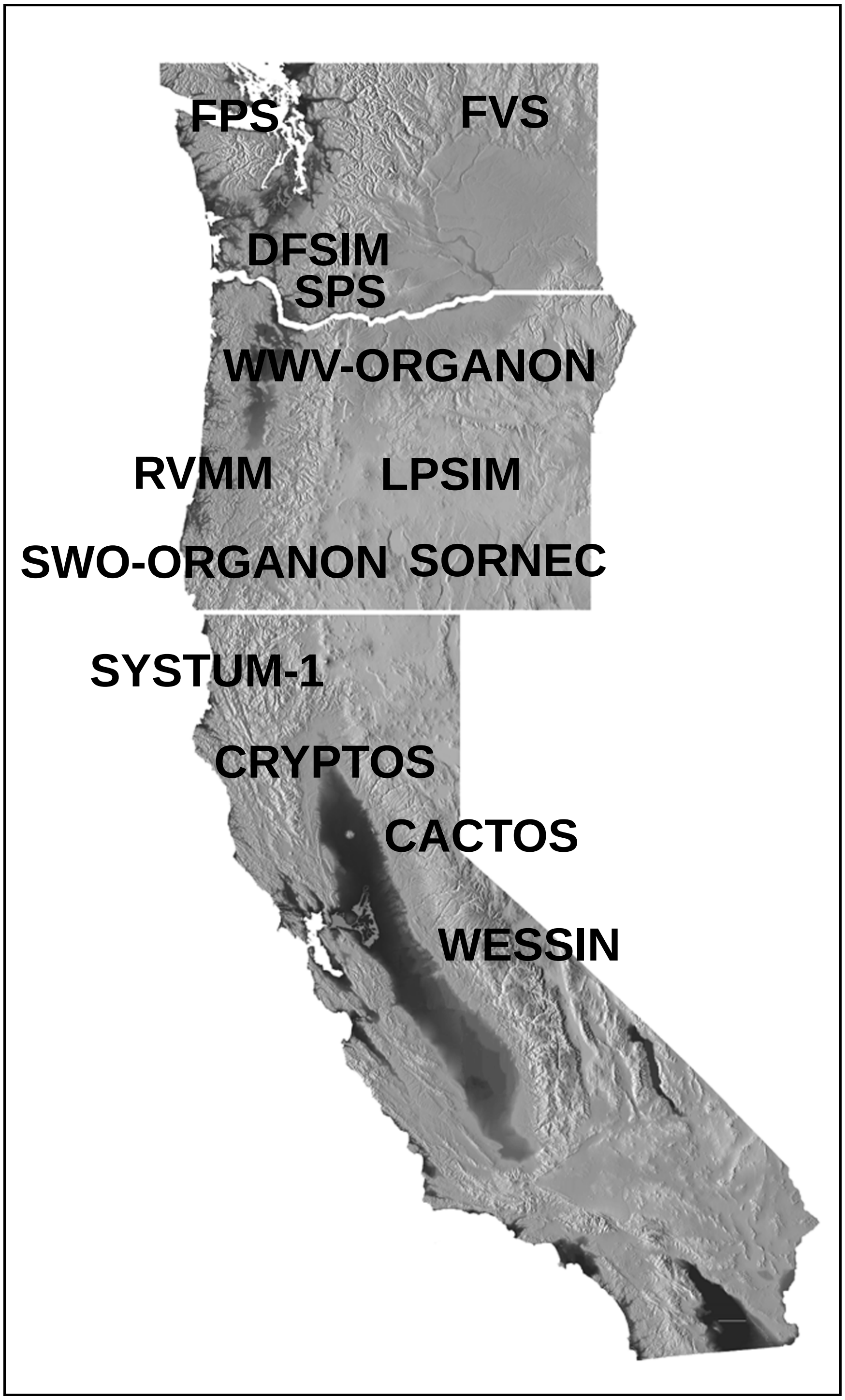
United States
Department
of Agriculture

Forest Service

Pacific Southwest
Research Station
http://www.psw.fs.fed.us/
General Technical Report
PSW-GTR-174

A Compendium of Forest Growth and Yield Simulators for the Pacific Coast States

Martin W. Ritchie



Publisher:

Albany, California
Mailing address:
PO Box 245, Berkeley, CA
94701-0245

(510) 559-6300

http://www.psw.fs.fed.us

January 1999

Pacific Southwest Research Station

Forest Service
U.S. Department of Agriculture

Abstract

Ritchie, Martin W. 1999. **A compendium of forest growth and yield simulators for the Pacific Coast states**. Gen. Tech. Rep. PSW-GTR-174. Albany CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 59 p.

The capabilities of 31 existing growth and yield simulators for California, Oregon, Washington, and Alaska were analyzed to determine their relevance in forest management and planning. Most of the simulators are available for the PC environment. Some are available at no charge, but others may require users to purchase a license. Simulators are classified in five groups: individual-tree/distance-independent, individual-tree/distance-dependent, whole stand, disaggregative, and gap. Simulators are briefly described in terms of the range of data, appropriate species, data requirements, and hardware requirements for execution.

Retrieval Terms: computer models, simulation.

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The Forest Service, U.S. Department of Agriculture, is responsible for Federal Leadership in forestry.
It carries out this role through four main activities:

- Protection and management of resources on 191 million acres of National Forest System lands
- Cooperation with State and local governments, forest industries, and private landowners to help protect and manage non-Federal forest and associated range and watershed lands
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- Research on all aspects of forestry, rangeland management, and forest resources utilization.

The Pacific Southwest Research Station

- Represents the research branch of the Forest Service in California, Hawaii, American Samoa, and the western Pacific.

A Compendium of Forest Growth and Yield Simulators for the Pacific Coast States

Martin W. Ritchie

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[1] Numbers in parentheses refer to the simulator index for tree species in *appendix A*.

In Brief. . .

Ritchie, Martin W. 1999. **A compendium of forest growth and yield simulators for the Pacific Coast states**. Gen. Tech. Rep. PSW-GTR-174. Albany CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 59 p.

Retrieval Terms: computer models, simulation

Growth and yield simulators are available for many of the forested regions of the western United States. A forest simulator is a computer program which, through a system of equations, produces forecasts of forest stand development. Historically, growth and yield information was published in the form of tables indexed to discreet ages and levels of site productivity. With time the transition has been made to computer generated output. Currently, users generate yield information geared to their exact specifications on the computer.

This information is useful in evaluating the potential for various treatment regimes to produce some desired future outcome. Such information is also needed to develop forest plans. The planning process depends on knowledge of forest conditions over time. While forest managers can easily measure the current conditions, the simulator is a tool which provides a look into the future so as to catch a glimpse of the likely or potential conditions.

No simulators are perfect. All simulators have danger zones: those combinations of species, stand and site conditions that produce shaky results. A given simulator may be totally incapable of completing some tasks and may handle others poorly. However, output from a simulator rarely comes with any warnings when the user is operating in a danger zone. The prevailing philosophy is one of caveat emptor. Users must not rely on a simulator to review its own output. Determining legitimacy of output is the purview of the user.

Simulators vary in architecture. Some of the simulators require stand level statistics as input; these are typically referred to as whole stand simulators. Others require individual-tree information as input; most of these are classified as individual-tree simulators. There are also a couple of hybrid disaggregative simulators that have been developed for this region.

Simulators may also vary with respect to input, output and management options. Some simulators are designed to be run in a "batch" mode. That is, process of multiple stands is easily facilitated. Others are designed to be most efficiently run interactively on a stand-by-stand basis. Management options may include various thinning options, fertilization, pruning, and final harvest.

Simulators are categorized herein as belonging to one of five distinct types: individual-tree/distance-independent, individual-tree/distance-dependent, whole stand, disaggregative, and gap (otherwise referred to as successional models).

This manuscript provides information needed for the user to access current information about forest growth and yield simulators. Ultimately, the best source of information for any simulator is the user's guide and the sage advice of those who built the simulator. In some instances, these people are easy to find and are willing to provide all the support for the program. Other simulators have, unfortunately, been abandoned due to retirements and other career moves of researchers. Users should take advantage of the opportunity to make direct contact with developers whenever possible. Much which is useful is not published, and much which is published is not useful.

Glossary

ASCII: the American Standard Code for Information Interchange (ASCII) is a standard code for representing numbers, letters, and symbols.

BAF: basal area factor.

BAL: basal area per unit area of trees larger than the subject tree.

Basal area: cross-sectional area of a tree at 4.5 feet above the ground.

Basal area factor: amount of basal area per unit area represented by a single tree in a sample drawn with probability proportional to size (basal area) of the tree.

Basal diameter: diameter of the stem at 0.5 feet.

CCF: crown competition factor (Krajicek and others 1961).

Compile: a process whereby code for a given language, such as FORTRAN, is converted to instructions which may be executed by the computer.

Cover: vertical projection of crown area expressed as a percent.

CPU: central processing unit.

Crown ratio: live crown ratio, the ratio between crown length (numerator) and total tree height (denominator) wherein both are measured in the same units.

DBH: diameter at breast height (4.5 feet), outside bark unless otherwise specified.

d/D ratio: ratio of quadratic mean diameter of trees cut divided by the quadratic mean diameter of all trees prior to cutting.

DOS: acronym for disk operating system, the operating system for most IBM compatible computers.

Deterministic: used to describe a process that does not contain a random element.

Driving function: a function responsible for directly forecasting a dynamic element of any particular simulator.

Expansion factor: number of stems per unit area for each sampled individual. For a 10^{th} acre plot, the expansion factor is 10. For a variable-radius plot, expansion factor is a function of tree diameter and basal area factor (BAF). For English units expansion factor.

FVS: Forest Vegetation Simulator, formerly Prognosis Model for Stand Development. FVS refers to all those simulators (variants) derived from the original Prognosis architecture.

Growth interval: the length of time associated with the dynamic functions embedded in a simulator. A growth interval of 10 indicates driving functions that predict 10-year change in the response variable.

Height: total tree height.

Housekeeping function: a species-specific, and/or simulator-specific function for producing output or quantifying certain parameters within a simulator (Bruce 1990).

HT40: Height of the 40 largest (diameter) trees on a unit area (typically an acre), also maybe referred to as dominant height.

K: kilobytes; one kilobyte is 1024 bytes.

MAI: mean annual increment.

MB: megabyte; one megabyte is 1000 kilobytes.

Primary driver: that driving function which occurs first in the progression of growth estimates and often has the greatest impact on overall simulator behavior because the results of this function permeate the forecasts throughout the simulator.

QMD: quadratic mean diameter; breast height diameter of the tree of mean basal area in a stand. Quadratic mean diameter is always larger than mean tree diameter.

RAM: random access memory.

SDI: stand density index (Reineke 1933); and index relating any given stand to a reference stand with a quadratic mean diameter of 10 inches as expressed by number of trees per acre.

SDI maximum: a specified maximum value that SDI may attain for any given species. By convention, forest stands will exist in log(N), log(D) space where SDI is greater than zero but less than SDI maximum.

Self-extracting file: an executable file that contains one or more compressed files. Execution of this type of file results in the decompression of the specified files.

Site index: height achieved by free-to-grow dominant or dominant and codominant trees at some specified base age.

Stochastic: random; a stochastic process is one that incorporates a random variable; hence, forecasts from a stochastic simulations will vary even when all input parameters are fixed.

Structural function: in growth and yield simulators, a standard, or generic function for producing some quantity in a common manner, e.g., stand basal area or stand growth rate (Bruce 1990).

Introduction

Effective management of more than 70 million acres of commercially productive forest land in the Pacific Coast states (herein defined as California, Oregon, Washington, and Alaska) requires not only knowledge of the current status of the resource, but the ability to forecast future conditions and effects of management practices as well.

To this end, many growth and yield simulators have been developed for forests of this region, as no single tool can satisfy all the needs of such a large and diverse landscape and potential user group. Yet, documentation of these simulators is often inadequate. Information is lacking on appropriate scenarios for application and on the scope of many existing simulators. Published resources on growth and yield models are often presented in journals or series, which are not readily available to those outside the research community.

Potential users need information on what simulators are available, their sources and capabilities. This report contains information useful for deciding which simulators (if any) are appropriate, for any given application. Information on data requirements and management options are included where appropriate.

This document is not intended to be a replacement for a user's guide, nor is it intended to answer all the questions pertaining to the detail of simulator functions. It is not possible to provide a complete technical support reference for so many different simulators in a single manuscript. Users are encouraged to go to the source for more complete and detailed information on any particular simulator. Typically, those who know a simulator best are those who built it, or those who work with it frequently. To this end, references for individual simulators are included in appendices.

For this presentation, a growth and yield simulator is a forecasting tool, which is executed on a computer. It is composed of a suite of mathematical relationships (models) which are integrated under some unifying concepts to form a system which can mimic the dynamics of selected stand parameters (e.g., volume, basal area, stems per acre) of forest ecosystems. These parameters may be expressed for the whole stand, or for some cohort of trees within the stand. That is, a simulator may produce only a forecast of volume per unit area over time for all trees in the stand, or the simulator may be capable of higher resolution output, say, volume for trees of a given species and/or range of diameters.

Growth and yield information presented in the form of equations or traditional yield tables is not included in this manuscript. Hann and Riitters (1982) have compiled an exhaustive reference to these for the Pacific Northwest.

It is important to note the close parallel between today's computer simulators and the yield tables of the past. Computer simulators represent a logical extension of pioneering growth and yield research (Dunning and Reineke 1933, McArdle and others 1961, Meyer 1934, Schumacher 1926, Schumacher 1930). One primary difference between a computer growth simulator and a yield table is the form of the presentation. Traditional yield tables present information in a rigid form for discrete increments of input data. Yields are typically presented for fixed levels of site index and age at 10-year intervals. A computer simulator may present information for many combinations of input variables, may operate at a higher resolution, and offers a greater variety of output. In order to provide users with a more powerful descriptive tool, these simulators have become increasingly complex.

The inclusion of a simulator here should not be interpreted as an endorsement for any particular application. Rather, the intent is to provide users with information for selecting decision support systems for application or, at the very least, to direct users toward sources which may provide more detailed information on simulators.

Proprietary simulators are not included in this manuscript unless they are marketed to the public. Some simulators may be viewed as freeware and are distributed as such. For some simulators, new versions are released frequently, most notably CACTOS, FVS, and ORGANON. Thus, with time, information on distribution and current version numbers may become obsolete. Because of ongoing modifications to many of these programs, it is highly recommended that users go to the source in order to obtain the most recent version and proper documentation.

The strengths and limitations of simulators are generally not well documented and may change as simulators are modified and updated. Few studies have evaluated simulator forecasts. Some notable exceptions are Curtis (1994), Curtis and Marshall (1993), Korpela and others (1992), and Zhang and others (1993). Unless reported in the literature, model reliability or lack thereof, is not presented here.

Because there is no standard for documentation of these simulators, the information presented for each varies. In all cases, I have endeavored to provide the reader with a source from which more information may be obtained. Where possible, Internet access to software and documentation are provided. All internet addresses are shown in bold. Users should be aware that these may change over time.

Form vs. Function

All questions pertaining to simulator utility and behavior relate to either the form or function of the simulator. Users typically have these concerns relating to form:

1. How to execute the simulator.
2. Management alternatives allowed by the simulator.
3. What kind of data input is required by the simulator.
4. Output options provided by the simulator.

Yet, users should also be concerned with what happens between input and output. This relates to function, the primary concern of modelers. Users who ignore this question must accept simulator output unquestioningly and run the risk of ignoring some of the faults of all simulators. In this manuscript I will attempt to provide answers to the primary questions of form and application of each simulator.

Users should be aware that the simulators are, of necessity, simplifications of complex systems. Whole-stand simulators ignore much of the information typically required for individual-tree simulators. Modelers understand that individual-tree information may be useful in forecasting stand development, but assume that this loss of information is not critical to the execution of whole-stand simulators. This assumption is most likely to be met when dealing with even-aged, single-species stands.

When forecasts are made for conditions beyond the range of the data, or when forecasts are made for long time frames, simulators may exhibit unreasonable behavior. Users should exercise caution by not regarding output from any simulator as "correct." Simulator output should be presented as a likely scenario for stand development.

Five distinctly different types of simulators are presented: individual-tree/distance independent, individual-tree/distance-dependent, whole-stand, disaggregative, and gap models. The first three of these are described by Munro (1974). Using a strict interpretation of Munro's classification scheme, both gap simulators and disaggregative simulators may be classified as individual-tree/distance-independent simulators. Both accept input of tree-level data and do not require a stem map. However, gap simulators function very differently and have very different input requirements. Disaggregative simulators are constrained in the allocation of growth to individual sample trees.

Terminology

To fully understand the computer simulators presented here, it is imperative that one understand some basic concepts and terminology. Terminology varies somewhat by author, so I will attempt here to define some terms that will be used extensively.

It is important to understand what variables are used to derive forecasts of tree growth and how they enter into the process of any particular simulation. Bruce (1990) used a convenient classification of functions in growth and yield simulators which I will employ. In this classification, there are three distinct types of functions: driving functions, housekeeping functions, and structural functions. Driving functions are those functions which actually characterize the dynamic nature of stand and/or tree development. Examples are height growth, diameter growth, or basal area growth. The primary driver is that function which comes first in the progression of forecasts. Other drivers will be considered secondary. Housekeeping functions are those functions which may vary between simulators and even between species within a simulator but which do not directly impact the dynamic nature of the simulator itself. Examples are volume equations or some species-dependent indices of stand density such as crown competition factor (Krajicek and others 1961). Structural functions are common functions invariant across species and simulator. Examples are calculations for stand basal area or stems per acre.

