

Pacific Northwest Coast (PN) Variant Overview of the Forest Vegetation Simulator

September 2025



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Authors and Contributors:

The FVS staff has maintained model documentation for this variant in the form of a variant overview since its release in 1995. The original author was Dennis Donnelly. 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.

FVS Staff. 2008 (revised September 23, 2025). Pacific Northwest Coast (PN) Variant Overview – Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 73p.

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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)	612 - Siuslaw	
Plant Association Code	40 (CHS133 TSHE/GASH VAOV2)	
Slope	5 percent	
Aspect	0 (no meaningful aspect)	
Elevation	7 (700 feet)	
Latitude / Longitude	Latitude	Longitude
All location codes	46	123
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 for site species	
Volume Equations	National Volume Estimator Library	
Merchantable Cubic Foot Volume Specifications:		
Minimum DBH / Top Diameter	LP	All Other
708 – BLM Salem; 709 BLM Eugene;		
712 – BLM Coos Bay	7.0 / 5.0 inches	7.0 / 5.0 inches
All other 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
708 – BLM Salem; 709 BLM Eugene;		
712 – BLM Coos Bay	7.0 / 5.0 inches	7.0 / 5.0 inches
All other location codes	6.0 / 4.5 inches	7.0 / 4.5 inches
Stump Height	1.0 foot	1.0 foot
Sampling Design:		
Basal Area Factor	40 BAF	
Small-Tree Fixed Area Plot	1/300 th 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 Pacific Northwest coast (PN) variant was developed in 1995. It covers an area bounded by a line between Coos Bay and Roseburg, Oregon on the south; the northern shore of the Olympic Peninsula in Washington on the north; the shore of the Pacific Ocean on the west; and the eastern slope of the Coast Range and Olympic Mountains on the east. Data used to build the PN variant came from forest inventories and silviculture stand examinations. The forest inventories came from the Forest Service, U.S. Department of Agriculture as well as the Bureau of Land Management and Quinalt Indian Reservation. In 2013, new small tree growth equations from Gould and Harrington (2012) were embedded in the WC variant. Relationships for redwood were incorporated in 2021.

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 PN variant was fit to data representing forest types in the Coast Range and Olympic Peninsula physiographic provinces. Data used in initial model development came from forest inventories, managed stand surveys. Forest inventories came from US. Forest Service Siuslaw and Olympic National Forests, BLM – Oregon, and BIA – Quinault Indian Reservation. Distribution of data samples for species fit from this data are shown in Appendix A.

The PN variant covers forest types on the coast of the Pacific Northwest states of Washington and Oregon. The suggested geographic range of use for the PN variant is shown in figure 2.0.1.

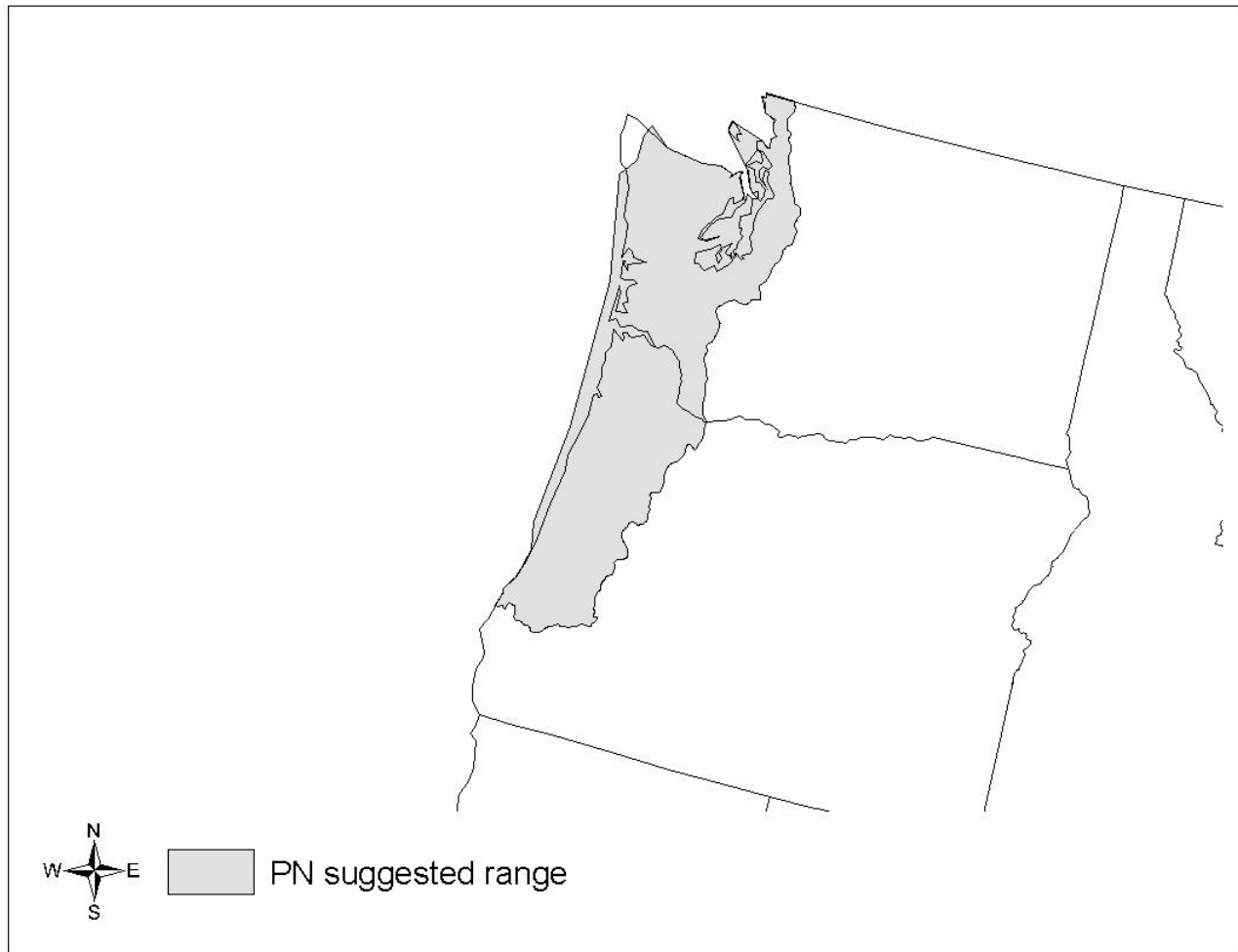


Figure 2.0.1 Suggested geographic range of use for the PN variant.

3.0 Control Variables

FVS users need to specify certain variables used by the PN 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- or 4-digit code where, in general, the first digit of the code represents the USDA 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 PN variant, a default forest code of 612 (Siuslaw National Forest) will be used. Location codes recognized in the PN variant are shown in tables 3.1.1 and 3.1.2.

Table 3.1.1 Location codes used in the PN variant.

Location Code	Location
609	Olympic National Forest
612	Siuslaw National Forest
708	BLM Salem Admin Unit
709	BLM Eugene Admin Unit
712	BLM Coos Bay Admin Unit
800	Quinalt Indian Reservation

Table 3.1.2 Bureau of Indian Affairs reservation codes used in the PN variant.

Location Code	Location
8101	Grand Ronde Community (mapped to 612)
8102	Siletz Reservation (mapped to 612)
8103	Coos, Lower Umpqua, Siuslaw Off-Res. Trust Land (mapped to 612)
8104	Cow Creek Reservation (mapped to 712)
8105	Coquille Reservation (mapped to 712)
8110	Chehalis Reservation (mapped to 609)
8111	Hoh Indian Reservation (mapped to 609)
8113	Shoalwater Bay Indian Reservation (mapped to 609)
8114	Skokomish Reservation (mapped to 609)
8115	Squaxin Island Reservation (mapped to 609)
8116	Lower Elwha Off-Res. Trust Land (mapped to 609)
8119	Lummi Reservation (mapped to 609)
8120	Muckleshoot Reservation (mapped to 609)
8121	Nisqually Reservation (mapped to 609)
8122	Port Gamble Reservation (mapped to 609)

Location Code	Location
8123	Port Madison Reservation (mapped to 609)
8125	Swinomish Reservation (mapped to 609)
8126	Tulalip Reservation (mapped to 609)
8127	Upper Skagit Reservation (mapped to 609)
8128	Samish Tdsa (mapped to 609)
8129	Snoqualmie Reservation (mapped to 609)

3.2 Species Codes

The PN variant recognizes 37 species, plus one other composite species category. 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 PN 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 PN variant.

