FVS Out of the Box—Assembly Required

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Abstract—The Forest Vegetation Simulator (FVS) is a prominent growth and yield model used for forecasting stand dynamics. However, users need to be aware of model behavior regarding stocking density, tree senescence, and understory recruitment; otherwise over long projections, FVS tends to concentrate substantial growth on few survivor trees. If the intent is to forecast endemic conditions, model performance can be modified by establishing baseline trends from measured inventory data and configuring FVS to stay within the observed ranges. This paper will present the steps needed to carefully craft an endemic FVS run. Techniques include using the FVS self-calibrating feature; accounting for tree defect; limiting stand maximum density; determining tree species size attainment; and, accounting for regeneration response. A case example from the Blue Mountains project area in northeast Oregon will be presented.

Introduction

Have you ever purchased an item from a store that comes in a box only to realize that once opened, all the components are there but you must carefully assemble the parts to properly construct the object? You may have a manual or diagram to consult, but getting from the raw materials to the final product can be challenging. This analogy can be applied to using the Forest Vegetation Simulator (Dixon 2002). Users may naively assume that after initially installing the software, they are fully ready to go. This can be problematic in matching measured trends to modeled projections.

Three projection scenarios are recognized in this paper: (1) full site occupancy, (2) endemic stand development, and (3) epidemic area disturbance[2]. By default, FVS will forecast stand development to full stocking. In contrast, compilation of large field inventory data sets void of significant impacts will typically render endemic conditions. Whereas, bark beetle outbreaks, dwarf mistletoe epicenters, and active crown fires render epidemic, stand replacing events. Users of FVS need to be cognizant of the modeling context and take steps necessary to ensure simulation results portray logical outcomes. The purpose of this paper will be to present the fundamental steps needed to project stand development under endemic conditions with FVS. The methodology prescribed will be based on the procedures used to construct vegetation pathways for regional assessments and forest planning.

[2]Endemic implies being constantly present in a particular region and generally considered under control. In contrast, epidemic refers to out of control situations where the vector is spreading rapidly among many individuals (Ref: Webster's New World Dictionary, Third College Edition).

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Whether planning at the national, broad, mid, or base level, the analysis process for projecting vegetation should contain the following elementary steps:

P erform vegetation stratification
I dentify data sources
C alibrate FVS model
T ailor natural growth runs
U tilize treatment prescriptions
R eport vegetation pathways
E valuate output values

Having a good 'PICTURE' in mind before beginning a project will aid the endeavor. Each of these analysis topics will be elaborated upon relative to development of vegetation pathways for a landscape assessment of the Blue Mountains project area.

Vegetation Stratification

Forest planning efforts often require developing estimates of conditions and outcomes by stand type. A stand type is a combination of the physical, vegetative, and developmental characteristics used to identify homogeneous forest strata (Davis and Johnson 1987). Physical attributes describe the site aspects of the forest, such as topography, soils, and habitat type. Vegetative attributes characterize the flora aspects of the forest, such as overstory dominant species, its relative size and density. Developmental attributes portray the human aspects of the forest, such as roads, buildings, and administrative boundaries. In this context, stand types are non-spatial but are comprised of many geographically identifiable forest stands.

Biophysical settings of plant associations (habitat types) arrayed by prevailing tree species comprised the stand types used to describe the vegetation strata for the Blue Mountains project area. Figure 1 provides a relational schematic of ascending elevation adjoining to the potential vegetation types that represent the various temperature/hydrologic regimes.

The Warm Dry Ponderosa Pine (*Pinus ponderosa* C. Lawson) stand type will be used to demonstrate FVS assembly techniques employed in the construction of an endemic model run. Figure 2 displays a Stand Visualization System (SVS) (McGaughey 2004) rendering of this biome.

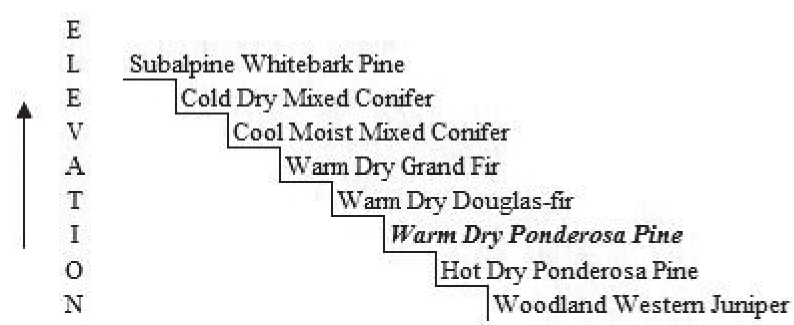


Figure 1—Biophysical settings of potential vegetation types within the Blue Mountains project area.

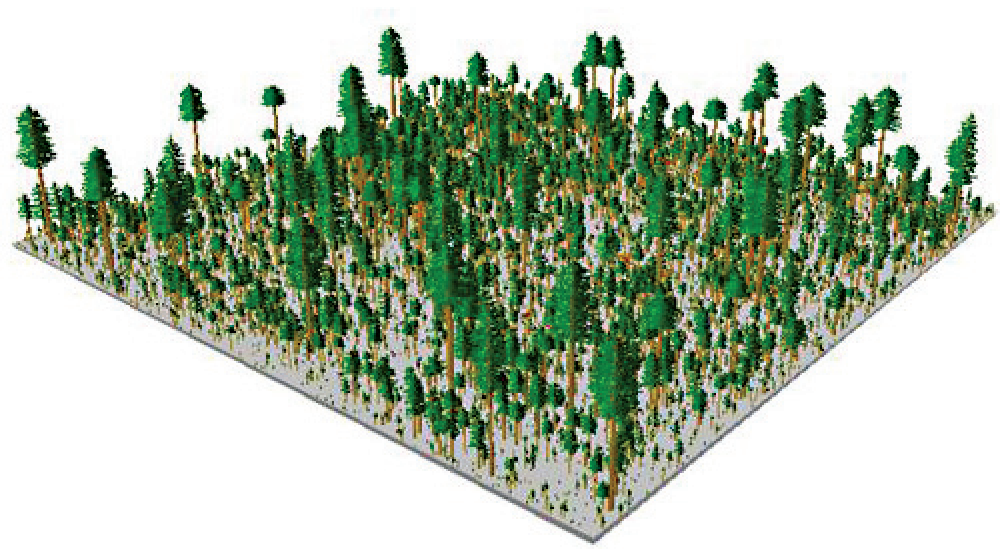


Figure 2—SVS ten-acre depiction of the Warm Dry Ponderosa Pine stand type.

