Forest Service
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East Cascades (EC) Variant Overview of the Forest Vegetation Simulator

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Conifer stand, Okanogan National Forest
(Jennifer Croft, FS-R)

East Cascades (EC) Variant Overview of the Forest Vegetation Simulator

Authors and Contributors:

The FVS staff has maintained model documentation for this variant in the form of a variant overview since its release in 1987. The original author was Ralph Johnson. In 2008, the previous document was replaced with this updated variant overview. Gary Dixon, Christopher Dixon, Robert Havis, Chad Keyser, Stephanie Rebain, Erin Smith-Mateja, and Don Vandendriesche were involved with this update. Erin Smith-Mateja cross-checked information contained in this variant overview with the FVS source code. The species list for this variant was expanded and this document was extensively revised by Gary Dixon in 2012.

FVS Staff. 2008 (revised May 31, 2023). East Cascades (EC) Variant Overview – Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 64p.

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Quick Guide to Default Settings

Parameter or Attribute	**Default Setting**	
Number of Projection Cycles	1 (10 if using FVS GUI)	
Projection Cycle Length	10 years	
Location Code (National Forest)	606 – Mount Hood	
Plant Association Code	114 (CPS 241 PIPO/PUTR/AGSP)	
Slope	5 percent	
Aspect	0 (no meaningful aspect)	
Elevation	45 (4500 feet)	
Latitude / Longitude	Latitude	Longitude
All location codes	47	121
Site Species	Plant Association Code specific	
Site Index	Plant Association Code specific	
Maximum Stand Density Index	Plant Association Code specific	
Maximum Basal Area	Based on maximum stand density index	
Volume Equations	National Volume Estimator Library	
Merchantable Cubic Foot Volume Specifications:		
Minimum DBH / Top Diameter	LP	All Other Species
All location codes	6.0 / 4.5 inches	7.0 / 4.5 inches
Stump Height	1.0 foot	1.0 foot
Merchantable Board Foot Volume Specifications:		
Minimum DBH / Top Diameter	LP	All Other Species
All location codes	6.0 / 4.5 inches	7.0 / 4.5 inches
Stump Height	1.0 foot	1.0 foot
Sampling Design:		
Large Trees (variable radius plot)	40 BAF	
Small Trees (fixed radius plot)	1/300th Acre	
Breakpoint DBH	5.0 inches	

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, fire effects, fuel loading, snag dynamics, and development of understory tree vegetation. FVS can simulate a wide variety of forest types, stand structures, and pure or mixed species stands.

New “variants” of the FVS model are created by imbedding new tree growth, mortality, and volume equations for a particular geographic area into the FVS framework. Geographic variants of FVS have been developed for most of the forested lands in the United States.

The East Cascades (EC) variant was developed in 1988. It covers the lands east of the Cascade crest in Washington over through the Okanogan National Forest and extends south through the portion of the Mt. Hood National Forest that lies east of the Cascade crest in northern Oregon. Data used in building the EC variant came from forest inventories, silviculture stand examinations, and tree nutrition studies. 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 (SO) variant, and western redcedar uses equations from the North Idaho (NI) variant.

Since the variant’s development in 1988, many of the functions have been adjusted and improved as more data has become available, and as model technology has advanced. In 2012 this variant was expanded from 11 species to 32 species. Species added include western hemlock, mountain hemlock, Pacific yew, whitebark pine, noble fir, white fir, subalpine larch, Alaska cedar, western juniper, bigleaf maple, vine maple, red alder, paper birch, giant chinquapin, Pacific dogwood, quaking aspen, black cottonwood, Oregon white oak, plum, and willow. The “other species” grouping was split into other softwood and other hardwood. White fir uses grand fir equations from the EC variant; mountain hemlock uses equations for the original other species grouping in the 11 species version of this variant; all other individual species groupings use equations from the Westside Cascades (WC) variant; other softwood uses the equations for the original other species grouping in the 11 species version of this variant; and other hardwood uses the WC quaking aspen equations.

To fully understand how to use this variant, users should also consult the following publication:

- Essential FVS: A User’s Guide to the Forest Vegetation Simulator (Dixon 2002)

This publication may be downloaded from the Forest Management Service Center (FMSC), Forest Service website. Other FVS publications may be needed if one is using an extension that simulates the effects of fire, insects, or diseases.

2.0 Geographic Range

The EC variant was fit to data representing forest types on the eastern slope of the Cascade range in Washington and the northern portion of the eastern slope of the Cascade range in Oregon. Data used in initial model development came from forest inventories, silviculture stand examinations, and tree nutrition studies. Forest inventories came from US. Forest Service National Forests, Warm Springs and Yakima Indian Reservations, and the state of Washington Dept. of Natural Resources. Distribution of data samples for species fit from this data are shown in Appendix A.

The EC variant covers forest types on the eastern slope of the Cascade range in Washington and the northern portion of the eastern slope of the Cascade range in Oregon. The suggested geographic range of use for the EC variant is shown in figure 2.0.1.

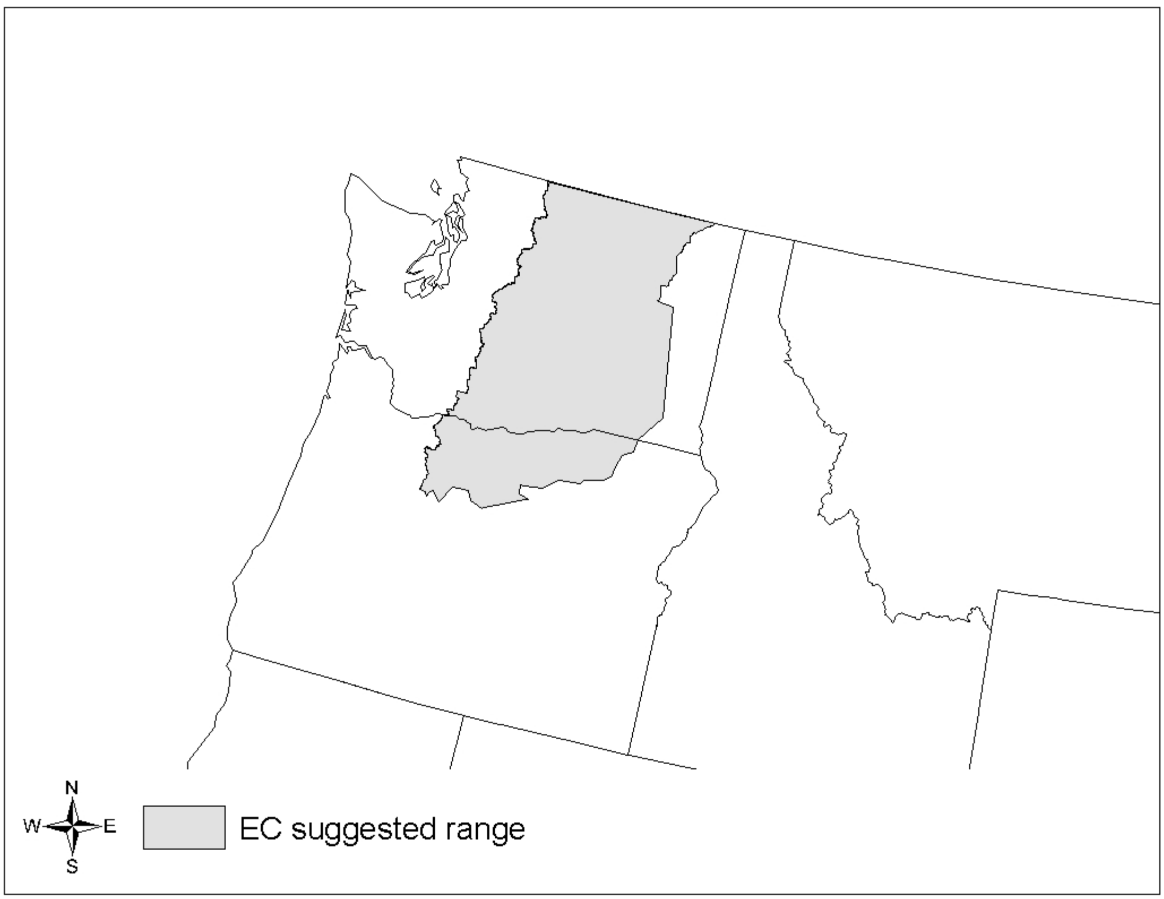

Figure 2.0.1 Suggested geographic range of use for the EC variant.

3.0 Control Variables

FVS users need to specify certain variables used by the EC variant to control a simulation. These are entered in parameter fields on various FVS keywords available in the FVS interface or they are read from an FVS input database using the Database Extension.

3.1 Location Codes

The location code is a 3-digit code where, in general, the first digit of the code represents the Forest Service Region Number, and the last two digits represent the Forest Number within that region. In some cases, a location code beginning with a “7” or “8” is used to indicate an administrative boundary that doesn’t use a Forest Service Region number (for example, other federal agencies, state agencies, or other lands).

If the location code is missing or incorrect in the EC variant, a default forest code of 606 (Mount Hood National Forest) will be used. A complete list of location codes recognized in the EC variant is shown in table 3.1.1.

Table 3.1.1 Location codes used in the EC variant.

Location Code	Location
603	Gifford Pinchot National Forest (mapped to 617)
606	Mount Hood National Forest
608	Okanogan National Forest
613	Mount Baker – Snoqualmie National Forest (mapped to 617)
617	Wenatchee National Forest
621	Colville National Forest (mapped to 699)
699	Okanogan National Forest (Tonasket RD)
8106	Colville Reservation (mapped to 608)
8117	Umatilla Reservation (mapped to 606)
8130	Yakama Nation Reservation (mapped to 613)
8131	Spokane Reservation (mapped to 617)

3.2 Species Codes

The EC variant recognizes 30 species, plus two other composite species categories. You may use FVS species codes, Forest Inventory and Analysis (FIA) species codes, or USDA Natural Resources Conservation Service PLANTS symbols to represent these species in FVS input data. Any valid western species code identifying species not recognized by the variant will be mapped to a similar species in the variant. The species mapping crosswalk is available on the FVS website variant documentation webpage. Any non-valid species code will default to the “other hardwood” category.

Either the FVS sequence number or species code must be used to specify a species in FVS keywords and Event Monitor functions. FIA codes or PLANTS symbols are only recognized during data input and may not be used in FVS keywords. Table 3.2.1 shows the complete list of species codes recognized by the EC variant.

When entering tree data, users should substitute diameter at root collar (DRC) for diameter at breast height (DBH) for woodland species (western juniper).

Table 3.2.1 Species codes used in the EC variant.

Species Number	Species Code	FIA Code	PLANTS Symbol	Scientific Name[1]	Common Name[1]
1	WP	119	PIMO3	*Pinus monticola*	western white pine
2	WL	073	LAOC	*Larix occidentalis*	western larch
3	DF	202	PSME	*Pseudotsuga menziesii*	Douglas-fir
4	SF	011	ABAM	*Abies amabilis*	Pacific silver fir
5	RC	242	THPL	*Thuja plicata*	western redcedar
6	GF	017	ABGR	*Abies grandis*	grand fir
7	LP	108	PICO	*Pinus contorta*	lodgepole pine
8	ES	093	PIEN	*Picea engelmannii*	Engelmann spruce
9	AF	019	ABLA	*Abies lasiocarpa*	subalpine fir
10	PP	122	PIPO	*Pinus ponderosa*	ponderosa pine
11	WH	263	TSHE	*Tsuga heterophylla*	western hemlock
12	MH	264	TSME	*Tsuga mertensiana*	mountain hemlock
13	PY	231	TABR2	*Taxus brevifolia*	Pacific yew
14	WB	101	PIAL	*Pinus albicaulis*	whitebark pine
15	NF	022	ABPR	*Abies procera*	noble fir
16	WF	015	ABCO	*Abies concolor*	white fir
17	LL	072	LALY	*Larix lyallii*	subalpine larch
18	YC	042	CANO9	*Callitropsis nootkatensis*	Alaska cedar
19	WJ	064	JUOC	*Juniperus occidentalis*	western juniper
20	BM	312	ACMA3	*Acer macrophyllum*	bigleaf maple
21	VN	324	ACCI	*Acer circinatum*	vine maple
22	RA	351	ALRU2	*Alnus rubra*	red alder
23	PB	375	BEPA	*Betula papyrifera*	paper birch
24	GC	431	CHCHC4	*Chrysolepis chrysophylla* var. *chrysophylla*	giant chinquapin
25	DG	492	CONU4	*Cornus nuttallii*	Pacific dogwood
26	AS	746	POTR5	*Populus tremuloides*	quaking aspen
27	CW	747	POBAT	*Populus balsamifera* ssp. *trichocarpa*	black cottonwood
28	WO	815	QUGA4	*Quercus garryana*	Oregon white oak
29	PL	760	PRUNU	*Prunus*	plum
30	WI	920	SALIX	*Salix*	willow
31	OS	299	2TN		other softwood[2]
32	OH	998	2TB		other hardwood[2]

[1]Set based on the USDA Forest Service NRM TAXA lists and the USDA Plants database.
[2]Other categories use FIA codes and NRM TAXA codes that best match the other category.

3.3 Habitat Type, Plant Association, and Ecological Unit Codes

Plant association codes recognized in the EC variant are shown in Appendix B. If an incorrect plant association code is entered or no code is entered FVS will use the default plant association code, which is 114 (PIPO/PUTR/AGSP). Plant association codes are used to set default site information such as site species, site indices, and maximum stand density indices as well as predicting snag dynamics in FFE-FVS. The site species, site index and maximum stand density indices can be reset via FVS keywords. Users may enter the plant association code or the plant association FVS sequence number on the STDINFO keyword, when entering stand information from a database, or when using the SETSITE keyword without the PARMS option. If using the PARMS option with the SETSITE keyword, users must use the FVS sequence number for the plant association.

3.4 Site Index

Site index is used in some of the growth equations for the EC variant. Users should always use the same site curves that FVS uses as shown in table 3.4.1. If site index is available, a single site index for the whole stand can be entered, a site index for each individual species in the stand can be entered, or a combination of these can be entered.

Table 3.4.1 Site index reference curves for species in the EC variant.

Species Code	Reference	BHA or TTA[1]	Base Age
WP	Brickell, J.E., 1970, USDA-FS Res. Pap. INT-75	TTA	50
WL, LL	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, GF, WF	Cochran, P.H.,1979, USDA-FS Res. Pap. PNW-252	BHA	50
RC	Hegyi, R.P.F., et. al. , 1979 (Revised 1981), Province of B.C., Forest Inv. Rep.[1]	TTA	100
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
WH	Wiley, K.N., 1978, Weyerhaeuser Forestry Pap. No. 17	BHA	50
MH, OS	Means, et. al., 1986, unpublished FIR Report. Vol. 10, No. 1, OSU[2]	BHA	100
NF	Herman, F.R. et al., 1978, USDA-FS Res. Pap. PNW-243	BHA	100
RA	Harrington, C.A. et al., 1986, USDA-FS Res. Pap. PNW-358	TTA	20
WO[4]	King, J.E., 1966, Weyhaeuser Forestry Pap. No. 8	BHA	50
Other[3]	Curtis, R.O. et al., 1974, Forest Science 20:307-316	BHA	100

[1]Equation is based on total tree age (TTA) or breast height age (BHA)
[2]The source equation is in metric units; site index values for mountain hemlock and other softwood are assumed to be in meters.
[3]Other includes all the following species: Pacific yew, whitebark pine, Alaska cedar, western juniper, bigleaf maple, vine maple, paper birch, giant chinquapin, Pacific dogwood, quaking aspen, black cottonwood, plum species, willow, and other hardwood.
[4]Site index values entered for white oak using the King reference are converted to a different basis for use in some portions of this variant.

If site index is missing or incorrect, the default site species and site index are determined by plant association codes found in Appendix B. If the plant association code is missing or incorrect, the site species is set to ponderosa pine with a default site index set to 75.

Site indices for species not assigned a site index are determined based on the site index of the site species (height at base age) with an adjustment for the reference age differences between the site species and the target species.

3.5 Maximum Density

Maximum stand density index (SDI) and maximum basal area (BA) are important variables in determining density related mortality and crown ratio change. Maximum basal area is a stand level metric that can be set using the BAMAX or SETSITE keywords. If not set by the user, a default value is calculated from maximum stand SDI each projection cycle. Maximum stand density index can be set for each species using the SDIMAX or SETSITE keywords. If not set by the user, a default value is assigned as discussed below.

The default maximum SDI is set based on a user-specified, or default, plant association code or a user specified basal area maximum. If a user specified basal area maximum is present, the maximum SDI for all species is computed using equation {3.5.1}; otherwise, the SDI maximum for the site species is assigned from the SDI maximum associated with the plant association code shown in Appendix B. SDI maximums were set based on growth basal area (GBA) analysis developed by Hall (1983) or an analysis of Current Vegetation Survey (CVS) plots in USFS Region 6 by Crookston (2008). Once maximum SDI is determined for the site species, maximum SDI for all other species not assigned a value is estimated using a relative adjustment as seen in equation {3.5.2}. Some SDI maximums associated with plant associations are unreasonably large, so SDI maximums are capped at 900. Maximum stand density index at the stand level is a weighted average, by basal area, of the individual species SDI maximums.

{3.5.1} $SDIMAX_i = BAMAX / (0.5454154 * SDIU)$

{3.5.2} $SDIMAX_i = SDIMAX(SSEC) * (SDIMAX(S) / SDIMAX(SS))$

where:

$SDIMAX_i$ is the species-specific SDI maximum
BAMAX is the user-specified stand basal area maximum
SDIMAX(SSEC) is maximum SDI for the site species for the given plant association (*SSEC*) from Appendix B

SDIMAX(SS) is maximum SDI for the site species (*SS*) shown in table 3.5.1
SDIMAX(S) is maximum SDI for the target species (*S*) shown in table 3.5.1

Table 3.5.1 Stand density index maximums by species in the EC variant.