Individual-Tree/Distance-Independent Simulators: FVS, CRYPTOS, CACTOS, SPS, ORGANON, SYSTUM-1, RVMM-Individual Tree, CONIFERS

Individual-tree/distance-independent simulators function with the tree as the basic modeling unit. All individual-tree simulators require a list of sampled trees to make forecasts of stand development over time. Some are capable of generating a list from some stand-level parameters. The tree list variables usually include diameter at breast height (DBH), height, crown ratio, and expansion factor. A standard format for tree lists does not exist, and users must ensure that the data are in a format consistent with the requirements of a particular simulator. Trees may be sampled on fixed- or variable-radius plots, or even on a combination of the two for most simulators. It is important that all trees be measured on a plot. Measurement of only crop trees, or completing partial measurements in such a way that favors the largest or most healthy trees will result in biased forecasts. Spatial coordinates (stem maps) are not required for execution of these simulators.

From the point of view of the simulator, the subject stand is characterized by a list of sampled individual trees. Each tree in the sampled tree list is representative of some number of trees per unit area. The larger the number of sampled plots for any given stand, the fewer trees represented by each sampled tree and the better the description of the candidate stand.

It is imperative that trees be sampled in such a way that they may be related to an expansion factor. The expansion factor is the number of trees per acre (or hectare) represented by each individual in the list. Expansion factor is a constant for trees sampled on a fixed-radius plot; the expansion factor varies by tree size (diameter) for those trees sampled using point sampling.

For example, *table 1* contains a tree list with plot number, tree number, DBH and expansion factor. Expansion factors for this particular example are derived assuming a

Table 1–*Example of a tree list showing a sample from three plots with expansion factors determined assuming a 1/100th-acre fixed-area plot for trees with DBH less than or equal to 6 inches in diameter and a 20 BAF variable-radius plot for all trees over 6 inches DBH.*

Plot	Tree	DBH	Expansion Factor
1	1	12	25
1	2	5	100
1	3	3	100
1	4	7	75
2	1	4	100
2	2	5	100
2	3	9	45
2	4	9	45
3	1	11	30
3	2	6	100
3	3	4	100
3	4	4	100
3	5	5	100

fixed-area, 0.01-acre plot for trees less than or equal to 6 inches DBH and a 20 basal area factor (BAF) variable-radius plot for larger trees. The individual-tree expansion factor is then the inverse of the plot area (100 for the smaller trees on the fixed-area plot and 3666.929/ DBH^2 for the trees larger than 6 inches). A stand density measure such as trees per acre may be calculated, but expansion factors must be adjusted to account for the number of plots; in this case all expansion factors must be divided by 3. Thus, the stand-level estimate of trees per acre from the example of *table 1* is 340. For stand-level summaries, then, the number of trees represented by any given sampled individual is a function of both plot size and sampling intensity.

Growth increments may be annual or periodic (5- or 10-year increments are common). If one wishes to predict growth for 10 years using a simulator with a 5-year forecast interval, the simulator will make two consecutive growth forecasts. The tree list is updated twice in this process.

The individual-tree/distance-independent simulator will forecast changes in diameter, height and usually live crown ratio for each growth interval, as well as mortality. The tree list data are updated and represent conditions forecast for some future period. The driving functions are typically height growth, diameter or diameter squared increment, change in crown ratio and mortality. Functions of tree growth will typically characterize growth as a function of four factors: size (or in some cases age), tree vigor, competitive stress, and site quality.

Tree size may be presented in the form of transformations of DBH or total tree height. Growth as a function of tree size should be a peaking function, that is, growth increases with increasing size, eventually reaching a peak, followed by decreasing growth rates as size further increases, tending toward zero for very large trees. This results in an effective upper limit for tree size.

Tree vigor is often quantified by crown ratio of the subject tree. Longer crowns typically result in greater predicted growth rates, all other factors being held constant. Crown ratio may be a very important factor in determining response to thinning. Models containing this variable will tend to continue to predict slower growth rates for trees with smaller live crown ratio.

Competitive stress affecting any particular tree may be quantified by such standard measures of density as number of stems or basal area per unit of area. There are many other quantities which may be interpreted as indices of competition: Crown competition factor (CCF) (Krajicek and others 1961), Curtis' relative density index (Curtis 1982), and Reineke's stand density index (Reineke 1933), to name a few. Competitive stress is most often averaged across all plots in a stand. However, in some simulators it will be explicitly defined at the plot level. Stand-level variables are derived using all individuals in a sampled stand, while the plot-level variables are calculated using only individuals from a sampled plot (or point) in a stand.

Some individual-tree simulators use an index, which is tied to tree size or position in relation to its competitors. Examples include basal area in trees larger than the subject tree and crown closure at 66 percent of tree height (CC66). Basal area in larger trees is a value which varies from zero (for the largest tree) to a value near total stand basal area for the smallest tree in the list. CC66 is a value which could vary from zero, or some value close to zero, for the largest tree, to a value close to total crown closure of the stand for the smallest tree.

Finally, site quality is present to affect changes in response due to variations in productivity of the site. Some simulators depend solely on site index, while others use combinations of factors. Many Forest Vegetation Simulator (FVS) variants, for example, use a combination of location, elevation, slope, aspect, and site index.

Mortality is simulated by predicting a probability of death for each tree in the tree list. Once this probability of death for a given period is estimated for each tree, the unit area expansion factor is reduced accordingly. Trees are not removed from the tree list; rather, the number of trees represented by each individual in the sample is reduced with each successive forecast by the amount indicated by the mortality function(s). Thinning is easily facilitated in a similar manner. Expansion factors are reduced according to the thinning regime specified by the user. It is quite possible that all trees of a given cohort will be removed, resulting in expansion factors of zero for some trees.

Individual-tree/distance-independent simulators may have a pseudo-stochastic feature. Typically this feature allows the simulator to better characterize the differentiation in size classes which becomes accentuated over time with stand development. This may be exhibited as a record duplication scheme such as that featured in CACTOS and ORGANON, or it may be a random error term attributed to each growth forecast for each tree as in SYSTUM-1. FVS variants feature both a record duplication scheme and a random growth component which may be added to each tree's growth prediction.

The power of individual-tree simulators is the capability to produce output summarized for the entire stand, or for higher levels of resolution (e.g., by species, or by size-classes). Also, individual-tree simulators are generally better suited to mixed-species or uneven-aged stands than are whole-stand simulators.

FVS

FVS (Forest Vegetation Simulator, also referred to as Prognosis) was originally developed for northern Idaho and western Montana (Stage 1973, Wykoff and others 1982). Numerous variants have been developed for different geographic regions throughout the United States, with most of these being in the western United States. There are currently nine variants for the Pacific Coast states (*table 2*). Default growth intervals are either 5 or 10 years, depending on the variant. However, interval length may be changed at runtime.

The FVS system has had numerous extensions developed which allow users to integrate such factors as pest outbreaks, into forecasts. Not all of these extensions are currently available for all of the Pacific Coast states FVS variants. Users need to check periodically on the availability of extensions for individual variants.

Each variant comes with documentation on aspects of execution unique to that particular variant. More general documentation on execution may be found in Wykoff and others (1982) and Wykoff (1986). Wykoff and others (1991) documents execution of version 6 for all existing variants.

The data needed for execution are generally the same for all of the FVS variants. Tree list variables include:

1. plot identifier (integer)
2. tree count (number of trees represented by the sample tree)
3. species (two letter code)
4. DBH (inches)
5. DBH increment (inches), period of this increment should correspond to the growth increment of the variant
6. height (feet)
7. height to topkill (feet)
8. height increment (feet), period of this increment should correspond to the growth increment of the variant
9. crown ratio (integer code from 1-9)
10. damage code(s)

Crown ratio, DBH increment, height increment, damage code, height to topkill, and height are not required. Crown ratio and height may be filled in by the simulator.

All FVS variants have a separate set of routines for juvenile stand development. Small trees (typically those less than 3 inches DBH) are modeled using a different set of functions than that used for large trees. Generally, FVS has a primary driver of diameter increment for trees greater than 3 inches, whereas height growth is the primary driver of small tree growth. The diameter growth function for large trees is derived from a linear least squares fit of a squared diameter increment model (Wykoff and others 1982) of the following form:

$$dds = \exp(b_0 + b_1 x_1 + ... + b_p x_p)$$

where:

dds = predicted increment of diameter squared

x_i = variable.

Table 2—*Current Forest Vegetation Simulator (FVS) variants for the Pacific Coast states and self-extracting file names for IBM-PC executable code associated with each version and documentation file.*

Variant name	File name	Documentation file
1. Southeast Alaska/Coastal British Columbia		akvar.txt
FVS with Dwarf Mistletoe Extension	akdos.exe	
2. Blue Mountains		bmvar.txt
FVS with Western Spruce Budworm Model	bmddos.exe	
FVS with Dwarf Mistletoe Model	bmdos.exe	
FVS with Douglas-fir Beetle Model	bmfdos.exe	
FVS with Lodgepole Mountain Pine Beetle Model	bmldos.exe	
FVS with Western Root Disease Model	bmrdos.exe	
FVS with Combined Pest Extension	bmxdos.exe	
3. East Cascades		ecvar.txt
FVS with Dwarf Mistletoe Model	ecdos.exe	
FVS with Western Root Disease Model	ecrdos.exe	
4. Inland Empire		nivar.txt
FVS with Annosus/Bark Beetle Model	niados.exe	
FVS with Western Spruce Budworm Damage Model	niddos.exe	
FVS with Dwarf Mistletoe Model	nidos.exe	
FVS with Douglas-fir Beetle Model	nifdos.exe	
FVS with Lodgepole Mountain Pine Beetle Model	nildos.exe	
FVS with Spatial Dwarf Mistletoe Model	nimdos.exe	
FVS with Western Root Disease Model	nirdos.exe	
FVS with Douglas-fir Tussock Moth Model	nitdos.exe	
FVS with White Pine Blister Rust Model	niudos.exe	
FVS with Fire Model	nifmdos.exe	
FVS with Parallel Processor	ppnidos.exe	
5. Klamath Mountains		ncvar.txt
FVS with Dwarf Mistletoe Model	ncdos.exe	
6. Pacific Northwest Coast		pnvar.w51
FVS with Dwarf Mistletoe Model	pndos.exe	
FVS with Douglas-fir Beetle Model	pnfdos.exe	
FVS with Western Root Disease Model	pnrdos.exe	
7. South Central Oregon/Northeast California		sovar.txt
FVS with Annosus/Bark Beetle Model	soados.exe	
FVS with Western Spruce Budworm Damage Model	soddos.exe	
FVS with Dwarf Mistletoe Model	sodos.exe	
FVS with Lodgepole Mountain Pine Beetle Model	soldos.exe	
FVS with Western Root Disease Model	sordos.exe	
FVS with Douglas-fir Tussock Moth Model	sotdos.exe	
FVS with Lodgepole Mountain Pine Beetle and Western Root Disease Model	sorldos.exe	
8. West Cascades		wcvar.w51
FVS with Dwarf Mistletoe Model	wcdos.exe	
FVS with Western Root Disease Model	wcrdos.exe	
9. Western Sierras		wsvar.txt
FVS with Annosus/Bark Beetle Model	wsados.exe	
FVS with Dwarf Mistletoe Model	wsdos.exe	

This function is appealing because it is strictly positive and intrinsically linear. That is, the model may be transformed by taking the natural logarithm of both sides of the equation such that the resulting model is linear with respect to the parameters. This transformation often results in an error term which is approximately normally distributed. Since this transformation results in a linear model, the parameters are easily estimated using ordinary linear least squares regression. Although the model is not explicitly defined as a potential times modifier, the model may be interpreted as such (Hann and Larsen 1991) by merely partitioning the explanatory (predictor) variables into those which are related to potential growth (site productivity and tree size) and those which are related to tree vigor or competitive stress (crown ratio, tree position, stand density):

$$dds = \exp(b_0 + b_1x_1 + ... + b_rx_r) \bullet \exp(b_{r+1}x_{r+1} + ... + b_px_p)$$

FVS offers a number of different output tables. The input summary table summarizes the keyword directives and calibration statistics for the run. The stand composition table includes a description of the stand DBH by percentiles (10^{th}, 30^{th}, 50^{th}, 70^{th}, 90^{th}, 100^{th}) of trees per acre and volume. The DBH associated with the percentiles of trees per acre is displayed in one line, the DBH associated with the percentiles of total stem cubic foot volume on another line, and so on. For example, in *table 3*, 90 percent of the 590 trees per acre are below 8.5 inches in diameter. However, 90 percent of total cubic foot volume is found in trees above 5.8 inches. Tree and stand attributes are presented in a similar fashion, by trees per acre percentile. Tree list output produces a tree list for each time step in the forecast. Finally, the stand summary table produces stand summaries at each growth interval in the forecast.

The nine variants applicable to the Pacific Coast states region are all very similar in execution. The primary difference between variants is in the parameterization of individual growth and mortality functions as well as static functions in the model, such as crown ratio and height-diameter relationships. Housekeeping functions such as volume equations also vary between simulators. The means by which site productivity is quantified also varies. In most variants, site productivity will be expressed as a function of some combination of slope, aspect, elevation, site index, and location. Site index reference depends on the variant and species prevalent in the region.

The form of driving functions (what variables are included) also may vary somewhat between simulators and within simulators between species. Users must also be aware of the individual species designators associated with each variant. This information is provided in the documentation file associated with each variant (*table 2*).

One key feature of the FVS system is the Event Monitor (Crookston 1990). The Event Monitor, while documented separately, is integrated into the code. It provides users with an expanded group of keywords which allow conditional execution of the simulator. Users may specify that thinnings or output of data will take place when certain stand conditions are reached. The target stand condition for execution of a thinning can be defined by the user. A powerful suite of functions in the Event Monitor give the user great latitude in defining new variables and specifying conditions for executing management options.

It is possible for the user to define a condition in the stand using the SPMCDBH function. This function will allow the user to specify that the simulator calculate trees per acre; basal area per acre; cubic volume per acre; board-foot volume per acre; quadratic mean diameter, or average height, by species; and tree value class within any specified range of diameters and or heights. These values may be calculated for either surviving trees or mortality. Values returned by the SPMCDBH function may be written as output or used to define timing and intensity of thinnings.

The system requirements for all variants: IBM compatible DOS 3.3 or higher, 4 MB RAM memory, hard disk, and 386DX or better with a math coprocessor (recommended).

Additional references are listed in *appendix B*. Current information on variants and the latest version may be downloaded off the World Wide Web at:

http://www.fs.fed.us/fmsc/fvs.htm

A general FVS overview may be found at:

http://forest.moscowfsl.wsu.edu/4154/fvsoview.html

Table 3—*Example FVS output table displaying percentile points of the diameter distribution.*

YEAR	STAND ATTRIBUTES	PERCENTILE POINTS IN THE DISTRIBUTION OF STAND ATTRIBUTES BY DBH 10	30	50	70	90	100	TOTAL/ACRE OF STAND ATTRIBUTES	DISTRIBUTION OF STAND ATTRIBUTES BY SPECIES AND 3 USER-DEFINED SUBCLASSES
		(DBH IN INCHES)							
1990	**TREES**	0.1	0.1	3.2	6.1	8.5	12.7	590. TREES	27.% DF2, 15.% WF2, 15.% WF1 12.% RF1
	VOLUME:								
	TOTAL	5.8	7.9	9.4	10.0	11.5	12.7	1290. CUFT	30.% SP1, 22.% WF1, 21.% DF1, 12.% SP2
	MERCH	8.0	9.4	9.6	10.4	11.5	12.7	851. CUFT	39.% SP1, 28.% DF1, 15.% SP2, 10.% WF1
	MERCH	10.0	10.4	10.9	11.5	12.7	12.7	1469. BDFT	21.% DF1, 21.% WF1, 19.% SP1, 18.% DF2

Southeast Alaska (1)[1]

Primary Species:
- Alaska yellow-cedar
- Lodgepole pine
- Mountain hemlock
- Pacific silver fir
- Sitka spruce
- Subalpine fir

Geographic Range:
Southeastern Alaska and coastal British Columbia

Site Index/Productivity:
Western hemlock and Sitka spruce site index (Farr 1984)

The southeast Alaska variant (Dixon and others 1992) was developed for the western hemlock-Sitka spruce type in southeast Alaska (*fig. 1*). There are four areas or localities within this range: the Chatham, Ketchikan, and Sitkine areas of the Tongass National Forest and the British Columbia/Makah Indian reservation. The user must specify the area within which the sampled stand resides.

The southeast Alaska variant uses the site index of Farr (1984). The user must input the site index and the species associated with that site index value (Sitka spruce or western hemlock). The simulator will calculate the site index for other species as a function of the value provided by the user.

The strength of the data base for this modeling effort was in western hemlock and Sitka spruce (*table 4*). Ten species, or species groups, are noted in the simulator documentation. Species other than those shown in the table are grown as Sitka spruce. White spruce, although listed in the species table, had no representation in the data base. It is possible that this distinction is due to the fact that users wish to categorize white spruce separately, or there may be housekeeping equations which justify the presence of white spruce as an acceptable input species.

As with other FVS variants, three separate procedures are associated with tree growth: establishment (for seedlings), small tree functions (for trees with small diameters), and large tree growth functions for trees with larger diameters. The establishment submodel allows users to simulate natural regeneration and plantings (Dixon and others 1992, pages 22-25). The primary driving function for small trees is height growth. There is a generic height growth function for small trees in which height growth is forecast as a function of crown ratio, basal area in larger trees, and site index. Small trees are nominally defined as those with breast height diameters less than 5 inches. However, for all trees between 2 and 5 inches DBH, the forecast height growth is actually a weighted average of the small and large tree height growth functions, such that there is a smooth transition between small and large tree height growth predictions. The large tree model employs a diameter growth model

[1]Numbers in parentheses refer to the simulator index for tree species in *appendix A.*

as the primary driver. The growth interval is 10 years for the large tree functions. Diameter growth for large trees is forecast as a function of stand basal area per acre, DBH, basal area in larger trees, crown ratio, tree height divided by height of the 40 largest trees (HT40), elevation, slope, aspect, and site index.

Mortality is driven by an approach to the maximum stand density index (SDI) (Reineke 1933). The functional maximum SDI is defined as 85 percent of maximum SDI. That is, stands will tend to approach this functional maximum over time. The maximum SDI value varies by species (*table 5*).