Species Number	Species Code	FIA Code	PLANTS Symbol	Scientific Name ¹	Common Name ¹
1	SF	011	ABAM	<i>Abies amabilis</i>	Pacific silver fir
2	WF	015	ABCO	<i>Abies concolor</i>	white fir
3	GF	017	ABGR	<i>Abies grandis</i>	grand fir
4	AF	019	ABLA	<i>Abies lasiocarpa</i>	subalpine fir
5	RF	020	ABMA	<i>Abies magnifica</i>	California red fir
6	SS	098	PISI	<i>Picea sitchensis</i>	Sitka spruce
7	NF	022	ABPR	<i>Abies procera</i>	noble fir
8	YC	042	CANO9	<i>Callitropsis nootkatensis</i>	Alaska cedar
9	IC	081	CADE27	<i>Calocedrus decurrens</i>	incense cedar
10	ES	093	PIEN	<i>Picea engelmannii</i>	Engelmann spruce
11	LP	108	PICO	<i>Pinus contorta</i>	lodgepole pine
12	JP	116	PIJE	<i>Pinus jeffreyi</i>	Jeffrey pine
13	SP	117	PILA	<i>Pinus lambertiana</i>	sugar pine
14	WP	119	PIMO3	<i>Pinus monticola</i>	western white pine
15	PP	122	PIPO	<i>Pinus ponderosa</i>	ponderosa pine

Species Number	Species Code	FIA Code	PLANTS Symbol	Scientific Name ¹	Common Name ¹
16	DF	202	PSME	<i>Pseudotsuga menziesii</i>	Douglas-fir
17	RW	211	SESE3	<i>Sequoia sempervirens</i>	redwood
18	RC	242	THPL	<i>Thuja plicata</i>	western redcedar
19	WH	263	TSHE	<i>Tsuga heterophylla</i>	western hemlock
20	MH	264	TSME	<i>Tsuga mertensiana</i>	mountain hemlock
21	BM	312	ACMA3	<i>Acer macrophyllum</i>	bigleaf maple
22	RA	351	ALRU2	<i>Alnus rubra</i>	red alder
23	WA	352	ALRH2	<i>Alnus rhombifolia</i>	white alder
24	PB	375	BEPA	<i>Betula papyrifera</i>	paper birch
25	GC	431	CHCHC4	<i>Chrysolepis chrysophylla</i> var. <i>chrysophylla</i>	giant chinquapin
26	AS	746	POTR5	<i>Populus tremuloides</i>	quaking aspen
27	CW	747	POBAT	<i>Populus balsamifera</i> ssp. <i>trichocarpa</i>	black cottonwood
28	WO	815	QUGA4	<i>Quercus garryana</i>	Oregon white oak
29	WJ	064	JUOC	<i>Juniperus occidentalis</i>	western juniper
30	LL	072	LALY	<i>Larix lyallii</i>	subalpine larch
31	WB	101	PIAL	<i>Pinus albicaulis</i>	whitebark pine
32	KP	103	PIAT	<i>Pinus attenuata</i>	knobcone pine
33	PY	231	TABR2	<i>Taxus brevifolia</i>	Pacific yew
34	DG	492	CONU4	<i>Cornus nuttallii</i>	Pacific dogwood
35	HT	500	CRATA	<i>Crataegus</i>	hawthorn
36	CH	768	PREM	<i>Prunus emarginata</i>	bitter cherry
37	WI	920	SALIX	<i>Salix</i>	willow
39	OT	999	2TREE		other ²

¹Set based on the USDA Forest Service NRM TAXA lists and the USDA Plants database.

²Other 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 PN 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 40 (CHS133 TSHE/GASH-VAOV2). Plant association codes are used to set default site information such as site species, site indices, and maximum stand density indices. 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 PN variant. Users should always use the same site curves that FVS uses, which are 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 PN variant.

Species Code	Reference	BHA or TTA ¹	Base Age
SF	Hoyer and Herman (1989)	BHA	100
GF, WF	Cochran (1979)	BHA	50
AF, ES	Alexander (1967)	BHA	100
RF	Dolph (1991)	BHA	50
SS, RC	Farr (1984)	BHA	50
NF	Herman et al. (1978)	BHA	100
LP	Dahms (1964)	TTA	50
WP, SP	Curtis et al. (1990)	BHA	100
PP, IC, JP	Barrett (1978)	BHA	100
DF, WO	King (1966)	BHA	50
WH	Wiley (1978)	BHA	50
MH	Means et al. (1986) ²	BHA	100
RA	Harrington and Curtis (1986)	TTA	20
LL	Cochran (1985)	BHA	50
Other ³	Curtis et al. (1974)	BHA	100
RW ⁴	Krumland and Eng (2005)	BHA	50

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 are assumed to be in meters.

³ Other includes all the following species: Alaska cedar, redwood, bigleaf maple, white alder, paper birch, giant chinquapin, quaking aspen, black cottonwood, western juniper, whitebark pine, knobcone pine, Pacific yew, Pacific dogwood, hawthorn, bitter cherry, willow.

⁴ Equation form is presented on page 34 and coefficients are provided on page 68

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 Douglas-fir with a default site index set to 98.

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. For some species that use the Curtis et al. (1974) equation, the site index estimate is adjusted by multiplying the site index estimate by an adjustment factor in table 3.4.2, if the species is not listed as the site species. Similarly, for Oregon white oak, an adjustment is made from the site species using the maximum height equation {3.4.1} from Gould and Harrington (2009).

Table 3.4.2 Site index adjustment factors for hardwood species using Curtis et al equations in the PN variant.

Species	Base Age
BM	0.75
WA	0.65
PB	1.50
GC	0.70
AS	0.75
CW	0.85
WJ	0.23
WB	0.70
PY	0.25
DG	0.60
HT	0.25
CH	0.50
WI	0.50

$$\{3.4.1\} Sl_{wo} = 114.24569[1 - \exp(-.02659 * Sl_{site})]^2.25993$$

where:

Sl_{wo} site index estimate of Oregon white oak

Sl_{site} Site Index of site 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 maximum SDI for all species is assigned from the SDI maximum associated with the site species for 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). Some SDI maximums associated with plant associations are unreasonably large, so SDI maximums are capped at 950. Maximum stand density index at the stand level is a weighted average, by basal area, of the individual species SDI maximums.

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

where:

<i>SDIMAX_i</i>	is species-specific SDI maximum
<i>BAMAX</i>	is the user-specified stand basal area maximum
<i>SDIU</i>	is the proportion of theoretical maximum density at which the stand reaches actual maximum density (default 0.85, changed with the SDIMAX keyword)

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 PN variant, FVS will dub in heights by one of two methods. By default, the PN variant will use the Curtis-Arney functional form as shown in equation {4.1.1} (Curtis 1967, Arney 1985). The Curtis-Arney equation is replaced by equation {4.1.4} for Sitka spruce greater than or equal to 100 inches dbh on the Olympic NF and Quinault Reservation. 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) or {4.1.3} that may be calibrated to the input data. However, the default in the PN variant is to use equation {4.1.1}.

FVS will not automatically use equations {4.1.2} and {4.1.3} 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 shown in table 4.1.1a and 4.1.1b sorted by species and location code. Coefficients for equations {4.1.2} and {4.1.3} are given in table 4.1.2 by species.