Species Code	SDI Maximum
WP	645
WL	648
DF	766
SF	766
RC	766
GF	766
LP	674
ES	766
AF	700
PP	645
WH	900
MH	766
PY	900
WB	900
NF	900
WF	766
LL	900
YC	900
WJ	900
BM	900
VN	900
RA	900
PB	900
GC	900
DG	900
AS	900
CW	900
WO	900
PL	900
WI	900
OS	766
OH	900

4.0 Growth Relationships

This chapter describes the functional relationships used to fill in missing tree data and calculate incremental growth. In FVS, trees are grown in either the small tree sub-model or the large tree sub-model depending on the diameter.

4.1 Height-Diameter Relationships

Height-diameter relationships in FVS are primarily used to estimate tree heights missing in the input data, and occasionally to estimate diameter growth on trees smaller than a given threshold diameter. In the EC variant, FVS 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 {4.1.1} (Curtis 1967, Arney 1985).

If the input data contains at least three measured heights for a species, then FVS can switch to a logistic height-diameter equation {4.1.2} (Wykoff, et.al 1982) that may be calibrated to the input data. FVS will not automatically use equation {4.1.2} even if you have enough height values in the input data. To override this default, the user must use the NOHTDREG keyword and change field 2 to a 1. Coefficients for equation {4.1.1} are given in table 4.1.1 sorted by species and location code. Coefficients for equation {4.1.2} are given in table 4.1.2.

{4.1.1} Curtis-Arney functional form

$DBH \geq 3.0''$: $HT = 4.5 + P_2 * \exp[-P_3 * DBH \wedge P_4]$

$DBH < 3.0''$: $HT = [(4.5 + P_2 * \exp[-P_3 * 3.0 \wedge P_4] - 4.51) * (DBH - 0.3) / 2.7] + 4.51$

{4.1.2} $HT = 4.5 + \exp(B_1 + B_2 / (DBH + 1.0))$

where:

HT	is tree height
DBH	is tree diameter at breast height
B_1 - B_2	are species-specific coefficients shown in table 4.1.2
P_1 - P_4	are species-specific coefficients shown in table 4.1.1

Table 4.1.1 Coefficients for Curtis-Arney equation {4.1.1} in the EC variant.

Species Code	Mount Hood (606)			Gifford Pinchot (603) Mt. Baker / Snoqualmie (613)		
	P_2	P_3	P_4	P_2	P_3	P_4
WP	433.7807	6.3318	-0.4988	1143.6254	6.1913	-0.3096
WL	220.0	5.0	-0.6054	255.4638	5.5577	-0.6054
DF	234.2080	6.3013	-0.6413	519.1872	5.3181	-0.3943
SF	441.9959	6.5382	-0.4787	171.2219	9.9497	-0.9727
RC	487.5415	5.4444	-0.3801	616.3503	5.7620	-0.3633
GF	376.0978	5.1639	-0.4319	727.8110	5.4648	-0.3435
LP	121.1392	12.6623	-1.2981	102.6146	10.1435	-1.2877
ES	2118.6711	6.6094	-0.2547	211.7962	6.7015	-0.6739

AF	66.6950	13.2615	-1.3774	113.5390	9.0045	-0.9907
PP	324.4467	8.0484	-0.5892	324.4467	8.0484	-0.5892
WH	341.9034	6.4658	-0.5379	504.1935	6.3635	-0.4658
MH	224.6205	7.2549	-0.6890	631.7598	5.8492	-0.3384
PY	127.1698	4.8977	-0.4668	127.1698	4.8977	-0.4668
WB	139.0727	5.2062	-0.5409	73.9147	3.9630	-0.8277
NF	328.1443	5.9501	-0.5088	178.7700	9.1133	-0.9131
WF	376.0978	5.1639	-0.4319	727.8110	5.4648	-0.3435
LL	119.7985	4.7067	-0.6751	119.7985	4.7067	-0.6751
YC	126.1074	6.2499	-0.8091	126.1074	6.2499	-0.8091
WJ	60.6009	4.1543	-0.6277	60.6009	4.1543	-0.6277
BM	220.9772	4.2639	-0.4386	220.9772	4.2639	-0.4386
VN	179.0706	3.6238	-0.5730	179.0706	3.6238	-0.5730
RA	88.1838	2.8404	-0.7343	94.5048	4.0657	-0.9592
PB	88.4509	2.2935	-0.7602	88.4509	2.2935	-0.7602
GC	10707.3906	8.4670	-0.1863	10707.3906	8.4670	-0.1863
DG	444.5618	3.9205	-0.2397	444.5618	3.9205	-0.2397
AS	1709.7229	5.8887	-0.2286	1709.7229	5.8887	-0.2286
CW	178.6441	4.5852	-0.6746	178.6441	4.5852	-0.6746
WO	55.0	5.5	-0.95	55.0	5.5	-0.95
PL	73.3348	2.6548	-1.2460	73.3348	2.6548	-1.2460
WI	149.5861	2.4231	-0.1800	149.5861	2.4231	-0.1800
OS	34.8330	2.6030	-0.5352	34.8330	2.6030	-0.5352
OH	34.8330	2.6030	-0.5352	34.8330	2.6030	-0.5352
Species Code	**Okanagan (608, 699)**			**Wenatchee (617)**		
	P_2	**P_3**	**P_4**	**P_2**	**P_3**	**P_4**
WP	12437.6601	8.1207	-0.1757	254.5262	4.7234	-0.5029
WL	248.1393	4.8505	-0.5833	170.8511	5.8759	-0.7865
DF	305.4997	4.7889	-0.4347	318.2462	5.1952	-0.4679
SF	303.7380	5.8516	-0.5474	356.1556	6.0615	-0.4783
RC	1246.8831	6.9633	-0.3113	307.7977	5.9217	-0.5040
GF	727.8110	5.4648	-0.3435	436.2309	5.5680	-0.4296
LP	130.5332	3.6797	-0.6573	100.6367	7.0781	-1.1163
ES	342.9319	5.4757	-0.4805	233.8124	6.9380	-0.6620
AF	188.7833	5.8908	-0.6732	166.0115	6.1799	-0.6792
PP	1047.4768	6.0765	-0.2927	1167.0325	6.2295	-0.2793
WH	369.9034	6.7038	-0.5424	662.9170	5.7985	-0.3668
MH	493.6376	6.0162	-0.3765	206.3060	6.7321	-0.6265
PY	127.1698	4.8977	-0.4668	19.6943	25.0881	-2.3675
WB	89.1852	4.7008	-0.7043	98.3035	4.7213	-0.6613
NF	178.7700	9.1133	-0.9131	178.7700	9.1133	-0.9131
WF	436.2309	5.5680	-0.4296	436.2309	5.5680	-0.4296

LL	119.7985	4.7067	-0.6751	1442.5197	6.1880	-0.2037
YC	694.2233	5.9131	-0.3484	126.1074	6.2499	-0.8091
WJ	60.6009	4.1543	-0.6277	60.6009	4.1543	-0.6277
BM	220.9772	4.2639	-0.4386	220.9772	4.2639	-0.4386
VN	179.0706	3.6238	-0.5730	179.0706	3.6238	-0.5730
RA	94.5048	4.0657	-0.9592	94.5048	4.0657	-0.9592
PB	83.2440	3.5984	-0.9561	88.4509	2.2935	-0.7602
GC	10707.3906	8.4670	-0.1863	10707.3906	8.4670	-0.1863
DG	444.5618	3.9205	-0.2397	444.5618	3.9205	-0.2397
AS	184.1658	3.4801	-0.5127	1507.7287	5.3428	-0.1982
CW	178.6441	4.5852	-0.6746	178.6441	4.5852	-0.6746
WO	55.0	5.5	-0.95	55.0	5.5	-0.95
PL	73.3348	2.6548	-1.2460	73.3348	2.6548	-1.2460
WI	55.0	5.5	-0.95	55.0	5.5	-0.95
OS	34.8330	2.6030	-0.5352	34.8330	2.6030	-0.5352
OH	34.8330	2.6030	-0.5352	34.8330	2.6030	-0.5352

Table 4.1.2 Coefficients for the logistic Wykoff equation {4.1.2} in the EC variant.

Species Code	Default B_1	B_2
WP	5.035	-10.674
WL	4.961	-8.247
DF	4.920	-9.003
SF	5.032	-10.482
RC	4.896	-8.391
GF	5.032	-10.482
LP	4.854	-8.296
ES	4.948	-9.041
AF	4.834	-9.042
PP	4.884	-9.741
WH	5.298	-13.240
MH	3.9715	-6.7145
PY	5.188	-13.801
WB	5.188	-13.801
NF	5.327	-15.450
WF	5.032	-10.482
LL	5.188	-13.801
YC	5.143	-13.497
WJ	5.152	-13.576
BM	4.700	-6.326
VN	4.700	-6.326
RA	4.886	-8.792

Species Code	Default B_1	B_2
PB	5.152	-13.576
GC	5.152	-13.576
DG	5.152	-13.576
AS	5.152	-13.576
CW	5.152	-13.576
WO	5.152	-13.576
PL	5.152	-13.576
WI	5.152	-13.576
OS	3.9715	-6.7145
OH	5.152	-13.576

When a user turns on calibration of the height-diameter equation using the NOHTDREG keyword, and calibration does occur, trees of some species which have a diameter less than a threshold diameter may use equations other than the calibrated {4.1.2} for dubbing heights.

Ponderosa pine trees less than 3.0” in diameter use equation {4.1.3}.

{4.1.3} $HT = 8.31485 + 3.03659 * DBH – 0.592 * JCR))$

Western hemlock trees less than 5.0” in diameter use equation {4.1.4}.

{4.1.4} $HT = \exp(1.3608 + (0.6151 * DBH) - (0.0442 * DBH^2) + 0.0829)$

Pacific yew, whitebark pine, subalpine larch, and Alaska yellow cedar trees less than 5.0” in diameter use equation {4.1.5}.

{4.1.5} $HT = \exp(1.5097 + (0.3040 * DBH))$

Noble fir trees less than 5.0” in diameter use equation {4.1.6}.

{4.1.6} $HT = \exp(1.7100 + (0.2943 * DBH))$

Western juniper, bigleaf maple, vine maple, red alder, paper birch, giant chinquapin, Pacific dogwood, quaking aspen, black cottonwood, Oregon white oak, plum, willow, and other hardwood use equation {4.1.7} for trees less than 5.0” in diameter.

{4.1.7} $HT = 0.0994 + (4.9767 * DBH)$

where:

HT is tree height
DBH is tree diameter
JCR is tree crown ratio code (1 = 0-10 percent, 2 = 11-20 percent, …, 7 = 61-100 percent)

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 for western white pine, western larch, Douglas-fir, Pacific silver fir, western redcedar, grand fir, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, western hemlock, mountain hemlock, Pacific yew, whitebark pine, noble fir, white fir, subalpine larch, Alaska cedar, western juniper, and other softwood is shown in equation {4.2.1}; bigleaf maple, vine maple, red alder, paper birch, giant chinquapin, Pacific dogwood, quaking aspen, black cottonwood, plum, willow, and other hardwood use equation {4.2.2}; white oak uses equation {4.2.3}. Coefficients (b_1, b_2) for each species are shown in table 4.2.1.

{4.2.1} *BRATIO* = b_1

{4.2.2} *BRATIO* = (b_1 + b_2 * DBH) / DBH

{4.2.3} *BRATIO* = (b_1 * DBH^b_2) / DBH

where:

BRATIO is species-specific bark ratio (bounded to $0.80 \leq BRATIO \leq 0.99$)
DBH is tree diameter at breast height
b_1, b_2 are species-specific coefficients shown in table 4.2.1

Table 4.2.1 Coefficients for equations {4.2.1} - {4.2.3} in the EC variant.

Species Code	b_1	b_2
WP	0.964	-
WL	0.851	-
DF	0.844	-
SF	0.903	-
RC	0.950	-
GF	0.903	-
LP	0.963	-
ES	0.956	-
AF	0.903	-
PP	0.889	-
WH	0.93371	-
MH	0.934	-
PY	0.93329	-
WB	0.93329	-
NF	0.904973	-
WF	0.903	-
LL	0.9	-
YC	0.837291	-
WJ	0.94967	-
BM	0.0836	0.94782
VN	0.0836	0.94782
RA	0.075256	0.94967
PB	0.0836	0.94782

Species Code	b_1	b_2
GC	0.15565	0.90182
DG	0.075256	0.94967
AS	0.075256	0.94967
CW	0.075256	0.94967
WO	0.8558	1.0213
PL	0.075256	0.94967
WI	0.075256	0.94967
OS	0.934	-
OH	0.075256	0.94967

4.3 Crown Ratio Relationships

Crown ratio equations are used for three purposes in FVS: (1) to estimate tree crown ratios missing from the input data for both live and dead trees; (2) to estimate change in crown ratio from cycle to cycle for live trees; and (3) to estimate initial crown ratios for regenerating trees established during a simulation.

4.3.1 Crown Ratio Dubbing

In the EC variant, crown ratios missing in the input data are predicted using different equations depending on tree species and size. For western white pine, western larch, Douglas-fir, Pacific silver fir, western redcedar, grand fir, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, mountain hemlock, white fir, and "other softwood" live trees less than 1.0" in diameter and dead trees of all sizes use equations {4.3.1.1} and {4.3.1.2} to compute crown ratio. Equation coefficients are found in table 4.3.1.1.

{4.3.1.1} $X = R_1 + R_2 * DBH + R_3 * HT + R_4 * BA + R_5 * PCCF + R_6 * HT_{Avg} / HT + R_7 * HT_{Avg} + R_8 * BA * PCCF + R_9 * MAI$

{4.3.1.2} $CR = 1 / (1 + \exp(X + N(0,SD)))$ where absolute value of $(X + N(0,SD)) < 86$

where:

CR	is crown ratio expressed as a proportion (bounded to 0.05 < CR < 0.95)
DBH	is tree diameter at breast height
HT	is tree height
BA	is total stand basal area
PCCF	is crown competition factor on the inventory point where the tree is established
HTAvg	is average height of the 40 largest diameter trees in the stand
MAI	is stand mean annual increment
N(0,SD)	is a random increment from a normal distribution with a mean of 0 and a standard deviation of SD
R1 – R9	are species-specific coefficients shown in table 4.3.1.1

Western hemlock, Pacific yew, whitebark pine, noble fir, subalpine larch, Alaska cedar, western juniper, bigleaf maple, vine maple, red alder, paper birch, giant chinquapin, Pacific dogwood, quaking aspen, black cottonwood, Oregon white oak, plum, willow, and "other hardwood" live trees less than 1.0" in diameter and dead trees of all sizes use equations {4.3.1.3} and {4.3.1.4}, and the coefficients shown in table 4.3.1.1.

{4.3.1.3} $X = R_1 + R_3 * HT + R_4 * BA + N(0,SD)$

{4.3.1.4} $CR = ((X - 1.0) * 10 + 1.0) / 100$

where:

X	is crown ratio expressed as a code (0-9)
CR	is crown ratio expressed as a proportion (bounded to $0.05 \leq CR \leq 0.95$)
HT	is tree height
BA	is total stand basal area
N(0,SD)	is a random increment from a normal distribution with a mean of 0 and a standard deviation of SD
R_1, R_3, R_4	are species-specific coefficients shown in table 4.3.1.1

Table 4.3.1.1 Coefficients for the crown ratio equations {4.3.1.1} and {4.3.1.3} in the EC variant.

	Alpha Code							
Coefficient	**WP, WL, LP, PP**	**DF, SF, GF, RC, ES, AF, WF**	**WH, YC**	**PY, WB, LL**	**NF**	**WJ**	**BM, VN, RA, PB, GC, DG, AS, CW, WO, PL, WI, OH**	**MH, OS**
R_1	-1.669490	-0.426688	7.558538	6.489813	8.042774	9.0	5.0	-2.19723
R_2	-0.209765	-0.093105	0	0	0	0	0	0
R_3	0	0.022409	-0.015637	-0.029815	0.007198	0	0	0
R_4	0.003359	0.002633	-0.009064	-0.009276	-0.016163	0	0	0
R_5	0.011032	0	0	0	0	0	0	0
R_6	0	-0.045532	0	0	0	0	0	0
R_7	0.017727	0	0	0	0	0	0	0
R_8	-0.000053	0.000022	0	0	0	0	0	0
R_9	0.014098	-0.013115	0	0	0	0	0	0
SD	0.5*	0.6957**	1.9658	2.0426	1.3167	0.5	0.5	0.2

*0.6124 for lodgepole pine; 0.4942 for ponderosa pine

**0.9310 for grand fir and white fir

A Weibull-based crown model developed by Dixon (1985) as described in Dixon (2002) is used to predict crown ratio for all trees 1.0" in diameter or larger. To estimate crown ratio using this methodology, the average stand crown ratio is estimated from stand density index using equation {4.3.1.5}. Weibull parameters are estimated from the average stand crown ratio using equations in equation set {4.3.1.6}. Individual tree crown ratio is then set from the Weibull distribution, equation {4.3.1.7} based on a tree's relative position in the diameter distribution and multiplied by a scale factor, shown in equation {4.3.1.8}, which accounts for stand density. Crowns estimated from the Weibull distribution are bounded to be between the 5 and 95 percentile points of the specified Weibull distribution. Equation coefficients for each species are shown in table 4.3.1.2.