Data Sources

Two types of data are generally used for planning projects: spatial and temporal. Spatial data is usually compiled from remote sensing imagery, and acreage compilation is accomplished by summing the various stand types residing within mapped polygons. Temporal data is collected during a field inventory, and place-in-time attributes are gathered to provide an estimate of forest conditions. Inventory values provide per acre estimates. When spatial data that complies with the vegetation stratification scheme is multiplied by temporal data obtained from field inventories, total strata estimates are produced. These values are then incorporated into the landscape assessment.

The spatial data source for the Blue Mountains was assembled using Gradient Nearest Neighbor technology (Ohmann and Gregory 2002). The primary data source available for the area was the USFS Pacific Northwest Region Current Vegetation Survey (CVS) (Max and others 1996) that predates the standardized installation of the Forest Inventory and Analysis (FIA) (Miles 2001) sample design. Table 1 summarizes the CVS inventory sample used to represent the Warm Dry Ponderosa Pine stand type on the Malheur, Umatilla, and Wallowa-Whitman National Forests.

Table 1—Data set used for the Warm Dry Ponderosa Pine stand type on the Blue Mountains Project Area.

National Forest	Inventory Occasion 1 [a]	Inventory Occasion 2 [b]	Total Sample
	- - - - - - - - *number of plots* - - - - - - - - -		
Malheur	156	120	276
Umatilla	33	33	66
Wallowa-Whitman	42	31	73
Total:	231	184	415

[a] Occasion 1: Initial Installation of Current Vegetation Survey

[b] Occasion 2: First Remeasurement of Current Vegetation Survey

Portioning the Warm Dry Ponderosa Pine stratum by size class resulted in the plot distribution listed in table 2. Stand age was incorporated into the definition of size class. Stand age provides a general measure of important ecological processes. Each successional stage provides structural components critical for particular plants and animals. Vegetation pathways developed for contemporary mid-scale plans account for distribution of stand structure across the forest landscape.

Table 2—Plot sample distribution by size class.

Stand type	Size class [a]	Stand age [b]	Plot sample
	Seedling-Sapling (0-5”)	0-20	7
Warm	Small Tree (5-10”)	20-50	31
Dry	Medium Tree (10-15”)	50-90	178
Ponderosa	Large Tree (15-20”)	90-140	143
Pine	Very Large Tree (20-25”)	140-200	31
	Giant Tree (25”+)	200-270+	6
Non-Vegetated [c]	Grass/Forbs/Brush	~	19
Total:			415

[a] Based on the quadratic mean diameter (qmd) of the largest 20 percent of the trees with a minimum of 20 trees.

[b] Origin date of the oldest cohort (i.e. qmd size class) inferred as time since the last stand replacement disturbance.

[c] Although non-vegetated with tree cover at the time of inventory, these plot samples reside in Warm Dry Ponderosa Pine plant associations.

Model Calibration

An essential step in appropriate use of the Forest Vegetation Simulator is calibration of the model. The FVS geographic variants are comprised of numerous mathematical relationships. One prediction equation may provide input to another. For long-term projections, users should validate virtual world estimates generated by FVS against real world values obtained from inventory data.

Determining the modeling context matters in regards to constructing a verifiable FVS projection. As conceived and implemented, stand development within FVS trends toward full site occupancy. If endemic or epidemic conditions are to be portrayed, users should be aware of existing software extensions and addfiles that account for insect, disease, and fire effects. These utilities address additional mortality impacts during long-term projections. In the absence of available disturbance model extensions, users assume the responsibility to ensure simulation runs provide reasonable results. Inventory data should be acquired that represents either full stocking, common conditions, or impacted landscapes to provide the sideboards for FVS model predictions. The focus of the remainder of this paper will be targeting endemic conditions that characterize vegetation pathways for landscape planning.

Figure 3 depicts measured trends in the Warm Dry Ponderosa Pine stand type as compared to modeled FVS projections of the seedling-sapling size class. The images were derived by averaging individual plots. The graphics portray structural trends from stand ages 10 to 260 years by size class increments. Note that the initial seedling-sapling size class images for the measured and modeled frames are identical. The modeled projections were produced by the Blue Mountain variant of FVS without and with user intervention. Comparing measured trends (left column in fig. 3) with FVS modeled projections, without adjustments (middle column in fig. 3), demonstrates vast differences in stand development.