{4.1.1} Curtis-Arney functional form

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

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

For Douglas-fir at locations 612, 708, and 712 where $DBH \geq 5.0''$: $HT = 4.5 + P_2 * \exp[-P_3 * DBH^{P_4}]$

$$\text{For Douglas-fir at locations 612, 708, and 712 where } DBH < 5.0'': HT = [(4.5 + P_2 * \exp[-P_3 * 5.0^{P_4}] - 4.51) * (DBH - 0.3) / 4.7] + 4.51$$

{4.1.2} Wykoff functional form

$$DBH \geq 5.0'': HT = 4.5 + \exp(B_1 + B_2 / (DBH + 1.0))$$

{4.1.3} Other functional form

Species: 1-14, 20, 30 or 33

$$DBH < 5.0'': HT = \exp(H_1 + (H_2 * DBH) + (H_3 * CR) + (H_4 * DBH^2) + H_5)$$

Species: 16, 18, 19, 21-29, 31, 32, 34-39

$$DBH < 5.0'': HT = H_1 + (H_2 * DBH) + (H_3 * CR) + (H_4 * DBH^2) + H_5$$

Species: 15

$$DBH < 4.0'': HT = 8.31485 + 3.03659 * DBH - 0.59200 * CRC$$

{4.1.4} Sitka spruce with $DBH \geq 100.0''$: $HT = 248 + (0.25 * DBH)$

where:

HT is tree height

DBH is tree diameter at breast height

CR is crown ratio expressed in percent

CRC is crown ratio code ($CRC=6$)

$B_1 - B_2$ are species-specific coefficients shown in table 4.1.2

$P_2 - P_4$ are species and location specific coefficients shown in table 4.1.1

$H_1 - H_5$ are species-specific coefficients shown in table 4.1.2

Table 4.1.1a Coefficients for equation {4.1.1} in the PN variant.

Species Code	Coefficient	609 - Olympic, 800 - Quinault	612 – Siuslaw, 712 – BLM Coos	708 – BLM Salem	709 – BLM Eugene
SF	P_2	697.6316	697.6316	223.3492	237.9189
	P_3	6.6807	6.6807	6.3964	7.7948
	P_4	-0.4161	-0.4161	-0.6566	-0.7261
WF	P_2	604.845	604.845	475.1698	475.1698
	P_3	5.9835	5.9835	6.2472	6.2472
	P_4	-0.3789	-0.3789	-0.4812	-0.4812
GF	P_2	356.1148	432.2186	432.2186	432.2186
	P_3	6.41	6.2941	6.2941	6.2941
	P_4	-0.5572	-0.5028	-0.5028	-0.5028
AF	P_2	89.0298	133.8689	290.5142	133.8689
	P_3	6.9507	6.7798	6.4143	6.7798
	P_4	-0.9871	-0.7375	-0.4724	-0.7375
RF	P_2	202.886	202.886	375.382	375.382
	P_3	8.7469	8.7469	6.088	6.088
	P_4	-0.8317	-0.8317	-0.472	-0.472
SS	P_2	3844.388	708.7788	375.382	375.382
	P_3	7.068	5.7677	6.088	6.088
	P_4	-0.2122	-0.3629	-0.472	-0.472
NF	P_2	483.3751	483.3751	247.7348	483.3751
	P_3	7.2443	7.2443	6.183	7.2443
	P_4	-0.5111	-0.5111	-0.6335	-0.5111
YC	P_2	1220.096	1220.096	255.4638	97.7769
	P_3	7.2995	7.2995	5.5577	8.8202
	P_4	-0.3211	-0.3211	-0.6054	-1.0534
IC	P_2	4691.634	4691.634	4691.634	4691.634
	P_3	7.4671	7.4671	7.4671	7.4671
	P_4	-0.1989	-0.1989	-0.1989	-0.1989
ES	P_2	206.3211	206.3211	206.3211	206.3211
	P_3	9.1227	9.1227	9.1227	9.1277

Species Code	Coefficient	609 - Olympic, 800 - Quinault	612 – Siuslaw, 712 – BLM Coos	708 – BLM Salem	709 – BLM Eugene
	P ₄	-0.8281	-0.8281	-0.8281	-0.8281
LP	P ₂	100	100	139.7159	105.4453
	P ₃	6	6	4.0091	7.9694
	P ₄	-0.86	-0.86	-0.708	-1.0916
JP	P ₂	1031.52	1031.52	1031.52	1031.52
	P ₃	7.6616	7.6616	7.6616	7.6616
	P ₄	-0.3599	-0.3599	-0.3599	-0.3599
SP	P ₂	702.1856	702.1856	702.1856	702.1856
	P ₃	5.7025	5.7025	5.7025	5.7025
	P ₄	-0.3798	-0.3798	-0.3798	-0.3798
WP	P ₂	433.7807	514.1575	1333.818	514.1575
	P ₃	6.3318	6.3004	6.6219	6.3004
	P ₄	-0.4988	-0.4651	-0.312	-0.4651
PP	P ₂	1181.724	1181.724	1181.724	1181.724
	P ₃	6.6981	6.6981	6.6981	6.6981
	P ₄	-0.3151	-0.3151	-0.3151	-0.3151
DF	P ₂	1091.853	407.1595	949.1046	439.1195
	P ₃	5.2936	7.2885	5.8482	5.8176
	P ₄	-0.2648	-0.5908	-0.3251	-0.4854
RW	P ₂	595.1068	595.1068	595.1068	595.1068
	P ₃	5.8103	5.8103	5.8103	5.8103
	P ₄	-0.3821	-0.3821	-0.3821	-0.3821
RC	P ₂	665.0944	227.14	1560.685	1012.127
	P ₃	5.5002	6.1092	6.2328	6.0957
	P ₄	-0.3246	-0.6009	-0.2541	-0.3083
WH	P ₂	609.4235	1196.619	317.8257	395.4976
	P ₃	5.5919	5.7904	6.8287	6.4222
	P ₄	-0.3841	-0.2906	-0.6034	-0.532
MH	P ₂	170.2653	170.2653	2478.099	192.9609
	P ₃	10.0684	10.0684	7.0762	7.3876
	P ₄	-0.8791	-0.8791	-0.2456	-0.7231
BM	P ₂	600.0957	92.2964	76.517	160.2171
	P ₃	3.8297	4.189	2.2107	3.3044
	P ₄	-0.238	-0.983	-0.6365	-0.5299
RA	P ₂	139.4551	254.9634	484.4591	10099.72
	P ₃	4.6989	3.8495	4.5713	7.6375
	P ₄	-0.7682	-0.4149	-0.3643	-0.1621
WA	P ₂	139.4551	254.8634	133.7965	133.7965
	P ₃	4.6989	3.8495	6.405	6.405
	P ₄	-0.7682	-0.4149	-0.8329	-0.8329

Species Code	Coefficient	609 - Olympic, 800 - Quinault	612 – Siuslaw, 712 – BLM Coos	708 – BLM Salem	709 – BLM Eugene
PB	P ₂	1709.723	1709.723	1709.723	1709.723
	P ₃	5.8887	5.8887	5.8887	5.8887
	P ₄	-0.2286	-0.2286	-0.2286	-0.2286
GC	P ₂	10707.39	10707.39	10707.39	10707.39
	P ₃	8.467	8.467	8.467	8.467
	P ₄	-0.1863	-0.1863	-0.1863	-0.1863
AS	P ₂	1709.723	1709.723	1709.723	1709.723
	P ₃	5.8887	5.8887	5.8887	5.8887
	P ₄	-0.2286	-0.2286	-0.2286	-0.2286
CW	P ₂	178.6441	178.6441	178.6441	178.6441
	P ₃	4.5852	4.5852	4.5852	4.5852
	P ₄	-0.6746	-0.6746	-0.6746	-0.6746
WO	P ₂	89.4301	89.4301	59.4214	55
	P ₃	6.6321	6.6321	5.3178	5.5
	P ₄	-0.8876	-0.8876	-1.367	-0.95
WJ	P ₂	503.6619	503.6619	503.6619	503.6619
	P ₃	4.9544	4.9544	4.9544	4.9544
	P ₄	-0.2085	-0.2085	-0.2085	-0.2085
LL	P ₂	503.6619	503.6619	503.6619	503.6619
	P ₃	4.9544	4.9544	4.9544	4.9544
	P ₄	-0.2085	-0.2085	-0.2085	-0.2085
WB	P ₂	89.5535	89.5535	73.9147	73.9147
	P ₃	4.2281	4.2281	3.963	3.963
	P ₄	-0.6438	-0.6438	-0.8277	-0.8277
KP	P ₂	34749.47	34749.47	34749.47	34749.47
	P ₃	9.1287	9.1287	9.1287	9.1287
	P ₄	-0.1417	-0.1417	-0.1417	-0.1417
PY	P ₂	127.1698	139.0727	77.2207	139.0727
	P ₃	4.8977	5.2062	3.5181	5.2062
	P ₄	-0.4668	-0.5409	-0.5894	-0.5409
DG	P ₂	403.3221	403.3221	403.3221	444.5618
	P ₃	4.3271	4.3271	4.3271	3.9205
	P ₄	-0.2422	-0.2422	-0.2422	-0.2397
HT	P ₂	55	55	55	55
	P ₃	5.5	5.5	5.5	5.5
	P ₄	-0.95	-0.95	-0.95	-0.95
CH	P ₂	73.3348	73.3348	73.3348	73.3348
	P ₃	2.6548	2.6548	2.6548	2.6548
	P ₄	-1.246	-1.246	-1.246	-1.246
WI	P ₂	149.5861	149.5861	149.5861	149.5861

Species Code	Coefficient	609 - Olympic, 800 - Quinault	612 – Siuslaw, 712 – BLM Coos	708 – BLM Salem	709 – BLM Eugene
OT	P ₃	2.4231	2.4231	2.4231	2.4231
	P ₄	-0.18	-0.18	-0.18	-0.18
	P ₂	1709.723	1709.723	1709.723	1709.723
	P ₃	5.8887	5.8887	5.8887	5.8887
	P ₄	-0.2286	-0.2286	-0.2286	-0.2286

Table 4.1.2 Coefficients for equations {4.1.2} and {4.1.3} in the PN variant.