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

where: $RELSDI = SDI_{stand} / SDI_{max}$

{4.3.1.6} Weibull parameters A, B, and C are estimated from average crown ratio

$A = a_0$
$B = b_0 + b_1 * \text{ACR}$ ($B \geq 3$)
$C = c_0 + c_1 * \text{ACR}$ ($C \geq 2$)

{4.3.1.7} $Y = 1\text{-exp}(-((X\text{-A})/\text{B})\text{\^{}C})$

{4.3.1.8} $SCALE = 1 – (0.00167 * (CCF – 100))$

where:

ACR	is predicted average stand crown ratio for the species
SDI_{stand}	is stand density index of the stand
SDI_{max}	is maximum stand density index
A, *B*, *C*	are parameters of the Weibull crown ratio distribution
X	is a tree's crown ratio expressed as a percent / 10
Y	is a trees rank in the diameter distribution (1 = smallest; ITRN = largest) divided by the total number of trees (ITRN) multiplied by *SCALE*
SCALE	is a density dependent scaling factor (bounded to $0.3 \leq SCALE \leq 1.0$)
CCF	is stand crown competition factor

a_0, $b_{0\text{-}1}$, $c_{0\text{-}1}$, and $d_{0\text{-}1}$ are species-specific coefficients shown in table 4.3.1.2

Table 4.3.1.2 Coefficients for the Weibull parameter equations {4.3.1.5} and {4.3.1.6} in the EC variant.

Species Code	Model Coefficients						
	a_0	b_0	b_1	c_0	c_1	d_0	d_1
WP	0	0.08106	1.10253	1.04477	0.42828	5.23986	-0.02569
WL	0	0.00603	1.12276	2.73400	0	4.98675	-0.02466
DF	0	-0.28295	1.18232	3.03400	0	4.99727	-0.01043
SF	0	-0.09734	1.14675	2.71600	0	4.79981	-0.00653
RC	0	-0.01129	1.11665	3.35500	0	5.74915	-0.01090
GF	0	-0.09734	1.14675	2.71600	0	4.79981	-0.00653
LP	0	-0.00047	1.13172	2.22700	0	3.85379	-0.00795
ES	0	-0.15678	1.14894	3.05300	0	6.04394	-0.01825
AF	0	0.08247	1.10804	1.45931	0.25495	6.00795	-0.02301
PP	0	0.08106	1.10253	1.04477	0.42828	5.23986	-0.02569
WH	0	0.490848	1.014138	3.164558	0	5.488532	-0.007173
MH	0	-0.01129	1.11665	3.35500	0	5.74915	-0.01090
PY	0	0.196054	1.073909	0.345647	0.620145	5.417431	-0.011608
WB	0	0.196054	1.073909	0.345647	0.620145	5.417431	-0.011608
NF	0	-0.135807	1.147712	3.017494	0	5.568864	-0.021293
WF	0	-0.09734	1.14675	2.71600	0	4.79981	-0.00653
LL	0	0.196054	1.073909	0.345647	0.620145	5.417431	-0.011608
YC	1	-0.811424	1.056190	-3.831124	1.401938	5.200550	-0.014890
WJ	0	-0.238295	1.180163	3.044134	0	4.625125	-0.016042
BM	1	-0.818809	1.054176	-2.366108	1.202413	4.420000	-0.010660
VN	1	-0.818809	1.054176	-2.366108	1.202413	4.420000	-0.010660
RA	1	-1.112738	1.123138	2.533158	0	4.120478	-0.006357
PB	0	-0.238295	1.180163	3.044134	0	4.625125	-0.016042
GC	0	-0.238295	1.180163	3.044134	0	4.625125	-0.016042
DG	0	-0.238295	1.180163	3.044134	0	4.625125	-0.016042
AS	0	-0.238295	1.180163	3.044134	0	4.625125	-0.016042
CW	0	-0.238295	1.180163	3.044134	0	4.625125	-0.016042
WO	0	-0.238295	1.180163	3.044134	0	4.625125	-0.016042
PL	0	-0.238295	1.180163	3.044134	0	4.625125	-0.016042
WI	0	-0.238295	1.180163	3.044134	0	4.625125	-0.016042
OS	0	-0.01129	1.11665	3.35500	0	5.74915	-0.01090
OH	0	-0.238295	1.180163	3.044134	0	4.625125	-0.016042

4.3.2 Crown Ratio Change

Crown ratio change is estimated after growth, mortality and regeneration are estimated during a projection cycle. Crown ratio change is the difference between the crown ratio at the beginning of the cycle and the predicted crown ratio at the end of the cycle. Crown ratio predicted at the end of the projection cycle is estimated for live tree records using the Weibull distribution, equations {4.3.1.5}-{4.3.1.8}. Crown change is checked to make sure it doesn't exceed the change possible if all height growth produces new crown. Crown change is further bounded to 1% per year for the length of the cycle to avoid drastic changes in crown ratio. Equations {4.3.1.1} – {4.3.1.4} are not used when estimating crown ratio change.

4.3.3 Crown Ratio for Newly Established Trees

Crown ratios for newly established trees during regeneration are estimated using equation {4.3.3.1}. A random component is added in equation {4.3.3.1} to ensure that not all newly established trees are assigned exactly the same crown ratio.

{4.3.3.1} $CR = 0.89722 - 0.0000461 * PCCF + RAN$

where:

CR	is crown ratio expressed as a proportion (bounded to $0.2 \le CR \le 0.9$)
PCCF	is crown competition factor on the inventory point where the tree is established
RAN	is a small random component

4.4 Crown Width Relationships

The EC variant calculates the maximum crown width for each individual tree, based on individual tree and stand attributes. Crown width for each tree is reported in the tree list output table and used for percent canopy cover (*PCC*) calculations in the model.

Crown width is calculated using equations {4.4.1} – {4.4.5}, and coefficients for these equations are shown in table 4.4.1. The minimum diameter and bounds for certain data values are given in table 4.4.2. Equation numbers in tables 4.4.1 and 4.4.2 are given with the first three digits representing the FIA species code, and the last two digits representing the equation source.

{4.4.1} Bechtold (2004); Equation 02

$DBH \ge MinD: CW = a_1 + (a_2 * DBH) + (a_3 * DBH\text{^}2) + (a_4 * CR\%) + (a_5 * BA) + (a_6 * HI)$
$DBH < MinD: CW = [a_1 + (a_2 * MinD) + (a_3 * MinD\text{^}2) + (a_4 * CR\%) + (a_5 * BA) + (a_6 * HI)] * (DBH / MinD)$

{4.4.2} Crookston (2003); Equation 03

$DBH \ge MinD: CW = [a_1 * \exp[a_2 + (a_3 * \ln(CL)) + (a_4 * \ln(DBH)) + (a_5 * \ln(HT)) + (a_6 * \ln(BA))]]$
$DBH < MinD: CW = [a_1 * \exp[a_2 + (a_3 * \ln(CL)) + (a_4 * \ln(MinD)) + (a_5 * \ln(HT)) + (a_6 * \ln(BA))]] * (DBH / MinD)$

{4.4.3 Crookston (2005); Equation 04

$DBH \ge MinD: CW = a_1 * DBH\text{^}a_2$
$DBH < MinD: CW = [a_1 * MinD\text{^}a_2] * (DBH / MinD)$

{4.4.4} Crookston (2005); Equation 05

$DBH \ge MinD: CW = (a_1 * BF) * DBH\text{^}a_2 * HT\text{^}a_3 * CL\text{^}a_4 * (BA + 1.0)\text{^}a_5 * (\exp(EL))\text{^}a_6$

$DBH < MinD$: $CW = [(a_1 * BF) * MinD^{\wedge}a_2 * HT^{\wedge}a_3 * CL^{\wedge}a_4 * (BA + 1.0)^{\wedge}a_5 * (\exp(EL))^{\wedge}a_6] * (DBH / MinD)$

{4.4.5} Donnelly (1996); Equation 06

$DBH \geq MinD$: $CW = a_1 * DBH^{\wedge a2}$
$DBH < MinD$: $CW = [a_1 * MinD^{\wedge a2}] * (DBH / MinD)$

where:

BF	is a species-specific coefficient based on forest code
CW	is tree maximum crown width
CL	is tree crown length
DBH	is tree diameter at breast height
HT	is tree height
BA	is total stand basal area
EL	is stand elevation in hundreds of feet
MinD	is the minimum diameter
$a_1 - a_6$	are species-specific coefficients shown in table 4.4.1

Table 4.4.1 Coefficients for crown width equations {4.4.1}-{4.4.5} in the EC variant.

Species Code	Equation Number*	a_1	a_2	a_3	a_4	a_5	a_6
WP	11905	5.3822	0.57896	-0.19579	0.14875	0	-0.00685
WL	07303	1.02478	0.99889	0.19422	0.59423	-0.09078	-0.02341
DF	20205	6.0227	0.54361	-0.20669	0.20395	-0.00644	-0.00378
SF	01105	4.4799	0.45976	-0.10425	0.11866	0.06762	-0.00715
RC	24205	6.2382	0.29517	-0.10673	0.23219	0.05341	-0.00787
GF	01703	1.0303	1.14079	0.20904	0.38787	0	0
LP	10805	6.6941	0.81980	-0.36992	0.17722	-0.01202	-0.00882
ES	09305	6.7575	0.55048	-0.25204	0.19002	0	-0.00313
AF	01905	5.8827	0.51479	-0.21501	0.17916	0.03277	-0.00828
PP	12205	4.7762	0.74126	-0.28734	0.17137	-0.00602	-0.00209
WH	26305	6.0384	0.51581	-0.21349	0.17468	0.06143	-0.00571
MH	26403	6.90396	0.55645	-0.28509	0.20430	0	0
PY	23104	6.1297	0.45424	0	0	0	0
WB	10105	2.2354	0.66680	-0.11658	0.16927	0	0
NF	02206	3.0614	0.6276	0	0	0	0
WF	01505	5.0312	0.53680	-0.18957	0.16199	0.04385	-0.00651
LL	07204	2.2586	0.68532	0	0	0	0
YC	04205	3.3756	0.45445	-0.11523	0.22547	0.08756	-0.00894
WJ	06405	5.1486	0.73636	-0.46927	0.39114	-0.05429	0
BM	31206	7.5183	0.4461	0	0	0	0
VN	32102	5.9765	0.8648	0	0.0675	0	0

Species Code	Equation Number*	a_1	a_2	a_3	a_4	a_5	a_6
RA	35106	7.0806	0.4771	0	0	0	0
PB	37506	5.8980	0.4841	0	0	0	0
GC	63102	3.1150	0.7966	0	0.0745	-0.0053	0.0523
DG	35106	7.0806	0.4771	0	0	0	0
AS	74605	4.7961	0.64167	-0.18695	0.18581	0	0
CW	74705	4.4327	0.41505	-0.23264	0.41477	0	0
WO	81505	2.4857	0.70862	0	0.10168	0	0
PL	35106	7.0806	0.4771	0	0	0	0
WI	31206	7.5183	0.4461	0	0	0	0
OS	26403	6.90396	0.55645	-0.28509	0.20430	0	0
OH	74605	4.7961	0.64167	-0.18695	0.18581	0	0

*Equation number is a combination of the species FIA code (###) and equation source (##).

Table 4.4.2 *MinD* values and data bounds for equations {4.4.1}-{4.1.5} in the EC variant.

Species Code	Equation Number*	*MinD*	EL min	*EL* max	*HI* min	*HI* max	*CW* max
WP	11905	1.0	10	75	n/a	n/a	35
WL	07303	1.0	n/a	n/a	n/a	n/a	40
DF	20205	1.0	1	75	n/a	n/a	80
SF	01105	1.0	4	72	n/a	n/a	33
RC	24205	1.0	1	72	n/a	n/a	45
GF	01703	1.0	n/a	n/a	n/a	n/a	40
LP	10805	1.0	1	79	n/a	n/a	40
ES	09305	1.0	1	85	n/a	n/a	40
AF	01905	1.0	10	85	n/a	n/a	30
PP	12205	1.0	13	75	n/a	n/a	50
WH	26305	1.0	1	72	n/a	n/a	54
MH	26403	n/a	n/a	n/a	n/a	n/a	45
PY	23104	1.0	n/a	n/a	n/a	n/a	30
WB	10105	1.0	n/a	n/a	n/a	n/a	40
NF	02206	1.0	n/a	n/a	n/a	n/a	40
WF	01505	1.0	2	75	n/a	n/a	35
LL	07204	1.0	n/a	n/a	n/a	n/a	33
YC	04205	1.0	16	62	n/a	n/a	59
WJ	06405	1.0	n/a	n/a	n/a	n/a	36
BM	31206	1.0	n/a	n/a	n/a	n/a	30
VN	32102	5.0	n/a	n/a	n/a	n/a	39
RA	35106	1.0	n/a	n/a	n/a	n/a	35
PB	37506	1.0	n/a	n/a	n/a	n/a	25
GC	63102	5.0	n/a	n/a	-55	15	41
DG	35106	1.0	n/a	n/a	n/a	n/a	35

Species Code	Equation Number*	*MinD*	EL min	*EL* max	*HI* min	*HI* max	*CW* max
AS	74605	1.0	n/a	n/a	n/a	n/a	45
CW	74705	1.0	n/a	n/a	n/a	n/a	56
WO	81505	1.0	n/a	n/a	n/a	n/a	39
PL	35106	1.0	n/a	n/a	n/a	n/a	35
WI	31206	1.0	n/a	n/a	n/a	n/a	30
OS	26403	n/a	n/a	n/a	n/a	n/a	45
OH	74605	1.0	n/a	n/a	n/a	n/a	45

Table 4.4.3 *BF* values for equation {4.4.4} in the EC variant.

Species Code	Location Code					
	603	606	608	613	617	699
WP	1.128	1.081	1.081	1	1	1
WL	0.952	0.907	0.952	1	0.879	1
DF	1	1	1	1	0.975	1
SF	1.032	1.296	1	1	1	1
RC	0.920	1.115	0.905	1	0.905	1
GF	1	1.086	1	1	0.972	1
LP	1	0.944	1.114	1	0.969	1
ES	1	1	1	1	0.949	1
AF	0.906	1.038	1	1	0.906	1
PP	1	1	1	1	0.946	1
WH	1.028	1.260	1	1	0.962	1
MH	1.077	1.106	0.900	1	0.952	1
PY	1	1	1	1	1	1
WB	1	1	1	1	1	1
NF	1.123	1.301	1	1	1	1
WF	1	1.130	1	1	1	1
LL	1	1	1	1	1	1
YC	1	1.493	1	1	1	1
WJ	1	1	1	1	1	1
BM	1	1	1	1	1	1
VN	1	1	1	1	1	1
RA	1	1	1	1	1	1
PB	1	1	1	1	1	1
GC	1	1	1	1	1	1
DG	1	1	1	1	1	1
AS	1	1	1	1	1	1
CW	1	1	1	1	1	1
WO	1	1	1	1	1	1
PL	1	1	1	1	1	1

Species Code	Location Code					
	603	606	608	613	617	699
WI	1	1	1	1	1	1
OS	1.077	1.106	0.900	1	0.952	1
OH	1	1	1	1	1	1

4.5 Crown Competition Factor

The EC variant uses crown competition factor (*CCF*) as a predictor variable in some growth relationships. Crown competition factor (Krajicek and others 1961) is a relative measurement of stand density that is 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.

For western white pine, western larch, Douglas-fir, Pacific silver fir, western redcedar, grand fir, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, mountain hemlock, white fir, and other softwood crown competition factor for an individual tree is calculated using the equation set {4.5.1}. All species coefficients are shown in table 4.5.1.

{4.5.1} CCF_t equations

$DBH \geq 1.0''$: $CCF_t = R_1 + (R_2 * DBH) + (R_3 * DBH\text{^}2)$
$0.1'' < DBH < 1.0''$: $CCF_t = R_4 * DBH\text{^}R_5$
$DBH \leq 0.1''$: $CCF_t = 0.001$

For western hemlock, Pacific yew, whitebark pine, noble fir, subalpine larch, Alaska cedar, western juniper, bigleaf maple, vine maple, red alder, paper birch, giant chinquapin, Pacific dogwood, quaking aspen, black cottonwood, Oregon white oak, plum, willow, and other hardwood crown competition factor for an individual tree is calculated using equation {4.5.1} for trees greater than or equal to 1.0" in diameter and equation {4.5.4} for trees less than 1.0" in diameter. All species coefficients are shown in table 4.5.1.

{4.5.4} $DBH < 1.0''$: $CCF_t = (R_1 + R_2 + R_3) * DBH$

where:

CCF_t is crown competition factor for an individual tree
DBH is tree diameter at breast height
$R_1 – R_5$ are species-specific coefficients shown in table 4.5.1

Table 4.5.1 Coefficients for the *CCF* equations in the EC variant.

Species Code	Model Coefficients				
	R_1	R_2	R_3	R_4	R_5
WP	0.03	0.0167	0.00230	0.009884	1.6667
WL	0.02	0.0148	0.00338	0.007244	1.8182
DF	0.0388	0.0269	0.00466	0.017299	1.5571
SF	0.04	0.0270	0.00405	0.015248	1.7333

Species Code	Model Coefficients				
	R_1	R_2	R_3	R_4	R_5
RC	0.03	0.0238	0.00490	0.008915	1.7800
GF	0.04	0.027	0.00405	0.015248	1.7333
LP	0.01925	0.01676	0.00365	0.009187	1.7600
ES	0.03	0.0173	0.00259	0.007875	1.7360
AF	0.03	0.0216	0.00405	0.011402	1.7560
PP	0.0219	0.0169	0.00325	0.007813	1.7780
WH	0.03758	0.0233	0.00361	0	0
MH	0.03	0.0215	0.00363	0.011109	1.7250
PY	0.0204	0.0246	0.0074	0	0
WB	0.01925	0.0168	0.00365	0	0
NF	0.02453	0.0115	0.00134	0	0
WF	0.04	0.027	0.00405	0.015248	1.7333
LL	0.0194	0.0142	0.00261	0	0
YC	0.0194	0.0142	0.00261	0	0
WJ	0.0194	0.0142	0.00261	0	0
BM	0.0204	0.0246	0.0074	0	0
VN	0.0204	0.0246	0.0074	0	0
RA	0.03561	0.02731	0.00524	0	0
PB	0.0204	0.0246	0.0074	0	0
GC	0.0160	0.0167	0.00434	0	0
DG	0.0204	0.0246	0.0074	0	0
AS	0.0204	0.0246	0.0074	0	0
CW	0.0204	0.0246	0.0074	0	0
WO	0.0204	0.0246	0.0074	0	0
PL	0.0204	0.0246	0.0074	0	0
WI	0.0204	0.0246	0.0074	0	0
OS	0.03	0.0215	0.00363	0.011109	1.7250
OH	0.0204	0.0246	0.0074	0	0

4.6 Small Tree Growth Relationships

Trees are considered "small trees" for FVS modeling purposes when they are smaller than some threshold diameter. The threshold diameter is set to 3.0" for all species in the EC variant.

