East Cascades Variant

of the

Forest Vegetation Simulator

Compiled by

Erin Smith-Mateja
Forest Management Service Center
Fort Collins, Colorado

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QUICK GUIDE TO DEFAULT SETTINGS

Parameter or Attribute	---------------- Default Setting ---------------- EC variant
Number of projection cycles	1 (if using Suppose then 10)
Projection cycle length	10 years
National Forest	606 = Mount Hood NF
Plant Association Code	114 = CPS241 (PIPO/PUTR/AGSP)
Site Index	75 = Ponderosa pine
Maximum Stand Density Index	237 = Ponderosa pine
Slope	5%
Aspect	0 degrees = north
Elevation	45 = 4500 feet
Latitude	45 degrees
Volume equations used	National Volume Estimator Library
Cubic Foot Volume Specifications:	
Minimum DBH	7.0" dbh (lodgepole: 6.0")
Top diameter (inside bark)	4.5" dib
Stump height	1.0 foot
Board Foot Volume Specifications:	
Minimum DBH	7.0" dbh (lodgepole: 6.0")
Top diameter (inside bark)	4.5" dib
Stump height	1.0 foot
Sampling Design	
Large Trees (Variable Radius Plot)	40 BAF
Small Trees (Fixed Radius Plot)	1/300th acre
Breakpoint DBH	5.0"

1.0 INTRODUCTION

The Forest Vegetation Simulator (FVS) is an individual tree, distance independent growth and yield model with linkable modules, called extensions, which simulate various insect and pathogen impacts, development of understory vegetation, and fire effects. A general description of FVS structure and operation is given in Dixon (2002). This document presents codes, model relationships, and logic that is specific to the East Cascades Variant.

Data used in building the East Cascades Prognosis Model came from forest inventories, silviculture stand examinations, and tree nutrition studies (Table 2 and Appendix B.). Forest inventories came from the Forest Service as well as the Warm Springs and Yakima Indian Reservations and the State of Washington Department of Natural Resources. Western white pine uses equations developed for the Southern Oregon/Northeastern California (SORNEC) variant of the Prognosis model. Western redcedar uses equations from the Inland Empire Prognosis Model.

Technical Development of the East Cascades Variant was done by:

Ralph Johnson, Biometrician
USDA-FS, Fort Collins, CO

George Lightner, Mensurationist
USDA-FS, Portland, OR

Dr. Gary E. Dixon, Biometrician
USDA-FS, Fort Collins, CO

2.0 GEOGRAPHIC RANGE

The East Cascades variant covers National Forest land on the eastern slope of the Cascade range in Washington and the northern portion of the eastern slope of the Cascade range in Oregon (figure 1). Other forest land can be simulated provided stand attributes are similar to the National Forests listed in Table 1.

Figure 1. Approximate geographic range covered by the East Cascade variant of the Forest Vegetation Simulator.

3.0 CONTROL VARIABLES

Users need to specify certain variables used by the East Cascades (EC) variant to control a simulation. These are entered in parameter fields on various FVS keywords or if interfacing with FVS using SUPPOSE these are entered on the B record of the Stand List File (*.slf).

3.1 Forest Codes

Forest code is entered as a number in field 1 of the STDINFO keyword. If the forest code is missing or incorrect, a default forest code of 606, Mount Hood National Forest, will be used. A complete list of forest codes recognized in the EC variant is shown in Table 1.

Table 1. Forest codes used in the East Cascade FVS variant.

Forest Code	National Forest
603	Gifford Pinchot
606	Mount Hood
608	Okanogan
617	Wenatchee
699	Okanogan (Tonasket RD)

3.2 Species Codes

The East Cascades variant recognizes 11 species codes. Either the species alpha code or its' Forest Inventory and Analysis (FIA) code can be used in the FVS input data. The FVS sequence number or alpha code can be used to specify a species on the FVS keywords. Any unrecognized species will default to the "other species" category. A complete list of species codes recognized by the EC variant is shown in table 2.

Table 2. Species codes used in the East Cascades FVS variant.

FVS Number	Alpha Code	FIA Code	Common Name	Scientific Name	Number of Observations
1	WP	119	Western white pine	Pinus monticola	0
2	WL	073	Western larch	Larix occidentalis	652
3	DF	202	Douglas-fir	Pseudotsuga menziesii	6,249
4	SF	011	Pacific silver fir	Abies amabilis	1,210
5	RC	242	Western redcedar	Thuja plicata	0
6	GF	017	Grand fir	Abies grandis	1,950
7	LP	108	Lodgepole pine	Pinus contorta	1,479
8	ES	093	Engelmann spruce	Picea Engelmannii	623
9	AF	019	Subalpine fir	Abies lasiocarpa	729
10	PP	122	Ponderosa pine	Pinus ponderosa	4,040
11	OT	999	Mountain hemlock / Other	Tsuga mertensiana	1,443

3.3 Plant Association Codes

Plant association codes are used as site level information to obtain the default site index species, site indices, and maximum stand density indices. Plant association codes can be entered in field 2 of the STDINFO keyword. If users are interfacing with FVS though SUPPOSE, they can fill in the plant association code in field 7 of the B record of the Stand List File. Plant association codes recognized in the EC variant are shown in Appendix A. If an incorrect plant association code is entered or no code is entered, FVS will use the default plant association code, CPS241, in the East Cascades variant. If the default is not similar to the stand being run then there may be large unintended impacts on the simulation, because incorrect site indices and stand density indices are being used to grow and kill the simulated trees. If plant association code is not known it is imperative that site index and maximum stand density indices are entered at input to get reasonable estimates of growth and mortality.

3.4 Site Index

Site index is used in some of the growth equations for the EC variant. When possible users should enter their own values using the SITECODE keyword, instead of relying on values assigned from the plant association codes (Appendix A). If users are interfacing with FVS though SUPPOSE, they can fill in site index for the site species in fields 26 and 27 of the B record of the Stand List File. Users should always use the same site curves that FVS uses (Table 3).

Table 3. Site index reference curves for species in the East Cascade variant of FVS.

Species	Reference	BHA or TTA*	Base Age
WP	Brickell, J.E., 1970, USDA-FS Res. Pap. INT-75	TTA	50
WL	Cochran, P.H.,1985, USDA-FS Res. Note PNW-424	BHA	50
DF	Cochran, P.H.,1979, USDA-FS Res. Pap. PNW-251	BHA	50
SF	Cochran, P.H.,1979, USDA-FS Res. Pap. PNW-252	BHA	50
RC	Hegyi, R.P.F., et. al. , 1979, Province of B.C., Forest Inv. Rep. 1	TTA	100
GF	Cochran, P.H.,1979, USDA-FS Res. Pap. PNW-252	BHA	50
LP	Alexander, R.R., et. al., 1967, USDA-FS Res. Pap. RM-29	TTA	100
ES	Alexander, R.R.,1967, USDA-FS Res. Pap. RM-32	BHA	100
AF	Demars, D.J. et. al., 1970, USDA-FS Res. Note PNW-119	BHA	100
PP	Barrett, J.W., 1978, USDA-FS Res. Pap. PNW-232	BHA	100
OT	Means, et. al., 1986, unpublished FIR Report. Vol. 10, No. 1, OSU	BHA	100

* Equation is based on total tree age (TTA) or breast height age (BHA)

3.5 Maximum Stand Density Index

Maximum stand density index is an important variable in determining density related mortality, normal stocking for automatic thinnings, and changes in crown ratio. If values are not specified on input, FVS will use a default based on the plant association code (Appendix A). In some cases the maximum SDI assigned from the plant association code is very large, therefore a cap of 900 has been placed on these defaults. So if a plant association code indicates a Maximum SDI (in Appendix A) of more than 900, it has been reset to be 900. When possible users should enter their own maximum stand density index, which can be specified using the SDIMAX keyword. If users are interfacing with FVS though SUPPOSE, they can fill in the maximum stand density index for the site species in field 25 of the B record of the Stand List File.

4.0 GROWTH MODEL RELATIONSHIPS

4.1 Height-Diameter Relationships

Height-diameter relationships are used to estimate heights missing in the input data. In the EC variant, the model will dub in heights by one of two methods. By default, the EC variant will use the Curtis-Arney functional form as shown in equation {1} or {2} (Curtis 1967, Arney 1985). If the input data contains at least three measured heights for a species then a logistic height-diameter equation {3} (Wykoff, et.al 1982), can be calibrated to the input data. The default in the EC variant is to use equation {1} or {2}, and not to calibrate the logistic equation. To override the default you must use the NOHTDREG keyword and change field 2 to a 1.

{1} $HT = 4.5 + a * e^{[-1.0 * b * DBH \wedge c]}$ $DBH \geq 3.0$

{2} $HT = [(4.5 + a * e^{[-1.0 * b * 3.0 \wedge c]} - 4.51) * (DBH-0.3)/2.7]+4.51$ $DBH \leq 3.0$

{3} $HT = 4.5 + e^{[a + b/(DBH+1)]}$

where:
HT is the total tree height in feet
DBH is the tree diameter at breast height
a, b, c are species specific coefficients shown in table 4 or 5

Table 4. Default coefficients for the Curtis-Arney height-diameter relationship in the East Cascades FVS variant, see equation {1} and {2}.