Species Code	Default B ₁	B ₂	H ₁	H ₂	H ₃	H ₄	H ₅
SF	5.487	-16.701	1.3134	0.3432	0.0366	0	0
WF	5.308	-13.624	1.4769	0.3579	0	0	0
GF	5.308	-13.624	1.4769	0.3579	0	0	0
AF	5.313	-15.321	1.4261	0.3334	0	0	0
RF	5.313	-15.321	1.3526	0.3335	0.0367	0	0
SS	5.517	-17.944	1.3526	0.3335	0.0367	0	0
NF	5.327	-15.450	1.7100	0.2943	0	0	0.1054
YC	5.143	-13.497	1.5907	0.3040	0	0	0
IC	5.188	-13.801	1.5907	0.3040	0	0	0
ES	5.188	-13.801	1.5907	0.3040	0	0	0
LP	4.865	-9.305	0.9717	0.3934	0.0339	0	0.3044
JP	5.333	-17.762	1.0756	0.4369	0	0	0
SP	5.382	-15.866	0.9717	0.3934	0.0339	0	0.3044
WP	5.382	-15.866	0.9717	0.3934	0.0339	0	0.3044
PP	5.333	-17.762	1.0756	0.4369	0	0	0
DF	5.563	-16.475	7.1391	4.2891	-0.7150	0.2750	2.0393
RW	5.3401	-15.9354	1.5907	0.3040	0	0	0
RC	5.233	-14.737	2.3115	0.2370	-0.0556	0	0.3218
WH	5.355	-13.878	1.3608	0.6151	0	-0.0442	0.0829
MH	5.081	-13.430	1.2278	0.4000	0	0	0
BM	4.700	-6.326	0.0994	4.9767	0	0	0
RA	4.875	-8.639	0.0994	4.9767	0	0	0
WA	5.152	-13.576	0.0994	4.9767	0	0	0
PB	5.152	-13.576	0.0994	4.9767	0	0	0
GC	5.152	-13.576	0.0994	4.9767	0	0	0
AS	5.152	-13.576	0.0994	4.9767	0	0	0
CW	5.152	-13.576	0.0994	4.9767	0	0	0
WO	5.152	-13.576	0.0994	4.9767	0	0	0
WJ	5.152	-13.576	0.0994	4.9767	0	0	0
LL	5.188	-13.801	1.5907	0.3040	0	0	0
WB	5.188	-13.801	1.5907	0.3040	0	0	0
KP	5.188	-13.801	1.5907	0.3040	0	0	0

Species Code	Default B ₁	B ₂	H ₁	H ₂	H ₃	H ₄	H ₅
PY	5.188	-13.801	1.5907	0.3040	0	0	0
DG	5.152	-13.576	0.0994	4.9767	0	0	0
HT	5.152	-13.576	0.0994	4.9767	0	0	0
CH	5.152	-13.576	0.0994	4.9767	0	0	0
WI	5.152	-13.576	0.0994	4.9767	0	0	0
OT	5.152	-13.576	0.0994	4.9767	0	0	0

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. In the PN variant, bark ratio values are determined using estimates from DIB equations. Equations used in the PN variant are shown in {4.2.1} -{4.2.3}. Coefficients (b₁ and b₂) and equation reference for each species are shown in table 4.2.1.

{4.2.1} $DIB = b_1 * (DBH ^ b_2)$; $BRATIO = DIB / DBH$

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

{4.2.3} $DIB = b_1 * DBH$; $BRATIO = b_1$

where:

BRATIO is species-specific bark ratio (bounded to $0.80 \leq BRATIO \leq 0.99$)

DBH is tree diameter at breast height

DIB is tree diameter inside bark at breast height

b₁, b₂ are species-specific coefficients shown in table 4.2.1

Table 4.2.1 Coefficients and equation reference for bark ratio equations in the PN variant.

Species Code	b ₁	b ₂	Equation Used	Equation Source
SF	0.904973	1.0	{4.2.1}	Larsen and Hann, 1985
WF	0.904973	1.0	{4.2.1}	Larsen and Hann, 1985
GF	0.904973	1.0	{4.2.1}	Larsen and Hann, 1985
AF	0.904973	1.0	{4.2.1}	Larsen and Hann, 1985
RF	0.904973	1.0	{4.2.1}	Larsen and Hann, 1985
SS	0.958330	1.0	{4.2.1}	Harlow and Harrar, p. 129
NF	0.904973	1.0	{4.2.1}	Larsen and Hann, 1985
YC	0.837291	1.0	{4.2.1}	Larsen and Hann, 1985
IC	0.837291	1.0	{4.2.1}	Larsen and Hann, 1985
ES	0.90	0	{4.2.3}	Wykoff et al, 1982
LP	0.90	0	{4.2.3}	Wykoff et al, 1982
JP	0.859045	1.0	{4.2.1}	Larsen and Hann, 1985
SP	0.859045	1.0	{4.2.1}	Larsen and Hann, 1985
WP	0.859045	1.0	{4.2.1}	Larsen and Hann, 1985
PP	0.809427	1.016866	{4.2.1}	Larsen and Hann, 1985

Species Code	b ₁	b ₂	Equation Used	Equation Source
DF	0.903563	0.989388	{4.2.1}	Larsen and Hann, 1985
RW	0.7012	1.04862	{4.2.1}	Castle 2021
RC	0.949670	1.0	{4.2.1}	Wykoff et al, 1982
WH	0.933710	1.0	{4.2.1}	Wykoff et al, 1982
MH	0.949670	1.0	{4.2.1}	Wykoff et al, 1982
BM	0.08360	0.94782	{4.2.2}	Pillsbury and Kirkley, 1984
RA	0.075256	0.94373	{4.2.2}	Pil. & Kirk.; Harlow & Harrar
WA	0.075256	0.94373	{4.2.2}	Pil. & Kirk.; Harlow & Harrar
PB	0.08360	0.94782	{4.2.2}	Pillsbury and Kirkley, 1984
GC	0.15565	0.90182	{4.2.2}	Pillsbury and Kirkley, 1984
AS	0.075256	0.94373	{4.2.2}	Pil. & Kirk.; Harlow & Harrar
CW	0.075256	0.94373	{4.2.2}	Pil. & Kirk.; Harlow & Harrar
WO	0.8558	1.0213	{4.2.1}	Gould & Harrington, 2009
WJ	0.949670	1.0	{4.2.1}	Wykoff et al, 1982
LL	0.90	0	{4.2.3}	Wykoff et al, 1982
WB	0.933290	1.0	{4.2.1}	Walters et al; Wykoff et al
KP	0.933290	1.0	{4.2.1}	Walters et al; Wykoff et al
PY	0.933290	1.0	{4.2.1}	Walters et al; Wykoff et al
DG	0.075256	0.94373	{4.2.2}	Pil. & Kirk.; Harlow & Harrar
HT	0.075256	0.94373	{4.2.2}	Pil. & Kirk.; Harlow & Harrar
CH	0.075256	0.94373	{4.2.2}	Pil. & Kirk.; Harlow & Harrar
WI	0.075256	0.94373	{4.2.2}	Pil. & Kirk.; Harlow & Harrar
OT	0.90	0	{4.2.3}	Wykoff et al, 1982

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 PN variant, crown ratios missing in the input data for live and dead trees are predicted using different equations depending on tree size. For all species except redwood, 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.

$$\{4.3.1.1\} X = R_1 + R_2 * HT + R_3 * BA + N(0,SD)$$

$$\{4.3.1.2\} CR = ((X - 1) * 10 + 1) / 100$$

where:

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
 $R_1 - R_3$ are species-specific coefficients shown in table 4.3.1.1

Table 4.3.1.1 Coefficients for the crown ratio equation {4.3.1.1} in the PN variant.