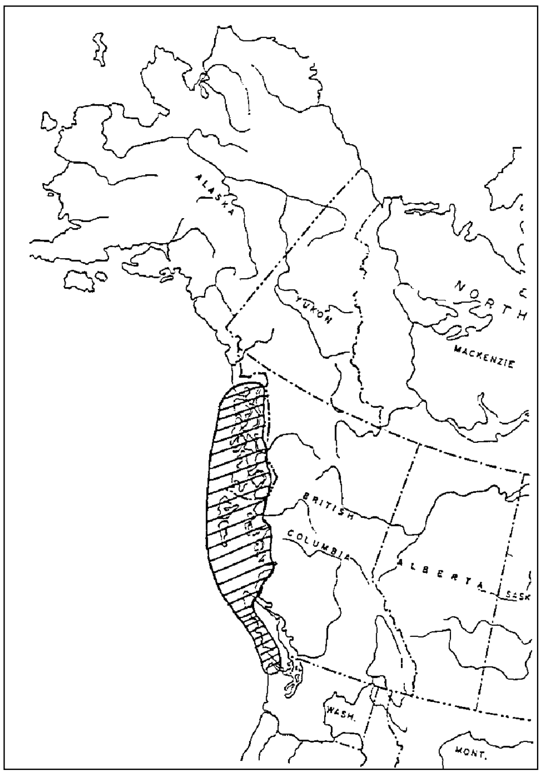

Figure 1—Geographic range of the Southeast Alaska variant of the Forest Vegetation Simulator (Dixon and others 1992).

Table 4—*Distribution of tree records with observed growth across species for the southeast Alaska/coastal British Columbia variant of the Forest Vegetation Simulator (Dixon and others 1992).*

Species	Code	Number of records
White spruce	WS	0
Western redcedar	RC	402
Pacific silver fir	SF	98
Mountain hemlock	MH	908
Western hemlock	WH	5,581
Alaska yellow-cedar	YC	880
Lodgepole pine	LP	78
Sitka spruce	SS	3,017
Subalpine fir	AF	1
Hardwood	HD	69

Table 5—*Stand Density Index (SDI) maximum (Reineke 1933) and functional maximum, expressed in trees per acre, for the mortality functions of the southeast Alaska/coastal British Columbia variant of the Forest Vegetation Simulator (Dixon and others 1992).*

Species	Code	SDI maximum	SDI functional maximum (85 percent of SDI)
White spruce	WS	470	400
Western redcedar	RC	565	480
Pacific silver fir	SF	590	502
Mountain hemlock	MH	600	510
Western hemlock	WH	623	530
Alaska yellow-cedar	YC	565	480
Lodgepole pine	LP	470	400
Sitka spruce	SS	600	510
Subalpine fir	AF	470	400
Hardwood	HD	470	400

Blue Mountain (2)

Primary Species:
- Douglas-fir
- Englemann spruce
- Grand fir
- Lodgepole pine
- Mountain hemlock
- Ponderosa pine
- Subalpine fir
- Western larch
- Western white pine

Geographic Range:
Northeast Oregon and southeast Washington

Site Index/Productivity:
Site index reference varies by species

The Blue Mountains FVS variant (Johnson 1993) was developed for the Malheur, Ochoco, Umatilla, and Wallowa-Whitman National Forests in northeast Oregon. The geographic range is displayed in *figure 2*. Primary species in the modeling data base were ponderosa pine, Douglas-fir, and grand fir. There were fewer numbers of white pine, western larch, mountain hemlock, lodgepole pine, Englemann spruce, and subalpine fir (*table 6*). Western juniper was not represented in the data base; the simulator employs the functions from the SORNEC variant (see 7) for this species. Site productivity is characterized by site index (*table 7*).

The small-tree model's primary driver is height growth. Height growth in this submodel is forecast as a function of site index, height, CCF, and crown ratio. Diameter growth is a secondary driver. Diameter growth is derived indirectly from a height-diameter relationship.

The simulator operates on a 10-year growth cycle for the large tree models (DBH>3 inches). Site index is used in both the height growth and diameter growth equations of the large tree component. In addition, the diameter growth model requires location code (unique for each National Forest), slope, aspect, and elevation of the sampled site as well as DBH, crown ratio, basal area per acre, plot-level CCF, basal area in larger trees, and a relative density function that is not defined in the documentation.

Mortality functions are driven by an approach to 85 percent of the maximum SDI. Maximum SDI values for each species are shown in *table 8*.

Figure 2—Geographic range of the Blue Mountains variant of the Forest Vegetation Simulator (Johnson 1993).

Table 6—*Distribution of observations in the modeling data base for the Blue Mountains variant of the Forest Vegetation Simulator.*

Species	Number of trees
Western white pine	256
Western larch	1,209
Douglas-fir	3,478
Grand fir	2,963
Mountain hemlock	1,000
Lodgepole pine	1,117
Englemann spruce	596
Subalpine fir	599
Ponderosa pine	6,577

Table 7—*Site index curve references for the Blue Mountains variant of the Forest Vegetation Simulator (Johnson 1993).*

Species	Reference	Base age
Western white pine	Brickell 1970	Total age 50
Western larch	Cochran 1985	Breast height age 50
Douglas-fir	Cochran 1979a	Breast height age 50
Grand fir	Cochran 1979b	Breast height age 50
Mountain hemlock	Not available	Breast height age 100
Englemann spruce	Alexander 1967	Breast height age 100
Lodgepole pine	Dahms 1964	Breast height age 50
Ponderosa pine	Barrett 1978	Breast height age 100
Subalpine fir	Demars and others 1970	Breast height age 100

Table 8–*Maximum Stand Denisty Index (SDI) values, by species, used by default in the Blue Mountains variant of the Forest Vegetation Simulator (Cochran and others 1994).*

Species	Maximum SDI
Ponderosa pine	365
Lodgepole pine	276
Western larch	410
White fir and grand fir	560
Douglas-fir	380
Subalpine fir	416
Englemann spruce	469

East Cascades (3)

Primary Species:
- Douglas-fir
- Engelmann spruce
- Grand fir
- Lodgepole pine
- Mountain hemlock
- Pacific silver fir
- Ponderosa pine
- Subalpine fir
- Western larch

Geographic Range:
East side of the Cascades in Washington and northern Oregon

Site Index/ Productivity:
Site index reference varies by species

The east Cascades variant was developed using data from the Gifford Pinchot, Mount Hood, Okanogan, and Wenatchee National Forests (Johnson 1990). As with other FVS variants, the data came from a variety of sources. The species most well represented were Douglas-fir, grand fir, and ponderosa pine (*table 9*). The geographic range of the simulator is shown in *figure 3*.

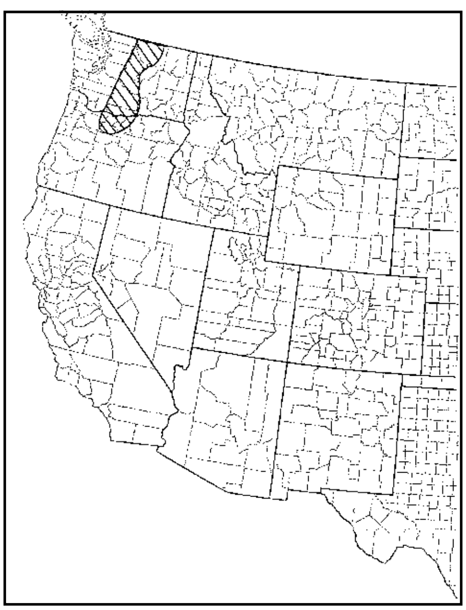

Figure 3—Geographic range of the East Cascades variant of the Forest Vegetation Simulator (Johnson 1990).

Table 9—*Number of observations by species used in development of the east Cascades variant of the Forest Vegetation Simulator (Johnson 1990).*

Species	Code	Number of Records
Western white pine	WP	0
Western larch	WL	652
Douglas-fir	DF	6,249
Western redcedar	RC	0
Grand fir	GF	1,950
Ponderosa pine	PP	4,040
Lodgepole pine	LP	1,479
Englemann spruce	ES	623
Subalpine fir	AF	729
Mountain hemlock	MH	1,443
Pacific silver fir	SF	1,210

This simulator features a 10-year growth interval for large trees (those greater than 3 inches DBH). In the large tree submodel, diameter increment is forecast as a function of location, slope, aspect, elevation, site index, DBH, crown ratio, BAL, CCF, and stand basal area.

A variety of site index functions are used, depending on species (*table 10*).

Table 10—*Site index curves employed by the east Cascades variant of the Forest Vegetation Simulator (Johnson 1990).*

Species	Code	Reference
Western white pine	WP	Brickell (1970)
Western larch	WL	Cochran (1985)
Douglas-fir	DF	Cochran (1979a)
Pacific silver fir	SF	Cochran (1979b)
Grand fir	GF	Cochran 1979b)
Lodgepole pine	LP	Alexander and others (1967)
Englemann spruce	ES	Alexander (1967)
Subalpine fir	AF	DeMars and others (1970)
Ponderosa pine	PP	Barrett (1978)
Mountain hemlock	MH	Not available

Inland Empire (4)

Primary Species:
- Douglas-fir
- Engelmann spruce
- Grand fir
- Lodgepole pine
- Mountain hemlock
- Ponderosa pine
- Subalpine fir
- Western hemlock
- Western larch
- Western redcedar
- Western white pine

Geographic Range:
Eastern Montana, central Idaho and northeastern Washington

Site Index/Productivity:
Habitat type designation (Wykoff and others 1982)

The Inland Empire variant is the original version of the simulator. Operation of the simulator is described by Wykoff and others (1982) and Wykoff (1986). Models were parameterized for: western white pine, western larch, Douglas-fir, grand fir, western hemlock, western redcedar, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine and mountain hemlock. The relevant national forests are Bitterroot, Clearwater, Coeur d'Alene, Colville, Flathead, Kaniksu, Kootenai, Lolo, Nezperce, and St. Joe (*fig. 4*).

Large tree height growth is a function of height, DBH, site factors, and predicted diameter growth. The static crown ratio model is a function of basal area, CCF, DBH, height and the tree's basal area percentile.

As with other variants, small tree growth is driven by a separate height growth function for trees less than 2 inches DBH. For trees between 2 and 10 inches, the small tree predicted height growth is combined with the large tree estimate.

Large tree growth is driven by a squared diameter-inside-bark 10-year growth equation. One important characteristic of this function, and the variant as a whole, is that site index is not a factor used to forecast growth. Rather, site productivity is reflected in variables such as slope, aspect, elevation, location, and habitat type. Habitat type is input into the simulator by a three-digit code which is used in diameter growth, crown ratio, and height growth equations (*table 11*).

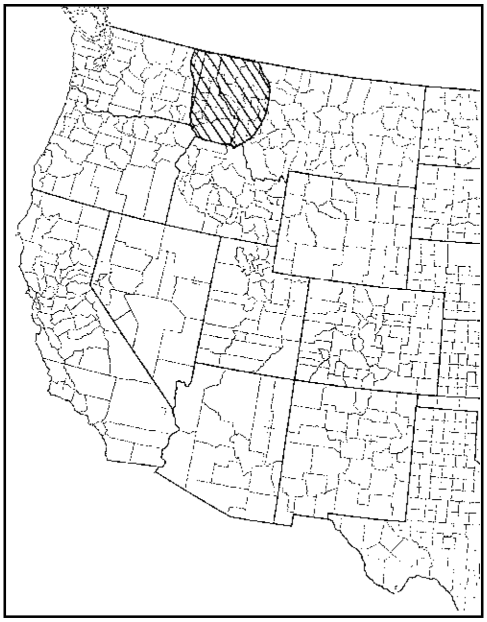

Figure 4—Geographic range of the Inland-Empire variant of the Forest Vegetation Simulator.

Table 11–*Habitat types and associated codes for the Inland Empire variant of the Forest Vegetation Simulator (Wykoff and others 1982).*

Code	Abbreviation	Habitat type name
130	PIPO/AGSP	*Pinus ponderosa/Agropyron spicatum*
170	PIPO/SYAL	*Pinus ponderosa/Symphorocarpus albus*
250	PSME/VACA	*Pseudotsuga menziesii/Vaccinium caespitosum*
260	PSME/PHMA	*Pseudotsuga menziesii/Physocarpus malvaceus*
280	PSME/VAGL	*Pseudotsuga menziesii/Vaccinium globulare*
290	PSME/LIBO	*Pseudotsuga menziesii/Linnaea borealis*
310	PSME/SYAL	*Pseudotsuga menziesii/Symphorcarpus albus*
320	PSME/CARU	*Pseudotsuga menziesii/Calamagrostis rubescens*
330	PSME/CAGE	*Pseudotsuga menziesii/Carex geryeri*
420	PICEA/CLUN	*Picea/Clintonia uniflora*
470	PICEA/LIBO	*Picea/Linnaea borealis*
510	ABGR/XETE	*Abies grandis/Xerophyllum tenax*
520	ABGR/CLUN	*Abies grandis/Clintonia uniflora*
530	THPL/CLUN	*Thuja plicata/Clintonia uniflora*
540	THPL/ATFI	*Thuja plicata/Athyrium filiz-femina*
550	THPL/OPHO	*Thuja plicata/Oplopanax horridum*
570	TSHE/CLUN	*Tsuga heterophylla/Clintonia uniflora*
610	ABLA/OPHO	*Abies lasiocarpa/Oplopanax horridum*
620	ABLA/CLUN	*Abies lasiocarpa/Clintonia uniflora*
640	ABLA/VACA	*Abies lasiocarpa/Vaccinum caespitosum*
660	ABLA/LIBO	*Abies lasiocarpa/Linnaea borealis*
670	ABLA/MEFE	*Abies lasiocarpa/Menziesia ferruginea*
680	TSME/MEFE	*Tsuga mertensiana/Menziesia ferruginea*
690	ABLA/XETE	*Abies lasiocarpa/Xerophyllum tenax*
710	TSME/XETE	*Tsuga mertensiana/Xerophyllum tenax*
720	ABLA/VAGL	*Abies lasiocarpa/Vaccinium globulare*
730	ABLA/VASC	*Abies lasiocarpa/Vaccinium scoparium*
830	ABLA/LUHI	*Abies lasiocarpa/Luzula hitchcockii*
850	PIAL/ABLA	*Pinus albicaulis/Abies lasiocarpa*
999	OTHER	

Klamath (5)

Primary Species:
- California black oak
- Douglas-fir
- Pacific madrone
- Ponderosa pine
- Tanoak
- White fir

Geographic Range:
Southwestern Oregon and northwestern California

Site Index/Productivity
site index reference varies by species

The Klamath variant of FVS (Dixon and Johnson 1993) was developed for the Klamath, Six Rivers, Siskiyou, and western Shasta-Trinity National Forests (*fig. 5*). Data were also provided by Hoopa Indian Reservation and Simpson Timber Company. The simulator incorporates some of the models presented by Dolph (1988a) for the WESSIN variant. The simulator operates on a 5-year forecasting interval. Height growth and diameter growth models use site index as one of the input variables (*table 12*). In addition, the diameter growth model requires elevation and slope. As with other FVS variants, there are separate models for small and large trees. The cutoff between large and small trees models is 3 inches DBH.

The data used in model development were heavily weighted to the smaller diameter classes. Primary tree species in the modeling data base are Douglas-fir and tanoak. Other hardwoods and conifers were not as well represented (*table 13*). For Douglas-fir, two thirds of the trees were less than 15 inches DBH. For ponderosa pine, 92 percent of the trees were less than 15 inches DBH. There was a very even representation of Douglas-fir for stands below 4,000 feet in elevation. However, ponderosa pine was limited primarily to stands above 2,000 feet in elevation.

Figure 5—Geographic range of the Klamath variant of the Forest Vegetation Simulator (Dixon and Johnson 1993).

Table 12–*Site index references for the Klamath variant of the Forest Vegetation Simulator (Dixon and Johnson 1993).*

Species	Reference
Douglas-fir, other conifers	King (1966)
White fir, incense cedar, red fir	Dolph (1987)
Pacific madrone	Porter and Wiant (1965)
California black oak	Powers (1972)
Tanoak	Porter and Wiant (1965)
Sugar pine, ponderosa pine	Powers and Oliver (1978)

Table 13—*Distribution of number of trees by species for the Klamath variant of the Forest Vegetation Simulator modeling effort (Dixon and Johnson 1993).*

Species	Number of trees
Douglas-fir	6,502
White fir	297
Pacific madrone	467
California black oak	198
Tanoak	2,376
Ponderosa pine	389

Pacific Northwest Coast (6)

Primary Species:	Geographic Range:	Site Index/Productivity:
• Douglas-fir • Western hemlock	Coast range of Oregon and Washington	Unknown

At this time, the Pacific Northwest Coast variant is an early release and is still being tested. The geographic range is displayed in *figure 6*.

Large tree diameter increment is forecast as a function of site index, elevation, slope, aspect, location (National Forest indicator), DBH, crown ratio, stand basal area, point CCF, and relative height. Height growth is a function of potential and a modifier. The potential height growth is determined by height and site index. The modifier is expressed as a function of crown ratio and relative height.

Figure 6—Geographic range of the Pacific Northwest Coast variant of the Forest Vegetation Simulator.

SORNEC (7)

Primary Species:	Geographic Range:	Site Index/Productivity:
• Douglas-fir • Incense-cedar • Lodgepole pine • Mountain hemlock • Red fir • Sugar pine • Western white pine	Southern Oregon and northeastern California	Site index varies by species

The south-central Oregon/northeastern California (SORNEC) variant of FVS was developed for a region dominated by interior ponderosa pine type and lodgepole pine type forests. Data for the SORNEC variant came primarily from National Forest inventories ranging from the Lassen National Forest in the south to the Deschutes National Forest in the north (Dixon 1992). Additional data from research plots were provided by the Pacific Northwest and Pacific Southwest Research Stations. The geographic range of the simulator is illustrated in *figure 7*.