National Forest	**Mount Hood (606)**			**All others (603, 608, 617, 699)**		
Species	**a**	**b**	**c**	**A**	**b**	**c**
Western white pine	433.7807	6.3318	-0.4988	1143.6254	6.1913	-0.3096
Western larch	220.0	5.0	-0.6054	255.4638	5.5577	-0.6054
Douglas-fir	234.2080	6.3013	-0.6413	519.1872	5.3181	-0.3943
Pacific silver fir	441.9959	6.5382	-0.4787	171.2219	9.9497	-0.9727
Western redcedar	487.5415	5.4444	-0.3801	616.3503	5.7620	-0.3633
Grand fir	376.09781	5.1639	-0.4319	727.8110	5.4648	-0.3435
Lodgepole pine	121.139	12.662	-1.2981	102.6146	10.1435	-1.2877
Engelmann spruce	2118.6711	6.6094	-0.2547	211.7962	6.7015	-0.6739
Subalpine fir	66.6950	13.2615	-1.3774	113.5390	9.0045	-0.9907
Ponderosa pine	324.4467	8.0484	-0.5892	324.4467	8.0484	-0.5892
Mountain hemlock/ Other	224.6205	7.2549	-0.6890	631.7598	5.8492	-0.3384

Table 5. Default coefficients for the logistic height-diameter relationship in the East Cascades FVS variant, see equation {3}.

Species	a	b
Western white pine	5.035	-10.674
Western larch	4.961	-8.247
Douglas-fir	4.920	-9.003
Pacific silver fir	5.032	-10.482
Western redcedar	4.896	-8.391
Grand fir	5.032	-10.482
Lodgepole pine	4.854	-8.296
Engelmann spruce	4.948	-9.041
Subalpine fir	4.834	-9.042
Ponderosa pine	4.884	-9.741
Mountain Hemlock/ Other	3.9715	-6.7145

4.2 Bark Ratio Relationships

Bark ratio estimates are used to convert between diameter outside bark and diameter inside bark in various parts of the model. The equation form is shown in equation {4} and coefficients for these equations are shown in Table 6.

{4} $DIB = b_1 * [1/DOB]$

where:
DIB is inside bark tree diameter (bounded between .80-.99)
DOB is outside bark tree diameter
b_1 is the species-specific bark ratio

Table 6. Coefficients for the bark ratio equation in the East Cascades variant of FVS, see equation {4}.

FVS Number	Species	b_1
1	Western white pine	0.964
2	Western larch	0.851
3	Douglas-fir	0.844
4	Pacific silver fir	0.903
5	Western redcedar	0.950
6	Grand fir	0.903
7	Lodgepole pine	0.963
8	Engelmann spruce	0.956
9	Subalpine fir	0.903
10	Ponderosa pine	0.889
11	Mountain hemlock / Other	0.934

4.4 Crown Competition Factor and Crown Width

The East Cascades variant uses crown competition factor (*CCF*) as a predictor variable in some growth relationships, and crown width is used for percent cover calculations in the model. Stand CCF is reported in the summary statistics table of the Main Output file and max crown width is reported for each tree in the Trees List Output file. Crown competition factor (Krajicek and others 1961) is a relative measurement of stand density that is also based on tree diameters. Individual tree CCF_t values estimate the percentage of an acre that would be covered by the tree's crown if the tree were open-grown. Stand *CCF* is the summation of individual tree (CCF_t) values. A stand *CCF* value of 100 theoretically indicates that tree crowns will just touch in an unthinned, evenly spaced stand. Crown competition factor for an individual tree is calculated using equations {7-9}. For Douglas-fir and Ponderosa pine greater than 1.0 inch dbh the coefficients were derived from Paine and Hann (1982). All others use the Inland Empire variant coefficients (Wykoff, et.al 1982).

{7} $CCF_t = a_1 + a_2 * DBH + a_3 * DBH^2 \qquad 1.0 \leq DBH$

{8} $CCF_t = b_1 * DBH^{b2} \qquad 0.1 < DBH < 1.0$

{9} $CCF_t = 0.001 \qquad DBH \leq 0.1$

where:
CCF_t is the crown competition factor for an individual tree
DBH is the tree diameter at breast height
b_1, b_2, a_1-a_3 are species-specific coefficients shown in Table 7

Table 7. Coefficients for computing the contribution of each tree record to the stand estimate of crown competition factor, in the East Cascades variant of FVS, see equations {7-8}.

	Model Coeffiecients				
Species	**b_1**	**b_2**	**a_1**	**a_2**	**a_3**
Western white pine	.009884	1.6667	.03	.0167	.00230
Western larch	.007244	1.8182	.02	.0148	.00338
Douglas-fir	.017299	1.5571	.0388	.0269	.00466
Pacific silver fir	.015248	1.7333	.04	.0270	.00405
Western redcedar	.008915	1.7800	.03	.0238	.00490
Grand fir	.015248	1.7333	.04	.027	.00405
Lodgepole pine	.009187	1.7600	.01925	.01676	.00365
Engelmann spruce	.007875	1.7360	.03	.0173	.00259
Subalpine fir	.011402	1.7560	.03	.0216	.00405
Ponderosa pine	.007813	1.7780	.0219	.0169	.00325
Mountain hemlock / Other	.011109	1.7250	.03	.0215	.00363

Crown width for the East Cascades variant of FVS is computed using equations {8-9} and coefficients shown in Table 8. These equations were developed by Dennis Donnelly of the Forest Management Service Center using R6 inventory data. Equations were fit for 30 species in the Pacific Northwest. Mountain hemlock/ Other species uses the western redcedar coefficients.

{10} $CW = a_0 * HT$ $HT \leq 4.5$ feet

{11} $CW = a_1 * DBH^{a2}$ $HT > 4.5$ feet

where:
CW is tree crown width in feet
DBH is tree diameter at breast height in inches
HT is total tree height in feet

Table 8. Coefficients for the crown width equations in the East Cascades variant of FVS, see equations {10} and {11}.

	Model Coefficients		
Species	**a_0**	**a_1**	**a_2**
Western white pine	0.476	3.4447	0.5185
Western larch	0.316	2.9571	0.6081
Douglas-fir	0.517	4.4215	0.5329
Pacific silver fir	0.473	3.9723	0.5177
Western redcedar	0.698	6.2318	0.4259
Grand fir	0.489	4.1870	0.5341
Lodgepole pine	0.298	2.4132	0.6403
Engelmann spruce	0.451	3.6802	0.4940
Subalpine fir	0.385	3.2348	0.5179
Ponderosa pine	0.407	2.8541	0.6400
Mountain hemlock / Other	0.698	6.2318	0.4259

4.5 Small-tree Growth Relationships

Trees are considered “small” trees for FVS modeling purposes when they are smaller than some threshold diameter. This threshold diameter is a function of the lower diameter limit in the data used to fit the model, and how well the model used to estimate growth of “large” trees fits trees in the lower end of the diameter range. The threshold diameters used in the East Cascades variant are shown in Table 9.

The small tree model is height-growth driven. That is to say, height growth is estimated first, then diameter growth is estimated from height growth, and finally crown ratio change is estimated.

Table 9. Threshold diameters for switching between small-tree growth equations and large tree growth equations in the East Cascades FVS variants, and the range of diameters (minimum and maximum) over which small tree height growth estimates are weighted with large tree estimates for transition between the two model formulations.

Species	Diameter growth Threshold DBH	Height growth Min. DBH	Height growth Max. DBH
Western white pine	3.0	2.0	4.0
Western larch	3.0	2.0	4.0
Douglas-fir	3.0	2.0	4.0
Pacific silver fir	3.0	2.0	4.0
Western redcedar	3.0	2.0	10.0
Grand fir	3.0	2.0	4.0
Lodgepole pine	3.0	1.0	5.0
Engelmann spruce	3.0	2.0	4.0
Subalpine fir	3.0	2.0	6.0
Ponderosa pine	3.0	2.0	6.0
Mountain hemlock / Other	3.0	2.0	6.0

4.5.1 Small -tree Height Increment Model

The small-tree height increment model for all species in the EC variant, predicts periodic (5-year) height increment (*HTG*) for small trees, based on site index. Potential height growth is estimated using equations {12} or {13}and coefficients in Table 10. Potential height growth is adjusted (reduced) based on stand density (*PCTRED*), equation {14}, and crown ratio (*VIGOR*), equation {15}. Height growth is estimated using equation {16}.

For all species, a small random error is then added to the height growth estimate. The estimated height growth, (*HTG*), is then adjusted to account for cycle length, user defined small-tree height growth adjustments, and adjustments due to small tree height model calibration from the input data.

Table 10. Coefficients for the small tree height growth equations in the East Cascades variant of FVS, see equations 10 and 11.

	Model Coefficients			
Species	**b_1**	**b_2**	**b_3**	**b_4**
Western white pine	0.375045	0.92503	-.02079	2.48811
Western larch	3.9725	0.50995	28.1168	0.05661
Douglas-fir	2.0	0.420	28.5	0.05
Pacific silver fir	-0.6667	0.4333	28.5	0.05
Western redcedar	0.752842	1.0	-0.0174	1.4711
Grand fir	-1.0470	0.4220	28.7739	0.0597
Lodgepole pine	0.3277	0.01296		
Engelmann spruce	-8.0	0.35	53.7254	0.274509
Subalpine fir	6.0	0.14	33.882	0.06588
Ponderosa pine	-1.0	0.32857	28.0	0.042857
Mountain hemlock / Other	0.965758	0.082969	55.2496	1.288852

Western white pine and redcedar use equation {12} to predict potential height growth.