Species Code	R_1	R_2	R_3	SD
SF	8.042774	0.007198	-0.016163	1.3167
WF	8.042774	0.007198	-0.016163	1.3167
GF	8.042774	0.007198	-0.016163	1.3167
AF	8.042774	0.007198	-0.016163	1.3167
RF	8.042774	0.007198	-0.016163	1.3167
SS	8.042774	0.007198	-0.016163	1.3167
NF	8.042774	0.007198	-0.016163	1.3167
YC	7.558538	-0.015637	-0.009064	1.9658
IC	7.558538	-0.015637	-0.009064	1.9658
ES	8.042774	0.007198	-0.016163	1.3167
LP	6.489813	-0.029815	-0.009276	2.0426
JP	6.489813	-0.029815	-0.009276	2.0426
SP	6.489813	-0.029815	-0.009276	2.0426
WP	6.489813	-0.029815	-0.009276	2.0426
PP	8.477025	-0.018033	-0.018140	1.3756
DF	8.477025	-0.018033	-0.018140	1.3756
RC	7.558538	-0.015637	-0.009064	1.9658
WH	7.558538	-0.015637	-0.009064	1.9658
MH	5.000000	0.000000	0.000000	0.5
BM	5.000000	0.000000	0.000000	0.5
RA	5.000000	0.000000	0.000000	0.5
WA	5.000000	0.000000	0.000000	0.5
PB	5.000000	0.000000	0.000000	0.5
GC	5.000000	0.000000	0.000000	0.5
AS	5.000000	0.000000	0.000000	0.5
CW	5.000000	0.000000	0.000000	0.5
WO	5.000000	0.000000	0.000000	0.5
WJ	9.000000	0.000000	0.000000	0.5
LL	6.489813	-0.029815	-0.009276	2.0426
WB	6.489813	-0.029815	-0.009276	2.0426
KP	6.489813	-0.029815	-0.009276	2.0426
PY	6.489813	-0.029815	-0.009276	2.0426
DG	5.000000	0.000000	0.000000	0.5

Species Code	R ₁	R ₂	R ₃	SD
HT	5.000000	0.000000	0.000000	0.5
CH	5.000000	0.000000	0.000000	0.5
WI	5.000000	0.000000	0.000000	0.5
OT	5.000000	0.000000	0.000000	0.5

A Weibull-based crown model developed by Dixon (1985) as described in Dixon (2002) is used to predict crown ratio for all live 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 {4.3.1.3}. Weibull parameters are then estimated from the average stand crown ratio using equations in equation set {4.3.1.4}. Individual tree crown ratio is then set from the Weibull distribution, equation {4.3.1.5} based on a tree's relative position in the diameter distribution and multiplied by a scale factor, shown in equation {4.3.1.6}, 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. Species equation index number is shown in table 4.3.1.2 with equation coefficients for each index shown in table 4.3.1.2.

$$\{4.3.1.3\} ACR = d_0 + d_1 * RELSDI * 100.0$$

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

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

$$A = a_0$$

$$B = b_0 + b_1 * ACR \quad (B \geq 3)$$

$$C = c_0 + c_1 * ACR \quad (C \geq 2)$$

$$\{4.3.1.5\} Y = 1 - \exp(-((X-A)/B)^C)$$

$$\{4.3.1.6\} SCALE = 1 - (0.00167 * (CCF - 100))$$

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

a₀, b₀₋₁, c₀₋₁, and d₀₋₁ are species-specific coefficients shown in table 4.3.1.2

Table 4.3.1.2 Species index number used in assigning Weibull parameters in the PN variant.

Species Code	Species Index Number	Species Code	Species Index Number
SF	1	BM	12

Species Code	Species Index Number	Species Code	Species Index Number
WF	2	RA	13
GF	2	WA	14
AF	3	PB	14
RF	3	GC	14
SS	17	AS	14
NF	4	CW	14
YC	15	WO	14
IC	11	WJ	14
ES	11	LL	11
LP	16	WB	11
JP	6	KP	11
SP	5	PY	11
WP	5	DG	14
PP	6	HT	14
DF	7	CH	14
RC	8	WI	14
WH	9	OT	14
MH	10		

Table 4.3.1.3 Coefficients for the Weibull parameter equations {4.3.1.3} and {4.3.1.4} in the WC variant.

Species Index	a ₀	b ₀	b ₁	c ₀	c ₁	d ₀	d ₁
1	0.0	-0.171680	1.161549	2.8263	0.0	5.073342	-0.011430
2	0.0	0.130939	1.093406	1.355139	0.350472	5.212394	-0.011623
3	1.0	-0.981113	1.092273	1.326047	0.318386	4.860467	-0.006173
4	0.0	-0.135807	1.147712	3.017494	0.0	5.568864	-0.021293
5	0.0	0.019948	1.108738	2.621230	0.186734	4.279655	-0.002484
6	0.0	-0.036696	1.132792	2.876094	0.0	5.073273	-0.020988
7	0.0	-0.012061	1.119712	3.2126	0.0	5.666442	-0.025199
8	0.0	-0.062693	1.139657	1.7664	0.0	4.481330	-0.018092
9	0.0	0.073435	1.107183	2.6237	0.0	5.671345	-0.023463
10	0.0	0.162672	1.073404	3.288501	0.0	6.484942	-0.023248
11	0.0	0.196054	1.073909	0.345647	0.620145	5.417431	-0.011608
12	1.0	-0.818809	1.054176	-2.366108	1.202413	4.420000	-0.010660
13	1.0	0.035786	1.121389	2.0408	0.0	4.656659	-0.022612
14	0.0	-0.238295	1.180163	3.044134	0.0	4.625125	-0.016042
15	1.0	-0.811424	1.056190	-3.831124	1.401938	5.200550	-0.014890
16	0.0	-0.131210	1.159760	.598238	0.0	4.890318	-0.018837
17	0.0	-0.107413	1.140775	3.0712	0.0	5.812879	-0.028504

For redwood, equation {4.3.1.7} and equation {4.3.1.8} are used to compute crown ratio for live trees less than 1" and dead trees of all sizes. For live trees greater than 1", equation {4.3.1.7} and equation {4.3.1.9} are used to compute crown ratio.

$$\{4.3.1.7\} X = -1.021064 + 0.309296 * \ln(H*12/D) + 0.869720 * PRD - 0.116274 * D/QMDPLT$$

$$\{4.3.1.8\} CR = 1 / (1 + \exp(X + N(0,SD)))$$

$$\{4.3.1.9\} CR = 1 / (1 + \exp(X))$$

where:

<i>CR</i>	is crown ratio expressed as a proportion (bounded to $0.05 \leq CR \leq 0.95$)
<i>D</i>	is tree diameter at breast height
<i>H</i>	is tree height
<i>PRD</i>	is relative density of the inventory point (point Zeide SDI / point SDI max)
<i>QMDPLT</i>	is quadratic mean diameter of the inventory point (constrained to minimum of 1")
<i>N(0,SD)</i>	is a random increment from a normal distribution with a mean of 0 and a standard deviation of SD (0.15)

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 {4.3.1.3}–{4.3.1.6}, for all species except redwood. For redwood, crown ratio predicted at the end of the projection cycle is estimated using equations {4.3.1.7} and {4.3.1.9}. 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} – {4.3.1.2} are not used when estimating crown ratio change.