The small tree model is height-growth driven, meaning height growth is estimated first and diameter growth is estimated from height growth. These relationships are discussed in the following sections.

4.6.1 Small Tree Height Growth

The small-tree height increment model predicts 10-year height growth (*HTG*) for small trees, based on site index. Potential height growth is estimated using equations {4.6.1.1} – {4.6.1.4}, and coefficients for these equations are shown in table 4.6.1.1.

{4.6.1.1} $POTHTG = (SI / c_1) * (1.0 - c_2 * \exp(c_3 * X_2))^{c_4} - (SI / c_1) * (1.0 - c_2 * \exp(c_3 * X_1))^{c_4}$

$X_1 = \text{ALOG}\,[(1.0 - (c_1 / SI * HT)^{(1 / c_4)}) / c_2] / c_3$
$X_2 = X_1 + A$

{4.6.1.2} $POTHTG = [(c_1 + c_2 * SI) / (c_3 - c_4 * SI)] * Y$

{4.6.1.3} $POTHTG = [(c_1 + c_2 * SI) / (c_3 - c_4 * SI)] * Y * 3.280833$

{4.6.1.4} $POTHTG = [(c_1 * \ln(1 - (SI / c_2)^{c3}) * c_4) - 0.1)] * Y$

where:

POTHTG	is potential height growth
SI	is species site index bounded by *SITELO* and *SITEHI* (shown in table 4.6.1.2)
Y	is the number of years for which a growth estimate is needed
HT	is tree height
$c_1 - c_4$	are species-specific coefficients shown in table 4.6.1.1

Table 4.6.1.1 Coefficients and equation reference for equations {4.6.1.1} and {4.6.1.2} in the EC variant.

Species Code	*POTHTG* Equation	Model Coefficients			
		c_1	c_2	c_3	c_4
WP	{4.6.1.1}	0.375045	0.92503	-0.020796	2.48811
WL	{4.6.1.2}	-3.97245	0.50995	28.11668	0.05661
DF	{4.6.1.2}	2.0	0.420	28.5	0.05
SF	{4.6.1.2}	-0.6667	0.4333	28.5	0.05
RC	{4.6.1.1}	0.752842	1.0	-0.0174	1.4711
GF	{4.6.1.2}	-1.0470	0.4220	28.7739	0.0597
LP	{4.6.1.2}	0.3277	0.01296	1.0	0
ES	{4.6.1.2}	-8.0	0.35	53.72545	0.274509
AF	{4.6.1.2}	6.0	0.14	33.882	0.06588
PP	{4.6.1.2}	-1.0	0.32857	28.0	0.042857
WH	{4.6.1.2}	-5.74874	0.54576	26.15767	0.03596
MH	{4.6.1.3}	0.965758	0.082969	55.249612	1.288852
PY	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
WB	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
NF	{4.6.1.2}	11.26677	0.12027	27.93806	0.02873
WF	{4.6.1.2}	-1.0470	0.4220	28.7739	0.0597
LL	{4.6.1.2}	-3.97245	0.50995	28.11668	0.05661
YC	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
WJ	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
BM	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
VN	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
RA	{4.6.1.2}	-0.007025	0.056794	1.0	0
PB	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
GC	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586

DG	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
AS	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
CW	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
WO	{4.6.1.4}	-37.60812	114.24569	0.44444	0.01
PL	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
WI	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586
OS	{4.6.1.3}	0.965758	0.082969	55.249612	1.288852
OH	{4.6.1.2}	1.47043	0.23317	31.56252	0.05586

Table 4.6.1.2 *SITELO* and *SITEHI* values for equations {4.6.1.1-4.6.1.3} in the EC variant.

Species Code	*SITELO*	*SITEHI*
WP	20	80
WL	50	110
DF	50	110
SF	50	110
RC	15	30
GF	50	110
LP	30	70
ES	40	120
AF	50	150
PP	70	140
WH	0	999
MH	15	30
PY	0	999
WB	0	999
NF	0	999
WF	50	110
LL	0	999
YC	0	999
WJ	0	999
BM	0	999
VN	0	999
RA	0	999
PB	0	999
GC	0	999
DG	0	999
AS	0	999
CW	0	999
WO	0	999
PL	0	999
WI	0	999

Species Code	*SITELO*	*SITEHI*
OS	15	30
OH	0	999

Potential height growth is then adjusted based on stand density (*PCTRED*) and crown ratio (*VIGOR*) as shown in equations {4.6.1.5} and {4.6.1.6} respectively, to determine an estimated height growth as shown in equation {4.6.1.7}.

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

$Z = HT_{Avg} * (CCF / 100)$ bounded so $Z \leq 300$ and $0.01 \leq PCTRED \leq 1.0$

{4.6.1.6} $VIGOR = (150 * CR^3 * \exp(-6 * CR)) + 0.3$

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

where:

PCTRED	is reduction in height growth due to stand density
HT_{Avg}	is average height of the 40 largest diameter trees in the stand
CCF	is stand crown competition factor
VIGOR	is reduction in height growth due to tree vigor (bounded to $VIGOR \leq 1.0$)
CR	is a tree's live crown ratio (compacted) expressed as a proportion
HTG	is estimated height growth for the cycle
POTHTG	is potential height growth

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.

Height growth estimates from the small-tree model are weighted with the height growth estimates from the large tree model over a range of diameters (X_{min} and X_{max}) in order to smooth the transition between the two models. For example, the closer a tree's *DBH* value is to the minimum diameter (X_{min}), the more the growth estimate will be weighted towards the small-tree growth model. The closer a tree's *DBH* value is to the maximum diameter (X_{max}), the more the growth estimate will be weighted towards the large-tree growth model. If a tree's *DBH* value falls outside of the range given by X_{min} and X_{max}, then the model will use only the small-tree or large-tree growth model in the growth estimate. The weight applied to the growth estimate is calculated using equation {4.6.1.8}, and applied as shown in equation {4.6.1.9}. The range of diameters for each species is shown in Table 4.6.1.3.

{4.6.1.8}

$DBH \leq X_{min}: XWT = 0$
$X_{min} < DBH < X_{max}: XWT = (DBH - X_{min}) / (X_{max} - X_{min})$
$DBH \geq X_{max}: XWT = 1$

{4.6.1.9} Estimated growth = [(1 - *XWT*) * *STGE*] + [*XWT* * *LTGE*] where:

XWT	is the weight applied to the growth estimates
DBH	is tree diameter at breast height
X_{max}	is the maximum *DBH* is the diameter range
X_{min}	is the minimum *DBH* in the diameter range
STGE	is the growth estimate obtained using the small-tree growth model
LTGE	is the growth estimate obtained using the large-tree growth model

Table 4.6.1.3 Diameter bounds by species in the EC variant.

Species Code	X_{min}	X_{max}
WP	2.0	4.0
WL	2.0	4.0
DF	2.0	4.0
SF	2.0	4.0
RC	2.0	10.0
GF	2.0	4.0
LP	1.0	5.0
ES	2.0	4.0
AF	2.0	6.0
PP	2.0	6.0
WH	2.0	4.0
MH	2.0	6.0
PY	2.0	4.0
WB	2.0	4.0
NF	2.0	4.0
WF	2.0	4.0
LL	2.0	4.0
YC	2.0	4.0
WJ	2.0	4.0
BM	2.0	4.0
VN	2.0	4.0
RA	2.0	4.0
PB	2.0	4.0
GC	2.0	4.0
DG	2.0	4.0
AS	2.0	4.0
CW	2.0	4.0
WO	2.0	4.0
PL	2.0	4.0
WI	2.0	4.0
OS	2.0	6.0

Species Code	X_{min}	X_{max}
OH	2.0	4.0

4.6.2 Small Tree Diameter Growth

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. By definition, diameter growth is zero for trees less than 4.5 feet tall. Diameter growth for trees whose diameter is 3.0" or greater at the start of the projection cycle is estimated using equations discussed in section 4.7.1.

When calibration of the height-diameter curve is turned off or does not occur for a species, these two predicted diameters are estimated using the species-specific Curtis-Arney functions shown in equation {4.1.1} with diameter solved as a function of height. When calibration of the height-diameter curve is turned on and does occur for a species, these two predicted diameters are estimated using the species specific logistic relationships shown in equation {4.1.2} with diameter solved as a function of height except in the following cases.

Ponderosa pine trees use equation {4.1.3} with diameter solved as a function of height and JCR set to 7.

Western hemlock trees use equation {4.6.2.1}.

{4.6.2.1} $D = -0.674 + 1.522 * \ln(H)$

Pacific yew, whitebark pine, noble fir, and subalpine larch trees use equation {4.6.2.2}.

{4.6.2.2} $D = -2.089 + 1.980 * \ln(H)$

Alaska yellow cedar and western juniper trees use equation {4.6.2.3}.

{4.6.2.3} $D = -0.532 + 1.531 * \ln(H)$

Bigleaf maple, vine maple, red alder, paper birch, giant chinquapin, Pacific dogwood, quaking aspen, black cottonwood, Oregon white oak, plum, willow, and other hardwood trees use equation {4.6.2.4}.

{4.6.2.4} $D = 3.102 + 0.021 * \ln(H)$

Where:

D	is tree diameter
H	is total tree height

4.7 Large Tree Growth Relationships

Trees are considered "large trees" for FVS modeling purposes when they are equal to, or larger than, some threshold diameter. This threshold diameter is set to 3.0" for all species in the EC variant.

The large-tree model is driven by diameter growth meaning diameter growth is estimated first, and then height growth is estimated from diameter growth and other variables. These relationships are discussed in the following sections.

4.7.1 Large Tree Diameter Growth

The large tree diameter growth model used in most FVS variants is described in section 7.2.1 in Dixon (2002). For most variants, instead of predicting diameter increment directly, the natural log of the periodic change in squared inside-bark diameter (ln(*DDS*)) is predicted (Dixon 2002; Wykoff 1990; Stage 1973; and Cole and Stage 1972). For variants predicting diameter increment directly, diameter increment is converted to the *DDS* scale to keep the FVS system consistent across all variants.

The EC variant predicts diameter growth using equation {4.7.1.1} for all species except red alder. Coefficients for this equation are shown in table 4.7.1.1 and 4.7.1.3.

{4.7.1.1} $\ln(DDS) = b_1 + (b_2 * EL) + (b_3 * EL^2) + (b_4 * \ln(SI)) + SASP + b_6 + (b_7 * \ln(DBH)) + b_8 + (b_9 * CR) + (b_{10} * CR^2) + (b_{11} * DBH^2) + (b_{12} * BAL / (\ln(DBH + 1.0))) + (b_{13} * PCCF) + (b_{14} * RELHT * PCCF / 100) + (b_{15} * PCCF^2 / 1000) + (b_{16} * RELHT) + (b_{17} * MAI * CCF) + (b_{22} * BAL) + (b_{23} * BA)$

For western white pine, western larch, Douglas-fir, Pacific silver fir, western redcedar, grand fir, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, mountain hemlock, white fir, and other softwood:

for $SL = 0$, $SASP = b_5$
for $SL \neq 0$, $SASP = [b_{18} * \sin(ASP) * SL] + [b_{19} * \cos(ASP) * SL] + [b_{20} * SL] + [b_{21} * SL^2]$

For all other species, except red alder:

$SASP = [b_{18} * \sin(ASP) * SL] + [b_{19} * \cos(ASP) * SL] + [b_{20} * SL] + [b_{21} * SL^2]$

where:

DDS	is the square of the diameter growth increment
EL	is stand elevation in hundreds of feet (bounded to $30 \leq EL$ for western juniper, paper birch, giant chinquapin, Pacific dogwood, quaking aspen, black cottonwood, plum, willow, other hardwood)
SI	is species site index (for other softwood and mountain hemlock, $SI = SI * 3.281$)
ASP	is stand aspect
SL	is stand slope
CR	is crown ratio expressed as a proportion
DBH	is tree diameter at breast height
BAL	is total basal area in trees larger than the subject tree
PCCF	is crown competition factor on the inventory point where the tree is established

RELHT	is tree height divided by average height of the 40 largest diameter trees in the stand
MAI	is stand mean annual increment
CCF	is stand crown competition factor
b_1	is a location-specific coefficient shown in table 4.7.1.1
$b_2 – b_{23}$	are species-specific coefficients shown in table 4.7.1.3

Table 4.7.1.1 b_1 values by location class for equation {4.7.1.1} in the EC variant.

Location Class	Species Code									
	WP	WL	DF	SF	RC	GF, WF	LP	ES	AF	PP
1	-4.64535	-0.605649	-4.081038	-0.441408	1.49419	-3.811100	-1.084679	-0.098284	-0.420205	-3.102028
2	0	0	-3.965956	-0.538987	0	-3.673109	-1.172470	0.117987	-0.312955	0
3	0	0	0	0	0	0	0	0	0	0
Location Class	WH	MH	PY, WB, LL	NF	YC	WJ, PB, GC, DG, AS, CW, PL, WI, OH	BM, VN	RA	WO	OS
1	-0.147675	-1.407548	-1.310067	-1.127977	-1.277664	-0.107648	-7.753469	0	-1.33299	-1.407548
2	-0.298310	-1.131934	0	-1.401865	0	0	0	0	0	-1.131934
3	0	-1.539078	0	0	0	0	0	0	0	-1.539078

Table 4.7.1.2 Location class by species and location code in the EC variant.

Location Code	Species Code									
	WP	WL	DF	SF	RC	GF, WF	LP	ES	AF	PP
603 – Gifford Pinchot	1	1	1	1	1	1	1	2	1	1
606 – Mount Hood	1	1	1	1	1	1	1	1	1	1
608 – Okanogan	1	1	2	2	1	1	1	1	1	1
613 – Mount Baker – Snoqualmie	1	1	1	1	1	1	1	1	1	1
617 – Wenatchee	1	1	1	1	1	1	2	1	1	1
699 – Okanogan (Tonasket RD)	1	1	2	1	1	2	1	2	2	1
Location Code	WH	MH	PY, WB, LL	NF	YC	WJ, PB, GC, DG, AS, CW, PL, WI, OH	BM, VN	RA	WO	OS
603 – Gifford Pinchot	1	1	1	1	1	1	1	1	1	1
606 – Mount Hood	1	1	1	1	1	1	1	1	1	1
608 – Okanogan	2	2	1	2	1	1	1	1	1	2

613 – Mount Baker – Snoqualmie	1	1	1	1	1	1	1	1	1	1
617 – Wenatchee	2	3	1	2	1	1	1	1	1	3
699 – Okanogan (Tonasket RD)	2	3	1	2	1	1	1	1	1	3

Table 4.7.1.3 Coefficients (b_2- b_{21}) for equation 4.7.1.1 in the EC variant.