{12} $POTHTG = (SI/b_1)*(1.0-b_2*EXP(b_3*X_1))**b_4 - (SI/b_1)*(1.0-b_2*EXP(b_3*X_2))**b_4$

where:

$X_1 = LN((1.0 - (b_1/SI * H)**(1/b_4))/b_2) / b_3$

$X_2 = LN (1.0 - (b_1/SI * H)**(1/b_4))/b_2) / b_3 + A$

POTHTG is the small tree potential height growth

H is the present height of the tree

SI is the species site index, bounded by SITELO and SITEHI in Table 11.

A is the age of tree

LN is natural log

b_1-b_4 are species specific coefficients shown in Table 12

Western larch, Douglas-fir, subalpine fir, grand fir, lodgepole pine, Engelmann spruce, ponderosa pine, and other species use equation {13} to predict potential height growth.

{13} $POTHTG = ((b1 + b2*SI)/(b3 - b4*SI))*A$

where:

POTHTG is the small tree potential height growth

SI is the species site index, bounded by SITELO and SITEHI in Table 11.

A is the age of tree

Table 11. The site index bounds for species in the East Cascades variant to predict small tree height growth.

Species	SITELO	SITEHI
Western white pine	20	80
Western larch	50	110
Douglas-fir	50	110
Pacific silver fir	50	110
Western redcedar	15	30
Grand fir	50	110
Lodgepole pine	30	70
Engelmann spruce	40	120
Subalpine fir	50	150
Ponderosa pine	70	140
Mountain hemlock / Other	15	30

{14} $PCTRED = 1.11436 - 0.011493*X + 0.43012E\text{-}04 * X^2 - 0.72221E\text{-}07 * X^3 + 0.5607E\text{-}10 * X^4 - 0.1641E\text{-}13 * X^5$

where:

PCTRED is the reduction proportion in height growth due to stand density, bounded between 0.01 and 1.0

X is *AVHT* * (*CCF*/100) with an upper bound of *X*=300

AVHT is average height of the 40 largest diameter trees in the stand

CCF is stand crown competition factor

{15} $VIGOR = (150 * CR^3 * e^{(-6 * CR)}) + 0.3$

where:

VIGOR is the reduction proportion in height growth due to tree vigor with an upper bound of 1.0

CR is a trees' live crown ratio (compacted) expressed as a proportion

{16} $HTG = POTHTG * PCTRED * VIGOR$

where:

HTG is estimated height growth in feet

POTHTG is potential height growth (equation {12} or {13})

PCTRED is reduction proportion due to stand density (equation {14})

VIGOR is reduction proportion due to tree vigor (equation {15})

Height growth estimates from the small-tree model are weighted, using equation {17}, with height growth estimates from the large tree model to smooth the transition between the two models.

{17} Predicted *HTG* = (small tree *HTG*)*(1 –weight) + (large tree *HTG*)*weight

where:

weight = (diameter – minimum *DBH*) / (maximum *DBH* – minimum *DBH*)

weight = 0 if diameter is less than the minimum *DBH* shown in Table 9

weight = 1 if diameter is greater than the maximum *DBH* shown in Table 9

4.5.2 Small-tree Diameter Increment Model

As stated previously, for trees being projected with the small tree equations, height growth is predicted first, and then diameter growth. So both height at the beginning of the cycle and height at the end of the cycle are known when predicting diameter growth. Small-tree diameter growth for trees over 4.5 feet tall is calculated as the difference of predicted diameter at the start of the projection period and the predicted diameter at the end of the projection period, adjusted for bark ratio. These two predicted diameters are estimated using the species specific height-diameter relationships discussed in section 4.1. By definition, diameter growth is zero for trees less than 4.5 feet tall.

4.5.3 Small-tree Changes in Crown Ratio

For all species, crown ratios are held constant until the tree reaches 1.0" in diameter. So up to that point the crown ratio will be the value entered in the input data or the estimated initial value if crown ratio was missing in the input data. Changes in crown ratio for all trees 1.0" in diameter and larger use the crown ratio relationships shown in section 4.6.3.

4.6 Large-tree Growth Relationships

Trees are considered "large" trees for FVS modeling purposes when they are larger than some threshold diameter. The threshold diameters used in the East Cascades variant are shown in Table 9.

The large tree model in FVS is diameter-growth driven. That is to say, diameter growth is estimated first, then height growth is estimated from diameter growth and other variables, and finally crown ratio change is estimated.

4.6.1 Large-tree Diameter Growth

A single equation form is used for large-tree diameter growth for all species in the East Cascades variant. This equation is shown in {16} with coefficients shown in Tables 16-17.

{18} $$\ln(DDS) = \beta_1 + (\beta_2 * ELEV) + (\beta_3 * ELEV^2) + (\beta_4 * ALOG(XSITE)) + (\beta_5 * SIN(ASP) + \beta_6 * COS(ASP) + \beta_7)*SL) + (\beta_8 * SL^2) + \beta_9 + (\beta_{10} * ALOG(DBH)) + (\beta_{11} * DUMMY) + (\beta_{12} * CR) + (\beta_{13} * CR^2) + (\beta_{14} * DBH^2) + (\beta_{15} * BAL/(ALOG(DBH+1.0))) + (\beta_{16} * PCCF) + (\beta_{17} * RELHT * PCCF/100) + (\beta_{18} * PCCF * PCCF/1000) + (\beta_{19} * RELHT) + (\beta_{20} * RMAI*STCCF) + \beta_{21}$$

where:

ELEV is stand elevation
XSITE is the species site index (if species 11, then xsite = 3.281*site index)
ASP is stand aspect
S*L* is stand slope
DBH is current tree diameter at breast height
CR is crown ratio expressed as a proportion
BAL is basal area in trees larger than the subject tree
PCCF is crown competition factor on a sample point
RELHT is the tree height divided by the average height of the 40 largest diameter trees
RMAI is stand mean annual increment
STCCF is stand crown competition factor
COR is diameter growth scale factor, by species
β_1-β_{21} are site and species specific coefficients (see Tables 12-13)

Table 12. Coefficients of the diameter increment model by species for the East Cascades variant of FVS, see equation {18}.

	Species[1]				
	1(WP)	**2(WL)**	**3(DF)**	**4(SF)**	**5(RC)**
β_1 =	**Location Constant[2]**				
1	-4.64535	-0.60565	-4.08104	-0.44141	1.49419
2	0	0	-3.96596	-0.53899	0
3	0	0	0	0	0

β_2 =	0	0.004379	-0.02109	-0.01509	-0.00175
β_3 =	0	0	0.000225	0	-6.7E-05
β_4 =	0.86756	0.351929	1.119725	0.323625	0
β_5 =	0.38002	-0.15624	-0.09215	-0.05906	-0.06625
β_6 =	-0.17911	0.258712	0.029947	-0.12813	0.05534
β_7 =	-0.8178	-0.6357	-0.30951	0.240178	0.11931
β_8 =	0.8	0	0	0.131356	0
β_9 =	Conditional of value of Slope (SL)				
If SL = 0	0	-0.29017	0	-0.1744	0
If SL $\neq$ 0	0	0	0	0	0
β_{10} =	1.3261	0.609098	0.855516	0.980383	0.58705
β_{11} =	0	0	0	-0.79908	0
β_{12} =	1.2973	1.158355	2.009866	1.709846	1.2936
β_{13} =	0	0	-0.44082	0	0
β_{14} =	0	-0.00017	-0.00026	-0.00022	0
β_{15} =	-0.00239	-0.00425	-0.00308	-0.00026	-0.02284
β_{16} =	-0.00044	-0.00057	-0.00044	-0.00064	-0.00094
β_{17} =	0	0	0	0	0
β_{18} =	0	0	0	0	0
β_{19} =	0.49649	0	0	0	0
β_{20} =	0	0	0	0	0
β_{21} =	0	0	0	0	0

[1]Species are defined in Tables 2- [2]Location classes are defined in Table 13.

Table 12 (continued). Coefficients of the diameter increment model by species for the East Cascades variant of FVS, see equation {18}.

	Species					
	6(GF)	**7(LP)**	**8(ES)**	**9(AF)**	**10(PP)**	**11(OT)**
β_1 =	**Location Constant**[2]					
1	-3.8111	-1.08468	-0.09828	-0.42021	-3.10203	-1.40755
2	-3.67311	-1.17247	0.117987	-0.31296	0	-1.13193
3	0	0	0	0	0	-1.53908
β_2 =	0.02302	-0.00112	-0.01494	-0.00943	-0.00535	0.012082
β_3 =	-0.00036	0	0	0	0	0
β_4 =	0.782092	0.458662	0.290959	0.23196	0.921987	0.346907
β_5 =	-0.23916	-0.06433	-0.05559	-0.04976	-0.18102	-0.09729
β_6 =	-0.18552	-0.14233	0.216231	0.00281	-0.14985	0.037062
β_7 =	1.466089	-0.0973	-0.00058	1.160345	-0.25271	0.089774
β_8 =	-1.81705	0.094464	0	-1.74011	0	0
β_9 =	Conditional of value of Slope (SL)					
If SL = 0	-0.3602	0	0	-0.2786	0	-0.09991
If SL $\neq$ 0	0	0	0	0	0	0
β_{10} =	1.042583	0.554261	0.823082	0.816917	0.665401	0.580156

β_{11} =	0.522079	0	0	0	0	0
β_{12} =	2.182084	1.423849	1.26361	1.119493	1.671186	1.212069
β_{13} =	-0.84352	0	0	0	0	0
β_{14} =	-0.00037	0	-0.0002	0	-0.00025	-1.9E-05
β_{15} =	-0.00132	-0.0048	-0.00516	-0.0007	-0.00807	0
β_{16} =	-0.00157	-0.00063	-0.00088	-0.0011	0.00112	-0.00122
β_{17} =	0	0	0	0	0	0.156459
β_{18} =	0	0	0	0	-0.00318	0
β_{19} =	0	0	0	0	0	0
β_{20} =	0	0	0	0	0	-2.1E-05
β_{21} =	0	0	0	0.3835	0	0

[1]Species are defined in Tables 2 . [2]Location classes are defined in Table 13.