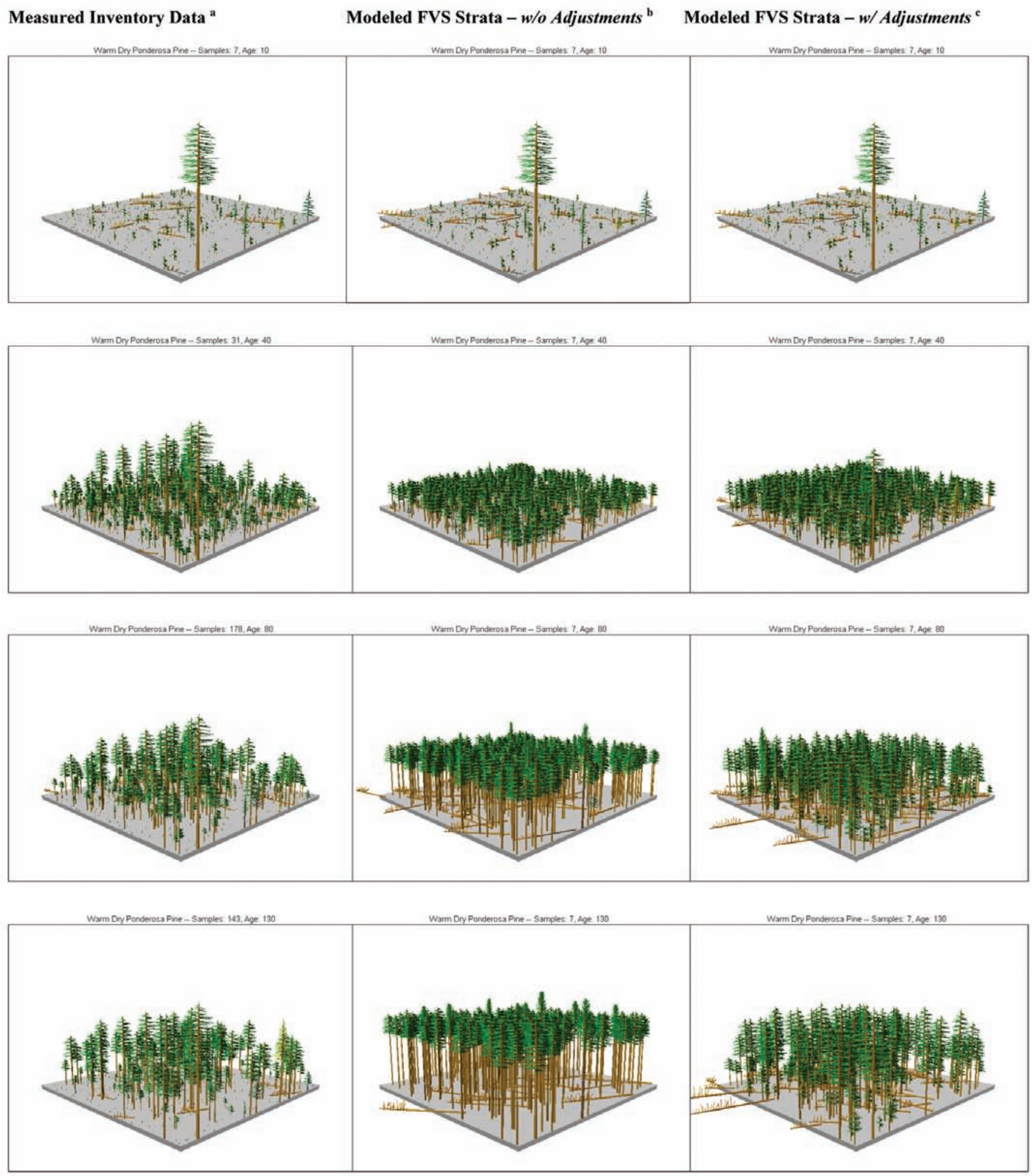


Figure 3—Measured versus modeled trends of Warm Dry Ponderosa Pine stratum.
[a] Left column: Measured inventory data from stand age 10 to 260 by size class increments.
[b] Middle column: Modeled strata projected from stand age 10 to 260 by size class increments without adjustments.
[c] Right column: Modeled strata projected from stand age 10 to 260 by size class increments with adjustments.

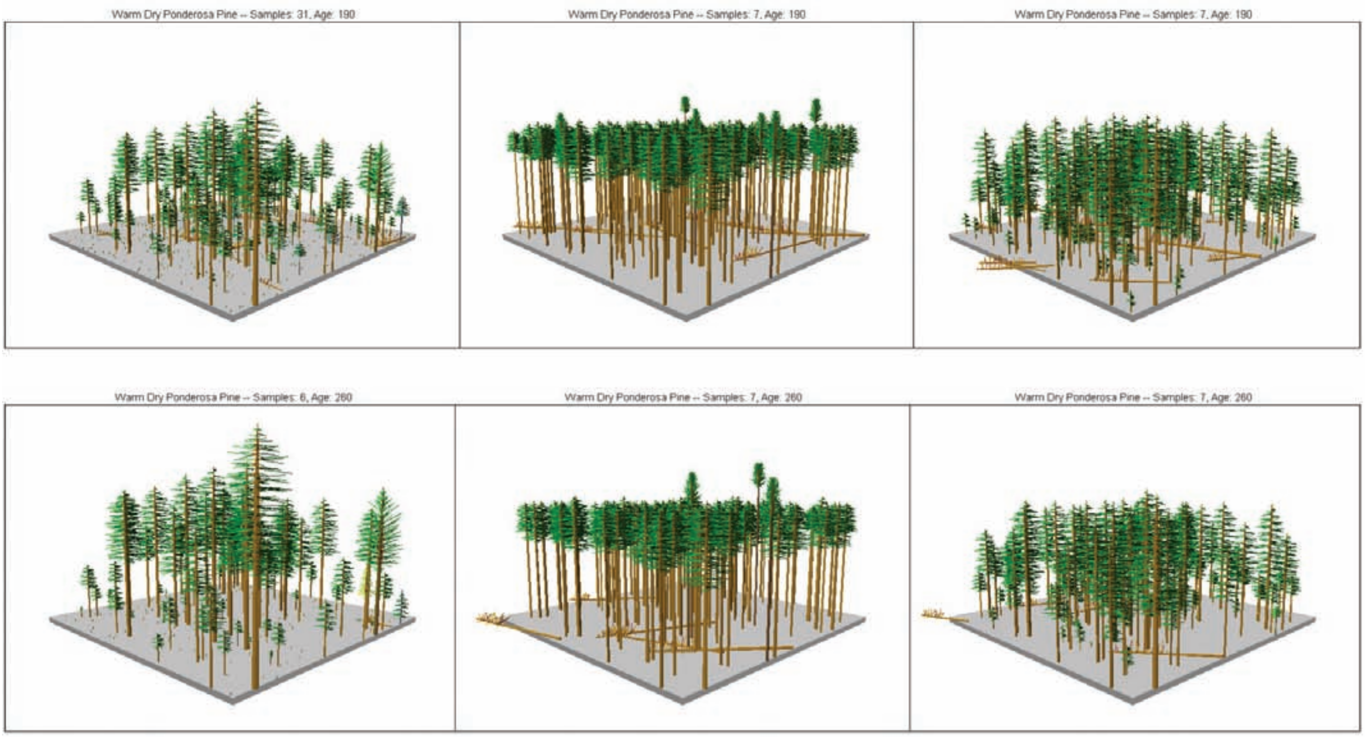


Figure 3—Continued.

Delving into two key attributes highlights the anomalies. Trees per acre plotted over stand age by size class increments are displayed in figure 4 (Inventory Data vs. FVS w/o Adjustment). Board foot volume per acre plotted over stand age by size class increments is displayed in figure 5 (Inventory Data vs. FVS w/o Adjustment). Contrasting the measured inventory data to the unadjusted modeled run over time, tree density is too low and stand volume is too high. Mortality and regeneration aspects are difficult components to model. One subtracts trees from the ecosystem; the other adds trees to it. The default mortality paradigm embedded in FVS allows stands to progress to full site occupancy (i.e. maximum stand density). However, this ceiling does not represent the generalized endemic growth pattern typified by inventory data sets used for landscape assessments. Consequently, densely stocked conditions are forecast. Note also that most FVS variants include only the partial establishment extension that lacks automatic natural regeneration features. Thus, tree frequencies steadily decline over time. Growth dynamics are accumulated in the survivor trees resulting in excessive stand volume.

FVS Self-Calibration

A unique feature of the Forest Vegetation Simulator is its ability to self-calibrate the small-tree height and large-tree diameter increment models based on measured growth rates per inventory plot (Stage 1981). This mechanism alters the inter-species tree competition from the basis that was used to build the model. Over long projections, species composition may differ from the base model forecast as a result of local observations.