4.3.3.1 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:

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

4.4 Crown Width Relationships

The PN 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} – {4.4.6}, 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 table 4.4.1 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

$$DBH \geq MinD: CW = a_1 + (a_2 * DBH) + (a_3 * DBH^2) + (a_4 * CR\%) + (a_5 * BA) + (a_6 * HI)$$

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

{4.4.2} Crookston (2003); Equation 03 (used only for Mountain Hemlock)

$$HT < 5.0: CW = [0.8 * HT * \text{MAX}(0.5, CR * 0.01)] * [1 - (HT - 5) * 0.1] * a_1 * DBH^{a_2} * HT^{a_3} * CL^{a_4} * (HT - 5) * 0.1$$

$$5.0 \leq HT < 15.0: CW = 0.8 * HT * \text{MAX}(0.5, CR * 0.01)$$

$$HT \geq 15.0: CW = a_1 * (DBH^{a_2}) * (HT^{a_3}) * (CL^{a_4})$$

{4.4.3} Crookston (2003); Equation 03

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

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

{4.4.4} Crookston (2005); Equation 04

$$DBH \geq MinD: CW = a_1 * DBH^{a_2}$$

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

{4.4.5} Crookston (2005); Equation 05

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

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

{4.4.6} Donnelly (1996); Equation 06

$$DBH \geq MinD: CW = a_1 * DBH^{a_2}$$

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

where:

BF is a species-specific coefficient based on forest code shown in table 4.4.3

CW is tree maximum crown width

CL is tree crown length

CR% is crown ratio expressed as a percent

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

HI is the Hopkins Index

$$HI = (ELEVATION - 5449) / 100 * 1.0 + (LATITUDE - 42.16) * 4.0 + (-116.39 - LONGITUDE) * 1.25$$

$a_1 - a_6$ are species-specific coefficients shown in table 4.4.1

Table 4.4.1 Coefficients for crown width equations {4.4.1}–{4.4.6} in the PN variant.

Species Code	Equation Number*	a_1	a_2	a_3	a_4	a_5	a_6
SF	01105	4.47990	0.45976	-0.10425	0.11866	0.06762	-0.00715
WF	01505	5.03120	0.53680	-0.18957	0.16199	0.04385	-0.00651
GF	01703	1.03030	1.14079	0.20904	0.38787	0	0
AF	01905	5.88270	0.51479	-0.21501	0.17916	0.03277	-0.00828
RF	02006	3.11460	0.57800	0	0	0	0
SS	09805	8.48000	0.70692	-0.38812	0.17127	0	0
NF	02206	3.06140	0.62760	0	0	0	0
YC	04205	3.37560	0.45445	-0.11523	0.22547	0.08756	-0.00894
IC	08105	5.04460	0.47419	-0.13917	0.14230	0.04838	-0.00616
ES	09305	6.75750	0.55048	-0.25204	0.19002	0	-0.00313
LP	10805	6.69410	0.81980	-0.36992	0.17722	-0.01202	-0.00882
JP	11605	4.02170	0.66815	-0.11346	0.09689	-0.63600	0
SP	11705	3.59300	0.63503	-0.22766	0.17827	0.04267	-0.00290
WP	11905	5.38220	0.57896	-0.19579	0.14875	0	-0.00685
PP	12205	4.77620	0.74126	-0.28734	0.17137	-0.00602	-0.00209
DF	20205	6.02270	0.54361	-0.20669	0.20395	-0.00644	-0.00378
RW	21104	3.70230	0.52618	0	0	0	0
RC	24205	6.23820	0.29517	-0.10673	0.23219	0.05341	-0.00787
WH	26305	6.03840	0.51581	-0.21349	0.17468	0.06143	-0.00571
MH	26403	6.90396	0.55645	-0.28509	0.20430	0	0
BM	31206	7.51830	0.44610	0	0	0	0
RA	35106	7.08060	0.47710	0	0	0	0
WA	31206	7.51830	0.44610	0	0	0	0

Species Code	Equation Number*	a ₁	a ₂	a ₃	a ₄	a ₅	a ₆
PB	37506	5.89800	0.48410	0	0	0	0
GC	63102	3.11500	0.79660	0	0.07450	-0.0053	0.05230
AS	74605	4.79600	0.64167	-0.18695	0.18581	0	0
CW	74705	4.4327	0.41505	-0.23264	0.41477	0	0
WO	81505	2.48570	0.70862	0	0.10168	0	0
WJ	06405	5.14860	0.73636	-0.46927	0.39114	-0.05429	0
LL	07204	2.25860	0.68532	0	0	0	0
WB	10105	2.23540	0.66680	-0.11658	0.16927	0	0
KP	10305	4.00690	0.84628	-0.29035	0.13143	0	-0.00842
PY	23104	6.12970	0.45424	0	0	0	0
DG	35106	7.08060	0.47710	0	0	0	0
HT	35106	7.08060	0.47710	0	0	0	0
CH	35106	7.08060	0.47710	0	0	0	0
WI	31206	7.51830	0.44610	0	0	0	0
OT	12205	4.77620	0.74126	-0.28734	0.17137	-0.00602	-0.00209

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

Table 4.4.2 *MinD* values and data bounds for equations {4.4.1}–{4.4.6} in the PN variant.

Species Code	Equation Number*	MinD	EL min	EL max	HI min	HI max	CW max
SF	01105	1.0	4	72	n/a	n/a	33
WF	01505	1.0	2	75	n/a	n/a	35
GF	01703	1.0	n/a	n/a	n/a	n/a	40
AF	01905	1.0	10	85	n/a	n/a	30
RF	02006	1.0	n/a	n/a	n/a	n/a	65
SS	09805	1.0	n/a	n/a	n/a	n/a	50
NF	02206	1.0	n/a	n/a	n/a	n/a	40
YC	04205	1.0	16	62	n/a	n/a	59
IC	08105	1.0	5	62	n/a	n/a	78
ES	09305	1.0	1	85	n/a	n/a	40
LP	10805	1.0	1	79	n/a	n/a	40
JP	11605	1.0	n/a	n/a	n/a	n/a	39
SP	11705	1.0	5	75	n/a	n/a	56
WP	11905	1.0	10	75	n/a	n/a	35
PP	12205	1.0	13	75	n/a	n/a	50
DF	20205	1.0	1	75	n/a	n/a	80
RW	21104	1.0	n/a	n/a	n/a	n/a	39
RC	24205	1.0	1	72	n/a	n/a	45
WH	26305	1.0	1	72	n/a	n/a	54
MH	26403	n/a	n/a	n/a	n/a	n/a	45
BM	31206	1.0	n/a	n/a	n/a	n/a	30

Species Code	Equation Number*	MinD	EL min	EL max	HI min	HI max	CW max
RA	35106	1.0	n/a	n/a	n/a	n/a	35
WA	31206	1.0	n/a	n/a	n/a	n/a	30
PB	37506	1.0	n/a	n/a	n/a	n/a	25
GC	63102	5.0	n/a	n/a	-55	15	41
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
WJ	06405	1.0	n/a	n/a	n/a	n/a	36
LL	07204	1.0	n/a	n/a	n/a	n/a	33
WB	10105	1.0	n/a	n/a	n/a	n/a	40
KP	10305	1.0	12	49	n/a	n/a	46
PY	23104	1.0	n/a	n/a	n/a	n/a	30
DG	35106	1.0	n/a	n/a	n/a	n/a	35
HT	35106	1.0	n/a	n/a	n/a	n/a	35
CH	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
OT	12205	1.0	13	75	n/a	n/a	50

Table 4.4.3 *BF* values for equation {4.4.5} in the PN variant.

Species Code	Location Code				
	609 800	612	708	709	712
SF	1.032		1.296		
SS	1.146				
LP	1.114		0.944	0.903	0.944
DF		0.977			0.961
RC	0.941	0.905	1.115		0.973
WH		0.924	1.260	1.087	1.028
WF			1.130		
GF			1.086	0.972	
AF			1.038	0.936	
NF			1.301		
YC			1.493	1.127	
WP			1.081	1.081	
MH			1.106		0.900
RA					0.810
IC					0.821
PP				1.070	0.951
ES				0.857	
SP				1.097	

*Any *BF* values not listed in Table 4.4.3 are assumed to be *BF* = 1.0

4.5 Crown Competition Factor

The PN 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.

Crown competition factor for an individual tree is calculated using equation set {4.5.1}. For Douglas-fir and ponderosa pine greater than 1.0 inch DBH, the coefficients were derived from Paine and Hann (1982). All others use the Inland Empire variant coefficients (Wykoff, et.al 1982). All species coefficients are shown in table 4.5.1.