Table 13. Classification of location effects by species among National Forests for the diameter increment model in the East Cascades variant of FVS, see equation {16}.

	Location effect by Species										
National Forest	**WP**	**WL**	**DF**	**SF**	**RC**	**GF**	**LP**	**ES**	**AF**	**PP**	**OT**
Gifford Pinchot	1	1	1	1	1	1	1	1	1	1	1
Mount Hood	1	1	2	2	1	1	1	1	1	1	2
Okanogan	1	1	1	1	1	1	2	1	1	1	3
Wenatchee	1	1	2	1	1	2	1	2	2	1	3
Okanogan (Tonasket RD)	1	1	1	1	1	1	1	2	1	1	1

4.6.2 Large-tree Height Growth

Height growth equations in the EC variant are based on site index curves (Table 3). Height increment is obtained by subtracting current height from estimated future height, then adjusting the estimate according to tree's vigor and social position in the stand.

Estimated height after 10-years for white pine

{19} $H10 = SI/(\beta_0*(1.0- \beta_1 *EXP(\beta_2*A))^{\beta 3})$

Estimated height after 10-years for western larch

{20} $H10 = 4.5 + \beta_1*A + \beta_2*A^2 + \beta_3*A^3 + \beta_4*A^4 + (SI -4.5)*(\beta_5 + \beta_6*A + \beta_7* A^2+ \beta_8* A^3) - \beta_9*(\beta_{10} + \beta_{11}*A + \beta_{12}* A^2+ \beta_{13}* A^3)$

Estimated height after 10-years for Douglas-fir

{21} $H10 = 4.5 + EXP(\beta_1 + \beta_2*ALOG(A) + \beta_3*(ALOG(A))^4) + \beta_4*(\beta_5 + \beta_6*(1.0 - EXP(\beta_7*A))^{\beta 8}) + (SI - 4.5)*(\beta_5 + \beta_6*(1.0 - EXP(\beta_7*A)^{\beta 8}))$

Estimated height after 10-years for grand fir and Pacific silver fir

{22} $H10 = EXP[\beta_0 + \beta_1*ALOG(A) + \beta_2*(ALOG(A))^4 + \beta_3*(ALOG(A))^9 + \beta_4*(ALOG(A))^{11} + \beta_5*(ALOG(A))^{18}] + \beta_{12} * EXP[\beta_6 + \beta_7*ALOG(A) + \beta_8*(ALOG(A))^2 + \beta_9*(ALOG(A))^7 + \beta_{10}*(ALOG(A))^{16} + \beta_{11}*(ALOG(A))^{24}] + (SI - 4.5)*EXP[\beta_6 + \beta_7*ALOG(A) + \beta_8*(ALOG(A))^2 + \beta_9*(ALOG(A))^7 + \beta_{10}*(ALOG(A))^{16} + \beta_{11}*(ALOG(A))^{24}] + 4.5$

Estimated height after 10-years for redcedar

{23} $H10 = \beta_1*SI * ((1.0 - EXP(\beta_2*A))** \beta_3)$

Estimated height after 10-years for lodgepole pine

{24} $H10 = \beta_0 + \beta_1*A + \beta_2* A^2+ \beta_3* 0.0*SI + \beta_4*A*SI + \beta_5* A^2*SI$

Estimated height after 10-years for Engelmann spruce

{25} $H10 = 4.5+((\beta_0*SI^{\beta 1})*(1.0-EXP(-\beta_2*A))\hat{}(\beta_3*SI^{\beta 4}))$

Estimated height after 10-years for subalpine fir

{26} $H10 = SI*(\beta_0 + \beta_1*A + \beta_2* A^2)$

Estimated height after 10-years for ponderosa pine

{27} $H10 =(\beta_0*(1.0 -EXP(\beta_1*A))^{\beta 2}) - ((\beta_3 + \beta_4*(1.0 - EXP(\beta_5*A))^{\beta 6})* \beta_7) + ((\beta_3 + \beta_4*(1.0 - EXP(\beta_5*A))^{\beta 6})*(SI - 4.5)) + 4.5$

Estimated height after 10- years for mountain hemlock/Other

{28} $H10 = [(\beta_0 + \beta_1*SI)*(1.0 - EXP(\beta_2*SQRT(SI)*A))^{(\beta 4 + \beta 5/SI)} +1.37] * 3.281$

where:
SI is species specific Site Index (see Table 3)
A is estimated age of tree in 10 years
β_1 - β_{13} are species specific coefficients (see Table 14)

Table 14. Coefficients for the height growth equations by species for the East Cascades variant of FVS, see equation {19-28}.

	Species				
	WP	**WL**	**DF**	**SF**	**RC**
β_0 =	0.375045	0.0	0.0	-0.30935	0.0
β_1 =	0.92503	1.46897	-0.37496	1.2383	1.3283
β_2 =	-0.020796	0.009247	1.36164	0.001762	-0.0174

β_3 =	-2.488107	-0.00024	-0.002434	-5.40E-06	1.4711
β_4 =	0.0	1.11E-06	-79.97	2.05E-07	0.0
β_5 =	0.0	-0.12528	-0.2828	-4.04E-13	0.0
β_6 =	0.0	0.039636	1.87947	-6.2056	0.0
β_7 =	0.0	-0.000428	-0.022399	2.097	0.0
β_8 =	0.0	1.70E-06	0.966998	-0.09411	0.0
β_9 =	0.0	73.57	0.0	-4.38E-05	0.0
β_{10} =	0.0	-0.12528	0.0	2.01E-11	0.0
β_{11} =	0.0	0.039636	0.0	-2.05E-17	0.0
β_{12} =	0.0	-0.000428	0.0	-84.73	0.0
β_{13} =	0.0	1.70E-06	0.0	0.0	0.0

Table 14.(continued) Coefficients for the height growth equations by species for the East Cascades variant of FVS, see equation {17-25}.

	Species					
	GF	**LP**	**ES**	**AF**	**PP**	**OT**
β_0 =	-0.30935	9.89331	2.7578	-0.07831	128.8952	22.8741
β_1 =	1.2383	-0.19177	0.83312	0.0149	-0.016959	0.950234
β_2 =	0.001762	0.00124	0.015701	-4.08E-05	1.23114	-0.002065
β_3 =	-5.40E-06	-0.00082	22.71944	0.0	-0.7864	0.5
β_4 =	2.05E-07	0.01387	-0.63557	0.0	2.49717	1.365566
β_5 =	-4.04E-13	-4.55E-05	0.0	0.0	-0.004504	2.045963
β_6 =	-6.2056	0.0	0.0	0.0	0.33022	0.0
β_7 =	2.097	0.0	0.0	0.0	100.43	0.0
β_8 =	-0.09411	0.0	0.0	0.0	0.0	0.0
β_9 =	-4.38E-05	0.0	0.0	0.0	0.0	0.0
β_{10} =	2.01E-11	0.0	0.0	0.0	0.0	0.0
β_{11} =	-2.05E-17	0.0	0.0	0.0	0.0	0.0
β_{12} =	-84.73	0.0	0.0	0.0	0.0	0.0
β_{13} =	0.0	0.0	0.0	0.0	0.0	0.0

Potential 10-year height growth is calculated by subtraction using equation {29}.

{29} $POTHTG = H10 - HT$

Modifiers are applied to height growth based on a tree's crown ratio (equation {30}), and relative height and shade tolerance (equation {31}). Equation {31} uses the Generalized Chapman – Richard's function (Donnelly et. al, 1992).

{30} $HGMDCR = (100 * (CR/100.0)^{3.0}) * EXP(-5.0*(CR/100.0))$

if $(0 < HGMDCR \leq 1.0)$, then $HGMDCR = 1.0$

{31} $HGMDRH = RELHT * [1.0 + ((RELHT/\beta_1)^{(\beta_2 - 1.0)} - 1.0) * EXP((-1.0*(\beta_3/(1.0-\beta_4)) * RELHT^{(1.0-\beta_4)})]^{(-1.0 / (\beta_2-1.0))}$

{32} HTGMOD = (0.25 * HGMDCR) + (0.75* HGMDRH)
if HTGMOD $\geq$ 2.0, then HTGMOD = 2.0
if HTGMOD $\leq$ 0.0, then HTGMOD = 0.1

{33} HTG = POTHTG * HTGMOD

where:
POTHTG is the potential height-growth (feet) (equation {29})
H10 is the estimated height after 10-years
HT is the beginning of cycle height (feet)
HGMDCR is the height growth modifier based on crown ratio(equation {30})
HGMDRH is the height growth modifier based on relative height and shade tolerance(equation {29})
HTGMOD is the weighted height growth modifier (equation {32})
CR is tree crown ratio
RELHT is the ratio of the tree's height to the height of the 40 largest diameter trees

After 10-year height growth is calculated and modified using the previous equations it is adjusted to the cycle length.