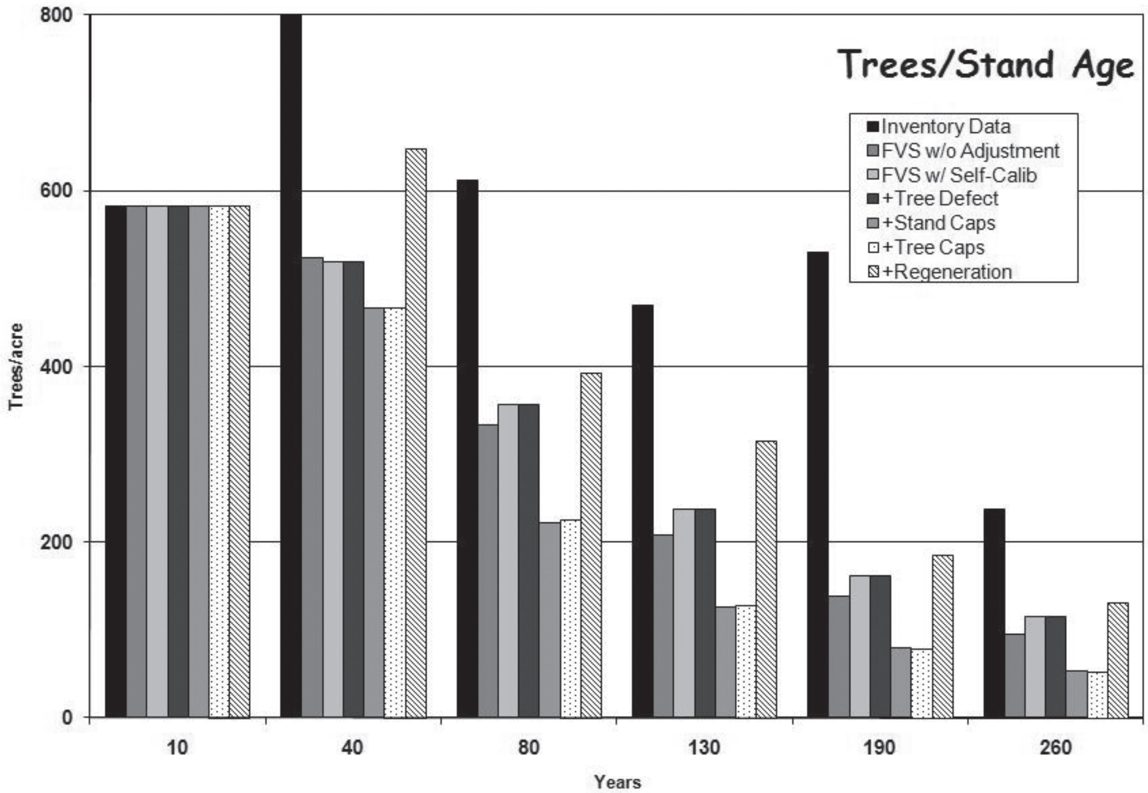


Figure 4—Comparison of trees per acre over stand age by size class increments for measured and modeled runs. Within grouping, recommended assembly steps are added to the unadjusted model run to properly configure FVS to conform to measured values.

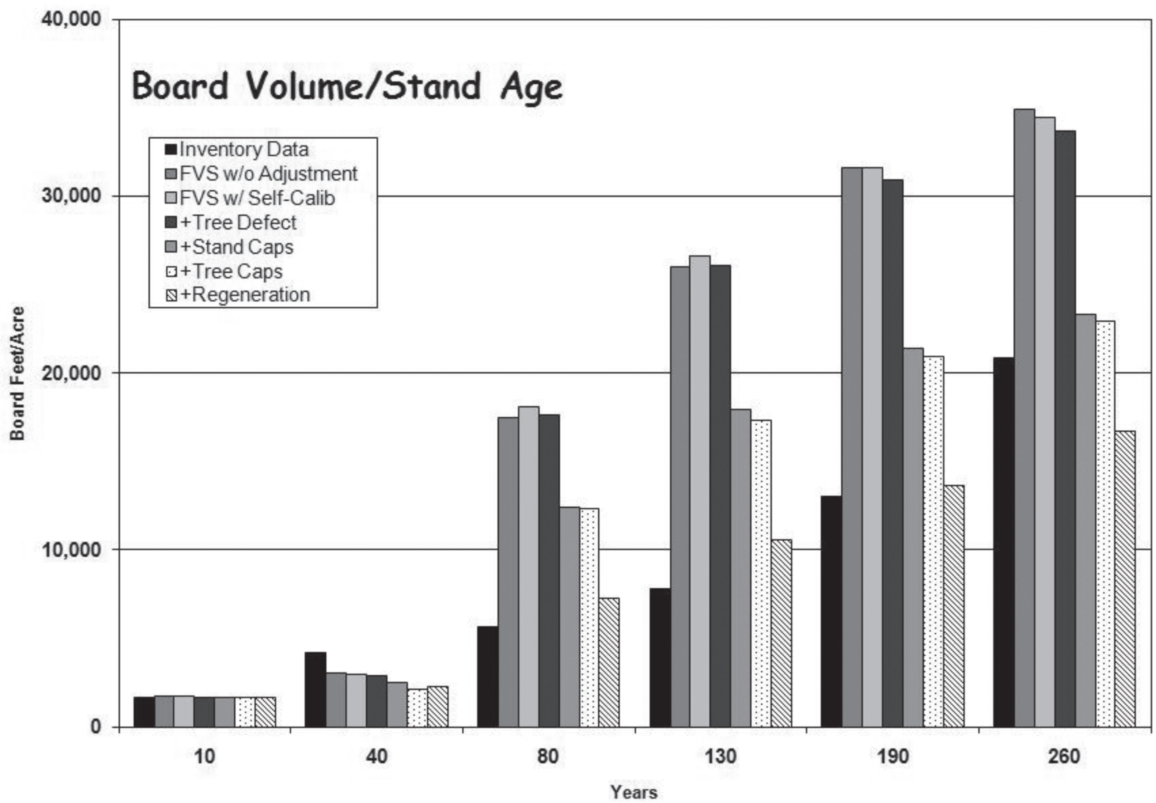


Figure 5—Comparison of board foot volume per acre over stand age by size class increments for measured and modeled runs. Within grouping, recommended assembly steps are added to the unadjusted model run to properly configure FVS to conform to measured values.

The FVS self-calibration process computes a scale factor that is used as a multiplier to the base growth equations. This scaling procedure is really quite simple. The affected models are linear with logarithmically scaled dependent variables. Therefore, the model intercepts are in effect growth multipliers. FVS predicts a growth increment to match each observed increment for a given species on a specific plot. The median difference is then added to the model for the species as an intercept term.

Growth multipliers can be developed across a large geographic area for a particular stand type. Using the CalbStat keyword in conjunction with the Calibration Summary Statistics post processing program produces average scale factors for all qualifying plots. ReadCorR (Readjust Correction for Regeneration) and ReadCorD (Readjust Correction for Diameter) keywords can be constructed from the mean multipliers listed in the Calibration Statistics Report. The ReadCorR and ReadCorD keywords alter the baseline estimate for small-tree height and large-tree diameter growth, respectively. For a particular species, the original baseline estimate is multiplied by the scale factor and the result becomes the new baseline estimate. These adjustments are done prior to the FVS self-calibration procedures per plot. Large-tree diameter increment scale factors attenuate toward the new baseline estimate at twenty-five year intervals as depicted in figure 6. Average scale factors computed for the Warm Dry Ponderosa Pine stand type within the Blue Mountains project area are displayed in table 3.