Coefficient	Species Code									
	WP	WL	DF	SF	RC	GF, WF	LP	ES	AF	PP
b_2	0	0.004379	-0.021091	-0.015087	-0.00175	0.023020	-0.001124	-0.014944	-0.009430	-0.005345
b_3	0	0	0.000225	0	-0.000067	-0.000364	0	0	0	0
b_4	0.86756	0.351929	1.119725	0.323625	0	0.782092	0.458662	0.290959	0.231960	0.921987
b_5	0	-0.290174	0	-0.174404	0	-0.360203	0	0	-0.278601	0
b_6	0	0	0	0	0	0	0	0	0.3835	0
b_7	1.32610	0.609098	0.855516	0.980383	0.58705	1.042583	0.554261	0.823082	0.816917	0.665401
b_8	0	0	0	-0.799079	0	0.522079	0	0	0	0
b_9	1.29730	1.158355	2.009866	1.709846	1.29360	2.182084	1.423849	1.263610	1.119493	1.671186
b_{10}	0	0	-0.44082	0	0	-0.843518	0	0	0	0
b_{11}	0	-0.000168	-0.000261	-0.000219	0	-0.000369	0	-0.000204	0	-0.000247
b_{12}	-0.00239	-0.004253	-0.003075	-0.000261	-0.02284	-0.001323	-0.004803	-0.005163	-0.000702	-0.008065
b_{13}	-0.00044	-0.000568	-0.000441	-0.000643	-0.00094	-0.001574	-0.000627	-0.000883	-0.001102	0.00112
b_{14}	0	0	0	0	0	0	0	0	0	0
b_{15}	0	0	0	0	0	0	0	0	0	-0.003183
b_{16}	0.49649	0	0	0	0	0	0	0	0	0
b_{17}	0	0	0	0	0	0	0	0	0	0
b_{18}	-0.17911	0.258712	0.029947	-0.128126	0.05534	-0.185520	-0.142328	0.216231	0.002810	-0.149848
b_{19}	0.38002	-0.156235	-0.092151	-0.059062	-0.06625	-0.239156	-0.064328	-0.055587	-0.049761	-0.181022
b_{20}	-0.81780	-0.635704	-0.309511	0.240178	0.11931	1.466089	-0.097297	-0.000577	1.160345	-0.252705
b_{21}	0.84368	0	0	0.131356	0	-1.817050	0.094464	0	-1.740114	0
b_{22}	0	0	0	0	0	0	0	0	0	0
b_{23}	0	0	0	0	0	0	0	0	0	0
Coefficient	Species Code									
	WH	MH	PY	WB	NF	LL	YC	WJ	BM, VN	RA
b_2	-0.040067	0.012082	0	0	-0.069045	0	0	-0.075986	-0.012111	0
b_3	0.000395	0	0	0	0.000608	0	0	0.001193	0	0
b_4	0.380416	0.346907	0.252853	0.252853	0.684939	0.252853	0.244694	0.227307	1.965888	0
b_5	0	-0.099908	0	0	0	0	0	0	0	0
b_6	0	0	0	0	0	0	0	0	0	0
b_7	0.722462	0.580156	0.879338	0.879338	0.904253	0.879338	0.816880	0.889596	1.024186	0
b_8	0	0	0	0	0	0	0	0	0	0
b_9	2.160348	1.212069	1.970052	1.970052	4.123101	1.970052	2.471226	1.732535	0.459387	0
b_{10}	-0.834196	0	0	0	-2.689340	0	0	0	0	0
b_{11}	-0.000155	-0.000019	-0.000132	-0.000132	-0.0003996	-0.000132	-0.000254	0	-0.000174	0
b_{12}	-0.004065	0	-0.004215	-0.004215	-0.006368	-0.004215	-0.005950	-0.001265	-0.010222	0

b_{13}	0	-0.001221	0	0	-0.000471	0	0	0	-0.000757	0
b_{14}	0	0.156459	0	0	0	0	0	0	0	0
b_{15}	0	0	0	0	0	0	0	0	0	0
b_{16}	-0.000358	0	0	0	0	0	0	0	0	0
b_{17}	0	-0.000021	0	0	0	0	0	0	0	0
b_{18}	0	0.037062	0	0	-0.207659	0	0.679903	-0.863980	0	0
b_{19}	0	-0.097288	0	0	-0.374512	0	-0.023186	0.085958	0	0
b_{20}	0.421486	0.089774	0	0	0.400223	0	0	0	0	0
b_{21}	-0.693610	0	0	0	0	0	0	0	0	0
b_{22}	0	0	0	0	0	0	0	0	0	0
b_{23}	0	0	-0.000173	-0.000173	0	-0.000173	-0.000147	-0.000981	0	0

Coefficient	Species Code									
	PB	**GC**	**DG**	**AS**	**CW**	**WO**	**PL**	**WI**	**OS**	**OH**
b_2	-0.075986	-0.075986	-0.075986	-0.075986	-0.075986	0	-0.075986	-0.075986	0.012082	-0.075986
b_3	0.001193	0.001193	0.001193	0.001193	0.001193	0	0.001193	0.001193	0	0.001193
b_4	0.227307	0.227307	0.227307	0.227307	0.227307	0.14995	0.227307	0.227307	0.346907	0.227307
b_5	0	0	0	0	0	0	0	0	-0.099908	0
b_6	0	0	0	0	0	0	0	0	0	0
b_7	0.889596	0.889596	0.889596	0.889596	0.889596	1.66609	0.889596	0.889596	0.580156	0.889596
b_8	0	0	0	0	0	0	0	0	0	0
b_9	1.732535	1.732535	1.732535	1.732535	1.732535	0	1.732535	1.732535	1.212069	1.732535
b_{10}	0	0	0	0	0	0	0	0	0	0
b_{11}	0	0	0	0	0	-0.00154	0	0	-0.000019	0
b_{12}	-0.001265	-0.001265	-0.001265	-0.001265	-0.001265	0	-0.001265	-0.001265	0	-0.001265
b_{13}	0	0	0	0	0	0	0	0	-0.001221	0
b_{14}	0	0	0	0	0	0	0	0	0.156459	0
b_{15}	0	0	0	0	0	0	0	0	0	0
b_{16}	0	0	0	0	0	0	0	0	0	0
b_{17}	0	0	0	0	0	0	0	0	-0.000021	0
b_{18}	-0.863980	-0.863980	-0.863980	-0.863980	-0.863980	0	-0.863980	-0.863980	0.037062	-0.863980
b_{19}	0.085958	0.085958	0.085958	0.085958	0.085958	0	0.085958	0.085958	-0.097288	0.085958
b_{20}	0	0	0	0	0	0	0	0	0.089774	0
b_{21}	0	0	0	0	0	0	0	0	0	0
b_{22}	0	0	0	0	0	-0.00326	0	0	0	0
b_{23}	-0.000981	-0.000981	-0.000981	-0.000981	-0.000981	-0.00204	-0.000981	-0.000981	0	-0.000981

Large-tree diameter growth for red alder is predicted using equation set {4.7.1.2}. Diameter growth is predicted based on tree diameter and stand basal area. While not shown here, this diameter growth estimate is eventually converted to the *DDS* scale.

{4.7.1.2} Used for red alder:

$DBH \leq 18.0”: DG = CON – (0.166496 * DBH) + (0.004618 * DBH^{\wedge 2})$
$DBH > 18.0”: DG = CON – (CON / 10) * (DBH – 18)$

where:

$CON = (3.250531 – 0.003029 * BA)$
DG is potential diameter growth
DBH is tree diameter at breast height
BA is stand basal area

4.7.2 Large Tree Height Growth

For all species except white oak, height growth equations in the EC variant are based on the site index curves shown in section 3.4. Equations for white oak are shown later in this section.

Using a species site index and tree height at the beginning of the projection cycle, an estimated tree age is computed using the site index curves. Also, a maximum species height is computed using equations {4.7.2.1 – 4.7.2.4}.

{4.7.2.1} used for western white pine, western larch, Douglas-fir, Pacific silver fir, western redcedar, grand fir, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine and white fir

$$HTMAX = a_0 + a_1 * SI$$

{4.7.2.2} used for mountain hemlock and other softwood

$$HTMAX = a_0 + a_1 * SI * 3.281$$

{4.7.2.3} used for western hemlock, Pacific yew, whitebark pine, noble fir, subalpine larch, Alaska cedar, western juniper, bigleaf maple vine maple, red alder, paper birch, giant chinquapin, Pacific dogwood, quaking aspen, black cottonwood, Oregon white oak, plum, willow, and other hardwood

$$HTMAX = a_0 + a_1 * DBH$$

{4.7.2.4} used for western hemlock, Pacific yew, whitebark pine, noble fir, subalpine larch, Alaska cedar, western juniper, bigleaf maple vine maple, red alder, paper birch, giant chinquapin, Pacific dogwood, quaking aspen, black cottonwood, Oregon white oak, plum, willow, and other hardwood

$$HTMAX2 = a_0 + a_1 * (DBH + (DG/BARK))$$

where:

HTMAX is maximum expected tree height in feet at the start of the projection cycle
HTMAX2 is maximum expected tree height in feet 10-years in the future
SI is the species specific site index
DBH is tree diameter at the start of the projection cycle
DG is estimated 10-year inside-bark diameter growth
BARK is tree bark ratio
$a_0 – a_1$ are species-specific coefficients shown in table 4.7.2.1

For western white pine, western larch, Douglas-fir, Pacific silver fir, western redcedar, grand fir, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, mountain hemlock, white fir, and other softwood, if tree height at the beginning of the projection cycle is greater than the maximum species height (*HTMAX*), then height growth is computed using equation {4.7.2.5}. For western hemlock, Pacific yew, whitebark pine, noble fir, subalpine larch, Alaska cedar, western juniper, bigleaf maple vine maple, red alder, paper birch, giant chinquapin, Pacific dogwood, quaking aspen, black cottonwood, Oregon white oak, plum, willow, and other hardwood, if tree height at the beginning of the projection cycle is greater than the maximum species height (*HTMAX*) and less than the maximum species height at the end of the projection cycle (HTMAX2), then height growth is computed using equation {4.7.2.5}.

{4.7.2.5} *HTG* = 0.1

For western hemlock, Pacific yew, whitebark pine, noble fir, subalpine larch, Alaska cedar, western juniper, bigleaf maple vine maple, red alder, paper birch, giant chinquapin, Pacific dogwood, quaking aspen, black cottonwood, Oregon white oak, plum, willow, and other hardwood, if tree height at the beginning of the projection cycle is greater than the maximum species height (*HTMAX*) and greater than or equal to the maximum species height at the end of the projection cycle (HTMAX2), then height growth is computed using equation {4.7.2.6}.

{4.7.2.6} *HTG* = 0.5 * DG

where:

HTG is estimated 10-year tree height growth (bounded $0.1 \leq HTG$)
DG is species estimated 10-year diameter growth
$a_0 - a_1$ are species-specific coefficients shown in table 4.7.2.1

Table 4.7.2.1 Maximum height coefficients for equations {4.7.2.1 – 4.7.2.4}, and maximum age, in the EC variant.

Species Code	a_0	a_1	Maximum Age
WP	2.3	2.39	200
WL	12.86	1.32	110
DF	-2.86	1.54	180
SF	21.29	1.24	130
RC	52.27	1.14	250
GF	21.29	1.24	130
LP	2.3	1.75	140
ES	20.0	1.10	150
AF	45.27	1.24	150
PP	-5.00	1.30	200
WH	51.9732476	4.0156013	200
MH	-2.06	1.54	180
PY	62.7139427	3.2412923	200
WB	62.7139427	3.2412923	200
NF	39.6317079	4.3149844	200
WF	21.29	1.24	130
LL	62.7139427	3.2412923	200

Species Code	a_0	a_1	Maximum Age
YC	62.7139427	3.2412923	200
WJ	62.7139427	3.2412923	200
BM	59.3370816	3.9033821	200
VN	59.3370816	3.9033821	200
RA	59.3370816	3.9033821	200
PB	59.3370816	3.9033821	200
GC	59.3370816	3.9033821	200
DG	59.3370816	3.9033821	200
AS	59.3370816	3.9033821	200
CW	59.3370816	3.9033821	200
WO	59.3370816	3.9033821	200
PL	59.3370816	3.9033821	200
WI	59.3370816	3.9033821	200
OS	-2.06	1.54	180
OH	59.3370816	3.9033821	200

If tree height at the beginning of the projection cycle is less than the maximum species height, height increment is obtained by estimating a tree's potential height growth and adjusting the estimate according to the tree's crown ratio and height relative to other trees in the stand.

If estimated tree age at the beginning of the projection cycle is greater than or equal to the species maximum age, then for all species except ponderosa pine, potential height growth is calculated using equation {4.7.2.7}. For ponderosa pine, equation {4.7.2.8} is used.

{4.7.2.7} used for all species except PP when estimated tree age is greater than or equal to the maximum age for the species

$$POTHTG = 0.1$$

{4.7.2.8} used for PP when estimated tree age is greater than or equal to the maximum age for the species

$$POTHTG = -1.31 + 0.5 * SI$$

where:

POTHTG is estimated potential 10-year tree height growth (bounded $0.1 \leq HTG$)
SI is species site index

When estimated tree age at the beginning of the projection cycle is less than the species maximum age, then potential height growth is obtained by subtracting estimated current height from an estimated future height. In all cases, potential height growth is then adjusted according to the tree's crown ratio and height relative to other trees in the stand. Estimated current height (ECH) and estimated future height (H10) are both obtained using the equations shown below. Estimated current height is obtained using estimated tree age at the start of the projection cycle and site index. Estimated future height is obtained using estimated tree age at the start of the projection cycle plus 10-years and site index.

{4.7.2.9} Used for white pine

$$H = SI / [b_0 * (1.0 - b_1 * (\exp(b_2 * A)))^{b_3}]$$

{4.7.2.10} Used for western larch and subalpine larch

$$H = 4.5 + (b_1 * A) + (b_2 * A^2) + (b_3 * A^3) + (b_4 * A^4) + (SI - 4.5) * [b_5 + (b_6 * A) + (b_7 * A^2) + (b_8 * A^3)] - b_9 * [b_{10} + (b_{11} * A) + (b_{12} * A^2) + (b_{13} * A^3)]$$

{4.7.2.11} Used for Douglas-fir

$$H = 4.5 + \exp[b_1 + (b_2 * \ln(A)) + (b_3 * \ln(A)^4)] + b_4 * [b_5 + (b_6 * (1 - \exp(b_7 * A))^{b_8})] + (SI - 4.5) * [b_5 + b_6 * (1 - \exp(b_7 * A)^{b_8})]$$

{4.7.2.12} Used for Pacific silver fir, grand fir, and white fir

$$H = \exp[b_0 + b_1 * \ln(A) + b_2 * (\ln(A))^4 + b_3 * (\ln(A))^9 + b_4 * (\ln(A))^{11} + b_5 * (\ln(A))^{18}] + b_{12} * \exp[b_6 + b_7 * \ln(A) + b_8 * (\ln(A))^2 + b_9 * (\ln(A))^7 + b_{10} * (\ln(A))^{16} + b_{11} * (\ln(A))^{24}] + (SI - 4.5) * \exp[b_6 + b_7 * \ln(A) + b_8 * (\ln(A))^2 + b_9 * (\ln(A))^7 + b_{10} * (\ln(A))^{16} + b_{11} * (\ln(A))^{24}] + 4.5$$

{4.7.2.13} Used for red cedar

$$H = b_1 * SI * [(1 - \exp(b_2 * A))^{b_3}]$$

{4.7.2.14} Used for lodgepole pine

$$H = b_0 + (b_1 * A) + (b_2 * A^2) + (b_4 * A * SI) + (b_5 * A^2 * SI)$$

{4.7.2.15} Used for Engelmann spruce

$$H = 4.5 + [(b_0 * SI^{b_1}) * (1 - \exp(-b_2 * A))^{(b_3 * SI^{b_4})}]$$

{4.7.2.16} Used for subalpine fir

$$H = SI * [b_0 + (b_1 * A) + b_2 * A^2)]$$

{4.7.2.17} Used for ponderosa pine

$$H = [b_0 * (1 - \exp(b_1 * A))^{b_2}] - [(b_3 + b_4 * (1 - \exp(b_5 * A))^{b_6}) * b_7] + [(b_3 + b_4 * (1 - \exp(b_5 * A))^{b_6}) * (SI - 4.5)] + 4.5$$

{4.7.2.18} Used for western hemlock

$$H = [A^2 / \{b_0 + (b_1 * Z) + ((b_2 + b_3 * Z) * A) + ((b_4 + b_5 * Z) * A^2)\}] + 4.5$$
$$Z = 2500 / (SI - 4.5)$$

{4.7.2.19} Used for mountain hemlock and other softwood

$$H = [(b_0 + b_1 * SI) * (1 - \exp(b_2 * (SI^{b_3}) * A))^{(b_4 + b_5/SI)} + 1.37] * 3.281$$

{4.7.2.20} Used for Pacific yew, whitebark pine, Alaska cedar, western juniper, bigleaf maple, vine maple, paper birch, golden chinkapin, Pacific dogwood, quaking aspen, black cottonwood, plum, willow, and other hardwood

$H = \{(SI – 4.5) / [b0 + (b1 / (SI – 4.5)) + (b2 *A^{-1.4}) + ((b3 / (SI – 4.5)) *A^{-1.4})]\} + 4.5$

{4.7.2.21} Used for noble fir

$H = \{(SI – 4.5) / [(X_1 * (A^{-1})^2) + (X_2 * (A^{-1})) + 1.0 – 0.0001 * X_1 – 0.01 * X_2]\} + 4.5$
$X1 = b0 + (b1 * (SI – 4.5)) – (b2 * (SI – 4.5)^2)$
$X2 = b3 + (b4 * (SI – 4.5)^{-1}) + (b5 * (SI – 4.5)^{-2})$

{4.7.2.22} Used for red alder

$H = SI + \{[b0 + (b1 * SI)] * [1 – \exp((b2 + (b3 * SI)) * A)]^{b4}\} - \{[b0 + (b1 * SI)] * [1 – \exp((b2 + (b3 * SI)) * 20)]^{b4}\}$

where:

H is estimated height of the tree
SI is species site index
A is estimated age of the tree
$b_0 – b_{13}$ are species-specific coefficients shown in table 4.7.2.2

Table 4.7.2.2 Coefficients (b_0 - b_{13}) for height-growth equations in the EC variant.

	Species Code					
Coefficient	**WP**	**WL, LL**	**DF**	**SF, GF, WF**	**RC**	**LP**
b_0	0.37504453	0	0	-0.30935	0	9.89331
b_1	0.92503	1.46897	-0.37496	1.2383	1.3283	-0.19177
b_2	-0.0207959	0.0092466	1.36164	0.001762	-0.0174	0.00124
b_3	-2.4881068	-0.00023957	-0.00243434	-5.40E-06	1.4711	0
b_4	0	1.1122E-06	-79.97	2.046E-07	0	0.01387
b_5	0	-0.12528	-0.2828	-4.04E-13	0	-0.0000455
b_6	0	0.039636	1.87947	-6.2056	0	0
b_7	0	-0.0004278	-0.022399	2.097	0	0
b_8	0	1.7039E-06	0.966998	-0.09411	0	0
b_9	0	73.57	0	-0.00004382	0	0
b_{10}	0	-0.12528	0	2.007E-11	0	0
b_{11}	0	0.039636	0	-2.054E-17	0	0
b_{12}	0	-0.0004278	0	-84.93	0	0
b_{13}	0	1.7039E-06	0	0	0	0
	Species Code					
Coefficient	**ES**	**AF**	**PP**	**WH**	**MH, OS**	**PY, WB, YC, WJ, BM, VN, PB, GC, DG, AS, CW, PL, WI, OH**
b_0	2.75780	-0.07831	128.8952205	-1.7307	22.8741	0.6192
b_1	0.83312	0.0149	-0.016959	0.1394	0.950234	-5.3394

b_2	0.015701	-4.0818E-05	1.23114	-0.0616	-0.00206465	240.29
b_3	22.71944	0	-0.7864	0.0137	0.5	3368.9
b_4	-0.63557	0	2.49717	0.00192	1.365566	0
b_5	0	0	-0.004504	0.00007	2.045963	0
b_6	0	0	0.33022	0	0	0
b_7	0	0	100.43	0	0	0
b_8	0	0	0	0	0	0
b_9	0	0	0	0	0	0
b_{10}	0	0	0	0	0	0
b_{11}	0	0	0	0	0	0
b_{12}	0	0	0	0	0	0
b_{13}	0	0	0	0	0	0

Coefficient	**Species Code**	
	NF	**RA**
b_0	-564.38	59.5864
b_1	22.25	0.7953
b_2	0.04995	0.00194
b_3	6.80	-0.00074
b_4	2843.21	0.9198
b_5	34735.54	0
b_6	0	0
b_7	0	0
b_8	0	0
b_9	0	0
b_{10}	0	0
b_{11}	0	0
b_{12}	0	0
b_{13}	0	0

Potential 10-year height growth (*POTHTG*) is calculated by using equation {4.7.2.23}. Modifiers are then applied to the height growth based upon a tree's crown ratio (using equation {4.7.2.24}), and relative height and shade tolerance (using equation {4.7.2.25}). Equation {4.7.2.26} uses the Generalized Chapman – Richard's function (Donnelly et. al, 1992) to calculate a height-growth modifier. Final height growth is calculated using equation {4.7.2.27} as a product of the modifier and potential height growth. The final height growth is then adjusted to the length of the cycle.