{4.5.1} CCF Equations

$$DBH \geq 1.0'': CCF_t = R_1 + (R_2 * DBH) + (R_3 * DBH^2)$$

$$0.1 \leq DBH < 1.0'': CCF_t = (R_1 + R_2 + R_3) * DBH$$

$$DBH < 0.1'': CCF_t = 0.001$$

where:

CCF_t is crown competition factor for an individual tree

DBH is tree diameter at breast height

$R_1 - R_3$ are species-specific coefficients shown in table 4.5.1

Table 4.5.1 Coefficients for the CCF equation set {4.5.1} in the PN variant.

Species Code	R_1	R_2	R_3
SF	0.10142	0.0432725	0.00461575
WF	0.0690403	0.0224682	0.00182799
GF	0.0690403	0.0224682	0.00182799
AF	0.0245276	0.0114741	0.0013419
RF	0.0172	0.00876	0.00112
SS	0.0761779	0.0421908	0.0058418
NF	0.0245276	0.0114741	0.0013419
YC	0.0194415	0.0142461	0.00260979
IC	0.0194415	0.0142461	0.00260979
ES	0.0288484	0.0173091	0.00259636
LP	0.0220871	0.0252424	0.0072121
JP	0.0219	0.0168	0.00325
SP	0.0219	0.0168	0.00325
WP	0.0387616	0.0268821	0.00466086
PP	0.0219	0.0168	0.00325
DF	0.0387616	0.0268821	0.00466086
RW	0.0387616	0.0268821	0.00466086
RC	0.0288484	0.0237999	0.00490874
WH	0.037577	0.0232893	0.00360853
MH	0.037577	0.0232893	0.00360853

Species Code	R ₁	R ₂	R ₃
BM	0.0160051	0.0166659	0.00433848
RA	0.115394	0.0441381	0.0042207
WA	0.115394	0.0441381	0.0042207
PB	0.0170887	0.0213617	0.00667579
GC	0.0160051	0.0166659	0.00433848
AS	0.0170887	0.0213617	0.00667579
CW	0.000450757	0.0029209	0.00473186
WO	0.0170887	0.0213617	0.00667579
WJ	0.0318054	0.0215065	0.00363562
LL	0.0219	0.0168	0.00325
WB	0.01925	0.01676	0.00365
KP	0.01925	0.01676	0.00365
PY	0.0318054	0.0215065	0.00363562
DG	0.0160051	0.0166659	0.00433848
HT	0.0170887	0.0213617	0.00667579
CH	0.0160051	0.0166659	0.00433848
WI	0.0160051	0.0166659	0.00433848
OT	0.0220871	0.0252424	0.0072121

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 PN variant.

The small tree model is diameter-growth driven, meaning diameter growth is estimated first, then height growth is estimated from diameter growth. These relationships are discussed in the following sections and were developed by Gould and Harrington (2012).

4.6.1 Small Tree Height Growth

With the exception of redwood, for trees being projected with the small tree equations, diameter growth is predicted first, and then height growth. Five year height increment is calculated using a height-diameter ratio equation {4.6.1.1}.

{4.6.1.1} Small Tree Height Growth

$$H5 = D5/a_1$$

Where:

D5 is 5-yr diameter increment (in)

H5 is 5-yr height increment (ft)

*a*₁ is a species-specific coefficient from table 4.6.1.1

For trees that have not yet reached breast height, the *D5* value (equation 4.6.2.1) is temporarily calculated to calculate *H5* using equation {4.6.2.2}. If the new height is less than 4.5 feet, than

D5 value remains 0. If the new height is greater than 4.5 feet then the trees diameter is calculated using equation 4.6.2.2

Table 4.6.1.1 Coefficient (a_1) and equation reference for small-tree height increment equations {4.6.1.1} and equation {4.6.2.2} in the PN variant.

Species Code	a_1
SF	0.2474
WF	0.2175
GF	0.1797
AF	0.2056
RF	0.2168
SS	0.2168
NF	0.2822
YC	0.2168
IC	0.2815
ES	0.1704
LP	0.1682
JP	0.2168
SP	0.2168
WP	0.2168
PP	0.2369
DF	0.1635
RC	0.1829
WH	0.1727
MH	0.3029
BM	0.2168
RA	0.2168
WA	0.2168
PB	0.2168
GC	0.2168
AS	0.2168
CW	0.2168
WO	0.2168
WJ	0.2168
LL	0.2168
WB	0.2168
KP	0.1682
PY	0.2168
DG	0.2168
HT	0.2168
CH	0.2168
WI	0.2168

Species Code	a ₁
OT	0.1635

For redwood, a potential height growth curve is used to estimate small tree height growth. Height growth is computed by subtracting the current predicted height from the predicted height 5 years in the future, as depicted in equation {4.6.1.2}.

$$\{4.6.1.2\} POTHTG = 2.242202 * SI * [1.0 - \exp(-0.010742 * AGE1)]^{0.919076}$$

where:

POTHTG is predicted tree height, used for current and future height growth

SI is species site index

AGE1 is tree age

$$AGE1 = 1 / -0.010742 * (\ln(1 - (HT/2.242202/SI)^{1/0.919076}))$$

For all species, a small random error is then added to the height growth estimate. The estimated height growth is then adjusted to account for cycle length, user defined small-tree height growth adjustments, and adjustments due to small tree height increment calibration from 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 {4.6.1.3}, and applied as shown in equation {4.6.1.4}. The range of diameters for each species is shown in table 4.6.1.2.

{4.6.1.3}

$$DBH \leq X_{min}: XWT = 0$$

$$X_{min} < DBH < X_{max}: XWT = (DBH - X_{min}) / (X_{max} - X_{min})$$

$$DBH \geq X_{max}: XWT = 1$$

{4.6.1.4}

$$\text{Estimated growth} = [(1 - XWT) * STGE] + [XWT * LTGE]$$

$$\text{Redwood estimated growth} = [(1 - XWT) * ((STGE+LTGE)/2.0)] + [XWT * LTGE]$$

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 4.6.1.2 Diameter bounds by species in the PN variant.

Species Code	X_{min}	X_{max}	Species Code	X_{min}	X_{max}
SF	2.0	4.0	MH	2.0	4.0
WF	2.0	4.0	BM	2.0	4.0
GF	2.0	4.0	RA	2.0	4.0
AF	2.0	4.0	WA	2.0	4.0
RF	2.0	4.0	PB	2.0	4.0
SS	2.0	4.0	GC	2.0	4.0
NF	2.0	4.0	AS	2.0	4.0
YC	2.0	4.0	CW	2.0	4.0
IC	2.0	4.0	WO	2.0	4.0
ES	2.0	4.0	WJ	2.0	4.0
LP	1.0	3.0	LL	2.0	4.0
JP	2.0	4.0	WB	2.0	4.0
SP	2.0	4.0	KP	2.0	4.0
WP	2.0	4.0	PY	2.0	4.0
PP	2.0	4.0	DG	2.0	4.0
DF	2.0	4.0	HT	2.0	4.0
RW	2.0	10.0	CH	2.0	4.0
RC	2.0	4.0	WI	2.0	4.0
WH	2.0	4.0	OT	2.0	4.0

4.6.2 Small Tree Diameter Growth

The small-tree diameter model predicts 5-year diameter increment growth for small trees. For all species except redwood, diameter growth is estimated using equations {4.6.2.1} and coefficients for these equations are shown in table 4.6.2.1. In the case that height is initially less than 4.5 feet, but after height growth is calculated a tree grows to be greater than 4.5 feet, a height-diameter equation {4.6.2.2} is used to calculate an initial diameter for the tree.