Table 15. Coefficients for the modifiers for the height growth equations by species for the East Cascades variant of FVS, see equation {28-29}.

	Species										
	WP	**WL**	**DF**	**SF**	**RC**	**GF**	**LP**	**ES**	**AF**	**PP**	**OT**
β_1 =	0.1	0.01	0.1	0.2	0.2	0.15	0.01	0.15	0.15	0.05	0.1
β_2 =	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
β_3 =	15	12	15	20	20	16	12	16	16	13	15
β_4 =	-1.45	-1.6	-1.45	-1.1	-1.1	-1.2	-1.6	-1.2	-1.2	-1.6	-1.45

4.6.3 Large-tree Crown Ratio Change

The Weibull distribution is used to predict future crown ratio. First, average stand crown ratio is estimated from the stand density index (SDI) (Reineke, 1933) using equation {34}. Weibull parameters are then estimated from the average stand crown ratio using equations {33 - 35}. Individual trees are assigned a crown ratio from the Weibull distribution. The change in crown ratio from one cycle to the next is obtained by subtraction the crown ratios assigned from the crown ratio that the tree presently has. This change is bounded by 10 percent to avoid drastic changes from one cycle to the next.

{34} $ACR = d_0 + d_1 * RELSDI * 100.0$

where:

ACR is average crown ratio for the species

RELSDI = Stand *SDI* / Maximum *SDI* (*RELSDI* bounded $\leq$ 1.5)

d_0, d_1 are coefficients shown in Table 20

{35} $A = a_0$

{36} $B = b_0 + b_1 * ACR$ (B bounded ≥ 3)

{37} $C = c_0 + c_1 * ACR$ (C bounded ≥ 2)

where:

A, *B*, *C* are parameters of the Weibull distribution of crown ratios

a_0, b_0, b_1, c_0, c_1 are coefficients shown in Table 16

Table 16. Coefficients for the crown model in the East Cascades variant of FVS**.**

	Model Coefficients						
Species	a_0	b_0	b_1	c_0	c_1	d_0	d_1
Western white pine	0.0	0.08106	1.10253	1.04477	0.42828	5.23986	-0.02569
Western larch	0.0	0.00603	1.12276	2.734	0.0	4.98675	-0.02466
Douglas-fir	0.0	-0.28295	1.18232	3.034	0.0	4.99727	-0.01043
Pacific silver fir	0.0	-0.09734	1.14675	2.716	0.0	4.79981	-0.00653
Western redcedar	0.0	-0.01129	1.11665	3.355	0.0	5.74915	-0.0109
Grand fir	0.0	-0.09734	1.14675	2.716	0.0	4.79981	-0.00653
Lodgepole pine	0.0	-0.00047	1.13172	2.227	0.0	3.85379	-0.00795
Engelmann spruce	0.0	-0.15678	1.14894	3.053	0.0	6.04394	-0.01825
Subalpine fir	0.0	0.08247	1.10804	1.45931	0.25495	6.00795	-0.02301
Ponderosa pine	0.0	0.08106	1.10253	1.04477	0.42828	5.23986	-0.02569
Mountain hemlock / Other	0.0	-0.01129	1.11665	3.355	0.0	5.74915	-0.0109

Crown ratios are then assigned based on a tree's relative position in the diameter distribution and multiplied by a scale factor (equation {38} which accounts for stand density.

{38} $SCALE = 1.0 - 0.00167 * (SCCF - 100.0)$

where:

SCALE is the density dependent scaling factor

SCCF is stand crown competition factor

Crown ratio values estimated from the Weibull distribution are bounded between the .05 to .95 percentile points of the distribution.

4.7 Mortality

In the EC variant there are two types of mortality, background mortality and density related mortality. Background mortality accounts for the occasional mortality in stands when stand density is below a specified level. Density related mortality determines mortality rates for individual trees, when stand density reaches a specified level or above. A detailed description of the mortality equations and how it is applied to individual trees can be found in section 7.3.2 of the Essential FVS guide (Dixon 2002).

The background mortality rate (equations {39}) is first calculated annually, and then adjusted to the cycle length using a compound interest formula (equation {40}). Table 17 contains the coefficients for the annual background mortality equation.

{39} $RI = [1 / (1 + e^{(\beta_0 + \beta_1 * DBH)})] / 2$

where:
RI is annual background mortality
DBH is tree diameter at breast height
β_0 and β_1 are coefficients shown in Table 21

{40} $RIP = 1 - (1-RI)^{YRS}$

where:
RIP is background mortality rate for an individual tree record in the current projection cycle
YRS is the number of years in current projection cycle

Table 17. Coefficients for the background mortality equation in the East Cascades variant of FVS**.**

Species	β_0	β_1
Western white pine	6.5112	-0.0052
Western larch	6.5112	-0.0052
Douglas-fir	7.2985	-0.0129
Grand fir	5.1677	-0.0078
Western hemlock	9.6943	-0.0127
Western redcedar	5.1677	-0.0078
Lodgepole pine	5.9617	-0.034
Engelmann spruce	9.6943	-0.0127
Subalpine fir	5.1677	-0.0078
Ponderosa pine	5.5877	-0.0053
Mountain hemlock/ Other	5.1677	-0.0078

Background mortality switches to density related mortality when the stand reaches a particular percent of the specified maximum stand density index (SDI). By default this is 55%, however this and the maximum SDI's for each species can be changed with the SDIMAX keyword. The weighted maximum SDI, (which is the weighted average of each species' SDI, based on the amount of basal area each species represents in the stand.), is calculated each growth cycle and mortality is determined based on the stands' density relative to the maximum SDI (Dixon 2002).

5.0 REGENERATION

The FVS regeneration / establishment model in the East Cascades variant is used to simulate stand establishment from bare ground, or to bring seedlings into a simulation with existing trees. Table 29 shows the bud width, minimum seedling heights, and maximum seedling heights by species for the East Cascades variant.

Establishment of all species in the East Cascades variant must be user specified with the PLANT or NATURAL keywords. The East Cascades variant does not have any species that automatically produce stump sprouts when cut.

Two steps are used to grow regenerating trees in height from the time they are established until the end of the cycle in which they are established. The first step estimates tree height five years after seedlings are established, or at the end of the cycle if the cycle boundary is within five years of the establishment date. The second set grows the trees from the point five years after establishment to the end of the cycle.

The first step estimates the height of the seeding at five years or at the end of a cycle if the cycle is less than five years. It uses the equations in section 4.5.1 to predict this height. Users can override this value by specifying an average seedling height in field 6 of the PLANT or NATURAL keywords. The height specified in field 6 is not subject to the minimum height restrictions shown in Table 18 and seedlings as small as 0.1 foot can be established.

The second step also uses the equations in section 4.5.1, which grow the trees in height from the point five years after establishment to the end of the cycle. After seedling height is estimated, diameter growth is estimated using equations described in section 4.5.2.

Regenerating trees become visible in FVS at the end of the growth cycle. FVS automatically generates tree records corresponding to regenerating trees. These tree records can be found in the tree list output file with tree identification numbers beginning with the letters "ES".

Table 18. Bud widths and minimum and maximum seedling height for species in the East Cascades variant of FVS**.**

Species	**Bud Width (in)**	**Minumum Height (ft)**	**Maximum Height (ft)**
Western white pine	0.4	1.0	23.0
Western larch	0.3	1.0	27.0
Douglas-fir	0.3	1.0	21.0
Grand fir	0.3	0.5	21.0
Western hemlock	0.2	0.5	22.0
Western redcedar	0.3	0.5	20.0
Lodgepole pine	0.4	1.0	24.0

Engelmann spruce	0.3	0.5	18.0
Subalpine fir	0.3	0.5	18.0
Ponderosa pine	0.5	1.0	17.0
Mountain hemlock/ Other	0.2	0.5	22.0

6.0 FIRE AND FUELS EXTENSION

The fire and fuels extension to FVS is linked to the East Cascades variant of FVS. Documentation of the extension's relationships can be found in The Fire and Fuels Extension to the Forest Vegetation Simulator (Reinhardt and Crookston 2003).

7.0 LITERATURE CITED

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8.0 APPENDICES

Appendix A. Plant Association Codes

Table 30. Plant Assocaition Codes used in the East Cascades variant of FVS.