Ponderosa pine, lodgepole pine, and white fir are well represented in the modeling data base (*table 14*). Seven other species were also present on far fewer plots. *Table 15* shows the number of plots in the modeling data base by National Forest. A total of 23,143 tree records from 1,500 sample plots were used. The actual ranges of heights and diameters of these trees have not been published, but given the number of plots and the number of tree records observed, these should reflect a broad range of tree sizes and stand conditions.

The establishment model (Ferguson and Crookston 1991) guides establishment of trees up to the time of a tally. From this point until a tree reaches 3 inches DBH, the small tree submodel is responsible for forecasting tree growth. Growth forecasts of trees greater than 3 inches DBH employ the large tree submodel.

Height growth is the primary driving function for growth of small trees. As with some other FVS variants there is actually an averaging of the forecasts from the small-tree and large-tree height growth models falling within a transition range. The average is weighted in such a way that trees near the low end of this diameter range have a growth prediction that is weighted more heavily toward the estimate from the small tree model. For trees near the high end of the range, the opposite is true. For SORNEC, this transition range is 2 to 4 inches DBH for most species. Exceptions are ponderosa pine and red fir (2 to 6 inches) and lodgepole pine (1 to 5 inches). A diameter-height relationship is used to predict diameter growth as a function of predicted height growth for trees less than 3 inches DBH.

The growth interval for the large tree submodel is 10 years, and logarithm of diameter squared increment is the primary driving function. In the large tree model, diameter growth is forecast as a function of location, slope, aspect, site index, elevation, DBH, crown ratio, basal area in larger trees, point-level CCF, stand-level CCF, relative height (H/HT40) and stand potential MAI (derived from yield table values). Height growth is a potential-modifier type of function. The potential growth is derived from site-age-height relationships (*table 16*). The modifier function adjusts potential growth as a function of relative height and crown ratio.

Mortality is guided by an approach to a maximum size-density relationship (85 percent of the maximum SDI). The default maximum SDI values in SORNEC are shown in *table 17*. As with other FVS variants these values may be changed by the user in order to modify rates of mortality.

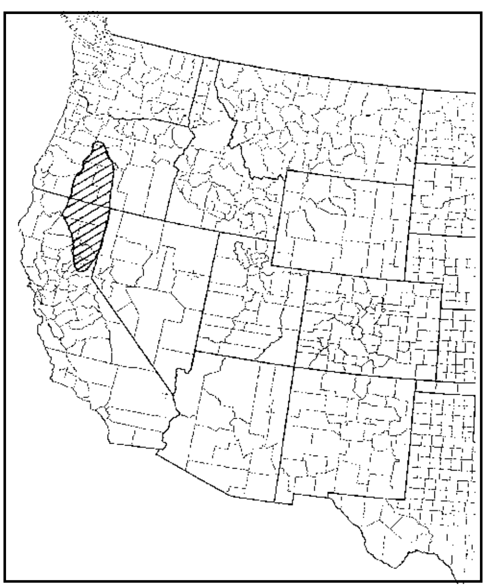

Figure 7—Geographic range of the SORNEC variant of the Forest Vegetation Simulator.

Table 14—*Number of trees with growth measurements used in the SORNEC modeling effort (Dixon 1992).*

Species	Number of trees
Western white pine	260
Sugar pine	326
Douglas-fir	717
White fir	5,797
Mountain hemlock	783
Incense-cedar	511
Lodgepole pine	3,416
Englemann spruce	31
Red fir	1,216
Ponderosa pine	10,038

Table 15—*Number of plots with given species present displayed by source for the southern Oregon/northeastern California variant of the Forest Vegetation Simulator (Dixon 1992).*

Species	Deschutes NF	Winema NF	Fremont NF	Klamath NF	Modoc NF	Lassen NF	Other
Western white pine	37	32	13	0	26	11	0
Sugar pine	3	35	13	0	2	44	1
Douglas-fir	51	76	1	2	0	25	4
White fir	88	167	181	19	170	165	9
Mountain hemlock	79	16	2	0	5	1	0
Incense-cedar	10	23	40	0	24	52	4
Lodgepole pine	360	102	79	5	39	34	2
Englemann spruce	9	3	0	0	0	0	0
Red fir	37	74	2	4	50	25	0
Ponderosa pine	377	203	261	29	292	177	68

Table 16—*Site index sources for the southern Oregon/northeastern California variant of the Forest Vegetation Simulator (Dixon 1992).*

Species	Reference
Western white pine	Brickell (1970)
Sugar pine	Barrett (1978)
Douglas-fir	Cochran (1979a)
White fir	Cochran (1979b)
Mountain hemlock	Not available
Incense-cedar	Cochran (1979b)
Lodgepole pine	Dahms (1964)
Engelmann spruce	Alexander (1967)
Red fir	DeMars and others (1970)
Ponderosa pine	Barrett (1978)
Other	Cochran (1979a)

Table 17–*Maximum Stand Density Index (SDI) (Reineke 1933) values for the southern Oregon/northeastern California variant of the Forest Vegetation Simulator.*

Species	Region 5		Region 6	
	Max. SDI	85 percent of max.	Max. SDI	85 percent of max.
Western white pine	624	530	447	380
Sugar pine	647	550	447	380
Douglas-fir	547	465	447	380
White fir	759	645	659	560
Mountain hemlock	624	530	758	644
Incense-cedar	706	600	447	380
Lodgepole pine	406	345	541	460
Englemann spruce	671	570	659	560
Red fir	800	680	659	560
Ponderosa pine	571	485	429	365

West Cascades (8)

Primary Species:
- Alaska yellow-cedar
- Douglas-fir
- Engelmann spruce
- Grand fir
- Incense-cedar
- Lodgepole pine
- Noble fir
- Pacific silver fir
- Ponderosa pine
- Red alder
- Shasta red fir
- Subalpine fir
- Sugar pine
- Western hemlock
- Western redcedar
- Western white pine
- White fir

Geographic Range:
Western Cascades of Oregon and Washington

Site Index/Productivity:
Site index reference varies by species

The West Cascades FVS variant was developed for forests of the western slope of the Cascade range throughout Oregon and Washington (*fig. 8*). Data were obtained from six National Forests: Gifford Pinchot, Mt. Baker/Snoqualmie, Mt. Hood, Rogue River, Umpqua, and Willamette. The primary species in the data base were Douglas-fir, western hemlock, mountain hemlock, and Pacific silver fir; however, a number of other species were represented (*table 18*).

As with other variants, there are separate submodels for small trees and large trees. Presumably there is also an establishment submodel for simulating plantings and natural regeneration, but this is not documented by Johnson (1992). The small-tree model, for trees less than 3 inches DBH, has height growth as its primary driver. Diameter growth is derived from the predicted height growth model. Small-tree height growth is forecast as a function of point-level CCF, basal area per acre, and crown ratio. The large-tree submodel has diameter

Table 18—*Percent distribution of sample trees by National Forest used in model development for the West Cascades variant of the Forest Vegetation Simulator (Johnson 1992).*

Species	Code	Gifford Pinchot NF	Mt. Baker Snoqualmie NF	Mt. Hood NF	Rogue River NF	Umpqua NF	Willamette NF	Number of observations
Pacific silver fir	SF	12	24	33	0	4	28	3,878
White fir	WF	4	0	35	28	21	11	1,044
Grand fir	GF	4	0	35	28	21	11	504
Subalpine fir	AF	28	12	18	1	23	19	227
California red fir	RF				75	25	0	44
Shasta red fir					75	25	0	515
Noble fir	NF	4	3	32	2	17	43	1,555
Alaska yellow-cedar	YC	7	46	19			28	112
Western larch	L							74
Incense-cedar	IC							296
Englemann spruce	ES	4	1	13	17	36	29	209
Sitka spruce	SS							2
Lodgepole pine	LP	5		30	8	44	13	898
Sugar pine	SP							240
Western white pine	WP	2	0	9	11	46	33	414
Ponderosa pine	PP	2		67	14	15	2	432
Douglas-fir	DF	9	5	20	4	23	40	17,250
Western redcedar	RC	8	24	28		3	37	1,354
Western hemlock	WH	8	24	31	1	6	30	5,008
Mountain hemlock	MH	3	7	16	3	22	49	3,019
Bigleaf maple	BM							89
Red alder	RA	11	23	52		6	7	125
White alder	WA							2
Pacific madrone	PM							70
Giant chinkapin	GC							62
Tanoak	TO							1
Black cottonwood	CO							8
Oregon white oak	WO							12
California black oak	CB							4
Whitebark pine	WB							2
Pacific yew	PY							5

growth as a primary driver. The predictor variables for the diameter growth function are location, site index, elevation, aspect, slope, DBH, crown ratio, and basal area in larger trees. Site index references are shown in *table 19*. Large tree height growth is obtained from potential-modifier type of function with height, crown ratio and relative height (height divided by HT40) in the modifier function.

Mortality is derived from an approach to maximum SDI (Reineke 1933); however, the default maximum values are not presented in the documentation. As with other FVS variants, the user may modify mortality rates by specifying the maximum SDI value to be used for any given species in the stand. Raising the default SDI value will delay the onset of mortality and result in denser stands forecast over long periods of time, and lowering it will have the opposite effect. The zone of imminent mortality is at 55 percent of maximum SDI.

Figure 8—Geographic range of the West Cascades variant of the Forest Vegetation Simulator (Johnson 1992).

Table 19—*Site index references, by species, for the West Cascades variant of the Forest Vegetation Simulator (Johnson 1992).*

Species	Reference
Pacific silver fir	Hoyer and Herman (1989)
Grand fir	Cochran (1979)
Subalpine fir	Alexander (1967)
Red fir	Dolph (1991)
Noble fir	Herman and others (1978)
Engelmann spruce	Alexander (1967)
Alaska yellow-cedar	Curtis (1974)
Lodgepole pine	Dahms (1964)
Ponderosa pine	Barrett (1978)
White pine	Curtis (1990)
Douglas-fir	Curtis (1974)
Western hemlock	Wiley (1978)
Mountain hemlock	Not available
Red alder	Worthington and others (1960)

WESSIN (9)

Primary Species:
- Douglas-fir
- Incense-cedar
- Jeffrey pine
- Lodgepole pine
- Ponderosa pine
- Sugar pine
- White fir

Geographic range:
Western Sierra Nevada of California

Site Index/Productivity:
Dunning (1942) for most species

WESSIN is the western Sierra Nevada variant of FVS. Data for the modeling effort were obtained from National Forest inventory and the growth analysis data of Dolph (1988a, 1988b). The original models developed by Dolph have undergone some revision with additional data. The geographic range for the WESSIN variant is the west side of the Sierra Nevada (Dixon 1994) as shown in *figure 9*.

The distribution of growth sample trees by species for the FVS WESSIN variant is shown in *table 20* (Dixon 1994). The WESSIN documentation presents models with parameter estimates but does not go into any detail on ranges of data. For greater detail, users may refer to Dolph (1988a, 1988b). *Table 21* shows the diameter distribution, by species, of trees used by Dolph (1988a) in fitting the basal area increment model.

The establishment submodel handles trees from establishment (from planting or natural regeneration) until a tally is made. From that point on, tree growth is guided by the functions in the small-tree submodel. In this submodel, height growth is the primary driving function. The small-tree height growth function forecasts tree growth as a function of basal area in larger trees, site index, and crown ratio for most conifers. The function for Douglas-fir, giant sequoia, red and white fir is similar but does not have site index. The black oak and tanoak functions forecast height increment as a function of basal area in larger trees only for trees from 2 to 3.5 inches DBH, the small tree height growth prediction is averaged with the

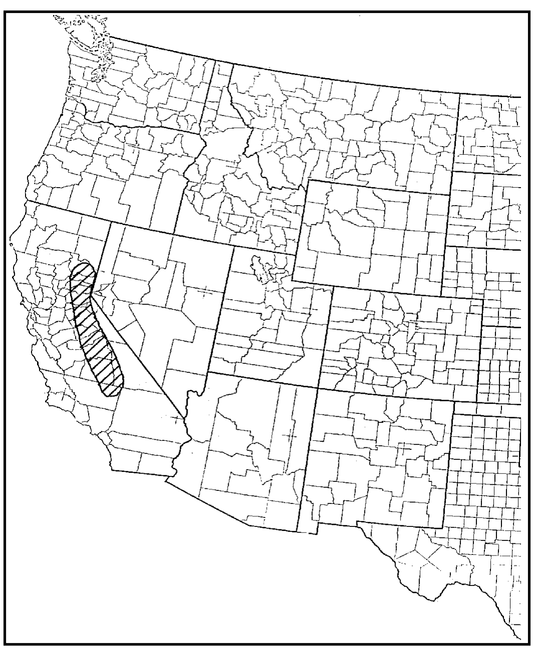

Figure 9—Geographic range of the WESSIN variant of the Forest Vegetation Simulator (Dixon 1994).

Table 20—*Number of diameter growth and height growth measurements available for the western Sierra variant of the Forest Vegetation Simulator (Dixon 1994).*

Species	Diameter growth	Height growth
White fir	3,301	407
Incense-cedar	1,339	208
Douglas-fir	480	46
Ponderosa pine	1,528	158
Sugar pine	650	68
Jeffrey pine	1,144	31
Lodgepole pine	419	0
Total	8,861	918

large-tree model to produce a smooth transition between the two. Diameter increment for trees less than 3 inches DBH is derived from a simple linear DBH-height relationship.

For trees larger than 3 inches DBH, growth forecasts are made on a 5-year interval, with diameter increment as the primary driver. The diameter increment function employs DBH, point-level basal area in larger trees, stand basal area, point-level CCF, crown ratio, elevation, slope, aspect, site index, and a location code as predictor variables. The height growth function uses predicted diameter increment, stand basal area, basal area increment, crown ratio, elevation, slope, site index, and a location code as predictors.

Mortality is derived from an approach to maximum stand density index. The zone of imminent mortality threshold is at 55 percent of maximum stand density index, and stands tend to track toward a level of 85 percent of maximum stand density index. Users may change default maximum values for SDI (*table 22*).

Table 21–*Distribution of trees by species and DBH (inches), used in development of the basal area increment model for the western Sierra variant of the Forest Vegetation Simulator (Dolph 1988a).*

DBH	Number of Trees					
	White fir	Incense-cedar	Ponderosa pine	Sugar pine	Jeffrey pine	Douglas-fir
0-4.9	160	144	38	17	8	22
5.0-9.9	495	278	148	54	25	55
10.0-14.9	455	165	133	58	32	45
15.0-19.9	253	46	122	39	27	9
20.0-24.9	109	36	51	17	12	6
25.0-29.9	35	9	24	8	6	3
30.0+	19	24	23	13	4	3
Total	1,526	702	539	206	114	143

Table 22—*Default maximum Stand Density Index (SDI) (Reineke 1933) values for mortality functions in the western Sierra variant of the Forest Vegetation Simulator.*

Species	Maximum SDI	55 pct of max. SDI	85 pct of max. SDI
Other conifers	624	343	530
Sugar pine	647	356	550
Douglas-fir	547	301	456
White fir	759	417	645
Giant sequoia	588	323	500
Incense-cedar	706	388	600
California black oak	382	210	325
Jeffrey pine	571	314	485
Red fir	800	440	680
Ponderosa pine	571	314	485
Tanoak	759	417	645

CRYPTOS (10)

Primary Species:	Geographic Range:	Site Index/Productivity:
• Redwood • Douglas-fir	Coast range of northern California	Krumland and Wensel (1977)

CRYPTOS (California Redwood Yield Project's Timber Output Simulator) is similar to CACTOS in overall design and model forms. The design and philosophical underpinnings of the model are described by Krumland and Wensel (1980). Execution of the model is described by Krumland and Wensel (1982) and Wensel and others (1987).

The CRYPTOS simulator was developed for the north coast of California. All of the stands were within the redwood/Douglas-fir type. Species-specific models were developed for redwood, Douglas-fir and tanoak. Other conifers (e.g., grand fir) are assumed to have the growth form of Douglas-fir.

The modeling data were obtained from permanent and temporary growth plots in Mendocino, Humboldt and Del Norte counties. Trees sampled for growth model development were Douglas-fir (8,168), coast redwood (2,280), alder (26), and tanoak (626) (Krumland 1982).

Data were obtained from 412 plots, and 70 percent of these were from the coastal zone that is subject to fog influence. These stands were predominantly composed of young growth timber, but 15 percent had at least one residual old-growth tree. Approximately 25 percent had been subjected to some form of partial harvest prior to growth measurements (Krumland 1982). Model form and results of analysis for redwood, Douglas-fir, and tanoak are presented by Krumland and Wensel (1981).

Execution of CRYPTOS is very similar to that of CACTOS. One notable difference is that CRYPTOS is capable of accepting input from fewer species (Krumland and Wensel 1982). CRYPTOS requires a tree list with species, DBH, total height, live crown ratio, and expansion factor (trees per acre) for each tree, as well as site index, in an ASCII file with format similar to that of CACTOS. As with CACTOS, a utility is provided to fill in missing values and, if necessary, develop a tree list from stand basal area and number of trees per acre.

Requirements for the simulator are DOS version 2.1 or later, at least 320K of RAM, math coprocessor, and hard disk sufficient in size to handle the CRYPTOS files.

Additional references for CRYPTOS are listed in *appendix C*. The most recent version is CRYPTOS v7.8. Purchasing information on the University of California, Berkeley's Web site: **http://www.cnr.berkeley.edu/~wensel/cryptos/crypt.htm**

CACTOS (11)

Primary Species:	Geographic Range:	Site Index/Productivity:
• Douglas-fir • Incense-cedar • Ponderosa pine • Red fir • Sugar pine • White fir	Mixed conifer region of northern California	Biging (1985)

CACTOS (CAlifornia Conifer Timber Output Simulator) is a mixed-conifer growth and yield simulator for northern California (Wensel and others 1986). This simulator is the result of a cooperative research effort. CACTOS is actually a suite of programs produced by researchers at the University of California. CACTOS itself is an interactive simulator that allows users to simulate the growth of sampled mixed conifer stands. Provided along with CACTOS are a number of related utility programs: STAG (a stand generation routine which allows users to fill in missing data), COMPARE (a routine which allows for comparison of actual and predicted yield for either CACTOS or CRYPTOS), YDAVG (produces average yields or summaries of average stocking condition for strata or management units), and SDAVG (a program for obtaining diameter distributions, stand and stock tables of sampled stands).