{4.7.2.23} $POTHTG = H10 - ECH$

{4.7.2.24} $HGMDCR = (100 * (CR / 100)^3) * \exp(-5 * (CR / 100))$ bounded $HGMDCR \leq 1.0$

{4.7.2.25} $HGMDRH = [1 + ((1 / b_1)^{(b_2 - 1)} - 1) * \exp((-1 * (b_3 / (1 - b_4)) * RELHT^{(1 - b_4)}]^{(-1 / (b_2 - 1))}$

{4.7.2.26} $HTGMOD = (0.25 * HGMDCR) + (0.75 * HGMDRH)$ bounded $0.0 \leq HTGMOD \leq 2.0$

{4.7.2.27} *HTG = POTHTG * HTGMOD*

where:

POTHTG	is potential height growth
H10	is estimated height of the tree in ten years
ECH	is estimated height of the tree at the beginning of the cycle
HGMDCR	is a height growth modifier based on crown ratio
HGMDRH	is a height growth modifier based on relative height and shade tolerance
HTGMOD	is a weighted height growth modifier
CR	is crown ratio expressed as a proportion
RELHT	is tree height divided by average height of the 40 largest diameter trees in the stand
$b_1 – b_4$	are species-specific coefficients shown in table 4.7.2.3

Table 4.7.2.3 Coefficients ($b_1 – b_4$) for equation {4.7.2.25} in the EC variant.

Species Code	Coefficient			
	b_1	b_2	b_3	b_4
WP	0.10	1.1	15	-1.45
WL	0.01	1.1	12	-1.60
DF	0.10	1.1	15	-1.45
SF	0.20	1.1	20	-1.10
RC	0.20	1.1	20	-1.10
GF	0.15	1.1	16	-1.20
LP	0.01	1.1	12	-1.60
ES	0.15	1.1	16	-1.20
AF	0.15	1.1	16	-1.20
PP	0.05	1.1	13	-1.60
WH	0.20	1.1	20	-1.10
MH	0.10	1.1	15	-1.45
PY	0.20	1.1	20	-1.10
WB	0.10	1.1	15	0.10
NF	0.10	1.1	15	-1.45
WF	0.15	1.1	16	-1.20
LL	0.01	1.1	12	-1.60
YC	0.15	1.1	16	-1.20
WJ	0.05	1.1	13	-1.60
BM	0.20	1.1	20	-1.10
VN	0.20	1.1	20	-1.10
RA	0.05	1.1	13	-1.60
PB	0.05	1.1	13	-1.60
GC	0.10	1.1	15	-1.45
DG	0.20	1.1	20	-1.10
AS	0.01	1.1	12	-1.60

Species Code	Coefficient			
	b_1	**b_2**	**b_3**	**b_4**
CW	0.01	1.1	12	-1.60
WO	0.10	1.1	15	-1.45
PL	0.05	1.1	13	-1.60
WI	0.01	1.1	12	-1.60
OS	0.10	1.1	15	-1.45
OH	0.01	1.1	12	-1.60

For Oregon white oak, *POTHTG* is estimated using equation {4.7.2.28}.

{4.7.2.28} *POTHTG* = [4.5+{(114.24569(1-exp(-.02659**SI*))^2.25993)-18.602 / ln(2.71**BA*)}*{1-exp(-.13743**DBH2*)}^1.38994] – [4.5+{(114.24569(1-exp(-.02659**SI*))^2.25993)-18.602 / ln(2.71**BA*)}*{1-exp(-.13743**DBH1*)}^1.38994]

where:

POTHTG is potential height growth
BA is stand basal area
SI is site index for Oregon white oak
DBH1 is diameter of the tree at the beginning of the cycle
DBH2 is estimated diameter of the tree at the end of the cycle

Modifiers are then applied to the height growth as described above using equations {4.7.2.24} - {4.7.2.27}.

A check is done after computing height growth to limit the maximum height for a given diameter. This check is to make sure that current height plus height growth does not exceed the maximum height for the given diameter. The maximum height for a given diameter is calculated using equations {4.7.2.1} - {4.7.2.4}.

5.0 Mortality Model

The EC variant uses an SDI-based mortality model as described in Section 7.3.2 of Essential FVS: A User's Guide to the Forest Vegetation Simulator (Dixon 2002, referred to as EFVS). This SDI-based mortality model is comprised of two steps: 1) determining the amount of stand mortality (section 7.3.2.1 of EFVS) and 2) dispersing stand mortality to individual tree records (section7.3.2.2 of EFVS). In determining the amount of stand mortality, the summation of individual tree background mortality rates is used when stand density is below the minimum level for density dependent mortality (default is 55% of maximum SDI), while stand level density-related mortality rates are used when stands are above this minimum level.

The equation used to calculate individual tree background mortality rates for all species is shown in equation {5.0.1}, and this is then adjusted to the length of the cycle by using a compound interest formula as shown in equation {5.0.2}. Coefficients for these equations are shown in table 5.0.1. The overall amount of mortality calculated for the stand is the summation of the final mortality rate (*RIP*) across all live tree records.

{5.0.1} $RI = [1 / (1 + \exp(p_0 + p_1 * DBH))] * 0.5$

{5.0.2} $RIP = 1 – (1 – RI)^Y$

where:

RI	is the proportion of the tree record attributed to mortality
RIP	is the final mortality rate adjusted to the length of the cycle
DBH	is tree diameter at breast height
Y	is length of the current projection cycle in years
p_0 and p_1	are species-specific coefficients shown in table 5.0.1

Table 5.0.1 Coefficients used in the background mortality equation {5.0.1} in the EC variant.

Species Code	p_0	p_1
WP	6.5112	-0.0052485
WL	6.5112	-0.0052485
DF	7.2985	-0.0129121
SF	5.1677	-0.0077681
RC	9.6943	-0.0127328
GF	5.1677	-0.0077681
LP	5.9617	-0.0340128
ES	9.6943	-0.0127328
AF	5.1677	-0.0077681
PP	5.5877	-0.005348
WH	5.1677	-0.0077681
MH	5.1677	-0.0077681
PY	9.6943	-0.0127328
WB	6.5112	-0.0052485

Species Code	p_0	p_1
NF	6.5112	-0.0052485
WF	5.1677	-0.0077681
LL	5.9617	-0.0340128
YC	5.1677	-0.0077681
WJ	5.5877	-0.005348
BM	5.9617	-0.0340128
VN	5.9617	-0.0340128
RA	5.5877	-0.005348
PB	5.5877	-0.005348
GC	6.5112	-0.0052485
DG	9.6943	-0.0127328
AS	5.9617	-0.0340128
CW	5.9617	-0.0340128
WO	6.5112	-0.0052485
PL	5.5877	-0.005348
WI	5.9617	-0.0340128
OS	5.1677	-0.0077681
OH	5.9617	-0.0340128

When stand density-related mortality is in effect, the total amount of stand mortality is determined based on the trajectory developed from the relationship between stand SDI and the maximum SDI for the stand. This is explained in section 7.3.2.1 of EFVS.

Once the amount of stand mortality is determined based on either the summation of background mortality rates or density-related mortality rates, mortality is dispersed to individual tree records in relation to either a tree's percentile in the basal area distribution (PCT) using equations {5.0.3}. This value is then adjusted by a species-specific mortality modifier representing the species shade tolerance shown in equation {5.0.4}.

The mortality model makes multiple passes through the tree records multiplying a record's trees-per-acre value times the final mortality rate (*MORT*), accumulating the results, and reducing the trees-per-acre representation until the desired mortality level has been reached. If the stand still exceeds the basal area maximum sustainable on the site the mortality rates are proportionally adjusted to reduce the stand to the specified basal area maximum.

{5.0.3} $MR = 0.84525 – (0.01074 * PCT) + (0.0000002 * PCT^3)$

{5.0.4} $MORT = MR * MWT * 0.1$

where:

MR	is the proportion of the tree record attributed to mortality (bounded: $0.01 \leq MR \leq 1$)
DBH	is tree diameter at breast height
PCT	is the subject tree's percentile in the basal area distribution of the stand

MORT is the final mortality rate of the tree record
MWT is a mortality weight value based on a species' tolerance shown in table 5.0.2

Table 5.0.2 *MWT* values for the mortality equation {5.0.4} in the EC variant.

Species Code	*MWT*
WP	0.85
WL	1.0
DF	0.55
SF	0.6
RC	0.6
GF	0.5
LP	0.9
ES	0.5
AF	0.6
PP	0.85
WH	0.60
MH	0.75
PY	0.60
WB	0.85
NF	0.85
WF	0.50
LL	0.90
YC	0.50
WJ	0.85
BM	0.90
VN	0.90
RA	0.85
PB	0.85
GC	0.85
DG	0.60
AS	0.90
CW	0.90
WO	0.85
PL	0.85
WI	0.90
OS	0.75
OH	0.90

6.0 Regeneration

The EC variant contains a partial establishment model which may be used to input regeneration and ingrowth into simulations. A more detailed description of how the partial establishment model works can be found in section 5.4.5 of the Essential FVS Guide (Dixon 2002).

The regeneration model is used to simulate stand establishment from bare ground, or to bring seedlings and sprouts into a simulation with existing trees. Sprouts are automatically added to the simulation following harvest or burning of known sprouting species (see table 6.0.1 for sprouting species).

Table 6.0.1 Regeneration parameters by species in the EC variant.

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
WP	No	0.4	1.0	23.0
WL	No	0.3	1.0	27.0
DF	No	0.3	1.0	21.0
SF	No	0.3	0.5	21.0
RC	No	0.2	0.5	22.0
GF	No	0.3	0.5	20.0
LP	No	0.4	1.0	24.0
ES	No	0.3	0.5	18.0
AF	No	0.3	0.5	18.0
PP	No	0.5	1.0	17.0
WH	No	0.2	1.0	20.0
MH	No	0.2	0.5	22.0
PY	No	0.2	1.0	20.0
WB	No	0.4	1.0	20.0
NF	No	0.3	1.0	20.0
WF	No	0.3	0.5	20.0
LL	No	0.3	1.5	20.0
YC	No	0.2	1.0	20.0
WJ	No	0.2	1.0	20.0
BM	Yes	0.2	1.0	20.0
VN	Yes	0.2	1.0	20.0
RA	Yes	0.2	1.0	50.0
PB	Yes	0.2	1.0	20.0
GC	Yes	0.2	1.0	20.0
DG	Yes	0.2	1.0	20.0
AS	Yes	0.2	1.0	20.0
CW	Yes	0.2	1.0	20.0
WO	Yes	0.2	1.0	20.0
PL	Yes	0.2	1.0	20.0

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
WI	Yes	0.2	1.0	20.0
OS	No	0.2	0.5	22.0
OH	No	0.2	1.0	20.0

The number of sprout records created for each sprouting species is found in table 6.0.2. For more prolific stump sprouting hardwood species, logic rule {6.0.1} is used to determine the number of sprout records, with logic rule {6.0.2} being used for root suckering species. The trees-per-acre represented by each sprout record is determined using the general sprouting probability equation {6.0.3}. See table 6.0.2 for species-specific sprouting probabilities, number of sprout records created, and reference information.

Users wanting to modify or turn off automatic sprouting can do so with the SPROUT or NOSPROUT keywords, respectively. Sprouts are not subject to maximum and minimum tree heights found in table 6.0.1 and do not need to be grown to the end of the cycle because estimated heights and diameters are end of cycle values.

{6.0.1} For stump sprouting hardwood species

$DSTMP_i \leq 5$: $NUMSPRC = 1$
$5 < DSTMP_i \leq 10$: $NUMSPRC = \mathrm{NINT}(0.2 * DSTMP_i)$
$DSTMP_i > 10$: $NUMSPRC = 2$

{6.0.2} For root suckering hardwood species

$DSTMP_i \leq 5$: $NUMSPRC = 1$
$5 < DSTMP_i \leq 10$: $NUMSPRC = \mathrm{NINT}(-1.0 + 0.4 * DSTMP_i)$
$DSTMP_i > 10$: $NUMSPRC = 3$

{6.0.3} $TPA_s = TPA_i * PS$

{6.0.4} $PS = (TPA_i / (ASTPAR * 2)) * ((ASBAR / 198) * (40100.45 - 3574.02 * RSHAG^2 + 554.02 * RSHAG^3 - 3.5208 * RSHAG^5 + 0.011797 * RSHAG^7))$

{6.0.5} $PS = ((99.9 - 3.8462 * DSTMP_i) / 100)$

where:

$DSTMP_i$	is the diameter at breast height of the parent tree
$NUMSPRC$	is the number of sprout tree records
NINT	rounds the value to the nearest integer
TPA_s	is the trees per acre represented by each sprout record
TPA_i	is the trees per acre removed/killed represented by the parent tree
PS	is a sprouting probability (see table 6.0.2)
$ASBAR$	is the aspen basal area removed
$ASTPAR$	is the aspen trees per acre removed
$RSHAG$	is the age of the sprouts at the end of the cycle in which they were created

Table 6.0.2 Sprouting algorithm parameters for sprouting species in the EC variant.

Species Code	Sprouting Probability	Number of Sprout Records	Source
BM	0.9	{6.0.2}	Roy 1955 Tappenier et al. 1996 Ag. Handbook 654
VN	0.9	{6.0.2}	Uchytil 1989
RA	{6.0.5}	1	Harrington 1984 Uchytil 1989
PB	0.7	1	Hutnik and Cunningham 1965 Bjorkbom 1972
GC	0.9	{6.0.2}	Harrington et al. 1992 Meyer 2012
DG	0.9	{6.0.1}	Gucker 2005
AS	{6.0.4}	2	Keyser 2001
CW	0.9	{6.0.2}	Gom and Rood 2000 Steinberg 2001
WO	0.9	{6.0.1}	Roy 1955 Gucker 2007
PL	0.7	1	Ag. Handbook 654
WI	0.9	1	Ag. Handbook 654

Regeneration of seedlings must be specified by the user with the partial establishment model by using the PLANT or NATURAL keywords. Height of the seedlings is estimated in two steps. First, the height is estimated when a tree is 5 years old (or the end of the cycle – whichever comes first) by using the small-tree height growth equations found in section 4.6.1. Users may override this value by entering a height in field 6 of the PLANT or NATURAL keyword; however the height entered in field 6 is not subject to minimum height restrictions and seedlings as small as 0.05 feet may be established. The second step also uses the equations in section 4.6.1, which grow the trees in height from the point five years after establishment to the end of the cycle.

Seedlings and sprouts are passed to the main FVS model at the end of the growth cycle in which regeneration is established. Unless noted above, seedlings being passed are subject to minimum and maximum height constraints and a minimum budwidth constraint shown in table 6.0.1. After seedling height is estimated, diameter growth is estimated using equations described in section 4.6.2. Crown ratios on newly established trees are estimated as described in section 4.3.1.

Regenerated trees and sprouts can be identified in the treelist output file with tree identification numbers beginning with the letters “ES”.

7.0 Volume

In the EC variant, volume is calculated for three merchantability standards: total stem cubic feet, merchantable stem cubic feet, and merchantable stem board feet (Scribner). Volume estimation is based on methods contained in the National Volume Estimator Library maintained by the Forest Products Measurements group in the Forest Management Service Center (Volume Estimator Library Equations 2009). The default volume merchantability standards and equation numbers for the EC variant are shown in tables 7.0.1-7.0.3.

Table 7.0.1 Volume merchantability standards for the EC variant.

Merchantable Cubic Foot Volume Specifications:		
Minimum DBH / Top Diameter	LP	All Other Species
All location codes	6.0 / 4.5 inches	7.0 / 4.5 inches
Stump Height	1.0 foot	1.0 foot
Merchantable Board Foot Volume Specifications:		
Minimum DBH / Top Diameter	LP	All Other Species
All location codes	6.0 / 4.5 inches	7.0 / 4.5 inches
Stump Height	1.0 foot	1.0 foot

Table 7.0.2 Volume equation defaults for each species, at specific location codes, with model name.