With respect to large-tree diameter growth, western larch (*Larix occidentalis* Nutt.) and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) grow slightly faster whereas grand fir (*Abies grandis*), lodgepole pine (*Pinus contorta* Douglas ex Louden), and ponderosa pine (*Pinus ponderosa* C. Lawson) grow slightly slower (compared to a mean ReadCorD multiplier equal to 1.000) relative to the base model equations. Regarding this data set for long-term projections, the species composition differs slightly with the inclusion of the ReadCorD keyword than without.

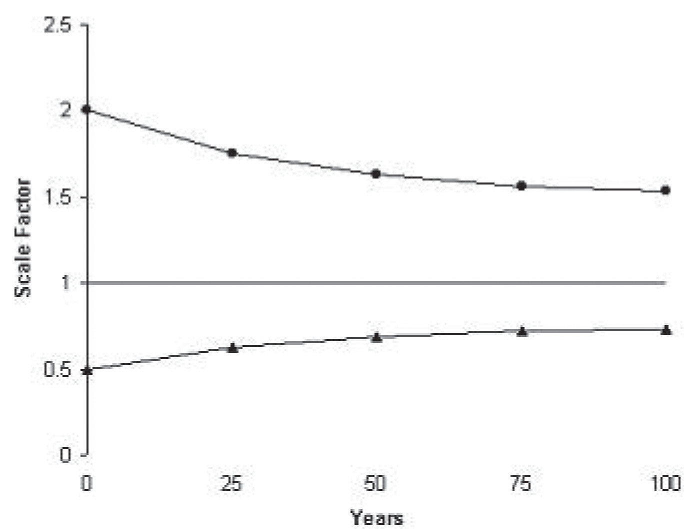


Figure 6—Scale factor attenuation occurs over time to the adjustment of the large-tree diameter growth equation.

Table 3—Calibration scale factors for the Warm Dry Ponderosa Pine stand type.

Tree species	Total tree records	Mean ReadCorR multiplier
Small-Tree Height Growth		
Ponderosa Pine	5	1.205
Large-Tree Diameter Growth		
Western Larch	32	1.096
Douglas-fir	118	1.001
Grand Fir	36	0.772
Lodgepole Pine	17	0.735
Ponderosa Pine	2741	0.813

FVS self-calibration does not address all 'measured' versus 'modeled' stand development discrepancies but rather only individual tree species small-tree height and large-tree diameter growth performance. In this case, due to the nominal differences in mean multipliers, board foot attainment was not dramatically improved by the inclusion of ReadCorR and ReadCorD keywords in the runstream. Refer to figure 5 (FVS w/ Self-Calib).

Tree Defect

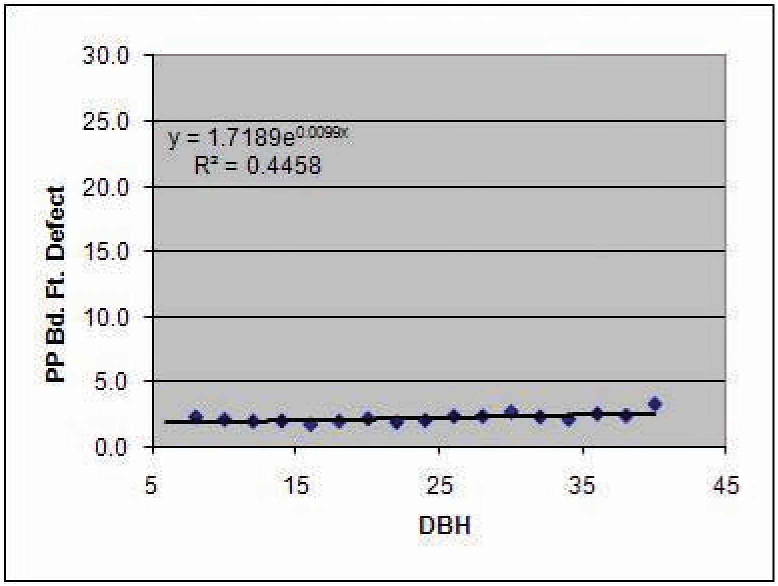
Determining net merchantable volume from gross tree dimensions requires an estimate of tree defect. Values can be obtained from field inventory data or recent timber sales. For example, defect estimates obtained from CVS data for the Blue Mountains project area was arrayed by tree species, by 5-inch diameter classes, to populate the Defect keyword. Figure 7 displays the board foot defect trend for ponderosa pine and grand fir.

Consult the Keyword Reference Guide (Van Dyck 2006) or the Suppose (Crookston 1997) interface for specific parameter fields associated with the Defect keyword. Applying board foot defect factors normally affects larger diameter trees and aids in reining in runaway sawtimber volume. Given that the Warm Dry Ponderosa Pine strata is comprised primarily of ponderosa pine tree species, the magnitude of board foot reduction is slight as observed in figure 5 (+Tree Defect). Certainly, the Warm Dry Grand Fir strata would display a more dramatic effect from accounting for board foot volume defect.

Natural Growth Runs

Landscapes that have been heavily impacted by disturbances may require forest planners to estimate stand development beyond the pool of existing stand structures. Very large and giant tree size classes may be absent among currently inventoried stands. In these situations, projections of old growth development are needed. A reasonable assumption would be an extrapolation of existing circumstances toward a 'steady-state' condition extending into the future.

The goal of developing natural growth runs is to try to capture ecosystem processes that sustain stand types to their reasonable extent. Adjustments are taken into account for stand and tree level mortality components. As growing space opens, regeneration fills the void. Crafting an endemic natural growth profile requires addressing mortality and regeneration interactions.



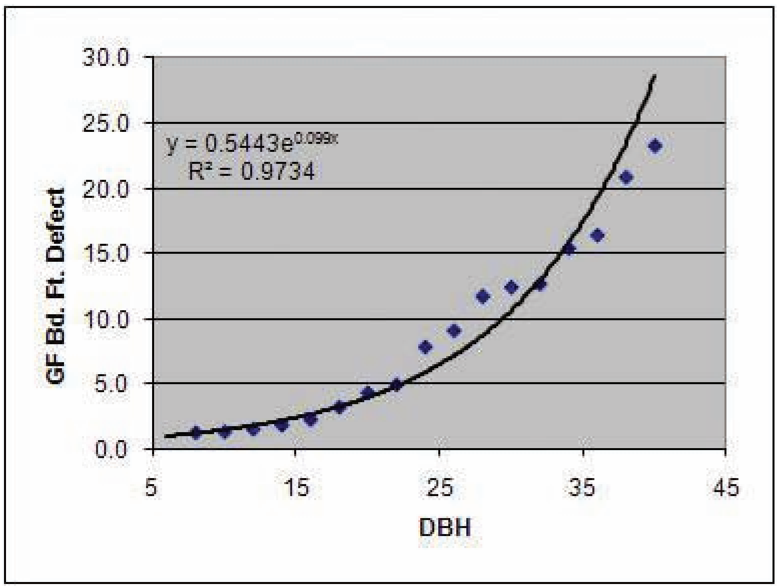


Figure 7—Measured board foot defect for ponderosa pine (PP) and grand fir (GF) on the Blue Mountains Project Area.