Data were obtained from permanent sample plots distributed throughout the northern Sierra Nevada, southern Cascades, and southern Klamath Mountains of California (*fig. 10*).

Data were provided by private landowners; there were no Forest Service data used in development of the CACTOS growth equations. However, development of the taper equations did include Forest Service data.

The primary trees species are ponderosa pine, sugar pine, Douglas-fir, white fir, red fir, and incense-cedar. In addition, the simulator will accept input of lodgepole pine, western white pine, Jeffrey pine, miscellaneous conifers, chinkapin, California black oak, tanoak, and miscellaneous hardwoods.

Tables 23 and *24* show a range of tree sizes used in the growth modeling effort. A broader range of tree heights and diameters was reflected in the diameter growth modeling effort than in height growth. However, since the height growth model is bounded by the potential height growth reflected in dominant height curves, these height growth models should be fairly robust to extrapolation beyond the range of heights shown in *table 23*.

To execute the simulator you will need to provide a stand description input file. This file contains a stand identifier, the number of tree records sampled, site index for each species present (up to 14), breast-height ages associated with each species sampled, and a list of sampled trees with the following data for each tree: species code, DBH (in inches), total height (in feet), live crown ratio (decimal fraction) and per-acre expansion factor. The user may also provide the simulator with information on ingrowth, user-defined calibrations, and species grouping for output. Execution is described in the user's guide (Wensel and others 1986) provided with the simulator.

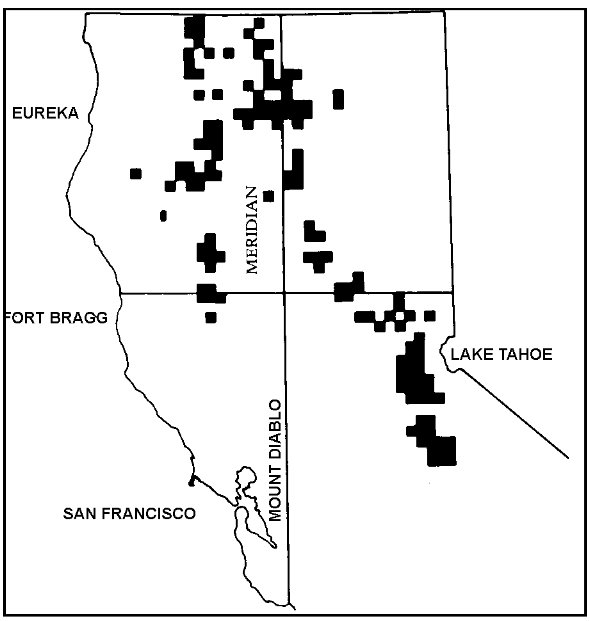

Figure 10—Geographic range of permanent plots used in the development of CACTOS (Wensel and others 1987).

Table 23—*The ranges of heights (feet) and site index values (feet) for the CACTOS height growth models presented in Wensel and others (1987).*

Species	Ht min.	Ht max.	Site min.	Site max.	No. of observations
Ponderosa pine	22	143	57	123	151
Sugar pine	38	121	54	119	47
Douglas-fir	30	141	55	116	145
White fir	13	122	51	115	279
Red fir	40	97	61	73	37
Incense-cedar	16	79	70	70	71

Table 24— *Ranges of height (feet) and breast height diameter (inches) for trees used in modeling diameter growth for CACTOS (Wensel and others 1987).*

Species	Ht min.	Ht max.	DBH min.	DBH max.	No. of observations
Ponderosa pine	0	184	0	41	2,064
Sugar pine	0	171	0	50	905
Douglas-fir	0	170	0	40	1,465
White fir	0	168	1	41	3,123
Red fir	5	154	1	51	579
Incense-cedar	4	182	1	67	1,138

If height and live crown ratio are not measured, these missing values may be filled in using the STAG program provided with the simulator. There are two modes, one for filling in missing tree data for which, as minimum, the species code, DBH and expansion factor must be given for all trees. In the second mode, stand descriptions can be created from summary information: basal area per acre and number of stems per acre for trees greater than 6 inches DBH for each species separately.

The simulator requires that simulations be made for trees on a plot-by-plot basis. If the user has a stand with 10 plots, these are run separately and a yield stream for the stand is generated by averaging the individual plot projections with a post processor called YDAVG. The growth increment is estimated for a 5-year period.

CACTOS allows the user to specify thinnings from the very simple to the very complex. The user may choose from four alternative cutting algorithms: (1) DBH control, (2) basal area control, (3) sanitation cut, and (4) a free cut. The sanitation cut allows the user to specify trees to be removed on the basis of live crown ratio. The free cut allows the user to specify any combination of variable-width diameter classes and harvest from any of these classes according to live crown ratio or DBH. Basal area control allows the user to specify a target basal area (to leave or to cut) and then to thin from above or below to this target. The DBH control allows the user to thin to any proportion of trees by diameter class.

The simulator is provided at no charge to members of the CACTOS cooperative. Others may purchase the simulator, copies of the user's guide and other CACTOS research notes for a nominal fee.

The most recent version is CACTOS v6.3. CACTOS comes with the stand generator (STAG v4.3) and utility programs. DOS version 2.1 or later and 320K RAM, a math coprocessor and hard disk space sufficient for all files, are required for installation. Additional references on CACTOS are listed in *appendix D*. For more information contact:

Professor Lee Wensel, Department of Environmental Science Policy & Management, 145 Mulford Hall, University of California, Berkeley CA 94720-3114
Web site: **http://www.cnr.berkeley.edu/~wensel/cactos/cactoss.htm**

SPS (12)

Primary Species:	**Geographic Range:**	**Site Index/Productivity:**
• Dependent on variant	Dependent on variant	Zeide (1978)

SPS is an individual-tree simulator originally developed for Douglas-fir in Oregon and Washington (Arney 1985). Although classed as an individual-tree simulator, SPS will allow users to input stand data at a number of levels of resolution: stand average values, stand table values, or a tree list. If stand averages are input, the simulator will generate a tree list internally.

Unlike most other individual-tree simulators, SPS is age-dependent through the top height function which drives all projections in the simulator. If age is not known, SPS will calculate an effective age from top height and the top height growth form (site index). This effectively makes SPS an even-aged stand simulator, since age for uneven-aged stands is a meaningless number.

SPS will allow users to evaluate both thinning and fertilizer response. Thinnings maybe done from above, from below, or to a target d/D ratio. Fertilizer applications may be simulated at rates between 0 and 400 pounds elemental nitrogen per acre.

SPS is adapted to other species by modifying the form of the top-height function. The simulator does not operate on a fixed forecasting time step; growth increments are presented in approximately equal steps of height increment (12 to 15 feet).

Five functions are employed for any given forecast:

1. Top height growth as a function of breast height age and site index, where top height is defined as the height of the 40 largest diameter trees per acre (HT40).
2. Breast height diameter growth as a function of top height, relative tree size, crown ratio, and CCF.
3. Height growth as a function of top height, relative height, crown ratio, and CCF.

4. Survival as a function of relative tree size, crown ratio and CCF.
5. Tree volume derived from taper functions.

The mortality function forecasts mortality rates for each diameter class as a function of CCF, crown ratio, and diameter.

Site productivity enters the model in the form of a site index value as derived using Zeide's (1978) principle of two points. Zeide's method uses two user-supplied height-age pairs separated by at least 20 years to index to a specific top height curve form.

The simulator comes with a comprehensive list of acceptable species and their associated coefficients (*table 25*), although the source of these coefficients is not presented. The species codes are indexed by geographic region. It should also be noted that not all species codes are presented for all geographic regions of the simulator because not all species occur in all regions.

The primary reference for the simulator is the SPS User's Guide (most recent version is 2.4). The current version of the simulator is Version 4.0. SPS requires an IBM compatible with DOS (version not specified) and will emulate a math coprocessor if one is not available. The SPS simulator is distributed and maintained by Mason Bruce and Girard. For more information see their web site: **http://www.masonbruce.com**

Table 25—*Acceptable species codes for SPS by geographic region. Source: SPS User's Guide, Mason Bruce & Girard and coefficient library file SPS.LIB. Region numbers (1-7) are those employed by SPS to index each geographic region.*

Species Code	Species	Regions[1]
DF	Douglas-fir	1,2,3,4,5,6
WH	Western hemlock	1,2,3,4,5,6
RC	Western redcedar	1,2,3,4,5,6
NF	Noble fir	1,4
SF	Pacific silver fir	1,5
GF	Grand fir	1,2,3,4,6
AF	Subalpine fir	1,2,3,6
SS	Sitka spruce	1,4,5
WP	Western white pine	1,2,3,4,5,6
LP	Lodgepole pine	1,2,3,4,5,6
RA	Red alder	1,4,5
WL	Western larch	1,2,3,6,7
PP	Ponderosa pine	1,2,3,4,6
ES	Engelmann spruce	1,2,3,6
MH	Mountain hemlock	1,2,5
BM	Bigleaf maple	1,5
QA	Quaking aspen	3,7
IC	Incense-cedar	4
SP	Sugar pine	4
AC	Alaska yellow-cedar	5
WF	White fir	5
CW	Black cottonwood	6
WS	White spruce	7
BS	Black spruce	7
JP	Jeffrey pine	7

[1] Regions appropriate for this simulator: Pacific northwest (1), inland northwest (2), western Montana (3), southwest Oregon/northern California (4), western British Columbia (5), interior British Columbia (6), Alberta, Saskatchewan, Manitoba (7).

SWO-ORGANON (13) and WWV-ORGANON (14)

Primary Species:
- California black oak (SWO)
- Douglas-fir (SWO&WWV)
- Giant chinkapin (SWO)
- Grand fir (SWO&WWV)
- Incense-cedar (SWO)
- Pacific madrone (SWO)
- Ponderosa pine (SWO)
- Sugar pine (SWO)
- Western hemlock (SWO)
- White fir (SWO)

Geographic Range:
Southwest Oregon mixed-conifer forests (SWO) and Western Willamette Valley (WWV)

Site Index/Productivity:
Hann and Scrivani (1987) for SWO
King (1966) for WWV

ORGANON is a simulator for mixed conifer stands developed at Oregon State University (OSU). There are two versions of the simulator embedded in the code: SWO and WWV (southwest Oregon and western Willamette valley respectively). Users select at run time which area is desired. SWO-ORGANON was developed with the support of a research cooperative. Data were obtained from the USDI Bureau of Land Management, USDA Forest Service, and private firms operating in southern Oregon.

The WWV-ORGANON models were developed using data from the OSU Forest Properties. The stands used to develop the WWV models are all located just west of Corvallis, Oregon, in the mid-Willamette Valley.

The diameter growth equations for the southwest Oregon version were developed using data from some 19,060 trees on which growth measurements were taken. The majority of these (11,974) were Douglas-fir (*table 26*).

Users need to provide the simulator with tree-level and stand-level data (Hann and others 1995). At the tree level, the simulator requires a sampled tree list with:

1. plot number,
2. species code (Forest Service three digit codes) (Curtis 1983)
3. DBH (in inches),
4. height (in feet),
5. live crown ratio (decimal fraction),
6. expansion factor (trees per acre) may be calculated by the simulator, given plot configuration, and
7. 5-year radial growth inside bark (inches).

At the stand level, the user must provide site index (Hann and Scrivani 1987) for Douglas-fir and ponderosa pine for SWO-ORGANON, or Douglas-fir alone (King 1966) for WWV-ORGANON. Optionally, the user may specify treatments of thinning, fertilization, and pruning.

Pruning to a given height may be targeted to trees of a given species and in a given diameter range. Pruning effects are reflected in the resulting change in crown ratio. Crown ratio is a key input variable in the driving functions for diameter growth, height growth, and mortality.

There are several harvest options. Among these are a diameter thin, basal area thin, SDI thin, and user code thin. The diameter thin allows thinnings specified for species based on an upper and lower DBH limit and percent removal (in terms of trees per acre). The basal area thin allows a thin to targeted basal area, with removal from above, below, or proportional to the diameter distribution. The SDI thin is similar to the basal area thin but the target is specified as SDI. The user code thinning allows removal of trees based on a user defined code associated with each tree.

Fertilizer application may be simulated for 200 pounds per acre. This management activity is restricted to even-aged stands less than 70 years old with at least 80 percent basal area in Douglas-fir. Fertilizer application may not be reapplied until three 5-year growth cycles have elapsed.

Model form and parameter estimates for the southwest Oregon height growth and diameter growth functions are presented by Ritchie and Hann (1990) and Hann and Larsen (1991). The western Willamette Valley version uses the same model forms, but different parameterizations (Zumrawi and Hann 1993).

There were six targeted species in southwest Oregon: Douglas-fir, white fir, grand fir, ponderosa pine, sugar pine, and incense-cedar. Diameter growth equations were also developed for western hemlock, bigleaf maple, California black oak, canyon live oak, giant chinkapin, tanoak, Pacific madrone, and Oregon white oak. There were no height growth equations for these secondary species. For these species, height growth is obtained from static height-diameter relationships. Target stands should have 80 percent basal area in Douglas-fir, grand fir, white fir, ponderosa pine, sugar pine, and incense-cedar. Stands sampled in southern Oregon (*fig. 11*) for SWO-ORGANON ranged from 900 to 5,100 feet in elevation and were dominated by the six targeted conifer species. Data ranges for trees used in diameter growth modeling are shown in *table 26* (Hann and Larsen 1991).

The WWV-ORGANON data base had 9,526 Douglas-fir trees and 595 grand fir trees in 136 stands sampled from the McDonald-Dunn Forest in northwest Oregon. DBH ranged from 4.1 to 87.1 inches for Douglas-fir, and 4.1 to 48.1 for grand fir. The diameter growth function forecasts diameter growth as a function of DBH, crown ratio, site index, basal area in larger trees, and stand basal area.

Height growth is the primary driving function in ORGANON, although predicted height growth is not a predictor variable in diameter growth. Height growth is forecast using a potential-modifier function The height growth modifier is a function of crown ratio and crown closure at tree height.

A PC with 386, or higher, CPU is required with a minimum of 2 MB of RAM and a hard disk. DOS 5.0 or higher is required.

ORGANON is available by mail or through the internet. The user's guide comes in the form of a WordPerfect file which can also be downloaded. Included on the ORGANON home page are answers to frequently asked questions and sample data files. All information on ORGANON, including instructions on downloading the current version, may be obtained through their World Wide Web home page:

http://www.cof.orst.edu/cof/fr/research/organon

Additional references are listed in *appendix E*.

Table 26–*Range of number of observations, DBH, crown ratio (CR), and site index in SWO-ORGANON data base (Hann and Larsen 1991).*

Species	No. of observations	DBH min.	DBH max.	CR min.	CR max.	Site min.	Site max.
Douglas-fir	11,974	0.3	83.8	0.02	1.00	54	141
Grand fir	942	0.8	48.9	0.01	1.00	59	124
Incense-cedar	1,008	0.2	66.3	0.05	1.00	55	124
Ponderosa pine	1,594	0.1	59.6	0.05	1.00	55	141
Sugar pine	350	1.1	59.9	0.10	1.00	54	127
Western hemlock	105	1.4	21.4	0.02	1.00	63	124
White fir	1,373	0.6	51.1	0.05	1.00	62	141
Bigleaf maple	41	1.9	19.8	0.13	1.00	76	141
California black oak	300	2.0	48.4	0.05	.96	55	121
Canyon live oak	89	2.4	9.2	0.08	1.00	54	108
Giant chinkapin	399	1.1	26.5	0.07	1.00	54	126
Pacific madrone	793	1.5	44.5	0.01	1.00	54	141
Oregon white oak	29	2.9	24.4	0.23	.64	55	80
Tanoak	63	1.3	11.8	0.18	.97	73	117

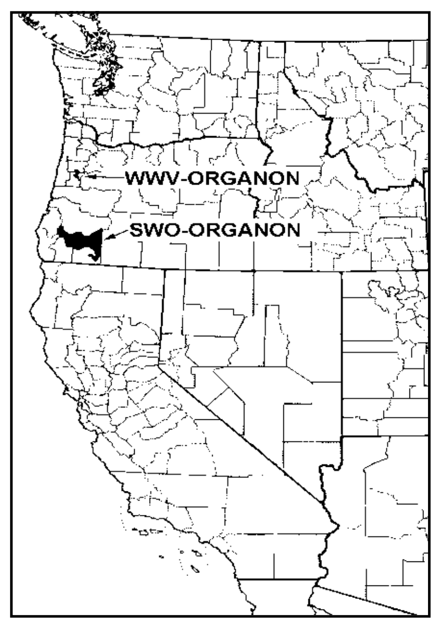

Figure 11—Geographic range of ORGANON.

SYSTUM-1 (15)

Primary Species:
- Douglas-fir
- Incense-cedar
- Ponderosa pine
- Sugar pine
- White fir

Geographic Range:
Mixed-conifer stands of southwestern Oregon and northwestern California

Site Index/Productivity:
Powers and Oliver (1978)

SYSTUM-1 is a simulator designed to simulate growth of young plantations in northern California and southern Oregon (Ritchie and Powers 1993). This is the result of a cooperative effort to produce a simulator geared towards young stand forecasts and the particular problems presented in simulating systems with both trees and shrubs. Data for parameter estimation were provided by private landowners, as well as the Forest Service and Bureau of Land Management.

The simulator is a prototype, developed using existing research data (permanent plots) and some plantation survey data. It was intended to illustrate the feasibility of modeling both trees and shrubs growing in competition with one another. The feature that separates SYSTUM-1 from many other simulators is the inclusion of competition from shrubs and grasses into the forecasts. The simulator requires input of a tree list and plot-by-plot descriptions of competing vegetation (species, percent cover and height).

Users are required to provide a sampled-tree list from the candidate plantation. This tree list may be in CACTOS, ORGANON, or free format (comma or space delimited). In addition to the tree list file, users are required to provide plot-level data on percent cover and height, by species, for competing vegetation. Site index (base age 50) is also required for the stand.