FVS Code = Plant Association Species Type	Alpha Code	Site Species	Site Index*	Max. SDI*	Reference
1 = PIAL/CARU Whitebark pine/pinegrass	CAG112	DF	25	279	PNW-GTR-360 p. 262
2 = PIAL/VASC/LUHI Whitebark pine/grouse huckleberry/smooth woodrush	CAS311	AF	45	179	PNW-GTR-359 p. 248
3 = THPL-ABGR/ACTR Western redcedar-grand fir/vanilla leaf	CCF211	DF	72	850	R6 E TP-004-88 p. 115
4 = THPL/ACTR Western redcedar/vanilla leaf	CCF212	GF	71	1016	R6 E TP-006-88 p. 93
5 = THPL/CLUN Western redcedar/queencup beadily	CCF221	DF	64	875	PNW-GTR-360 p. 246
6 = THPL/ARNU3 Western redcedar/wild sarsaparilla	CCF222	DF	69	1049	PNW-GTR-360 p. 240
7 = THPL/OPHO Western redcedar/devil's club	CCS211	RC	96	1306	PNW-GTR-360 p. 251
8 = THPL/VAME Western redcedar/big huckleberry	CCS311	DF	63	497	PNW-GTR-360 p. 256
9 = PSME/PEFR3 Douglas-fir/shrubby penstemon	CDF411	DF	58	229	PNW-GTR-359 p. 82
10 = PSME/ARUV-OKAN Douglas-fir/bearberry (Okanogan)	CDG123	DF	38	331	R6 E 132b-83 p. 27
11 = PSME/CARU-O&C Douglas-fir/pinegrass (Okanogan & Colville)	CDG131	DF	58	478	PNW-GTR-360 p. 49
12 = PSME/CAGE-WEN Douglas-fir/elk sedge (Wenatchee)	CDG132	DF	69	607	PNW-GTR-359 p. 60
13 = PSME/CARU-AGSP Douglas-fir/pinegrass-bluebunch wheatgrass	CDG134	DF	61	317	PNW-GTR-359 p. 64
14 = PSME/CAGE Douglas-fir/elk sedge	CDG141	DF	55	442	R6 E TP-004-88 p. 51
15 = PIPO-PSME/AGSP Ponderosa pine-Douglas-fir/bluebunch wheatgrass	CDG311	PP	79	202	PNW-GTR-360 p. 44
16 = PSME/FEOC Douglas-fir/western fescue	CDG321	DF	67	649	R6 E TP-004-88 p. 55
17 = PSME/AGSP-WEN Douglas-fir/bluebunch wheatgrass (Wenatchee)	CDG322	DF	39	218	PNW-GTR-359 p. 58
18 = PSME/AGSP-ASDE Douglas-fir/bluebunch wheatgrass-podfern	CDG323	DF	58	188	PNW-GTR-359 p. 80
19 = PSME/HODI/CAGE Douglas-fir/oceanspray/elk sedge	CDS231	DF	80	676	R6 E TP-004-88 p. 59
20 = PSME/ACCI/FEOC Douglas-fir/vine maple/western fescue	CDS241	DF	76	720	R6 E TP-006-88 p. 45
21 = PSME/PAMY- Douglas-fir/pachistima (Okanogan)	CDS411	DF	59	621	R6 E 132b-83 p. 41
22 = PSME/PAMY/CARU Douglas-fir/pachistima/pinegrass	CDS412	DF	57	478	PNW-GTR-359 p. 81
23 = PSME/ARUV-PUTR Douglas-fir/bearberry-bitterbrush	CDS631	DF	45	232	R6 E 132b-83 p. 24
24 = PSME/SYOR-O&C Douglas-fir/Mt. snowberry (Okanogan and Colville)	CDS632	DF	54	348	PNW-GTR-360 p. 71
25 = PSME/SYAL Douglas-fir/common snowberry	CDS633	DF	81	646	PNW-GTR-360 p. 66
26 = PSME/SYAL-WEN Douglas-fir/common snowberry (Wenatchee)	CDS636	DF	80	673	PNW-GTR-359 p. 72
27 = PSME/SYAL/AGSP Douglas-fir/common snowberry/bluebunch wheatgrass	CDS637	DF	67	340	PNW-GTR-359 p. 74
28 = PSME/SYAL/CARU Douglas-fir/common snowberry/pinegrass	CDS638	DF	77	574	PNW-GTR-359 p. 76
29 = PSME/SPBEL/CARU Douglas-fir/shiny-leaf spirea/pinegrass	CDS639	DF	65	488	PNW-GTR-359 p. 70

30 = PSME/SPBEL Douglas-fir/shiny-leaf spirea	CDS640	DF	68	417	PNW-GTR-359 p. 82
31 = PSME/ARUV-WEN Douglas-fir/bearberry (Wenatchee)	CDS653	DF	37	478	PNW-GTR-359 p. 80
32 = PSME/ARUV-PUTR Douglas-fir/bearberry-bitterbrush	CDS654	DF	51	185	PNW-GTR-359 p. 81
33 = PSME/ARUV/CARU Douglas-fir/bearberry/pinegrass	CDS655	DF	40	284	PNW-GTR-359 p. 80
34 = PSME/SYAL-MTH Douglas-fir/common snowberry (Mt Hood)	CDS661	DF	84	767	R6 E TP-004-88 p. 67
35 = PSME/ARNE Douglas-fir/pinemat manzanita	CDS662	DF	51	1118	R6 E TP-004-88 p. 63
36 = PSME/PUTR Douglas-fir/bitterbursh	CDS673	DF	50	279	PNW-GTR-359 p. 82
37 = PSME/PUTR/AGSP Douglas-fir/bitterbursh/bluebunch wheatgrass	CDS674	DF	62	400	PNW-GTR-359 p. 66
38 = PSME/PUTR/CARU Douglas-fir/bitterbrush/pinegrass	CDS675	DF	58	422	PNW-GTR-359 p. 68
39 = PSME/PHMA-O&C Douglas-fir/ninebark (Okanogan & Colville)	CDS715	DF	63	607	PNW-GTR-360 p. 55
40 = PSME/PHMA-LIBOL Douglas-fir/ninebark-twinflower	CDS716	DF	60	491	PNW-GTR-360 p. 61
41 = PSME/VACCI Douglas-fir/huckleberry	CDS811	DF	51	397	R6 E 132b-83 p. 33
42 = PSME/VACA-COL Douglas-fir/dwarf huckleberry (Colville)	CDS813	WL	66	527	PNW-GTR-360 p. 76
43 = PSME/VAME-COLV Douglas-fir/big huckleberry (Colville)	CDS814	DF	66	511	PNW-GTR-360 p. 82
44 = PSME/VACA Douglas-fir/dwarf huckleberry	CDS831	DF	60	362	PNW-GTR-359 p. 82
45 = PSME/VAME-WEN Douglas-fir/big huckleberry (Wenatchee)	CDS832	DF	53	323	PNW-GTR-359 p. 83
46 = PSME/VAMY/CARU Douglas-fir/low huckleberry/pinegrass	CDS833	DF	48	458	PNW-GTR-359 p. 83
47 = ABLA2/XETE Subalpine fir/beargrass	CEF111	AF	54	613	PNW-GTR-360 p. 178
48 = ABLA2/LIBOL-O&C Subalpine fir/twinflower (Okanogan & Colville)	CEF211	AF	80	558	PNW-GTR-360 p. 141
49 = ABLA2/LIBOL-WEN Subalpine fir/twinflower (Wenatchee)	CEF222	ES	90	822	PNW-GTR-359 p. 234
50 = ABLA2/CLUN Subalpine fir/queencup beadily	CEF421	AF	87	767	PNW-GTR-360 p. 131
51 = ABLA2/TRCA3 Subalpine fir/false bugbane	CEF422	AF	87	668	PNW-GTR-360 p. 157
52 = ABLA2/COCA Subalpine fir/bunchberry dogwood	CEF423	AF	75	549	PNW-GTR-360 p. 136
53 = ABLA2/ARLA-POPU Subalpine fir/broadleaf arnica-skunkleaf polemonium	CEF424	AF	65	720	PNW-GTR-359 p. 214
54 = ABLA2/LUHI-WEN Subalpine fir/smooth woodrush (Wenatchee)	CEG121	AF	65	729	PNW-GTR-359 p. 218
55 = ABLA2/CARU-WEN Subalpine fir/pinegrass (Wenatchee)	CEG310	AF	73	549	PNW-GTR-359 p. 216
56 = ABLA2/CARU-O&C Subalpine fir/pinegrass (Okanogan & Colville)	CEG311	AF	77	549	PNW-GTR-360 p. 126
57 = PIEN/EQAR Engelmann spruce/horsetail	CEM211	ES	72	527	PNW-GTR-360 p. 184
58 = ABLA2/PAMY-OKAN Subalpine fir/pachistima (Okanogan)	CES111	AF	90	381	R6 E 132b-83 p. 52
59 = ABLA2/PAMY-WEN Subalpine fir/pachistima (Wenatchee)	CES113	ES	111	701	PNW-GTR-359 p. 234
60 = ABLA2/RHAL-XETE Subalpine fir/Cascades azalea-beargrass	CES210	AF	56	582	PNW-GTR-360 p. 152
61 = ABLA2/RHAL Subalpine fir/Cascade azalea	CES211	AF	52	486	PNW-GTR-359 p. 220
62 = ABLA2/RHAL/LUHI Subalpine fir/Cascade azalea/smooth woodrush	CES213	AF	60	546	PNW-GTR-359 p. 222
63 = ABLA2/VACCI Subalpine fir/huckleberry	CES312	AF	102	511	R6 E 132b-83 p. 46