Stand Size Caps

The Forest Vegetation Simulator base model mortality predictions are intended to reflect mortality rates that allow for stand development to full site occupancy. Increases in mortality from insects, pathogens, and fire are accounted for in the various FVS model extensions. Mortality from other causes, such as logging operations, animal damage, or wind events, needs to be simulated with appropriate FVS keywords. There are three types of mortality base models used in FVS: (1) the original Prognosis type mortality model; (2) the Stand Density Index based mortality model; and (3) the Stand Density Index/TWIGS based mortality models.

The Prognosis type mortality model (Stage 1973) is used in western FVS variants where there were enough inventory data suitable for developing the associated equations. Two independent equations are involved. The first equation predicts an annual mortality rate as a function of habitat type, species, diameter, diameter increment, estimated potential diameter increment, stand basal area, and relative diameter. The estimated annual mortality rate is multiplied by a factor based on Reineke's (1933) Stand Density Index (SDI) that accounts for expected differences in mortality rates on different habitat types and National Forests. The second equation estimates mortality loss and is dependent on the proximity of stand basal area (BA) to the assumed maximum for a site, and on the estimated rate of basal area increment. The mortality rate applied to a tree record is a weighted average between equation one and two. The weights applied to the respective estimates are dependent on the proximity of the stand basal area to the maximum basal area specified for a site or strata (BAMax).

The Stand Density Index (SDI) based mortality model (Dixon 1986) is used in western FVS variants where there were not enough inventory data suitable for developing the Prognosis type mortality model, and no other suitable mortality model existed. Mortality predictions for the Blue Mountains variant are SDI based. The model has two steps. In the first step, the number of mortality trees is determined; in the second step, this mortality is dispersed to the individual tree records in FVS. Two types of base model mortality are estimated: (1) background mortality and (2) density related mortality. Density related mortality accounts for mortality in stands that are dense enough for competition to be the causal agent. All other mortality is attributable to background mortality. Background mortality gives way to density related mortality based on the relationship between current and maximum Stand Density Index. By default within FVS, density related mortality begins when the stand SDI is above 55 percent of maximum SDI, and stand density peaks at 85 percent of maximum SDI. Background mortality is used when current stand SDI is below 55 percent of maximum SDI. In FVS terminology, the 55 percent value is referred to as the lower limit of density related mortality, and the 85 percent value is the upper limit.

The Stand Density Index/TWIGS based mortality models are used in all eastern FVS variants. Mortality losses are determined using the SDI base model method. Mortality values are then dispersed to individual tree records using relationships found in the TWIGS type mortality models (Buchman 1983; Buchman and Lentz 1984; Buchman and others 1983; Teck and Hilt 1990). These equations are variant dependent and actually predict survival rate, rather than mortality rate. Survival rate is predicted as a function of diameter, diameter growth, basal area in larger trees, and/or site index. The survival rate is converted to a mortality rate for FVS processing. In addition, background mortality is estimated as 1/10th of the calculated TWIGS mortality rate for each individual tree record.

Thus, basal area or stand density index maximum control mortality predictions and associated stand-stocking attainment in all FVS variants. The bases for the default maximum density relationships within FVS are research studies that principally include pure, fully stocked, uniformly even-aged stands. Since most forest stands on public lands are very heterogeneous in regard to stocking and structure, FVS without adjustment tends to overestimate the carrying capacity of common conditions. Model projections tend toward full site occupancy estimates. To account for endemic or epidemic mortality loss caused by insects, diseases, fires, or other disturbance agents, use of FVS model extensions should be investigated. In their absence, if exogenous data is available that can be used to parameterize mortality modifying keywords; this method ought to be explored. Lacking model extensions or mortality keyword support, a proxy for estimating the endemic average maximum density can be derived from the inventory data sets that are used for the landscape analysis.

Users can set maximum SDI and BA values that represent endemic conditions. The Forest Vegetation Simulator can be used to compute the measured SDI value for each inventory plot. Filtering the SDI calculation to include trees 1.0-inch and greater in diameter enables excluding seedling tallies that can overwhelm the resultant value. Generally, the cluster of the top three percent of the inventory plots can then be averaged to determine the observed SDI maximum value[3]. To derive the average stand basal area maximum of the measured plots, multiply the observed SDI maximum value by 85 percent to represent an endemic maximum limit[4]. The observed basal area maximum is simply the basal area stocking most closely aligned with 85 percent of the observed Stand Density Index maximum value. The upper limit of density related mortality for the SDImax keyword should be set to 75 percent to represent the empirically derived endemic condition.

Table 4 contrasts the FVS default values for maximum SDI and BA (full site occupancy) against those derived from the inventory data (endemic conditions) for the Blue Mountains project area. Note that these two metrics have different basis and intended use. The FVS default values are indicative of theoretical stand density maximums. The data derived values are representative of average maximum stand density and have use for landscape planning projects.

The variant overview document should be consulted to determine the specific mortality model being employed for a given geographic area. The Blue Mountains variant uses the Stand Density Index based mortality model. Setting the stand density index maximum affects mortality predictions and stand-stocking attainment. Specifying a complementary basal area maximum is recommended. The effects of including an endemic stand density maximum that is more closely aligned to measurement data can be observed in figure 5 (+Stand Caps). Notice that as bars are being added to the right per stand age/size class grouping, the gap is closing between the inventory data and model projections with adjustments.

Tree Size Caps

The TreeSzCp keyword assists in setting the morphological limits for individual tree diameter and height development. The adjusted mortality rate is applied when a tree's diameter exceeds the threshold minimum diameter indicated for a given tree species. The threshold diameter acts as a surrogate for age to invoke senescence mortality. The process to parameterize the TreeSzCp keyword entails choosing the minimum diameter class that contains approximately one tree per acre (TPAmin) (the exact number is dependent on the relative abundance of a particular tree species) and targeting a maximum diameter class that contains

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[3] Edminster (1988) stated that: "For each stand in the database (1400 stands from USFS Region 2 and 2939 stands from USFS Region 3), Stand Density Index (SDI) was calculated, and stands with SDI values in the upper two percent from each Region were selected for further analysis to develop the Average Maximum Density (AMD) line. There was nothing special about using the top two percent, but for the six forest types analyzed, the selection has resulted in AMD lines which represent 'average maximum' conditions". Given smaller data sets to work with for landscape assessments, using the top three percent of the inventory plot set to determine AMD is reasonable and has worked repeatedly well for determining "average maximum" stand density index for FVS.