The model was originally intended for sampled stands from age 3 to about age 20. There are no age restrictions built in, but execution beyond age 25 or 30 is not recommended. Users can export a file from SYSTUM-1 in a form that may be read into either CACTOS, ORGANON or FVS (WESSIN, SORNEC and Klamath Variants) for simulation beyond this age limit.

Validation runs of the simulator (Powers and others 1989) indicated that the height growth models functioned well for stands less than 45 years of age. Diameter growth projections were found to be best for those stands where site index was known with some precision and where inter-tree competition is not a limiting factor for tree growth.

Users may specify management in the form of thinnings and reduction in the level of competing vegetation. Thinnings may be allocated by one of three different algorithms.

SYSTUM-1 does not have a record duplication scheme. Optimally, a random error term may be added to all tree height growth predictions. This is an important feature because of the very uniform nature of young plantations. The random error term facilitates forecasts with variation in tree size developing over time. Without this option, the simulator tends to produce forecasts of stand structure that are far too uniform.

The range of the of data used in development of this simulator is the northern Sierra Nevada, extending into the Cascades of southern Oregon, and the Klamath Mountains of northwestern California and southwestern Oregon.

The primary tree species in this simulator are ponderosa pine and Douglas-fir. Growth equations were also developed for sugar pine, incense-cedar, and white fir. Sample sizes for these three species were much smaller than those for ponderosa pine and Douglas-fir.

Execution of the simulator is interactive. SYSTUM-1 requires a tree list, but users may opt for a list generated from stand averages. Tree-level data input for SYSTUM-1 include:

1. plot number (integer), required
2. species (two letter code), required
3. DBH (inches), optional, may be filled in by the simulator
4. height (feet), required
5. crown ratio (decimal), optional
6. expansion factor (trees per acre), required, and
7. periodic annual height increment (feet), optional.

In addition, the user must input percent cover and height, by species, of competing vegetation for each plot. These values may be entered from the keyboard at runtime, or read from an ASCII file. The simulator will accept up to six species per plot.

The data ranges varied greatly across species and varied for the specific models being fit. For stands exceeding the recommended age range, established stand simulators such as CACTOS, ORGANON, or FVS should be considered.

Required hardware is a PC with DOS 3.0 or later version. A math coprocessor is not required but will speed execution of the simulator substantially. At least 400 K of RAM is required for execution. The simulator will operate under Microsoft Windows as well, although it does not take advantage of the graphical user interface or other features of Windows.

The most current version of the model is 2.14. It is provided at no charge to members of the cooperative. Nonmembers may make payment to:

Gary Nakamura, U. C. Cooperative Extension,
1851 Hartnell Avenue, Redding, CA 96002.

Additional information may be found on the World Wide Web site:
http://redding.psw.fs.fed.us/systum.html

RVMM: Individual-Tree (16)

Primary Species:	**Geographic Range:**	**Site Index/ Productivity:**
• Bitter cherry • California hazel • Douglas-fir • Red alder • Western hemlock • Vine maple	Coast range of Oregon and Washington, Cascades of Oregon and Washington	Shula 1998

RVMM (Regional Vegetation Management Model) is a simulator for young stands in western Oregon and Washington. There are two distinct segments to this simulator: an individual-tree simulator and disaggregative whole-stand simulator. The user may choose between the two at runtime.

Individual-tree RVMM maintains a list of trees for simulation. The acceptable species are bigleaf maple, bitter cherry, California hazel, cascara, Douglas-fir, red alder, western hemlock, vine maple, and willow. Breast height diameter is required input. Other variables (basal diameter, total height, crown width, height to crown base) are optional and, if missing, will be filled in by the simulator. Height to crown base and crown width apply only to Douglas-fir. Shrubs and herbaceous vegetation input is in the form of percent cover and height. Other input for execution includes site index (Shula 1998), plantation age, and years to breast height. Input may be either in metric or English units.

Management options include precommercial thinnings, simulated on a plant-by-plant basis. Users may also simulate release from competing vegetation by specifying either treatment efficacy or post-treatment percent cover and shrub height.

Files may be exported in the format of ORGANON, SPS, or FVS. The relevant variant of FVS has not been specified.

Data for model development include 3,455 tree growth records from 98 stands, 92 of these stands were less than 16 years old. Stands ranged in age from 1 to 20. Tree growth equations were developed for Douglas-fir, western hemlock, red alder, vine maple, California hazel, bitter cherry, and cascara.

The simulator requires Microsoft Windows 3.0 or Windows 95, a 486 or Pentium processor, and 7 megabytes of RAM.

Web site: **http://www.cof.orst.edu/cof/fr/research/organon/rvmm/rvmm_idx.htm**

CONIFERS (17)

Primary Species:	Geographic Range:	Site Index/Productivity:
• Deerbrush • Douglas-fir • Incense-cedar • Greenleaf manzanita • Pacific madrone • Ponderosa pine • Snowbrush • Sugar pine • Tanoak • White fir	Klamath Province	Soil depth, slope, aspect, and soil water holding capacity

This model is a result of a continuation of the young stand modeling effort that produced SYSTUM-1. The first version of this model is being parameterized for the Klamath Province of southwest Oregon and northern California.

The primary differences between this simulator and SYSTUM-1, besides the geographic range, are a more sophisticated front end and a more comprehensive data base for model development. Equations are being developed to simulate the growth of individual shrubs and hardwood trees as well as common species of conifers. It is expected that this will provide more reliable predictions of stand growth in response to changes in the levels of competing vegetation, particularly hardwood trees and shrubs.

More than 100 stands have been sampled in the Klamath Province of southwest Oregon and northwest California (*fig. 12*). The modeling data set includes more than 5,000 tree and shrub growth records. The geographic range of the data at this time is very similar to that of the Klamath version of FVS and overlaps most of the range of SWO- ORGANON.

Primary tree species include ponderosa pine, sugar pine, Douglas-fir, white fir, and incense-cedar. Other tree species present, although not as well represented in the data base, are Oregon white oak, California black oak, tanoak, and Pacific madrone.

The stands used in model development ranged from 3 to 26 years of age. Elevational range is approximately 2,000 to 5,000 feet. All stands are conifer plantations. A few of the selected stands have residual overstory trees.

A plant list is required to execute this simulator. Users will need to provide the simulator with a tree/shrub list for all woody vegetation on each plot in the sample. Shrubs that are not measured on a plant by plant basis may be input as percent cover and height by species for each plot. From this, the simulator generates a plant list for simulation.

The simulator currently operates on IBM compatibles with Windows 95. A Math coprocessor is required.

Access to documentation and the model is available through the World Wide Web site: **http://redding.psw.fs.fed.us/conifers.html**

Individual-Tree/Distance-Dependent Simulators: FPS, G-SPACE

Distance-dependent simulators require spatial coordinates of trees to execute growth forecasts; otherwise, they maintain a tree list in much the same manner as individual-tree/distance-independent simulators. The spatial coordinates are used to quantify inter-tree competition. Thus, growth forecasts are inter-tree distance-dependent. These models offer the potential for better thinning response and may better characterize inter-tree competition. However, they require more information to process and are generally more demanding of computer resources than distance-independent simulators.

Often these simulators will offer an option to generate spatial coordinates of trees. Under such a scenario, the user does not benefit from the information contained in actual spatial coordinates because none has been provided. The benefit then is in the structure of the simulator itself and the ability to derive, in theory, more reliable predictions from the tree list information.

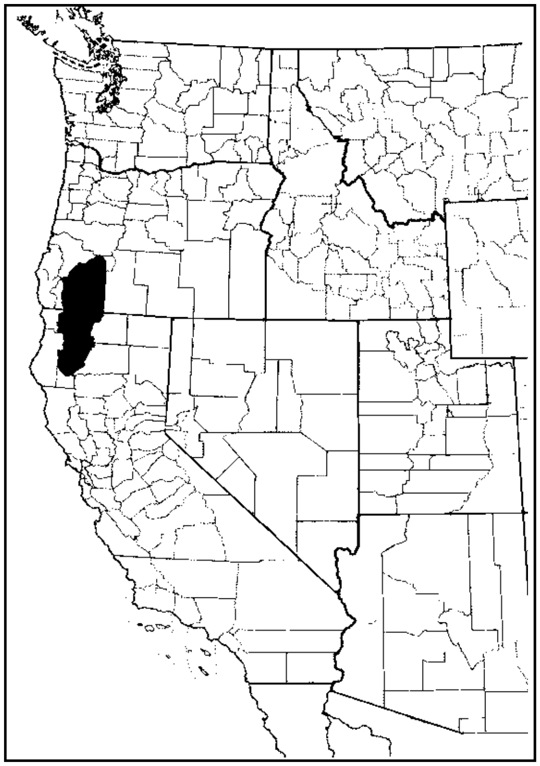

Figure 12—Geographic range of CONIFERS.

FPS (18)

Primary Species:	Geographic Range:	Site Index/Productivity:
• Douglas-fir • Red alder • Sitka spruce • Western redcedar • Western hemlock	Western Oregon and western Washington	May be specified by the user

The Forest Projection System (FPS version 5.3) is an individual-tree/distance-dependent growth simulator. FPS allows users flexibility in data input, in much the same fashion as SPS. Internally, the simulator grows a 0.1-hectare square plot. The simulator will accept observed x and y coordinates, but it will also generate coordinates for trees if coordinates are not supplied. The simulator will also accept stand summary information and is capable of disaggregating these data to a tree list internally. The usual application is to provide a stand table summary by species and 1-inch diameter classes.

The model is a Microsoft Windows application and maintains a link to a number of commercial data base packages which allows the simulator to pull data directly from an existing user data base. Users are not required to manipulate files directly for execution of the simulator. FPS can import either tree list or stand summary information directly from a commercial data base and generate forecasts accordingly. Another feature is the ability of this simulator to update data bases directly, facilitating easier simulations for large tracts of land.

There are two versions of this simulator (western Oregon and western Washington). The western Oregon version data base was dominated by Douglas-fir and western hemlock with lesser representation of western redcedar, red alder, and Sitka spruce. The composition of the western Washington data base was not available at the time of this writing.

The simulator will handle stands up to age 100.

Required hardware is a PC with 386, or higher CPU, and Microsoft Windows 3.1. For more information contact: Jim Arney at **jdarney@forestbiometrics.com,** or refer to the world wide web site: **http://www.forestbiometrics.com**

G-SPACE (19)

Primary Species:	**Geographic Range:**	**Site Index/Productivity:**
• White fir	Northern Sierra Nevada	Biging and Wensel (1985)

This is an individual-tree/distance-dependent model for white fir. Funding for this project was a result of a cooperative effort. The current version supports true fir. Future versions may be made available for ponderosa pine. As with all distance-dependent simulators, the model requires spatial coordinates of trees, although the model is capable of generating hypothetical spatial coordinates and thus facilitates predictions where spatial coordinates are not known.

Early work on the conceptual framework for this simulator is reported on by Cavallaro (1990). Tree volume growth equations are driven by a function for net assimilation rate which is a function of estimated leaf surface area and height (Cavallaro 1990).

Height growth is driven entirely by Biging and Wensel (1985) curves. These are dominant height curves developed for mixed conifer stands ranging in age from 10 to 100 years at breast height and site index values ranging from 35 to 131 feet. They do not reflect changes in height growth due to competition. That is, in this simulator, all trees assume height growth rates of dominant trees.

Data were collected from even-aged, pure, white fir stands in the northern Sierra Nevada. Sampled trees ranged from 65 to 120 feet in height; site index (Biging and Wensel 1985) ranged from 55 to 90 feet (at breast height age 50).

An IBM compatible PC with DOS 5.0 or higher, is required. Contact:

Dr. Janet Cavallaro, U.C. Department of Environmental Science,
Policy, and Management, 145 Mulford Hall, Berkeley, CA 94720.

Gap Simulators: CLIMACS, SILVA

Gap simulators are individual-tree based programs designed to simulate successional changes in forested ecosystems. As such, they are geared to producing descriptions of stand composition, in terms of number of trees by species, over long time horizons. They generally feature both mortality and ingrowth components. Gap simulators follow, to some degree, the concepts described by Botkin and others (1972). A distinguishing feature of this type of simulator is that trees are modeled on a specific fixed-area location in the stand, known as a gap. This gap typically is defined as an area corresponding to the area of the forest occupied by a fully mature tree. The assumed gap size is equal to the size of the sampled plot.

Gap simulators differ greatly in the foundational assumptions from most examples of individual-tree modeling found in the literature. Trees are treated as being located in or related to a gap in the forest canopy. Typically, gap simulators are driven by diameter growth. Height and crown ratio are not needed for input.

The gap simulator does not treat the tree as a representative of similar trees in the stand. Rather, in the gap simulator the forest is viewed as consisting of a number of gaps, or potential gaps, each of which is described by the tree or trees in that gap. Thus, each “gap” is described by a tree list associated with a plot. Thinning is generally not an option presented in these simulators because when trees die (or are harvested), they are, in effect, removed from the tree list altogether.

Another limitation of gap simulators is that they are not capable of accepting input in the form of trees sampled from nested and/or variable-radius plots. Some research also suggests that these models are sensitive to plot (gap) size selected (Shugart and West 1979). Since many forest survey sampling designs involve either variable-radius plots, nested fixed-area plots, or plots of a size which do not meet the definition of a “gap,” these simulators are poorly suited to forest growth and yield forecasts. They offer very little, if any, output of tree volume, and harvesting options are very limited.

Disturbance events, such as fire, may be integrated into some of these simulators and the growth models are more physiologically based than those driving many other types of growth and yield simulators. Ingrowth trees are brought into the simulation through a stochastic process. Mortality is also affected by removing trees from the tree list stochastically. There are no expansion factors. The expansion factor associated with any tree is an implied constant, based on the plot size. Output is related to per-unit area summaries by simply multiplying appropriate parameters by the expansion factor indicated by plot size, which remains static.

CLIMACS (20)

Primary Species:	Geographic Range:	Site Index/Productivity:
• N/A	Western Oregon and Washington	None

CLIMACS was derived from FORET (Shugart and West 1979). This simulator is like many other gap models in that it is intended to simulate successional patterns over long time horizons. It has no capability for growth and yield output such as volume by size class or species, and it is incapable of simulating the effects of any management activity other than clearcut harvest of trees. The model has been parameterized for four geographic regions of western Oregon and Washington (*fig. 13*).

Although a comprehensive list of species will be accepted by the simulator, the only five for which any data are reported are Douglas-fir, western hemlock, mountain hemlock, western redcedar, noble fir, and Pacific silver fir. Quadratic height-diameter functions are presented for these six species.

The simulator forecasts by annual steps and characterizes stands on the basis of individual trees greater than 3.9 inches (10 cm) breast height diameter. Trees are assumed to be sampled from a 0.5-acre (0.2-hectare) plot.

Regeneration is a stochastic event driven by species and leaf area index. Tree growth is essentially diameter-driven. All trees approach a chosen maximum diameter and height for the given species. Height growth is obtained from a density-independent quadratic height-diameter function. Diameter growth is affected by a position variable describing leaf area in trees taller than the subject tree.

The mortality function is diameter-driven and varies depending on the seral characteristics of a given species. Mortality may also be affected by disturbance events. Disturbance events recognized by the simulator are fire, windthrow, and clearcutting. No provision is made for partial cutting or other silvicultural treatments.

The code is maintained in the Forest Science Data Bank at: Forest Science Department, Oregon State University, Corvallis, OR 97331.

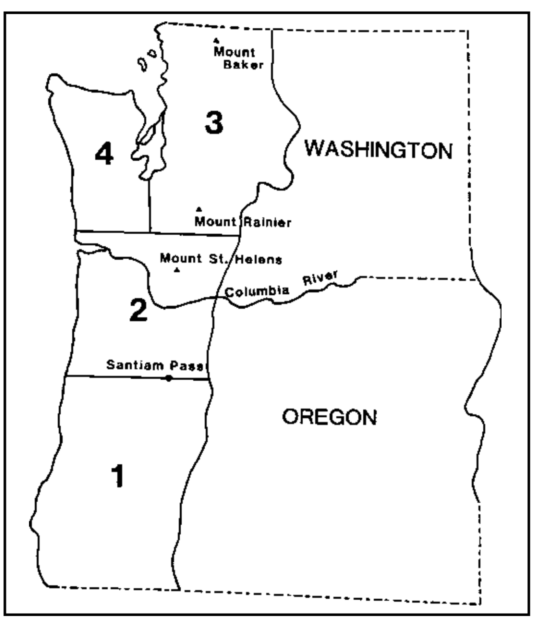

Figure 13—Four regions of the CLIMACS simulator.

SILVA (21)

Primary Species:	Geographic Range:	Site Index/Productivity:
• N/A	Sierra Nevada forests	Synthesis of climatic and edaphic factors

Silva (Kercher and Axelrod 1981, 1982, 1984) is a descendant of JABOWA (Botkin and others 1972). Silva was developed to investigate the possible effects of sulfur dioxide emissions on the composition of Sierra Nevada forests. Also integrated into the Silva model is a stochastic fire frequency model. This simulator was not built as a decision support tool and has evidently received little support or continued development by the authors.

Silva is stochastic with respect to certain discrete events such as mortality and birth of trees. Simulations must be repeated many times to obtain a forecast that represents some "central tendency." The model is deterministic with respect to growth of trees.

Growth is functionally linked to climatic and edaphic factors. Silva is driven directly by moisture and day length. This may facilitate evaluation of such factors as climate change and periodic drought effects. However, the edaphic factors component is very weak. Edaphic factors enter the model through a discrete carrying capacity classification which identifies all stands as belonging to one of two classes: true fir and ponderosa pine. This seems to be an oversimplification of the variation in site productivity to be found in the Sierra Nevada.

Ostensibly, the range of Silva includes Sierra Nevada forests; however, some of the component models were either hypothetical or derived from data outside the range of Sierra Nevada forests.