64 = ABLA2/VAME-COLV Subalpine fir/big huckleberry (Colville)	CES313	AF	76	715	PNW-GTR-360 p. 168
65 = ABLA2/VAME-WEN Subalpine fir/big huckleberry (Wenatchee)	CES342	DF	73	731	PNW-GTR-359 p. 235
66 = ABLA2/VASC-O&C Subalpine fir/grouse huckleberry (Okan & Colv)	CES412	AF	63	660	PNW-GTR-360 p. 173
67 = ABLA2/VASC/CARU-OKAN Subalpine fir/grouse huckleberry/pinegrass (Okan)	CES413	ES	62	367	PNW-GTR-359 p. 236
68 = ABLA2/VACA Subalpine fir/dwarf huckleberry	CES422	LP	94	265	PNW-GTR-359 p. 235
69 = ABLA2/RULA Subalpine fir/dwarf bramble	CES423	AF	90	762	PNW-GTR-359 p. 224
70 = ABLA2/VASC/ARLA Subalpine fir/grouse huckleberry/broadleaf arnica	CES424	AF	51	687	PNW-GTR-359 p. 230
71 = ABLA2/VASC/LUHI Subalpine fir/grouse huckleberry/smooth woodrush	CES425	AF	65	403	PNW-GTR-359 p. 232
72 = ABLA2/VASC-WEN Subalpine fir/grouse huckleberry (Wenatchee)	CES426	DF	69	1168	PNW-GTR-359 p. 228
73 = ABAM/TITRU Pacific silver fir/coolwort foamflower	CFF162	SF	143	1234	PNW-GTR-359 p. 168
74 = ABAM/ACTR-WEN Pacific silver fir/vanilla leaf (Wenatchee)	CFF254	SF	112	811	PNW-GTR-359 p. 158
75 = ABAM/VAAL-WEN Pacific Silver fir/Alaska huckleberry (Wenatchee)	CFS232	SF	104	872	PNW-GTR-359 p. 170
76 = ABAM/VAME/CLUN-WEN Silver fir/big huckleberry/queencup beadlily (Wen)	CFS233	SF	79	701	PNW-GTR-359 p. 172
77 = ABAM/VAME-PYSE Pacific silver fir/big huckleberry-sidebells pyrola	CFS234	SF	62	665	PNW-GTR-359 p. 174
78 = ABAM/MEFE-WEN Pacific silver fir/rusty menziesia (Wenatchee)	CFS542	SF	84	944	PNW-GTR-359 p. 160
79 = ABAM/RHAL-OKAN Pacific silver fir/Cascade azalea (Okanogan)	CFS553	SF	45	646	R6 E 132b-83 p. 75
80 = ABAM/RHAL-VAME-WEN Pac silver fir/Cascade azalea-big huckleberry (Wen)	CFS556	AF	40	740	PNW-GTR-359 p. 164
81 = ABAM/PAMY Pacific silver fir/pachistima	CFS558	DF	65	776	R6 E 132b-83 p. 75
82 = ABAM/ACCI Pacific silver fir/vine maple	CFS621	SF	104	845	PNW-GTR-359 p. 156
83 = TSHE-ABGR/CLUN Western hemlock-grand fir/queencup beadlily	CHC311	GF	81	798	R6 E TP-004-88 p. 111
84 = TSHE/ACTR-WEN Western hemlock/vanilla leaf (Wenatchee)	CHF223	DF	73	748	PNW-GTR-359 p. 138
85 = TSHE/CLUN Western hemlock/queencup beadlily	CHF311	DF	69	787	PNW-GTR-360 p. 204
86 = TSHE/ARNU3 Western hemlock/wild sarsaparilla	CHF312	DF	75	792	PNW-GTR-360 p. 199
87 = TSHE/ASCA3 Western hemlock/wild ginger	CHF313	DF	85	1253	PNW-GTR-359 p. 142
88 = TSHE/GYDR Western hemlock/oak-fern	CHF422	DF	83	1397	PNW-GTR-360 p. 209
89 = TSHE/XETE-COLV Western hemlock/beargrass (Colville)	CHF521	ES	90	999	PNW-GTR-360 p. 226
90 = TSHE/BENE-WEN Western hemlock/Cascade Oregon grape (Wenatchee)	CHS142	DF	82	591	PNW-GTR-359 p. 144
91 = TSHE/PAMY/CLUN Western hemlock/pachistima/queencup beadlily	CHS143	DF	74	635	PNW-GTR-359 p. 146
92 = TSHE/ARNE Western hemlock/pinemat manzanita	CHS144	DF	52	406	PNW-GTR-359 p. 140
93 = TSHE/ACCI/ACTR-WEN Western hemlock/vine maple/vanilla leaf (Wenatchee)	CHS225	DF	87	505	PNW-GTR-359 p. 132
94 = TSHE/ACCI/ASCA3 Western hemlock/vine maple/wild ginger	CHS226	DF	86	869	PNW-GTR-359 p. 134
95 = TSHE/ACCI/CLUN Western hemlock/vine maple/queencup beadlily	CHS227	GF	86	687	PNW-GTR-359 p. 136
96 = TSHE/RUPE Western hemlock/five-leaved bramble	CHS411	ES	103	1129	PNW-GTR-360 p. 221
97 = TSHE/MEFE Western hemlock/rusty menziesia	CHS711	DF	71	856	PNW-GTR-360 p. 215

98 = PICO/SHCA Lodgepole pine/russet buffaloberry	CLS521	LP	96	447	PNW-GTR-360 p. 267
99 = TSME/XETE-VAMY Mountain hemlock/beargrass-low huckleberry	CMF131	OT	23	676	PNW-GTR-359 p. 202
100 = TSME/LUHI Mountain hemlock/smooth woodrush	CMG221	OT	24	544	PNW-GTR-359 p. 184
101 = TSME/VASC/LUHI Mountain hemlock/grouse huckleberry/smooth woodrush	CMS121	OT	23	1463	PNW-GTR-359 p. 200
102 = TSME/RULA Mountain hemlock/dwarf bramble	CMS122	SF	79	709	PNW-GTR-359 p. 194
103 = TSME/MEFE-VAAL Mountain hemlock/rusty menziesia-Alaska huckleberry	CMS256	SF	94	742	PNW-GTR-359 p. 186
104 = TSME/MEFE-VAME Mountain hemlock/rusty menziesia-big huckleberry	CMS257	SF	102	834	PNW-GTR-359 p. 188
105 = TSME/VAAL-WEN Mountain hemlock/Alaska huckleberry (Wenatchee)	CMS258	OT	28	1132	PNW-GTR-359 p. 196
106 = TSME/VAME-WEN Mountain hemlock/big huckleberry (Wenatchee)	CMS259	OT	20	624	PNW-GTR-359 p. 198
107 = TSME/PHEM-VADE Mtn hemlock/red mountain heath-Cascade huckleberry	CMS354	AF	53	444	PNW-GTR-359 p. 190
108 = TSME/RHAL-VAAL Mountain hemlock/Cascade azalea-Alaska huckleberry	CMS355	OT	26	541	PNW-GTR-359 p. 204
109 = TSME/RHAL-VAME Mountain hemlock/Cascades azalea-big huckleberry	CMS356	OT	20	668	PNW-GTR-359 p. 192
110 = PIPO/AGSP-WEN Ponderosa pine/bluebunch wheatgrass (Wenatchee)	CPG141	PP	81	185	PNW-GTR-359 p. 42
111 = PIPO/CARU-AGSP Ponderosa pine/pinegrass-bluebunch wheatgrass	CPG231	PP	49	179	PNW-GTR-359 p. 44
112 = PIPO-QUGA/BASA Ponderosa pine-Or white oak/arrowleaf balsamroot	CPH211	PP	65	328	R6 E TP-004-88 p. 43
113 = PIPO-QUGA/PUTR Ponderosa pine-Oregon white oak/bitterbrush	CPH212	PP	63	342	R6 E TP-004-88 p. 47
114 = PIPO/PUTR/AGSP Ponderosa pine/bitterbursh/bluebunch wheatgrass	CPS241	PP	75	237	PNW-GTR-359 p. 46
115 = ABGR-PIEN/SMST Grand fir-Engelmann spruce/starry solomonseal	CWC511	GF	90	972	R6 E TP-004-88 p. 107
116 = ABGR/LIBO2 Grand fir/twinflower	CWF321	GF	83	709	R6 E TP-004-88 p. 87
117 = ABGR/ARCO Grand fir/heartleaf arnica	CWF444	GF	72	751	PNW-GTR-359 p. 102
118 = ABGR/TRLA2 Grand fir/starflower	CWF521	GF	91	930	R6 E TP-004-88 p. 83
119 = ABGR/ACTR Grand fir/vanillaleaf	CWF522	GF	100	822	R6 E TP-004-88 p. 95
120 = ABGR/POPU Grand fir/skunk-leaved polemonium	CWF523	GF	90	955	R6 E TP-004-88 p. 103
121 = ABGR/ACTR-WEN Grand fir/vanilla leaf (Wenatchee)	CWF524	GF	86	963	PNW-GTR-359 p. 100
122 = ABGR/CAGE Grand fir/elk sedge	CWG121	GF	104	712	R6 E TP-004-88 p. 71
123 = ABGR/CAGE-GP Grand fir/elk sedge (Gifford Pinchot)	CWG122	GF	100	1405	R6 E TP-006-88 p. 53
124 = ABGR/CARU Grand fir/pinegrass	CWG123	GF	112	1769	R6 E TP-006-88 p. 49
125 = ABGR/CARU-WEN Grand fir/pinegrass (Wenatchee)	CWG124	GF	85	483	PNW-GTR-359 p. 110
126 = ABGR/CARU-LUPIN Grand fir/pinegrass-lupine	CWG125	DF	58	591	PNW-GTR-359 p. 112
127 = ABGR/VAME/CLUN-COL Grand fir/big huckleberry/queencup beadlily (Colv)	CWS214	GF	86	996	PNW-GTR-360 p. 110
128 = ABGR/VAME/LIBO2 Grand fir/big huckleberry/twinflower	CWS221	GF	100	776	R6 E TP-006-88 p. 85
129 = ABGR/VAME/CLUN Grand fir/big huckleberry/queencup beadlily	CWS222	GF	103	949	R6 E TP-006-88 p. 89
130 = ABGR/RUPA/DIHO Grand fir/thimbleberry/fairy bells	CWS223	GF	108	916	R6 E TP-006-88 p. 81
131 = ABGR/BENE/ACTR Grand fir/dwarf Oregon grape/vanillaleaf	CWS224	DF	69	729	R6 E TP-006-88 p. 73