[4] Powell (1999) indicated in "Table 3 – Characterization of selected stand development benchmarks or stocking thresholds as percentages of maximum density and full stocking" that: "*Maximum Density* is the maximum stand density observed for a tree species; although rare in nature, it represents an upper limit. *Full stocking* refers to 'normal yield table' values; it has also been termed as 'Average Maximum Density.'" As a "percent of maximum density," full stocking was cited by Powell at 80 percent. (Recall in FVS, that density related mortality trends toward full site occupancy and peaks at 85 percent of maximum SDI.) The "*Lower Limit of Self Thinning Zone*, also referred to as the 'zone of imminent competition mortality' (Drew and Flewelling 1979)" is referenced by Powell at 60 percent of maximum density. (Recall in FVS, that density related mortality begins when the stand SDI is above 55 percent of maximum SDI.) Use of 75 percent of average maximum density as represented by the top three percent of selected plots renders an upper mid-range value between full stocking and the lower limit of self thinning zone. This is the suggested target for the *Endemic Stand Density Index Maximum*. Through repeat application of this process, FVS projection results support using this methodology to set stand density maximums

Table 4—Stand density maximums: Default values from Blue Mountains variant; derived values from inventory data.

Stand type	SDI Maximum FVS default	SDI Maximum Data derived	BA Maximum (ft^2/acre) FVS default	BA Maximum (ft^2/acre) Data derived
Subalpine Whitebark Pine	700	535	325	205
Cold Dry Mixed Conifer	593	505	275	175
Cold Moist Mixed Conifer	597	460	277	170
Warm Dry Grand Fir	604	415	280	160
Warm Dry Douglas-fir	446	340	207	150
Warm Dry Ponderosa Pine	***416***	***330***	***193***	***135***
Hot Dry Ponderosa Pine	361	290	167	115
Woodland Western Juniper	420	170	195	75

approximately one-tenth tree per acre (TPAmax)[5]. Subtracting the associated diameter minimum from the diameter maximum, then dividing by the average diameter growth rate renders the number of FVS projection cycles needed to get from the minimum to the maximum size diameter. Determining the mortality rate is akin to computing the discount interest rate needed to pay off a capital sum. The mortality rate equals one minus the ratio of TPAmax to TPAmin raised to the power of one over the number of projection cycles. Note that the mortality rate compounds each projection cycle. Thus, this is the factor needed to diminish the tree count from one to one-tenth. The mortality rate becomes the proportion of trees to succumb to mortality agents during successive projection cycles.

Table 5 displays stand table values for ponderosa pine based on the inventory plots from the Blue Mountains project area. The goal of developing the TreeSzCp keyword is to ensure morphological senescence for a given tree species based on measured observations. On average, ponderosa pine tree frequencies diminish from one to one-tenth in the 22-inch to 36-inch diameter range. The weighted average annual diameter growth rate within this diameter range was measured to be 0.088 inches. This implies that it would take approximately 160 years (i.e. sixteen 10-year FVS projection cycles) for ponderosa pine trees to grow from 22 inches in diameter to 36 inches. This aligns with the stand age estimates associated with the progression from the *very large* to *giant* tree size class listed in table 2.

Table 6 presents the values used in the determination of the mortality rate for ponderosa pine. Since the TreeSzCp keyword is applied from projection cycle to projection cycle during simulation runs, its effect is exponential. The relationship between the mortality rate and surviving trees is asymptotic and therefore not all trees die. A few trees (or portions of tree records in FVS terms) remain and grow to larger diameter greater than the maximum diameter value.

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[5] Shaw and others (2006) observed that: "However, the density-dependent self-thinning dynamic projected in the Southern variant of FVS may not be realistic for mature longleaf pine stands. Recent work suggests that the expected self-thinning trajectory does not hold for stands with a quadratic mean diameter greater than about 10 inches. Specifically, FVS projections of longleaf pine growth exceed the maximum limit of the size-density relationship, or "mature stand boundary," proposed by Shaw and Long (2007)." Application of the TreeSzCp keyword to the upper diameter range per tree species addresses this stand dynamic. Given that the mortality rate is applied exponentially over several projection cycles and across the "one-tenth" tree distribution target range, the TreeSzCp keyword implements the mature stand boundary concept. Repeat trials have supported methods used to construct the TreeSzCp keyword.

Table 5—Ponderosa Pine stand table, Blue Mountains Project Area, 415 inventory plots.

Diameter class (inches)	Trees/ acre	Average diameter (inches)	Diameter growth/year (inches)	Average height (ft)
<1.	261.518	0.10	0.302	1.0
2.	61.855	1.84	0.154	10.3
4.	42.051	3.87	0.111	18.4
6.	21.775	5.89	0.137	27.5
8.	18.171	7.92	0.132	36.3
10.	14.305	9.88	0.149	44.5
12.	10.320	11.87	0.141	52.5
14.	5.718	13.90	0.141	59.8
16.	3.727	15.86	0.133	66.6
18.	2.181	17.90	0.130	73.3
20.	1.538	19.86	0.100	79.6
22.	1.057	21.91	0.101	86.4
24.	0.715	23.84	0.092	91.6
26.	0.536	25.92	0.084	97.4
28.	0.406	27.89	0.082	100.7
30.	0.338	29.88	0.074	104.9
32.	0.193	31.91	0.072	109.3
34.	0.144	33.87	0.070	114.0
36.	0.091	35.93	0.079	118.2
38.	0.052	38.01	0.064	120.3
40.	0.088	42.12	0.063	128.0
Average: [a]			0.088	

[a] Weighted average annual diameter growth within specified range.

Table 6—Ponderosa Pine mortality rate computation.

Diameter class (inches)	Trees/ acre	Avg. diameter growth/year (inches)	10-Year project. cycles	Mortality rate[a]
22. — 36.	1.057 — 0.091	0.088	16	0.143

[a] Mortality Rate = $1 - (TPAmax/TPAmin)^{1/Proj\_Cycles}$

Although the impact of including size caps per tree species appears minimal in regards to board foot volume achievement, the importance can be observed in terms of tree frequency per stand size class. Refer to figure 4 (+Tree Caps +Regeneration). Having larger trees die provides opportunity for new trees to become established. These young recruits then grow in diameter and progress through the various size classes as would be expected in natural stand development.