The acceptable species for this model are ponderosa pine, sugar pine, incense-cedar, white fir, Douglas-fir, Jeffrey pine, and California black oak. However, the equations in the model are not derived empirically; there really is no data range to report. Pieces of the model have been derived from published relationships from a variety of sources (e.g., Botkin and others 1972, Jarvis and others 1976, Waring and others 1978).

Whole-Stand Simulators: DFIT, PPYMOD, DFSIM, PPSIM, PSME, DFETAL, SOS

A whole-stand simulator is one that accepts stand-level parameters as input. Typically, input includes such parameters as age, site index, number of stems per unit area, and quadratic mean diameter. They are best suited to simulation of even-aged, single-species stands (Curtis and Hyink 1985), although examples of application in uneven-aged stands have also been presented (Ek 1974, Moser 1972, Moser 1974). Stands are grown as aggregates. Whole stand simulators are usually driven by a gross growth or yield model. The gross growth may be for volume or basal area. Mortality also enters the simulation at the aggregate level.

Whole-stand simulators are computationally efficient and much less demanding of computer resources than individual-tree simulators. However, they do not provide users with as many options for output. Whole-stand simulators are limited in output to aggregate parameters such as stand basal area, total stem volume, merchantable volume, and trees per acre.

Some whole-stand simulators are more complex, in that they forecast diameter distributions in addition to stand-level yields. These simulators characterize the distribution of stems by means of a probability density function. While the distribution function provides for higher resolution, its use is limited in that these functions are not capable of describing the diameter distribution resulting from many silvicultural alternatives (Ek and Monserud 1981).

DFIT (22)

Primary Species:	Geographic Range:	Site Index/Productivity:
• Douglas-fir	Coast range of Oregon and Washington	McArdle and others (1961)

DFIT (Douglas-fir Interim Tables) is a whole-stand simulator for Douglas-fir in the Pacific Northwest. DFIT (Bruce and others 1977) is an outgrowth of the development of managed stand yield tables for Douglas-fir. Results and implications of forecasts derived from this simulator were described by Reukema and Bruce (1977). Site index has a base-age of 100 (McArdle and others 1961).

DFIT is not widely used; DFSIM has supplanted it as the stand-level simulator of choice for coastal Douglas-fir forests.

PPYMOD (23)

Primary Species:	**Geographic Range:**	**Site Index/Productivity:**
• Ponderosa pine	Westside ponderosa pine stands of California	Powers and Oliver (1978)

This variable density yield table (Oliver and Powers 1978) was not originally adapted for computer use but was presented as a set of tables for plantations with square spacing at four levels (6, 8, 10 and 12 feet). Some years later Scott Holmen developed a spreadsheet version of this for Lotus 1-2-3. The most recent version of this is version 1.2.

Users should be aware that this spreadsheet is an approximation to the values presented in Oliver and Powers (1978). It follows the predicted values of Oliver and Powers (1978) closely in some areas, but in others, most notably cubic foot volume, the differences can be quite substantial. Best agreement appears to be when age is between 15 and 40 and survival is set at 85 percent. This is the planting survival rate assumed by Oliver and Powers (1978). There appears to be better agreement with basal area than with volume in the runs I have made. Height follows Oliver and Powers (1978) very closely.

The user must input a site index value (Powers and Oliver 1978), a spacing value, and planting mortality. The yield table is then automatically updated. Although this was developed for Lotus 1-2-3 version 1 (a DOS product), it actually works well using any spreadsheet program that will import a Lotus .WKS file.

Data for the Oliver and Powers yield tables were obtained from twelve plantations in the southern Cascades and northern Sierra Nevada (*fig. 14*). Sampled plantations ranged from 3 x 3 foot spacing to 12 x 12 foot spacing on sites from 35 to 120 feet (at a base age of 50).

The original yield tables run from age 10 to 50. The tables presented in the PC version adaptation run to age 60. Required hardware is an IBM compatible PC with DOS or Windows.

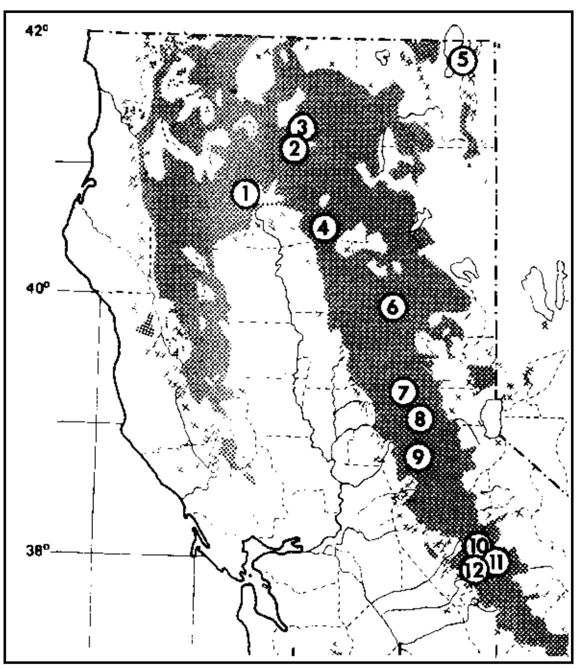

Figure 14—Geographic range of Oliver and Powers (1978). Numbers indicate locations of sampled stands.

Also required is a spreadsheet program which will import a version 1 Lotus file.

The spreadsheet file may be downloaded from the Pacific Southwest Research Station simulator web site: **http://redding.psw.fs.fed.us/sim.html**

DFSIM (24)

Primary Species:	**Geographic Range:**	**Site Index/Productivity:**
• Douglas-fir	Coastal Oregon and Washington	King (1996)

DFSIM is a simulator for managed stands dominated by Douglas-fir (Curtis and others 1981, Curtis and others 1982). Data came from a variety of sources; all were remeasured research plots. The model reflects the development of homogeneous, even-aged stands, and may be used to estimate probable future development of existing stands within the range of the data used to develop the model.

DFSIM requires input in the form of control cards that specify the run parameters. However, DFSIM comes with a companion program called SIMIN2.EXE that will query the user and set up a run file called TAPE3 with all the parameters in the appropriate columns. TAPE3 is the default input file for the simulator. The simulator sends output to the screen by default, but users may output to a file using the DOS redirection operators.

Users may specify a broad range of commercial thinning options. Among the information users may specify with regard to thinning are d/D ratio, residual basal area, and/or residual trees per acre (any two of these three). Timing of thinnings may be specified with respect to age, height, height increment, or thinning interval in years.

The model provides a yield stream with age, breast height age, dominant height (feet), height of tree of mean volume (feet), quadratic mean diameter (inches), basal area (square feet per acre), trees per acre (total stem cubic foot volume per acre), current annual increment (total stem cubic foot volume per acre), gross and net mean annual increment (cubic foot volume total stem, cubic foot volume to a 4-inch top), and board foot volume to a 6-inch top.

Board foot volumes are presented in both Scribner and International 1/4.

The authors have clearly documented the limitations of the simulator:

1. Stands with less than 300 stems per acre at establishment (or those pre-commercially thinned to this level) are outside the range of data.
2. The simulator should not be used to simulate more than one precommercial thinning and fertilization during the juvenile stage of stand development.
3. Users should not begin simulations for natural unthinned stands at dominant height less than 30 feet.
4. Users should avoid use of the simulator for very young plantations or precommercially thinned stands.
5. Users should avoid using data from very small plots or including understory stems of associated species, data which are otherwise inconsistent with the basic data used to develop the simulator.

There are also a number of published studies in which DFSIM has been validated. Curtis (1987) employed data from nine levels-of-growing-stock (LOGS) study sites in western Oregon and Washington to compare DFSIM forecasts with observed growth over time. Curtis (1987) found that DFSIM predicted gross stand volume and basal area growth well. However, the two most notable problems were mortality estimation and the lack of an ingrowth component in the simulator. While ingrowth had little effect on stand volume and basal area increment, inclusion of ingrowth can cause significant differences in quadratic mean diameter and number of stems.

The original version of DFSIM had a limiting relative density (Curtis 1982) of 70. Since many of the LOGS plots have exceeded this limit it appears that the relative density limit of 70 is somewhat low and produces unreasonably high rates of mortality in dense stands (Curtis 1987). The most recent version of the model has a modified upper relative density limit in response to these findings.

Remeasured plot data were provided by private landowners and public agencies. The authors do not display the specific locations of installations used in the modeling effort. However, the final data set used for analysis came from 203 installations in western Oregon, Washington, and British Columbia.

It is recommended that stands have 80 percent or greater basal area in Douglas-fir, as this restriction was used in the process of selecting stands for analysis.

Equations were developed using a total of 2,654 growth period measurements on 1,434 plots at 203 installations. The age range was roughly 10 to 100 years (total age). King's (1966) site index ranged from roughly 50 to 170 feet (at breast height base age 50). The authors report that there were no data from plantations greater than 40 years old and very little data from stands greater than 80 years of age. Stands with and without commercial and precommercial thinning were used in the analysis, as well as with and without fertilizer treatments.

The simulator requires site index (King 1966), starting age, and cutting and fertilization parameters for a generic yield stream. Then, if the user wishes to forecast growth of a specific observed stand, quadratic mean diameter, basal area, and number of trees per acre 1.6 inches and greater DBH at the start of the forecast are also required. Data are input as formatted lines in a text file (Curtis and others 1981, p 43-56); however, the input utility (SIMIN2.EXE) will facilitate creation of this file.

The most recent version is 1.4 and requires a PC with DOS 3.0 or higher. Additional references are listed in *appendix F*. Contact:

- Gary Clendenen, Mensurationist, Forestry Sciences Laboratory, 3625 93rd Ave. SW Olympia, WA 98512-9193, (360)753-7674.
- Robert O. Curtis, Mensurationist (retired), Forestry Sciences Laboratory, 3625 93rd Ave. SW, Olympia, WA 98512-9193, (360) 753-7669.

Web site: **http://forsys.cfr.washington.edu/~dfsim/**

PPSIM (25)

Primary Species:	**Geographic Range:**	**Site Index/Productivity:**
• Ponderosa pine	Ponderosa pine region of California, Oregon, and Washington	Barrett (1978)

PPSIM (DeMars and Barrett 1987) is a simulator for even-aged ponderosa pine stands. Data were derived from a variety of sources: permanent and temporary plots in Oregon and Washington and natural stand data from Meyer (1938). The model is structured in much the same manner as DFIT (Bruce and others 1977). An input file contains a description of the run and, optionally, a description of the stand as well.

The required input is a master control record. A master control record is required for each yield stream to be produced. Other records are optional. PPSIM requires input of site index (Barrett 1978), unless the user specifies the starting stand statistics, in which case the simulator will calculate site index given dominant height and stand breast height age.

The simulator is capable of generating generic yield streams, or yield streams for specific sampled stands. For a sampled stand, the simulator assumes one of three types of stands:

1. Understocked stands.
2. Recently thinned stands.
3. Fully stocked stands scheduled for immediate thinning prior to any growth forecasts.

The sampled stand record format is described in *table 27*. The sampled stand record must follow a master control record for each. Control records may be stacked in one file to provide for a number of forecasts in one run of the simulator.

Yearly volume growth may be adjusted to account for local growth conditions, fertilization, or genetic improvement. There is also a dwarf mistletoe option for managed stand simulations. The user may specify the number of trees infected and the age of the onset of dwarf mistletoe. Fertilization assumes:

1. An application of 200 pounds elemental nitrogen per acre, resulting in a 25 percent increase in growth at the minimum site index value of 40,
2. Fertilization response decreases linearly to zero at a site index of 200, and
3. The fertilizer effect lasts 5 years by default.

Output includes mean diameter, basal area, and cubic foot volume per tree. The single table of stand output contains trees per acre, basal area per acre, cubic foot volume per acre, mean tree diameter, and mean tree basal area for each report age. These statistics are output for the total stand, cut and leave. A sample output table is shown in *table 28*.

Data for natural stands were obtained from Meyer's (1938) yield study (*fig. 15*), using only data from Washington, Oregon, and California (DeMars, personal communication). Ages range from 25 to 182 years. Barrett's (1978) site index ranges from 46 to 184 feet (base age 100). Basal area ranged from 77 to 369 square feet per acre. Stems per acre ranged from 58 to 9,470.

Managed stand data consisted of 151 plots in Oregon and Washington. Site index among these stands ranged from 33 to 139 feet. Ages range from 15 to 93 at the start of the growth period. Basal area ranges from 1.5 to 194 square feet per acre. Stems per acre ranged from 36 to 1,000.

The simulator requires, as minimum input, a formatted file containing site index, total stand age, breast height age, age at mistletoe infestation (if any), and timing of thinnings (if any). This produces a generic stand table. If the user desires to forecast the growth of an existing forest stand under various management treatments, additional input required is height of the five largest trees in the stand, number of trees per acre at the start of the growth simulation, basal area per acre of the stand at the start of the growth simulation, and quadratic mean diameter at the start of the simulation. For thinnings, trees per acre, or d/D ratio, or SDI may be used to control thinning levels.

Table 27—*Sampled stand input record for PPSIM (DeMars and Barrett 1987, page 29) with read format.*

Input Columns	Variable Name	Variable Description	Read Format
1-4	STSITE	Site index of the stand (Barrett 1978). If blank or zero, then this variable is set to the site index from the master control record. If both are zero, then site index is calculated from STTAGE and STHT using Barrett's curves.	F4.0
5-8	STHT	Dominant height (height of the five tallest trees in the stand). If blank or zero, STHT is calculated from STSITE and STTAGE.	F4.0
9-12	STTAGE	Total age of the stand at the start of the forecast. If blank or zero, STTAGE is calculated from STSITE and STHT.	F4.0
13-16	STAGE	Breast height age of the stand at the start of the forecast. If blank or zero, STAGE is calculated from STTAGE and STSITE.	F4.0
17-22	STTA	Number of trees per acre at the start of the forecast. If blank or zero, then STTA is calculated from STGA and STDBH. If provided, STTA must be mathematically consistant with STGA and STDBH.	F6.0
23-28	STGA	Basal area per acre at the start of the forecast. If blank or zero, then STGA is calculated from STTA and STDBH. If provided, STGA must be mathematically consistent with STTA and STDBH.	F6.2
29-34	STDBH	Quadratic mean diameter at breast height at the start of the forecast. If blank or zero, then STDBH is calculated from STTA and STGA. If provided, STDBH must be mathematically consistent with STTA and STGA.	F6.2
35-78		BLANK	
79-80		Optional input record identification.	I2

Table 28—*Sample output table from PPSIM run (De Mars and Barrett 1987).*

PONDEROSA PINE
(PINUS PONDEROSA LAWS.)

MANAGED STAND TABLE

BARRETT SITE INDEX=160

Variables on master control record specify that:

Minimum diameter of a merchantable tree= 8.00
Number of thinning or output ages= 2
Number of years between thinning or output ages= 10
Harvest age= 10

Variables from optional input records:

REPORT OR THINNING NUMBER	REPORT OR THINNING AGE	THINNING HEIGHT	SQ.FT. BASAL AREA BEFORE CUT	SQ.FT. BASAL AREA AFTER CUT	STAND DENSITY INDEX BEFORE CUT	STAND DENSITY INDEX AFTER CUT	TREES PER ACRE AFTER CUT	RATIO DIAMETER CUT TO DIAMETER MERCH. PART OF STAND	NUMBER OF DWARF MISTLETOE TREES AFTER CUT
1	0.	0.	0.	0.	0.	0.	180.	0.	0.

Barrett Site Index= 160.

The starting stand is specified

TOTAL AGE YEARS	STAND HEIGHT FEET	STAND COMPONENT	MEAN TREE DBH INCHES	MEAN TREE G SQ FT	MEAN TREE VOL. CU FT	TREES PER ACRE	G PER ACRE SQ FT	CU FT VOLUME PER ACRE
40.	79.	Start stand	10.0	.545	12.8	350.0	190.9	4465.
		Cut	10.0	.545	12.8	170.0	92.7	2169.
		Total leave	10.0	.545	12.8	180.0	98.2	2296.
50.	97.1	Total stand	11.2	.689	19.4	180.0	124.1	3483.
		Cut	11.2	.689	19.4	80.0	55.1	1548.
		Total leave	11.2	.689	19.4	100.0	68.9	1935.
100.	155.2	Harvest cut	16.1	1,419	60.9	100.0	141.9	6094.

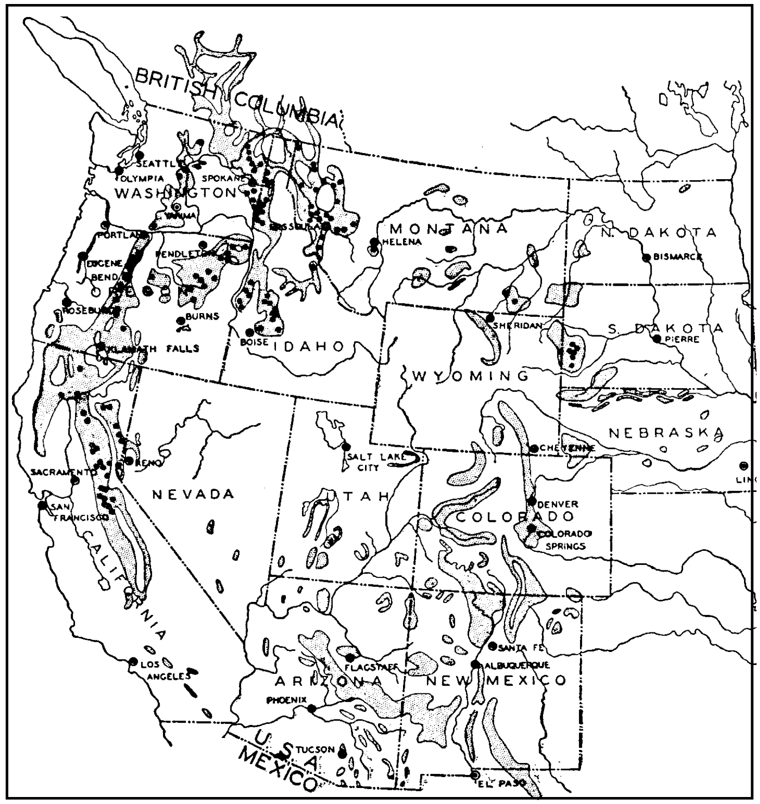

Figure 15— Managed stand plot locations of Meyer (1938) used in PPSIM.