Common Name	Location Code	Equation Number	Reference
western white pine	All	616BEHW119	Behre's Hyperbola
western larch	608, 617	I12FW2W122	Flewelling's 2-Point Profile Model
western larch	606, 699	616BEHW073	Behre's Hyperbola
Douglas-fir	606	F05FW2W202	Flewelling's 2-Point Profile Model
Douglas-fir	608, 617	I12FW2W202	Flewelling's 2-Point Profile Model
Douglas-fir	699	616BEHW202	Behre's Hyperbola
Pacific silver fir	606	I12FW2W017	Flewelling's 2-Point Profile Model
Pacific silver fir	608, 617	616BEHW011	Behre's Hyperbola
Pacific silver fir	699	616BEHW011	Behre's Hyperbola
western redcedar	All	616BEHW242	Behre's Hyperbola
grand fir	606	I13FW2W017	Flewelling's 2-Point Profile Model
grand fir	608, 617	I11FW2W017	Flewelling's 2-Point Profile Model
grand fir	699	616BEHW017	Behre's Hyperbola
lodgepole pine	606	I11FW2W108	Flewelling's 2-Point Profile Model
lodgepole pine	608, 617	I12FW2W108	Flewelling's 2-Point Profile Model
lodgepole pine	699	616BEHW108	Behre's Hyperbola
Engelmann spruce	606	I11FW2W093	Flewelling's 2-Point Profile Model

Common Name	Location Code	Equation Number	Reference
Engelmann spruce	608, 617	I11FW2W093	Flewelling's 2-Point Profile Model
Engelmann spruce	699	616BEHW093	Behre's Hyperbola
subalpine fir	All	616BEHW019	Behre's Hyperbola
ponderosa pine	606, 608, 617	I12FW2W122	Flewelling's 2-Point Profile Model
ponderosa pine	699	616BEHW122	Behre's Hyperbola
western hemlock	606	I11FW2W260	Flewelling's 2-Point Profile Model
western hemlock	608, 617, 699	616BEHW263	Behre's Hyperbola
mountain hemlock	All	616BEHW264	Behre's Hyperbola
Pacific yew	All	616BEHW231	Behre's Hyperbola
whitebark pine	All	616BEHW101	Behre's Hyperbola
noble fir	606	I13FW2W017	Flewelling's 2-Point Profile Model
noble fir	608, 617, 699	616BEHW022	Behre's Hyperbola
white fir	All	616BEHW015	Behre's Hyperbola
subalpine larch	All	616BEHW072	Behre's Hyperbola
Alaska cedar	All	616BEHW042	Behre's Hyperbola
western juniper	All	616BEHW064	Behre's Hyperbola
bigleaf maple	All	616BEHW312	Behre's Hyperbola
vine maple	All	616BEHW000	Behre's Hyperbola
red alder	All	616BEHW351	Behre's Hyperbola
paper birch	All	616BEHW375	Behre's Hyperbola
giant chinquapin	All	616BEHW431	Behre's Hyperbola
Pacific dogwood	All	616BEHW492	Behre's Hyperbola
quaking aspen	All	616BEHW746	Behre's Hyperbola
black cottonwood	All	616BEHW747	Behre's Hyperbola
Oregon white oak	All	616BEHW815	Behre's Hyperbola
plum	All	616BEHW000	Behre's Hyperbola
willow	All	616BEHW920	Behre's Hyperbola
other softwood	All	616BEHW298	Behre's Hyperbola
other hardwood	All	616BEHW998	Behre's Hyperbola

Table 7.0.3 Citations by Volume Model

Model Name	Citation
Behre's Hyperbola	USFS-R6 Sale Preparation and Valuation Section of Diameter and Volume Procedures - R6 Timber Cruise System. 1978.
Flewelling's 2-Point Profile Model	Unpublished. Based on work presented by Flewelling and Raynes. 1993. Variable-shape stem-profile predictions for western hemlock. Canadian Journal of Forest Research Vol 23. Part I and Part II.

8.0 Fire and Fuels Extension (FFE-FVS)

The Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS) (Reinhardt and Crookston 2003) integrates FVS with models of fire behavior, fire effects, and fuel and snag dynamics. This allows users to simulate various management scenarios and compare their effect on potential fire hazard, surface fuel loading, snag levels, and stored carbon over time. Users can also simulate prescribed burns and wildfires and get estimates of the associated fire effects such as tree mortality, fuel consumption, and smoke production, as well as see their effect on future stand characteristics. FFE-FVS, like FVS, is run on individual stands, but it can be used to provide estimates of stand characteristics such as canopy base height and canopy bulk density when needed for landscape-level fire models.

For more information on FFE-FVS and how it is calibrated for the EC variant, refer to the updated FFE-FVS model documentation (Rebain, comp. 2010) available on the FVS website.

9.0 Insect and Disease Extensions

FVS Insect and Pathogen models for dwarf mistletoe and western root disease have been developed for the EC variant through the participation and contribution of various organizations led by Forest Health Protection. These models are currently maintained by the Forest Management Service Center and regional Forest Health Protection specialists. Additional details regarding each model may be found in chapter 8 of the Essential FVS Users Guide (Dixon 2002).

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11.0 Appendices

11.1 Appendix A. Distribution of Data Samples

The following tables contain distribution information of data used to fit species relationships in this variant's geographic region (information from original variant overview).

Table 11.1.1. Distribution of samples by National Forest, expressed in whole percent of total observations for each species.

Species	National Forest					Total Number of Observations
	Gifford-Pinchot	Mt. Hood	Okanogan	Wenatchee	OK-Tonasket RD	
western white pine	0	0	0	0	0	0
western larch	1	15	8	55	20	652
Douglas-fir	7	22	12	55	5	6249
Pacific silver fir	20	31	2	47	0	1210
western redcedar	0	0	0	0	0	0
grand fir	3	24	<1	73	0	1950
lodgepole pine	3	17	25	50	5	1479
Engelmann spruce	6	4	49	38	3	623
subalpine fir	6	3	33	57	1	729
ponderosa pine	1	30	4	63	1	4040
other species	14	43	4	39	0	1443

Table 11.1.2. Distribution of samples for diameter breast high, expressed in whole percent of total observations for each species.

Species	DBH Range								
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40+
western white pine	0	0	0	0	0	0	0	0	0
western larch	<1	16	22	22	15	9	6	5	4
Douglas-fir	1	16	22	21	16	10	6	3	4
Pacific silver fir	<1	16	20	21	18	10	7	4	3
western redcedar	0	0	0	0	0	0	0	0	0
grand fir	1	19	27	25	14	7	4	1	2
lodgepole pine	<1	50	33	12	4	1	<1	0	0
Engelmann spruce	0	22	25	22	15	8	5	2	1
subalpine fir	<1	38	36	18	5	2	1	<1	0
ponderosa pine	<1	13	18	21	20	13	7	4	3
other species	<1	13	25	24	19	9	4	2	2

Table 11.1.3. Distribution of samples by Crown Ratio group, expressed in whole percent of total observations for each species.

Species	Crown Code (1=1-10,2=11-20,…,9=81-100)								
	1	2	3	4	5	6	7	8	9
western white pine	0	0	0	0	0	0	0	0	0
western larch	4	9	24	27	20	11	4	1	<1
Douglas-fir	1	6	16	22	20	16	10	6	3
Pacific silver fir	2	8	19	24	21	14	9	3	<1
western redcedar	0	0	0	0	0	0	0	0	0
grand fir	2	8	18	21	18	15	10	6	3
lodgepole pine	3	14	28	20	14	9	6	4	2
Engelmann spruce	<1	2	7	14	18	20	18	15	5
subalpine fir	2	3	9	17	20	20	16	8	4
ponderosa pine	2	8	18	23	20	16	8	3	1
other species	<1	4	9	18	20	18	14	9	7

Table 11.1.4. Distribution of samples by Aspect Code, expressed in percent of total observations for each species.

Species	Aspect Code								
	North	North-east	East	South-east	South	South-west	West	North-west	Level
western white pine	0	0	0	0	0	0	0	0	0
western larch	16	15	6	8	5	2	7	7	34
Douglas-fir	13	11	10	8	8	8	10	9	24
Pacific silver fir	19	12	11	11	11	10	6	10	10
western redcedar	0	0	0	0	0	0	0	0	0
grand fir	12	8	6	8	6	7	3	5	45
lodgepole pine	14	13	7	10	11	8	7	8	23
Engelmann spruce	14	13	3	7	6	13	6	11	27
subalpine fir	20	14	6	9	8	7	11	10	14
ponderosa pine	9	7	6	6	7	7	4	4	50
other species	18	15	15	9	6	10	5	14	10

Table 11.1.5. Distribution of samples by total stand basal area per acre, expressed in percent of total for each species.

Species	Basal Area								
	0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	≥ 400

Species	Basal Area								
	0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	≥ 400
western white pine	0	0	0	0	0	0	0	0	0
western larch	5	21	29	17	11	9	6	<1	2
Douglas-fir	14	23	22	14	11	7	5	2	2
Pacific silver fir	4	8	6	13	19	22	14	7	6
western redcedar	0	0	0	0	0	0	0	0	0
grand fir	5	15	20	18	18	15	5	3	5
lodgepole pine	10	21	34	20	9	4	1	1	<1
Engelmann spruce	2	10	17	29	22	12	7	1	<1
subalpine fir	1	10	19	25	28	10	6	1	<1
ponderosa pine	14	35	29	14	5	2	<1	<1	0
other species	6	12	11	14	16	20	11	5	4

Table 11.1.6. Distribution of samples by diameter growth, expressed in percent for each species.

Species	Diameter Growth (inches/10 years)							
	< 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
western white pine	0	0	0	0	0	0	0	0
western larch	51	34	11	3	1	<1	0	0
Douglas-fir	27	33	20	13	6	2	1	<1
Pacific silver fir	35	38	17	6	3	<1	<1	<1
western redcedar	0	0	0	0	0	0	0	0
grand fir	16	34	23	13	7	3	2	2
lodgepole pine	42	42	12	3	<1	<1	<1	<1
Engelmann spruce	32	39	16	8	3	1	<1	<1
subalpine fir	36	43	16	3	1	1	0	0
ponderosa pine	23	34	25	10	5	2	<1	<1
other species	38	41	15	5	1	<1	0	<1

Table 11.1.7. Distribution of samples by elevation, expressed in percent for each species.

Species	Elevation				
	< 3000	3000-4000	4000-5000	5000-6000	≥ 6000
western white pine	0	0	0	0	0
western larch	2	28	41	29	<1
Douglas-fir	26	37	29	8	<1

Species	Elevation				
	< 3000	3000-4000	4000-5000	5000-6000	> 6000
Pacific silver fir	3	25	56	16	0
western redcedar	0	0	0	0	0
grand fir	12	38	35	15	0
lodgepole pine	5	14	34	39	8
Engelmann spruce	4	11	34	33	18
subalpine fir	<1	5	30	50	16
ponderosa pine	37	40	18	4	<1
other species	4	33	41	21	2

11.2 Appendix B. Plant Association Codes

Table 11.2.1 Plant association codes recognized in the EC variant.

FVS Sequence Number = Plant Association Species Type	Alpha Code	Site Species	Site Index*	Max. SDI*	Source*	Reference
1 = PIAL/CARU Whitebark pine/pinegrass	CAG112	DF	25	625	C	PNW-GTR-360 p. 262
2 = PIAL/VASC/LUHI Whitebark pine/grouse huckleberry/smooth woodrush	CAS311	AF	45	700	C	PNW-GTR-359 p. 248
3 = THPL-ABGR/ACTR Western redcedar-grand fir/vanilla leaf	CCF211	DF	72	850	H	R6 E TP-004-88 p. 115
4 = THPL/ACTR Western redcedar/vanilla leaf	CCF212	GF	71	1016	H	R6 E TP-006-88 p. 93
5 = THPL/CLUN Western redcedar/queencup beadily	CCF221	DF	64	840	C	PNW-GTR-360 p. 246
6 = THPL/ARNU3 Western redcedar/wild sarsaparilla	CCF222	DF	69	670	C	PNW-GTR-360 p. 240
7 = THPL/OPHO Western redcedar/devil's club	CCS211	RC	96	775	C	PNW-GTR-360 p. 251
8 = THPL/VAME Western redcedar/big huckleberry	CCS311	DF	63	815	C	PNW-GTR-360 p. 256
9 = PSME/PEFR3 Douglas-fir/shrubby penstemon	CDF411	DF	58	229	H	PNW-GTR-359 p. 82
10 = PSME/ARUV-OKAN Douglas-fir/bearberry (Okanogan)	CDG123	DF	38	331	H	R6 E 132b-83 p. 27
11 = PSME/CARU-O&C Douglas-fir/pinegrass (Okanogan & Colville)	CDG131	DF	58	530	C	PNW-GTR-360 p. 49
12 = PSME/CAGE-WEN Douglas-fir/elk sedge (Wenatchee)	CDG132	DF	69	550	C	PNW-GTR-359 p. 60
13 = PSME/CARU-AGSP Douglas-fir/pinegrass-bluebunch wheatgrass	CDG134	DF	61	430	C	PNW-GTR-359 p. 64
14 = PSME/CAGE Douglas-fir/elk sedge	CDG141	DF	55	442	H	R6 E TP-004-88 p. 51
15 = PIPO-PSME/AGSP Ponderosa pine-Douglas-fir/bluebunch wheatgrass	CDG311	PP	79	270	C	PNW-GTR-360 p. 44
16 = PSME/FEOC Douglas-fir/western fescue	CDG321	DF	67	649	H	R6 E TP-004-88 p. 55
17 = PSME/AGSP-WEN Douglas-fir/bluebunch wheatgrass (Wenatchee)	CDG322	DF	39	235	C	PNW-GTR-359 p. 58
18 = PSME/AGSP-ASDE Douglas-fir/bluebunch wheatgrass-podfern	CDG323	DF	58	188	H	PNW-GTR-359 p. 80

FVS Sequence Number = Plant Association Species Type	Alpha Code	Site Species	Site Index*	Max. SDI*	Source*	Reference
19 = PSME/HODI/CAGE Douglas-fir/oceanspray/elk sedge	CDS231	DF	80	676	H	R6 E TP-004-88 p. 59
20 = PSME/ACCI/FEOC Douglas-fir/vine maple/western fescue	CDS241	DF	76	720	H	R6 E TP-006-88 p. 45
21 = PSME/PAMY- Douglas-fir/pachistima (Okanogan)	CDS411	DF	59	630	C	R6 E 132b-83 p. 41
22 = PSME/PAMY/CARU Douglas-fir/pachistima/pinegrass	CDS412	DF	57	450	C	PNW-GTR-359 p. 81
23 = PSME/ARUV-PUTR Douglas-fir/bearberry-bitterbrush	CDS631	DF	45	232	H	R6 E 132b-83 p. 24
24 = PSME/SYOR-O&C Douglas-fir/Mt. snowberry (Okanogan and Colville)	CDS632	DF	54	400	C	PNW-GTR-360 p. 71
25 = PSME/SYAL Douglas-fir/common snowberry	CDS633	DF	81	475	C	PNW-GTR-360 p. 66
26 = PSME/SYAL-WEN Douglas-fir/common snowberry (Wenatchee)	CDS636	DF	80	580	C	PNW-GTR-359 p. 72
27 = PSME/SYAL/AGSP Douglas-fir/common snowberry/bluebunch wheatgrass	CDS637	DF	67	325	C	PNW-GTR-359 p. 74
28 = PSME/SYAL/CARU Douglas-fir/common snowberry/pinegrass	CDS638	DF	77	425	C	PNW-GTR-359 p. 76
29 = PSME/SPBEL/CARU Douglas-fir/shiny-leaf spirea/pinegrass	CDS639	DF	65	550	C	PNW-GTR-359 p. 70
30 = PSME/SPBEL Douglas-fir/shiny-leaf spirea	CDS640	DF	68	555	C	PNW-GTR-359 p. 82
31 = PSME/ARUV-WEN Douglas-fir/bearberry (Wenatchee)	CDS653	DF	37	460	C	PNW-GTR-359 p. 80
32 = PSME/ARUV-PUTR Douglas-fir/bearberry-bitterbrush	CDS654	DF	51	375	C	PNW-GTR-359 p. 81
33 = PSME/ARUV/CARU Douglas-fir/bearberry/pinegrass	CDS655	DF	40	370	C	PNW-GTR-359 p. 80
34 = PSME/SYAL-MTH Douglas-fir/common snowberry (Mt Hood)	CDS661	DF	84	767	H	R6 E TP-004-88 p. 67
35 = PSME/ARNE Douglas-fir/pinemat manzanita	CDS662	DF	51	1118	H	R6 E TP-004-88 p. 63
36 = PSME/PUTR Douglas-fir/bitterbursh	CDS673	DF	50	525	C	PNW-GTR-359 p. 82
37 = PSME/PUTR/AGSP Douglas-fir/bitterbursh/bluebunch wheatgrass	CDS674	DF	62	305	C	PNW-GTR-359 p. 66
38 = PSME/PUTR/CARU Douglas-fir/bitterbrush/pinegrass	CDS675	DF	58	370	C	PNW-GTR-359 p. 68
39 = PSME/PHMA-O&C Douglas-fir/ninebark (Okanogan & Colville)	CDS715	DF	63	470	C	PNW-GTR-360 p. 55
40 = PSME/PHMA-LIBOL Douglas-fir/ninebark-twinflower	CDS716	DF	60	600	C	PNW-GTR-360 p. 61
41 = PSME/VACCI Douglas-fir/huckleberry	CDS811	DF	51	397	H	R6 E 132b-83 p. 33
42 = PSME/VACA-COL Douglas-fir/dwarf huckleberry (Colville)	CDS813	WL	66	600	C	PNW-GTR-360 p. 76
43 = PSME/VAME-COLV Douglas-fir/big huckleberry (Colville)	CDS814	DF	66	585	C	PNW-GTR-360 p. 82
44 = PSME/VACA Douglas-fir/dwarf huckleberry	CDS831	DF	60	362	H	PNW-GTR-359 p. 82
45 = PSME/VAME-WEN Douglas-fir/big huckleberry (Wenatchee)	CDS832	DF	53	530	C	PNW-GTR-359 p. 83
46 = PSME/VAMY/CARU Douglas-fir/low huckleberry/pinegrass	CDS833	DF	48	265	C	PNW-GTR-359 p. 83
47 = ABLA2/XETE Subalpine fir/beargrass	CEF111	AF	54	905	C	PNW-GTR-360 p. 178