Regeneration Inference

In the last stand visualization image for the FVS modeled run "without adjustments" (fig. 3, middle column), the lack of understory trees is readily apparent. Two versions of the Regeneration Establishment extension are used in FVS variants. One version is referred to as the "full" establishment model (Ferguson and Carlson 1993). This version has been calibrated for western Montana, central and northern Idaho, and coastal Alaska. It includes the full array of establishment options. The other version is referred to as the "partial" establishment model. This version only simulates regeneration from planting or stump sprouting; users must provide estimates of natural regeneration using keywords. The partial establishment model is used in variants for which the full establishment model has not been calibrated.

Most FVS variants rely on the partial establishment model. For those variants that support the full establishment model, the "with adjustment" run would have shown improved results in overall stand structure. The Blue Mountains variant relies on the partial establishment model. An empirical approach was used for estimating the natural regeneration response over time. Note that the tree count and board foot volume in figures 4 and 5 (+Regeneration) respectively reveal a comparable trend between measured data and model results. When regeneration is excluded, tree counts per acre steadily decline. When regeneration is included, canopy gaps caused by mortality agents are readily filled. Standing board foot volume is maintained in older age classes.

There are several methods available to induce a natural regeneration response for FVS variants that support only the partial establishment model. A portal in the FVS source code allows external programs to interact during the regeneration processing sequence (Robinson 2007). An understory estimation procedure has also been developed to import seedling/sapling recruitment (Vandendriesche 2009). One last method that should not be overlooked is local sources of expert opinion. Sophisticated FVS keyword sets can be constructed that depict expected natural regeneration response. Regardless of the process used, whether automatically invoked or user supplied, appropriate regeneration inferences are needed to configure a realistic FVS projection.

Board foot volume displayed in figure 5 (+Regeneration) reveals a significant reduction as a result of including regeneration impulses into the FVS projections. In conjunction with the tree size cap that injects overstory senescence, small trees can then occupy open space and influence the mortality prediction/stand density dynamic. Large trees are not allowed to simply grow and accumulate board foot volume. Large trees succumb to morphologic processes, which makes room for small tree establishment.

Assembly Process Summarized

Natural growth runs are a common starting point in the development of vegetation pathways for landscape assessments. It is quite possible in this day of constrained management that many stands will be left to let grow through the planning horizon. From a vegetation modeling standpoint, this scenario may appear to be the simplest to construct. However, due to our limited knowledge of older stand structures, this run stream may require the most time and imagination. Cultured stands are fairly straightforward with regard to stocking density at various stand ages. Also, the regeneration response may be highly regulated. Natural stands that are left to grow are more intricate to model. Forests are not static and in some cases are very dynamic over short periods of time.

Table 7 summarizes the assembly steps and associated FVS keywords that were employed to craft the endemic FVS runs for the Blue Mountains landscape assessment. Note that while the assembly steps are imperative, the suite of recommended FVS keywords is not exhaustive or conclusive. Use of the CrnMult or Prune keywords may be needed to adjust crown estimates during the model calibration phase. If priori information is available, perhaps the MortMult and FixMort keywords would be more appropriate for configuring the stand and tree size caps. If supportive expertise is accessible, use of existing insect and disease extensions and keyword component addfiles should also be explored.

Stand visualizations displayed in the right column of figure 3 show the improvements of applying the recommended assembly process. Comparing FVS "out of the box" with recommended adjustments, the difference between the measured trends and modeled projections is minimal. Individual plots have varying species compositions and structures but given sufficient time in the absence of disturbance will strive toward normality.

Looking again at two key characteristics highlights the similarities between the measured inventory data and the modeled FVS run with adjustments. Trees per acre plotted over stand age are displayed in figure 4. Board foot volume per acre plotted over stand age is presented in figure 5. Notice the magnitude in the inventory data bars on the left versus the fully assembly bars on the right of stand age/size class groupings. Reasonable similarity exists in terms of trees per acre and board foot volume attainment.

Table 7—Recommended checklist for assembling a FVS run.

Assembly steps:	FVS keywords:
Model calibration	
1. FVS Self-Calibration	{ReadCorR, ReadCorD}
2. Tree Volume Defect	{Defect}
Natural growth run	
3. Stand Stocking Attainment	{SDIMax, BAmax}
4. Tree Senescence Caps	{TreeSzCp}
5. Regeneration Response	{Natural}

Treatment Prescriptions

Once natural growth runs have been constructed using recommended FVS assembly techniques, various silvicultural prescription scenarios can be modeled. Management direction suggest action, be it passive or active. For planning projects, certain stand level treatments are postulated as potential activities to move the forest toward desired outcomes. For example, it may be proposed to reduce stocking densities to lessen insect impacts. Also, it may be recommended to provide remedial fuel treatments to minimize wildland fire intensity. Additionally, it may be advocated to produce a balance of stand size classes throughout the forest to furnish a full spectrum of wildlife habitats. Furthermore, it may be beneficial to explore predicted changes in climate. For each proposed action, a stand treatment schedule needs to be formulated to achieve the stated goal. The natural growth runs described in the previous section are a de facto prescription option to let stands grow with minimal management intervention.

Vegetation Pathways

A fundamental step in landscape planning is the analysis of the management situation. Various alternatives are proposed to guide future programmatic direction. Inherent to the analysis process is the gathering of inventory data and the projection of potential outcomes. Computer models play an important role in the projection process and formulation of management alternatives. Generally, two types of computer models are used for mid-scale forest planning: yield forecasting models and decision support systems. Yield models summarize current conditions and project future developments thus providing point-in-time value estimates. Decision support models pull together the state and transition components of forest planning. Coefficients computed by yield models are used by decision support systems to address management issues.

Evaluate Output

Preparing vegetation profiles in support of landscape planning projects is dissimilar to processing inventory data through static software. You can not simply feed data in one end and produce meaningful output at the other. Professional talents, including those of a mensurationist, ecologist, silviculturist, and forest analyst, are required to construct valid trends in vegetation development. This is not a complete list of specialty skills. Possessing these abilities does not ensure proper integration of tasks. Formal experience on several projects aids in solidifying the corporate memory to conduct such analyses. There is as much art as science that goes into the process.

Conclusions

In the *ideal* world of vegetation modeling, each of the fundamental biological processes that occur on an individual tree basis (i.e. diameter, height, and crown development) should be examined to verify expected performance. Does the diameter increment seem reasonable; do dominant trees obtain site-height at given stand ages; does tree crown development appear correct in open and closed canopy situations? Each of these aspects should be questioned and verified. Stand dynamics should also be checked. Are average maximum stocking densities obtainable; are successional trends captured; are forest gaps reclaimed by regeneration? These are basic stand level tenets that should be confirmed.

In the *real* world of vegetation modeling, time constrains such rigorous substantiation of predicted outcomes. Regardless, if a project requires analysis of one stand or many stand types, inventory data should be acquired that depicts the condition of interest. Calibration and maximum values can be derived from the associated data set. Regeneration response can also be gleaned empirically from measurement data. These are the facets that need to be examined and incorporated into a fully assembled FVS projection.

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