132 = ABGR/BENE Grand fir/Cascade Oregon grape	CWS225	GF	77	687	PNW-GTR-359 p. 106
133 = ABGR/BENE/CARU-WEN Grand fir/Cascade Oregon grape/pinegrass-Wenatchee	CWS226	GF	85	668	PNW-GTR-359 p. 108
134 = ABGR/SYMPH Grand fir/snowberry	CWS331	GF	90	770	R6 E TP-004-88 p. 79
135 = ABGR/SYMO/ACTR Grand fir/creeping snowberry/vanillaleaf	CWS332	GF	108	1082	R6 E TP-006-88 p. 65
136 = ABGR/SPEBL/PTAQ Grand fir/shiny-leaf spirea/bracken fern	CWS335	GF	74	593	PNW-GTR-359 p. 116
137 = ABGR/SYAL/CARU Grand fir/common snowberry/pinegrass	CWS336	GF	76	718	PNW-GTR-359 p. 118
138 = ABGR/SYOR Grand fir/mountain snowberry	CWS337	DF	70	643	PNW-GTR-359 p. 120
139 = ABGR/ARNE Grand fir/pinemat manzanita	CWS338	DF	49	431	PNW-GTR-359 p. 104
140 = ABGR/PHMA Grand fir/ninebark	CWS421	DF	79	662	PNW-GTR-360 p. 100
141 = ABGR/ACGLD/CLUN Grand fir/Douglas maple/queencup beadlilly	CWS422	GF	73	1259	PNW-GTR-360 p. 95
142 = ABGR/HODI Grand fir/oceanspray	CWS531	GF	95	1118	R6 E TP-004-88 p. 75
143 = ABGR/ACCI/ACTR Grand fir/vine maple/vanillaleaf	CWS532	GF	98	729	R6 E TP-004-88 p. 91
144 = ABGR/CACH Grand fir/chinkapin	CWS533	DF	57	591	R6 E TP-004-88 p. 99
145 = ABGR/HODI-GP Grand fir/oceanspray (Gifford Pinchot)	CWS534	GF	104	988	R6 E TP-006-88 p. 61
146 = ABGR/ACCI-BEAQ/TRLA2 Grand fir/vine maple-tall Oregongrape/starflower	CWS535	GF	116	1272	R6 E TP-006-88 p. 57
147 = ABGR/COCO2/ACTR Grand fir/California hazel/vanillaleaf	CWS536	GF	116	1377	R6 E TP-006-88 p. 69
148 = ABGR/CONU/ACTR Grand fir/pacific dogwood/vanillaleaf	CWS537	DF	64	908	R6 E TP-006-88 p. 77
149 = ABGR/ACCI-WEN Grand fir/vine maple (Wenatchee)	CWS551	GF	109	1410	PNW-GTR-359 p. 94
150 = ABGR/ACCI-CHUM Grand fir/vine maple-western prince's pine	CWS552	GF	100	1085	PNW-GTR-359 p. 96
151 = ABGR/ACCI/CLUN Grand fir/vine maple/queencup beadlily	CWS553	GF	104	1090	PNW-GTR-359 p. 98
152 = ABGR/HODI/CARU Grand fir/ocean-spray/pinegrass	CWS554	DF	70	712	PNW-GTR-359 p. 114
153 = ABGR/VACA Grand fir/dwarf huckleberry	CWS821	DF	74	566	PNW-GTR-360 p. 105
154 = POTR/CARU Quaking aspen/pinegrass	HQG111	LP	84	522	R6 E 132b-83 p. 75
155 = POTR/SYAL Quaking aspen/common snowberry	HQS211	WL	68	331	R6 E 132b-83 p. 75

Appendix B. Summary of Sampled Data

Table 31. Distribution of samples for diameter breast high (dbh), expressed in percent of total observations for each species.

			dbh	(inches)					
Species	**0-5**	**5-10**	**10-15**	**15-20**	**20-25**	**25-30**	**30-35**	**35-40**	**40+**
WP	0	0	0	0	0	0	0	0	0
WL	<1	16	22	22	15	9	6	5	4
DF	1	16	22	21	16	10	6	3	4
SF	<1	16	20	21	18	10	7	4	3
RC	0	0	0	0	0	0	0	0	0
GF	1	19	27	25	14	7	4	1	2
LP	<1	50	33	12	4	1	<1	0	0
ES	0	22	25	22	15	8	5	2	1
AF	<1	38	36	18	5	2	1	<1	0
PP	<1	13	18	21	20	13	7	4	3
OT	<1	13	25	24	19	9	4	2	2

Table 32. Distribution of samples by National Forest, expressed in percent of total observations for each species.

		National Forest			
Species	**Gifford-Pinchot**	**Mt. Hood**	**Okanogan**	**Wenatchee**	**OKanogan-Tonasket RD**
WP	0	0	0	0	0
WL	1	15	8	55	20
DF	7	22	12	55	5
SF	20	31	2	47	0
RC	0	0	0	0	0
GF	3	24	<1	73	0
LP	3	17	25	50	5
ES	6	4	49	38	3
AF	6	3	33	57	1
PP	1	30	4	63	1
OT	14	43	4	39	0

Table 33. Distribution of samples by Crown Ratio group, expressed in percent of total observations for each species.

			Crown	Code					
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
WP	0	0	0	0	0	0	0	0	0
WL	4	9	24	27	20	11	4	1	<1
DF	1	6	16	22	20	16	10	6	3
SF	2	8	19	24	21	14	9	3	<1
RC	0	0	0	0	0	0	0	0	0
GF	2	8	18	21	18	15	10	6	3
LP	3	14	28	20	14	9	6	4	2
ES	<1	2	7	14	18	20	18	15	5
AF	2	3	9	17	20	20	16	8	4

PP	2	8	18	23	20	16	8	3	1
OT	<1	4	9	18	20	18	14	9	7

Table 34. Distribution of samples by Aspect Code, expressed in percent of total observations for each species.

				Aspect	Code				
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
WP	0	0	0	0	0	0	0	0	0
WL	16	15	6	8	5	2	7	7	34
DF	13	11	10	8	8	8	10	9	24
SF	19	12	11	11	11	10	6	10	10
RC	0	0	0	0	0	0	0	0	0
GF	12	8	6	8	6	7	3	5	45
LP	14	13	7	10	11	8	7	8	23
ES	14	13	3	7	6	13	6	11	27
AF	20	14	6	9	8	7	11	10	14
PP	9	7	6	6	7	7	4	4	50
OT	18	15	15	9	6	10	5	14	10

Table 35. Distribution of samples by total stand basal area per acre, expressed in percent for each species.

			Basal	Area					
Species	**0-50**	**50-100**	**100-150**	**150-200**	**200-250**	**250-300**	**300-350**	**350-400**	**400+**
WP	0	0	0	0	0	0	0	0	0
WL	5	21	29	17	11	9	6	<1	2
DF	14	23	22	14	11	7	5	2	2
SF	4	8	6	13	19	22	14	7	6
RC	0	0	0	0	0	0	0	0	0
GF	5	15	20	18	18	15	5	3	5
LP	10	21	34	20	9	4	1	1	<1
ES	2	10	17	29	22	12	7	1	<1
AF	1	10	19	25	28	10	6	1	<1
PP	14	35	29	14	5	2	<1	<1	0
OT	6	12	11	14	16	20	11	5	4

Table 36. Distribution of samples by diameter growth, expressed in percent for each species.

			Diameter	Growth	(inches/10 yrs)			
Species	**0-0.5**	**0.5-1.0**	**1.0-1.5**	**1.5-2.0**	**2.0-2.5**	**2.5-3.0**	**3.0-3.5**	**>3.5**
WP	0	0	0	0	0	0	0	0
WL	51	34	11	3	1	<1	0	0
DF	27	33	20	13	6	2	1	<1
SF	35	38	17	6	3	<1	<1	<1
RC	0	0	0	0	0	0	0	0
GF	16	34	23	13	7	3	2	2

LP	42	42	12	3	<1	<1	<1	<1
ES	32	39	16	8	3	1	<1	<1
AF	36	43	16	3	1	1	0	0
PP	23	34	25	10	5	2	<1	<1
OT	38	41	15	5	1	<1	0	<1

Table 37. Distribution of samples by elevation, expressed in percent for each species.

		Elevation (feet)			
Species	**< 3000**	**3000-4000**	**4000-5000**	**5000-6000**	**>6000**
WP	0	0	0	0	0
WL	2	28	41	29	<1
DF	26	37	29	8	<1
SF	3	25	56	16	0
RC	0	0	0	0	0
GF	12	38	35	15	0
LP	5	14	34	39	8
ES	4	11	34	33	18
AF	<1	5	30	50	16
PP	37	40	18	4	<1
OT	4	33	41	21	2