FVS Sequence Number = Plant Association Species Type	Alpha Code	Site Species	Site Index*	Max. SDI*	Source*	Reference
48 = ABLA2/LIBOL-O&C Subalpine fir/twinflower (Okanogan & Colville)	CEF211	AF	80	685	C	PNW-GTR-360 p. 141
49 = ABLA2/LIBOL-WEN Subalpine fir/twinflower (Wenatchee)	CEF222	ES	90	700	C	PNW-GTR-359 p. 234
50 = ABLA2/CLUN Subalpine fir/queencup beadily	CEF421	AF	87	650	C	PNW-GTR-360 p. 131
51 = ABLA2/TRCA3 Subalpine fir/false bugbane	CEF422	AF	87	745	C	PNW-GTR-360 p. 157
52 = ABLA2/COCA Subalpine fir/bunchberry dogwood	CEF423	AF	75	675	C	PNW-GTR-360 p. 136
53 = ABLA2/ARLA-POPU Subalpine fir/broadleaf arnica-skunkleaf polemonium	CEF424	AF	65	880	C	PNW-GTR-359 p. 214
54 = ABLA2/LUHI-WEN Subalpine fir/smooth woodrush (Wenatchee)	CEG121	AF	65	785	C	PNW-GTR-359 p. 218
55 = ABLA2/CARU-WEN Subalpine fir/pinegrass (Wenatchee)	CEG310	AF	73	549	H	PNW-GTR-359 p. 216
56 = ABLA2/CARU-O&C Subalpine fir/pinegrass (Okanogan & Colville)	CEG311	AF	77	655	C	PNW-GTR-360 p. 126
57 = PIEN/EQAR Engelmann spruce/horsetail	CEM211	ES	72	535	C	PNW-GTR-360 p. 184
58 = ABLA2/PAMY-OKAN Subalpine fir/pachistima (Okanogan)	CES111	AF	90	381	H	R6 E 132b-83 p. 52
59 = ABLA2/PAMY-WEN Subalpine fir/pachistima (Wenatchee)	CES113	ES	111	820	C	PNW-GTR-359 p. 234
60 = ABLA2/RHAL-XETE Subalpine fir/Cascades azalea-beargrass	CES210	AF	56	790	C	PNW-GTR-360 p. 152
61 = ABLA2/RHAL Subalpine fir/Cascade azalea	CES211	AF	52	790	C	PNW-GTR-359 p. 220
62 = ABLA2/RHAL/LUHI Subalpine fir/Cascade azalea/smooth woodrush	CES213	AF	60	665	C	PNW-GTR-359 p. 222
63 = ABLA2/VACCI Subalpine fir/huckleberry	CES312	AF	102	511	H	R6 E 132b-83 p. 46
64 = ABLA2/VAME-COLV Subalpine fir/big huckleberry (Colville)	CES313	AF	76	700	C	PNW-GTR-360 p. 168
65 = ABLA2/VAME-WEN Subalpine fir/big huckleberry (Wenatchee)	CES342	DF	73	810	C	PNW-GTR-359 p. 235
66 = ABLA2/VASC-O&C Subalpine fir/grouse huckleberry (Okan & Colv)	CES412	AF	63	780	C	PNW-GTR-360 p. 173
67 = ABLA2/VASC/CARU-OKAN Subalpine fir/grouse huckleberry/pinegrass (Okan)	CES413	ES	62	670	C	PNW-GTR-359 p. 236
68 = ABLA2/VACA Subalpine fir/dwarf huckleberry	CES422	LP	94	620	C	PNW-GTR-359 p. 235
69 = ABLA2/RULA Subalpine fir/dwarf bramble	CES423	AF	90	785	C	PNW-GTR-359 p. 224
70 = ABLA2/VASC/ARLA Subalpine fir/grouse huckleberry/broadleaf arnica	CES424	AF	51	785	C	PNW-GTR-359 p. 230
71 = ABLA2/VASC/LUHI Subalpine fir/grouse huckleberry/smooth woodrush	CES425	AF	65	720	C	PNW-GTR-359 p. 232
72 = ABLA2/VASC-WEN Subalpine fir/grouse huckleberry (Wenatchee)	CES426	DF	69	720	C	PNW-GTR-359 p. 228
73 = ABAM/TITRU Pacific silver fir/coolwort foamflower	CFF162	SF	143	1234	H	PNW-GTR-359 p. 168
74 = ABAM/ACTR-WEN Pacific silver fir/vanilla leaf (Wenatchee)	CFF254	SF	112	935	C	PNW-GTR-359 p. 158
75 = ABAM/VAAL-WEN Pacific Silver fir/Alaska huckleberry (Wenatchee)	CFS232	SF	104	872	H	PNW-GTR-359 p. 170

FVS Sequence Number = Plant Association Species Type	Alpha Code	Site Species	Site Index*	Max. SDI*	Source*	Reference
76 = ABAM/VAME/CLUN-WEN Silver fir/big huckleberry/queencup beadlily (Wen)	CFS233	SF	79	1070	C	PNW-GTR-359 p. 172
77 = ABAM/VAME-PYSE Pacific silver fir/big huckleberry-sidebells pyrola	CFS234	SF	62	840	C	PNW-GTR-359 p. 174
78 = ABAM/MEFE-WEN Pacific silver fir/rusty menziesia (Wenatchee)	CFS542	SF	84	915	C	PNW-GTR-359 p. 160
79 = ABAM/RHAL-OKAN Pacific silver fir/Cascade azalea (Okanogan)	CFS553	SF	45	646	H	R6 E 132b-83 p. 75
80 = ABAM/RHAL-VAME-WEN Pac silver fir/Cascade azalea-big huckleberry (Wen)	CFS556	AF	40	940	C	PNW-GTR-359 p. 164
81 = ABAM/PAMY Pacific silver fir/pachistima	CFS558	DF	65	776	H	R6 E 132b-83 p. 75
82 = ABAM/ACCI Pacific silver fir/vine maple	CFS621	SF	104	550	C	PNW-GTR-359 p. 156
83 = TSHE-ABGR/CLUN Western hemlock-grand fir/queencup beadlily	CHC311	GF	81	798	H	R6 E TP-004-88 p. 111
84 = TSHE/ACTR-WEN Western hemlock/vanilla leaf (Wenatchee)	CHF223	DF	73	675	C	PNW-GTR-359 p. 138
85 = TSHE/CLUN Western hemlock/queencup beadlily	CHF311	DF	69	835	C	PNW-GTR-360 p. 204
86 = TSHE/ARNU3 Western hemlock/wild sarsaparilla	CHF312	DF	75	775	C	PNW-GTR-360 p. 199
87 = TSHE/ASCA3 Western hemlock/wild ginger	CHF313	DF	85	1253	H	PNW-GTR-359 p. 142
88 = TSHE/GYDR Western hemlock/oak-fern	CHF422	DF	83	900	C	PNW-GTR-360 p. 209
89 = TSHE/XETE-COLV Western hemlock/beargrass (Colville)	CHF521	ES	90	830	C	PNW-GTR-360 p. 226
90 = TSHE/BENE-WEN Western hemlock/Cascade Oregon grape (Wenatchee)	CHS142	DF	82	810	C	PNW-GTR-359 p. 144
91 = TSHE/PAMY/CLUN Western hemlock/pachistima/queencup beadlily	CHS143	DF	74	855	C	PNW-GTR-359 p. 146
92 = TSHE/ARNE Western hemlock/pinemat manzanita	CHS144	DF	52	705	C	PNW-GTR-359 p. 140
93 = TSHE/ACCI/ACTR-WEN Western hemlock/vine maple/vanilla leaf (Wenatchee)	CHS225	DF	87	565	C	PNW-GTR-359 p. 132
94 = TSHE/ACCI/ASCA3 Western hemlock/vine maple/wild ginger	CHS226	DF	86	720	C	PNW-GTR-359 p. 134
95 = TSHE/ACCI/CLUN Western hemlock/vine maple/queencup beadlily	CHS227	GF	86	630	C	PNW-GTR-359 p. 136
96 = TSHE/RUPE Western hemlock/five-leaved bramble	CHS411	ES	103	1129	H	PNW-GTR-360 p. 221
97 = TSHE/MEFE Western hemlock/rusty menziesia	CHS711	DF	71	765	C	PNW-GTR-360 p. 215
98 = PICO/SHCA Lodgepole pine/russet buffaloberry	CLS521	LP	96	530	C	PNW-GTR-360 p. 267
99 = TSME/XETE-VAMY Mountain hemlock/beargrass-low huckleberry	CMF131	OT	23	775	C	PNW-GTR-359 p. 202
100 = TSME/LUHI Mountain hemlock/smooth woodrush	CMG221	OT	24	544	H	PNW-GTR-359 p. 184
101 = TSME/VASC/LUHI Mountain hemlock/grouse huckleberry/smooth woodrush	CMS121	OT	23	650	C	PNW-GTR-359 p. 200
102 = TSME/RULA Mountain hemlock/dwarf bramble	CMS122	SF	79	940	C	PNW-GTR-359 p. 194

FVS Sequence Number = Plant Association Species Type	Alpha Code	Site Species	Site Index*	Max. SDI*	Source*	Reference
103 = TSME/MEFE-VAAL Mountain hemlock/rusty menziesia-Alaska huckleberry	CMS256	SF	94	742	H	PNW-GTR-359 p. 186
104 = TSME/MEFE-VAME Mountain hemlock/rusty menziesia-big huckleberry	CMS257	SF	102	1115	C	PNW-GTR-359 p. 188
105 = TSME/VAAL-WEN Mountain hemlock/Alaska huckleberry (Wenatchee)	CMS258	OT	28	1132	H	PNW-GTR-359 p. 196
106 = TSME/VAME-WEN Mountain hemlock/big huckleberry (Wenatchee)	CMS259	OT	20	885	C	PNW-GTR-359 p. 198
107 = TSME/PHEM-VADE Mtn hemlock/red mountain heath-Cascade huckleberry	CMS354	AF	53	780	C	PNW-GTR-359 p. 190
108 = TSME/RHAL-VAAL Mountain hemlock/Cascade azalea-Alaska huckleberry	CMS355	OT	26	541	H	PNW-GTR-359 p. 204
109 = TSME/RHAL-VAME Mountain hemlock/Cascades azalea-big huckleberry	CMS356	OT	20	935	C	PNW-GTR-359 p. 192
110 = PIPO/AGSP-WEN Ponderosa pine/bluebunch wheatgrass (Wenatchee)	CPG141	PP	81	200	C	PNW-GTR-359 p. 42
111 = PIPO/CARU-AGSP Ponderosa pine/pinegrass-bluebunch wheatgrass	CPG231	PP	49	420	C	PNW-GTR-359 p. 44
112 = PIPO-QUGA/BASA Ponderosa pine-Or white oak/arrowleaf balsamroot	CPH211	PP	65	328	H	R6 E TP-004-88 p. 43
113 = PIPO-QUGA/PUTR Ponderosa pine-Oregon white oak/bitterbrush	CPH212	PP	63	342	H	R6 E TP-004-88 p. 47
114 = PIPO/PUTR/AGSP Ponderosa pine/bitterbursh/bluebunch wheatgrass	CPS241	PP	75	210	C	PNW-GTR-359 p. 46
115 = ABGR-PIEN/SMST Grand fir-Engelmann spruce/starry solomonseal	CWC511	GF	90	972	H	R6 E TP-004-88 p. 107
116 = ABGR/LIBO2 Grand fir/twinflower	CWF321	GF	83	709	H	R6 E TP-004-88 p. 87
117 = ABGR/ARCO Grand fir/heartleaf arnica	CWF444	GF	72	785	C	PNW-GTR-359 p. 102
118 = ABGR/TRLA2 Grand fir/starflower	CWF521	GF	91	810	C	R6 E TP-004-88 p. 83
119 = ABGR/ACTR Grand fir/vanillaleaf	CWF522	GF	100	710	C	R6 E TP-004-88 p. 95
120 = ABGR/POPU Grand fir/skunk-leaved polemonium	CWF523	GF	90	955	H	R6 E TP-004-88 p. 103
121 = ABGR/ACTR-WEN Grand fir/vanilla leaf (Wenatchee)	CWF524	GF	86	963	H	PNW-GTR-359 p. 100
122 = ABGR/CAGE Grand fir/elk sedge	CWG121	GF	104	712	H	R6 E TP-004-88 p. 71
123 = ABGR/CAGE-GP Grand fir/elk sedge (Gifford Pinchot)	CWG122	GF	100	810	C	R6 E TP-006-88 p. 53
124 = ABGR/CARU Grand fir/pinegrass	CWG123	GF	112	1769	H	R6 E TP-006-88 p. 49
125 = ABGR/CARU-WEN Grand fir/pinegrass (Wenatchee)	CWG124	GF	85	635	C	PNW-GTR-359 p. 110
126 = ABGR/CARU-LUPIN Grand fir/pinegrass-lupine	CWG125	DF	58	750	C	PNW-GTR-359 p. 112
127 = ABGR/VAME/CLUN-COL Grand fir/big huckleberry/queencup beadlily (Colv)	CWS214	GF	86	996	H	PNW-GTR-360 p. 110

FVS Sequence Number = Plant Association Species Type	Alpha Code	Site Species	Site Index*	Max. SDI*	Source*	Reference
128 = ABGR/VAME/LIBO2 Grand fir/big huckleberry/twinflower	CWS221	GF	100	776	H	R6 E TP-006-88 p. 85
129 = ABGR/VAME/CLUN Grand fir/big huckleberry/queencup beadlily	CWS222	GF	103	745	C	R6 E TP-006-88 p. 89
130 = ABGR/RUPA/DIHO Grand fir/thimbleberry/fairy bells	CWS223	GF	108	455	C	R6 E TP-006-88 p. 81
131 = ABGR/BENE/ACTR Grand fir/dwarf Oregon grape/vanillaleaf	CWS224	DF	69	650	C	R6 E TP-006-88 p. 73
132 = ABGR/BENE Grand fir/Cascade Oregon grape	CWS225	GF	77	845	C	PNW-GTR-359 p. 106
133 = ABGR/BENE/CARU-WEN Grand fir/Cascade Oregon grape/pinegrass-Wenatchee	CWS226	GF	85	745	C	PNW-GTR-359 p. 108
134 = ABGR/SYMPH Grand fir/snowberry	CWS331	GF	90	695	C	R6 E TP-004-88 p. 79
135 = ABGR/SYMO/ACTR Grand fir/creeping snowberry/vanillaleaf	CWS332	GF	108	870	C	R6 E TP-006-88 p. 65
136 = ABGR/SPEBL/PTAQ Grand fir/shiny-leaf spirea/bracken fern	CWS335	GF	74	655	C	PNW-GTR-359 p. 116
137 = ABGR/SYAL/CARU Grand fir/common snowberry/pinegrass	CWS336	GF	76	580	C	PNW-GTR-359 p. 118
138 = ABGR/SYOR Grand fir/mountain snowberry	CWS337	DF	70	360	C	PNW-GTR-359 p. 120
139 = ABGR/ARNE Grand fir/pinemat manzanita	CWS338	DF	49	575	C	PNW-GTR-359 p. 104
140 = ABGR/PHMA Grand fir/ninebark	CWS421	DF	79	575	C	PNW-GTR-360 p. 100
141 = ABGR/ACGLD/CLUN Grand fir/Douglas maple/queencup beadlilly	CWS422	GF	73	1259	H	PNW-GTR-360 p. 95
142 = ABGR/HODI Grand fir/oceanspray	CWS531	GF	95	860	C	R6 E TP-004-88 p. 75
143 = ABGR/ACCI/ACTR Grand fir/vine maple/vanillaleaf	CWS532	GF	98	780	C	R6 E TP-004-88 p. 91
144 = ABGR/CACH Grand fir/chinkapin	CWS533	DF	57	690	C	R6 E TP-004-88 p. 99
145 = ABGR/HODI-GP Grand fir/oceanspray (Gifford Pinchot)	CWS534	GF	104	585	C	R6 E TP-006-88 p. 61
146 = ABGR/ACCI-BEAQ/TRLA2 Grand fir/vine maple-tall Oregongrape/starflower	CWS535	GF	116	520	C	R6 E TP-006-88 p. 57
147 = ABGR/COCO2/ACTR Grand fir/California hazel/vanillaleaf	CWS536	GF	116	1377	H	R6 E TP-006-88 p. 69
148 = ABGR/CONU/ACTR Grand fir/pacific dogwood/vanillaleaf	CWS537	DF	64	650	C	R6 E TP-006-88 p. 77
149 = ABGR/ACCI-WEN Grand fir/vine maple (Wenatchee)	CWS551	GF	109	740	C	PNW-GTR-359 p. 94
150 = ABGR/ACCI-CHUM Grand fir/vine maple-western prince's pine	CWS552	GF	100	695	C	PNW-GTR-359 p. 96
151 = ABGR/ACCI/CLUN Grand fir/vine maple/queencup beadlily	CWS553	GF	104	1090	H	PNW-GTR-359 p. 98
152 = ABGR/HODI/CARU Grand fir/ocean-spray/pinegrass	CWS554	DF	70	545	C	PNW-GTR-359 p. 114
153 = ABGR/VACA Grand fir/dwarf huckleberry	CWS821	DF	74	560	C	PNW-GTR-360 p. 105
154 = POTR/CARU Quaking aspen/pinegrass	HQG111	LP	84	522	H	R6 E 132b-83 p. 75
155 = POTR/SYAL Quaking aspen/common snowberry	HQS211	WL	68	331	H	R6 E 132b-83 p. 75

*Site index estimates are from GBA analysis. SDI maximums are set by GBA analysis (Source=H) or CVS plot analysis (Source=C).

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