The PC version requires DOS 3.0 or later. Unlike DFSIM, there is no preprocessor routine to set up runs. The user is required to set up an ASCII file with input records containing instructions in a fixed format.

The simulator is available on the World Wide Web at:

http://redding.psw.fs.fed.us/ppsim.html

PSME (26)

Primary Species:	**Geographic Range:**	**Site Index/Productivity:**
• Douglas-fir	Coast range of southern Oregon	None

PSME is a computer simulator for plantation-grown Douglas-fir stands with mixed evergreens (tanoak, Pacific madrone, giant chinkapin). It simulates the development of stands up to age 10, beginning at age 3 (Harrington, and others 1991b). The simulator will not allow projections beyond age 10. Forecasts are produced for stand development of Douglas-fir with only one of the three named hardwood species. Users must determine which of these three species occupies more than 66 percent of the hardwood basal area in the subject stand.

Equations were actually developed only for Douglas-fir trees growing in competition with tanoak or Pacific madrone. The simulator cannot distinguish between tanoak and chinkapin, the model reflects an assumption that chinkapin and tanoak will behave similarly and have the same effect on Douglas-fir growth.

Primary output of the simulator is a stand summary table of height and cover by species for Douglas-fir, the primary hardwood competition and herbaceous vegetation, as well as mean basal diameter of Douglas-fir. Optional output is a diameter distribution of Douglas-fir at age 10 derived from a Weibull distribution function. The simulator does not produce any volume or biomass estimates.

This is not a compiled program, rather it is written in BASIC. Users must have a BASIC interpreter installed to execute PSME

The data were obtained from three studies on the effect of varying levels of competing vegetation on young stand growth in southwest Oregon. These studies were conducted under the auspices of the FIR (Forestry Intensified Research) Cooperative. The southernmost site was located near Cave Junction, and the two northern sites were between Glendale and Riddle (Harrington and others 199la). Users should be aware that tanoak was dominant on two of the three plantations. The third plantation featured competition from Pacific madrone.

Plantations with initial age of 3 were observed up to age 10. Elevation on all three sites was between 700 and 900 feet. Site index ranged from 82 to 121 (McArdle and others 1961).

Pre-harvest basal area of hardwood trees, pre-harvest density of selected species, post harvest hardwood cover, Douglas-fir plantation age, herb and shrub cover, Douglas-fir mean height, Douglas-fir stem basal diameter, Douglas-fir crown width, and Douglas-fir density are required input for this simulator. The simulator is interactive and will prompt the user for each of these values.

An IBM compatible PC with DOS 3.0 or higher is required. The user's guide and the program may be obtained from: Forestry Publications Office, Oregon State University, Forest Research Laboratory, Corvallis, OR 97331.

DFETAL (27)

Primary Species:	Geographic Range:	Site Index/Productivity:
• Douglas-fir	Coast range of Oregon and Washington	None

The DFETAL simulator is a result of a cooperative research project entitled "A Diagnostic Tool for Predicting the Effects of Interspecific Competition on Growth and Yield of Young Douglas-fir Stands." A preliminary version of this simulator was released to cooperators in 1990 (Opalach and others 1990). There was no subsequent release of the simulator.

Equations for this simulator were developed using data from a CRAFTS competition release study (Harrington and Wagner 1986).

This model predicts the growth of homogeneous young Douglas-fir plantations (those less than 20 years old). The species allowed are Douglas-fir, red alder, vine maple, salmonberry, and thimbleberry. The model grows the average tree in the stand. It assumes that there are some known number of identical Douglas-fir trees per acre. Since it grows only one average tree in the stand, this is, in effect, a whole stand simulator.

Primary (required) input for Douglas-fir is starting plantation age, crown ratio, trees per acre, height, and cover. For other species, percent cover and height are required as input. The model will grow stands up to a specified age, not to exceed 20. The vegetation management option allows the user to simulate the effect of complete removal or application of triclopyr or glyphosate to plots containing thimbleberry and Douglas-fir.

DFETAL will produce a table showing percent cover and height of each species throughout the forecast, and more detailed statistics of Douglas-fir: height, crown ratio, crown radius, and trees per acre.

There is no ongoing technical support for this simulator, and no system for distribution.

SOS (28)

Primary Species:	Geographic Range:	Site Index/Productivity:
• Douglas-fir	Idaho, western Montana, northeast Oregon, central and northeast Washington	User specified site index Vander Ploeg and Moore (1989), or Thrower and Goudie (1992), or Milner (1992), or Monserud (1984)

The SOS simulator is a whole stand simulator for interior Douglas-fir stands in northern Idaho, Montana, central Idaho, northeast Oregon, central and northeast Washington reported on by Zhang and others (1993). The authors do not provide a specific description of the geographic range of the data. The data used in development of this simulator are from 229 plots in 94 thinning trials. Site index (Vander Ploeg and Moore 1989) ranged from 39 to 105 feet at 50 years.

There is some uncertainty as to the range of the data used in development of the model. Zhang and others (1993) show a range in age from 0 to 100, yet in reporting on the same data Moore and others (1991) and Shafii and others (1990) show a range from 27 to 100. Moore and others (1991) report percent basal area in Douglas-fir ranging from 27 to 100 with a mean of 87.

Both the survival and basal area prediction equations are constrained by defined minimum and maximum values.

The simulator has a primary driving function of top height growth, using the model presented by Vander Ploeg and Moore (1989). Predicted height is factored into the survival model and the basal area prediction equation. Finally, the model predicts total stem cubic foot volume per acre as a function of stand basal area per acre and top height.

Disaggregative Simulators: LPSIM, STIM, RVMM

Disaggregative models feature a two-stage process for growth simulation. The first step is to predict growth of the stand using a whole-stand growth or yield equation. In the second step, the resulting predicted stand growth or yield is allocated (disaggregated) among trees in a list. The simulator functions as a whole-stand model with respect to stand growth (Ritchie and Hann 1997a). The tree list is essentially maintained to describe the distribution of stand parameters.

LPSIM and STIM both disaggregate growth predictions, not yield. There are two basic methods for allocating growth: proportional allocation and additive allocation. With proportional allocation, consistency between tree and stand growth predictions is ensured by multiplying growth by some proportionality factor defined such that the sum of individual tree growth predictions is equal to forecast stand growth. Additive allocation employs an additive adjustment to each growth prediction such that the sum of individual tree growth forecasts equals the forecast for stand growth. With either method, the dynamic component of the stand-level forecast is driven by stand-level parameters, whereas individual-tree simulators aggregate individual-tree forecasts to obtain an aggregate prediction. Individual tree information does not have a first-order effect upon the stand-level growth prediction– only how that stand growth is distributed among trees within the stand.

The disaggregative simulator is capable of producing the type of high-resolution output common to individual-tree simulators, yet predictions are constrained by the forecasts derived from stand-level model. Ritchie and Hann (1997b) found that this approach provided inferior predictions when compared to the more traditional individual-tree approach for short term forecasts of gross stand basal area growth. However, for longer term projections this approach may provide some benefit.

LPSIM (29)

Primary Species:	**Geographic Range:**	**Site Index/ Productivity:**
• Lodgepole pine	Central Oregon	Dahms (1975)

LPSIM is an even-aged lodgepole pine simulator published by Dahms (1983). Recently, the gross volume growth equation has been refit with the hope that the model will provide more reliable forecasts for young stands (Pat Cochran, personal communication). The original version (Dahms 1983) was best suited to stands greater than 30 years old. The newer volume growth model and improved mortality functions may facilitate better predictions for younger stands.

Stands for development of gross volume growth equations were developed from 94 temporary plots in natural stands on the eastern slope of the Cascade range between Crater Lake National Park in the south, and Bend, Oregon in the north. Growth is allocated by means of a proportional volume growth disaggregation function.

The lodgepole pine stands sampled for this model were even-aged stands less than 100 years old (Pat Cochran, personal communication), with quadratic mean diameter below 22 inches. Site index ranged from 60 to 110 feet (100 year total base age) using the curves developed by Dahms (1975).

Required hardware is a PC with DOS 3.0 or later. Executable files take up about one megabyte of hard disk space. The current version of LPSIM can be found on the World Wide Web: **http://redding.psw.fs.fed.us/lpsim.html**

STIM (30)

Primary Species:	**Geographic Range:**	**Site Index/ Productivity:**
• Western hemlock	Southwestern British Columbia, western Oregon and Washington	User specified: Wiley (1978), or Bonner and others (1995)

The STIM simulator (Bonnor and others 1995) was developed for natural and planted stands of western hemlock of Oregon, Washington, and British Columbia (*fig. 16*). Data were collected from 1,339 permanent sample plots in pure, even-aged western hemlock stands. Age range for data was from 4 to 251, and the mean age was 36 (*table 29*). Site index ranged from 8.9 meters to 66 meters at a base age of 50. Either curves by Wiley (1978) or Flewelling (Bonnor and others 1995) may be used to predict top height.

The simulator includes both stand and tree growth algorithms that are reconciled through a proportional disaggregation process. The disaggregation process employed by STIM is more sophisticated than that in LPSIM, being driven by an allocation of forecast individual tree growth. The stand-level component forecasts top height increment, gross basal area increment, and annual mortality (basal area and trees per acre). The simulator also includes an ingrowth component that predicts the number of stems growing past the 5.08-cm (2-inch) diameter threshold in a period. The simulator is designed to accept stand-level input or tree-list input. Stand input can include site index, top height, basal area, quadratic mean diameter, diameter at the 10th percentile, and coefficient of variation of tree basal area; alternatively, default equations estimate any unspecified variables. Diameter at the 10th percentile is the diameter of a tree at the 10th percentile in the stand diameter distribution; that is, the diameter of a tree for which 90 percent of the trees in the stand would have a larger diameter.

Tree-list input requires site index, breast height age, plot size, and then for each sampled tree: DBH (cm), tree height (in), and trees per plot. The simulator will also allow the user to generate a sapling stand. The sapling stand input requires only site index. Top height, trees per hectare, and quadratic mean diameter are optional when providing input for a sapling stand.

The primary driving function in the simulator is change in top height, which operates internally on a 1-year growth increment. Basal area increment of an individual tree is forecast as a function of DBH, top height increment, stand basal area, and thinning intensity as defined by the ratio of residual basal area divided by the initial basal area. There are no pseudo-stochastic features in this simulator; forecasts are deterministic.

Currently, the only management activity the simulator will allow is thinning. Users may thin to basal area or trees per hectare by specifying either the amount to be removed or left. The user may also define a d/D ratio for the thinning as well.

STIM will allow both graphical output (e.g., diameter histograms) and yield reports by year.

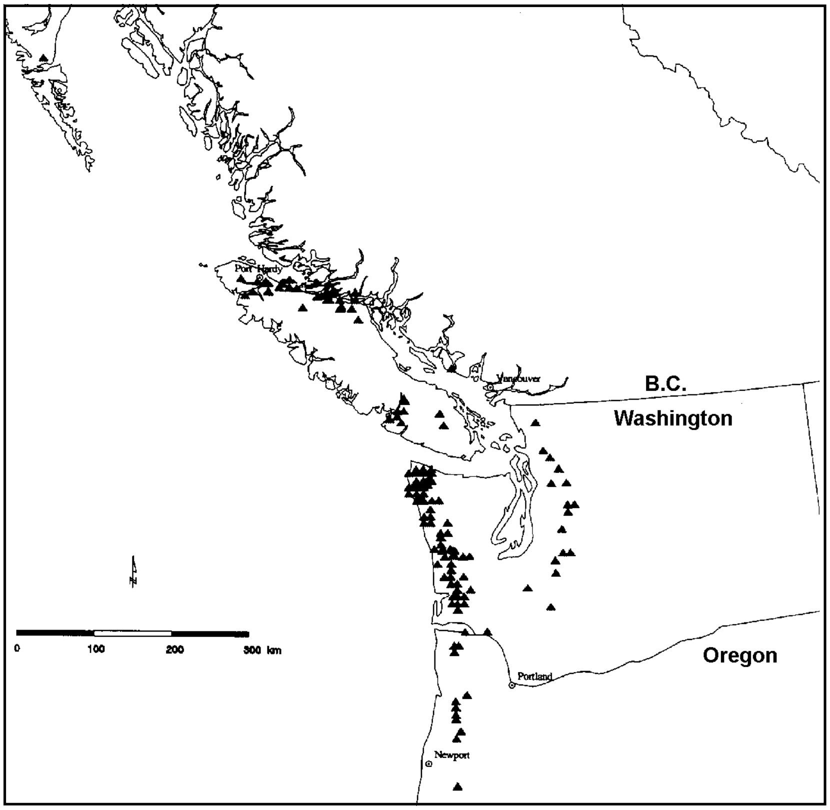

Figure 16—Geographic range of the plots used in development of STIM (Bonnor and others 1995).

Table 29–*Range of data used in development of STIM (Bonnor and others 1995).*

Variable	Minimum	Maximum	Mean
Basal area	0.3	154.0	49.3
Trees (number per hectare)	112.0	11,490.0	1,624.3
Top height (meters)	5.0	50.5	24.0
Quadratic mean diameter (cm)	5.0	64.8	22.1
Site index (meters at age 50)	8.9	66.0	32.9
Breast height age	4.0	251.0	36.0

STIM requires a PC with MS Windows 3.1 (or later). A 486 DX PC with 4 MB RAM is recommended as a minimally qualified machine to run the simulator, although it will execute on a 386 SX. Contact:

Steve Stearns-Smith, B.C. Ministry of Forests, Victoria. BC, Canada

World Wide Web: **http//www.for.gov.bcca/resinv/G&Y/software/STIM/STIM.htm**.

RVMM: Stand (31)

Primary Species:
- Bitter cherry
- California hazel
- Douglas-fir
- Red alder
- Vine maple
- Western hemlock

Geographic Range:
Coast range of Oregon and Washington

Site Index/Productivity:
Shula (1998)

The stand-level version of RVMM was derived from the same data as the individual-tree version. The stand-level version of RVMM requires dominant height, density, and plantation age to effect a simulation. Optional input includes silvicultural treatments, slope, aspect, elevation, basal area, and density of natural Douglas-fir, other conifers, and hardwoods as well as cover of shrubs and herbs. The default site index system is King (1966), but Means and Sabin (1989) or Hann and Scrivani (1987) may be specified by the user at run time.

Dynamics of the simulator include a dominant-height prediction model, basal area prediction model for Douglas-fir (Knowe and Stein 1995), and a function for predicting the diameter distribution of Douglas-fir trees (Knowe and others 1992), and survival prediction functions.

The simulator will output a tree-list file derived from a Weibull-based diameter distribution prediction system.

The simulator has not yet been released, and the user's guide has not yet been published. For more information access the web site:

http://www.cof.orst.edu/cof/fr/research/organon/rvmm/rvmm_idx.htm

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Appendix A: Referenced Tree Species List

Common name	Scientific name	Simulator index[1]
Alaska yellow-cedar	*Chamaecyparis nootkatensis* (D. Don) Spach	1, 8
Bigleaf maple	*Acer macrophyllum* Pursh.	13
Bitter cherry	*Prunus emarginata* Dougl.	15, 31
California black oak	*Quercus kelloggii* Newb.	5, 9, 13
California hazel	*Corylus cornuta californica* (A- DC.) Sharp	16
Canyon live oak	*Quercus chrysolepis* Liebm.	13
Coast redwood	*Sequoia sempervirens* (D. Don) Endl.	10
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 22, 24, 26, 28
Engelmann spruce	*Picea englemanii* Parry ex Englem.	2, 3, 4, 8
Giant chinkapin	*Castanopsis chrysophylla* (Dougl.) A- DC.	11, 13
Giant sequoia	*Sequoiadendron giganteum* (Lindl.) Buchholz	9
Grand fir	*Abies grandis* (Dougi. ex D. Don) Lindl.	2, 3, 4, 8, 13, 14
Incense-cedar	*Calocedrus decurrens* Torr.	8, 13, 15, 17
Jeffrey pine	*Pinus jeffreyi* Grev. & Balf	9, 11
Lodgepole pine	*Pinus contorta* Dougl. ex Loud.	1, 2, 3, 4, 7, 8, 9, 29
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.	1, 2, 3, 4, 7
Noble fir	*Abies procera* Rehd.	8
Oregon white oak	*Quercus garryana* Dougl. ex Hook.	13
Pacific madrone	*Arbutus menziesii* Pursh	5, 13, 17
Pacific silver fir	*Abies amabilis* Dougl. ex Forbes	1, 3, 8
Ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.	2, 3, 4, 5, 8, 9, 11, 13
Red alder	*Alnus rubra* Bong.	15, 16, 17, 18, 23, 25
Red fir	*Abies magnifica* A. Murr.	7, 8, 9, 11
Sitka spruce	*Picea sitchensis* (Bong.) Carr.	1, 18
Subalpine fir	*Abies lasiocarpa* (Hook) Nutt.	1, 2, 3, 4, 8
Sugar pine	*Pinus lambertiana* Dougl.	9, 11, 13, 15, 17
Tanoak	*Lithocarpus densiflorus* (Hook. & Arn) Rehd.	5, 9, 13, 17
Vine maple	*Acer circinatum* Pursh.	16
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.	4, 6, 8, 13, 16, 18, 31
Western larch	*Larix occidentalis* Nutt.	2, 3, 4
Western redcedar	*Thuja plicata* Donn ex D. Don	18
Western white pine	*Pinus monticola* Dougl. ex D. Don	1, 4, 7, 8, 11
White fir	*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.	5, 8, 9, 11, 13, 15, 17, 19
White spruce	*Picea glauca* (Moench) Voss	1

[1]Simulator index numbers correspond to the numbers in parentheses in the Table of Contents and throughout text subheadings.

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