{4.6.2.1} Small Tree Diameter Growth

$$HT < 4.5: D5 = 0$$

$$HT > 4.5: D5 = DMAX / (1 + \exp(c_0 + c_1*PTBA + c_2*PTBA2 + c_3*PTBAL + c_4*PTBAL2 + c_5*OPEN + c_6*CR + c_7*RELHT + c_8*RELHT2 + c_9*SI))$$

where:

$$OPEN = 1/(1 + \exp(-3.1 + 0.18*PTBA))$$

{4.6.2.2} Small tree Height – Diameter Equation

$$DBH = (HT - 4.5) \cdot a_1$$

where:

HT is tree height

<i>DBH</i>	is tree diameter at breast height
<i>D5</i>	is 5-yr diameter increment (in)
<i>DMAX</i>	is maximum diameter increment for the species (in).
<i>OPEN</i>	is an adjustment for open grown conditions
<i>PTBA</i>	is basal area (sq. ft. /ac.) on the inventory point where the tree is located
<i>PTBA2</i>	is the transformation of <i>PTBA</i> : $\log(PTBA + 2.71)$
<i>PTBAL</i>	is basal area of trees larger than the subject tree (ft ² /acre) on the inventory point Where the tree is located
<i>PTBAL2</i>	is the transformation of <i>PTBAL</i> : $\log(PTBAL + 2.71)$
<i>CR</i>	is crown ratio expressed as a proportion
<i>RELHT</i>	is tree height / height of 40 largest trees/acre, measured at the stand level (proportion, bound between 0 and 1.5)
<i>RELHT2</i>	is $RELHT^{0.5}$
<i>SI</i>	is species site index
<i>C₀-C₉</i>	are species-specific coefficients in table 4.6.2.1
<i>a₁</i>	are species-specific coefficients in table 4.6.1.1

Table 4.6.1.1 Coefficients (*c₀ – c₉*) and equation reference for small-tree diameter increment equations {4.6.1.1} in the PN variant.

Species Code	<i>DMAX</i>	Model Coefficients									
		<i>C₀</i>	<i>C₁</i>	<i>C₂</i>	<i>C₃</i>	<i>C₄</i>	<i>C₅</i>	<i>C₆</i>	<i>C₇</i>	<i>C₈</i>	<i>C₉</i>
SF	1.7035	2.9445	0	0	0.0068	0	0	-0.1895	0	-1.4049	-0.0168
WF	1.4964	1.7536	0	0.2928	0.0009	0	-0.0446	-2.0349	0	-1.3839	-0.0033
GF	1.6389	2.3571	0.0052	0	0.0006	0	-0.4269	-1.2219	0	0	-0.0170
AF	1.1961	2.5839	0	0.0410	0.0020	0	-0.0152	-2.2060	0	-0.5915	-0.0009
RF	1.5146	2.4743	0	0	0.0032	0	-0.8934	-2.2709	0	-1.0690	0
SS	3.3957	3.8205	0	0.0523	0.0051	0	-0.4102	-1.6968	0	-1.4001	-0.0109
NF	2.9394	0.3376	0	0	0.0101	0	0	0	0	0	-0.0043
YC	1.5400	-2.0216	0.0063	0	0	0.7175	0	0	0	0	0
IC	1.6825	0.5996	0	0	0.0080	0	0	0	-1.0479	0	0
ES	1.8853	0.0452	0.0080	0	0.0071	0	0	0	0	0	0
LP	1.6535	1.7400	0	0.3718	0.0027	0	-0.1712	-2.1359	0	-0.7266	-0.0074
JP	1.7985	1.8451	0	0	0.0167	0	-1.4737	0	0	-0.4103	-0.0112
SP	2.4740	3.8085	0	0	0.0023	0	-0.4265	-2.0913	0	-1.3932	-0.0093
WP	2.4740	3.8085	0	0	0.0023	0	-0.4265	-2.0913	0	-1.3932	-0.0093
PP	1.7985	1.8451	0	0	0.0167	0	-1.4737	0	0	-0.4103	-0.0112
DF	5.3730	2.4473	0	0	0.0098	0	-0.4290	-0.1710	0	-0.1879	-0.0110
RC	2.7899	1.6815	0	0	0.0068	0	0	0	0	-0.6049	-0.0121
WH	3.4187	2.9527	0	0	0.0066	0	0	-0.4734	0	-0.7394	-0.0207
MH	1.3834	2.6762	0.0024	0	0.0006	0	-0.4309	-1.6205	0	-0.5930	-0.0051
BM	3.0939	-1.2421	0.0124	0	0	0.4161	0	0	0	0	0
RA	3.0939	1.4593	0	0	0.0085	0	-0.6000	0	0	-1.2280	0
WA	2.0110	-1.1900	0.0158	0	0	0.6600	0	0	0	0	0
PB	2.1657	-1.2421	0.0124	0	0	0.7813	0	0	0	0	0
GC	3.0939	-1.2421	0.0124	0	0	0.6382	0	0	0	0	0
AS	2.4751	-1.2421	0.0124	0	0	0.6013	0	0	0	0	0
CW	3.7127	-1.2421	0.0124	0	0	0.6013	0	0	0	0	0
WO	0.9861	-2.1910	0	0	0	0.7191	-3.1321	0	0	0	0
WJ	1.2192	0.3755	0.0120	0	0	0	0	0	0	0	0

Species Code	D _{MAX}	Model Coefficients									
		C ₀	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈	C ₉
LL	0.6234	1.0527	0	0.3580	0.0019	0	0	-0.6008	0	-0.7451	-0.0101
WB	0.8070	2.4949	0	0	0.0049	0	-0.2085	-1.7001	0	-0.7952	-0.0177
KP	0.5859	-0.8085	0	0.5001	0	0	0	0	0	0	-0.0081
PY	0.8601	1.5156	0	0	0.0012	0	0	-0.5478	0	-0.6123	0
DG	1.0032	-3.8345	0	0	0	1.0701	0	0	0	0	0
HT	1.8903	3.5521	0	0	0.0002	0	0	-0.5932	0	-0.5029	-0.0038
CH	2.1657	-1.2421	0.0124	0	0	0.7312	0	0	0	0	0
WI	2.1657	-1.2421	0.0124	0	0	0.6598	0	0	0	0	0
OT	5.3730	2.4473	0	0	0.0098	0	-0.3575	-0.1710	0	-0.1879	-0.0110

For redwood, small tree height growth is predicted first, and then diameter growth. 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. Diameter growth is predicted with the height-diameter equations shown in section 4.1 inverted, so that diameter is a function of height. Diameter growth estimates for redwood are weighted with the diameter growth estimates from the large-tree model when DBH is between 2" and 7", in a similar manner to the weighting explained in section 4.6.1. By definition, diameter growth is zero for trees less than 4.5 feet tall.

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 PN 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 PN variant predicts diameter growth using equation {4.7.1.1} for all species except red alder and redwood. Coefficients for this equation are shown in tables 4.7.1.1 – 4.7.1.6.

In the PN variant, each species is mapped into a species index as shown in table 4.7.1.1. The coefficients for each species for equation 4.7.1.1 will depend on the species index of the subject species.

$$\{4.7.1.1\} \ln(DDS) = b_1 + (b_2 * EL) + (b_3 * EL^2) + (b_4 * \ln(SI)) + (b_5 * \sin(ASP) * SL) + (b_6 * \cos(ASP) * SL) + (b_7 * SL) + (b_8 * SL^2) + (b_9 * \ln(DBH)) + (b_{10} * CR) + (b_{11} * CR^2) + (b_{12} * DBH^2) + (b_{13} * BAL / (\ln(DBH + 1.0))) + (b_{14} * PCCF) + (b_{15} * RELHT) + (b_{16} * \ln(BA)) + (b_{17} * BAL) + (b_{18} * BA)$$

where:

<i>DDS</i>	is the square of the diameter growth increment
<i>EL</i>	is stand elevation in hundreds of feet (if species index 14, $EL \leq 30$)
<i>SI</i>	is species site index in feet (if species index =19, $SI = SI_{King}$; if species index =10 do a metric to feet conversion when using a Means site index curve)
<i>ASP</i>	is stand aspect
<i>SL</i>	is stand slope
<i>DBH</i>	is tree diameter at breast height
<i>BAL</i>	is total basal area in trees larger than the subject tree
<i>CR</i>	is crown ratio expressed as a proportion
<i>PCCF</i>	is crown competition factor on the inventory point where the tree is established
<i>RELHT</i>	is tree height divided by average height of the 40 largest diameter trees in the stand bounded to $RELHT \leq 1.5$)
<i>BA</i>	is total stand basal area
b_1	is a location-specific coefficient shown in table 4.7.1.3
b_2 - b_{18}	are species-specific coefficients shown in tables 4.7.1.2 and 4.7.1.5

Table 4.7.1.1 Mapped species index for each species for large-tree diameter growth in the PN variant.

Species Code	Species Index	Species Code	Species Index
SF	1	BM	12
WF	2	RA	13
GF	2	WA	14
AF	3	PB	14
RF	4	GC	14
SS	18	AS	14
NF	4	CW	14
YC	15	WO	19
IC	11	WJ	14
ES	11	LL	11
LP	16	WB	11
JP	6	KP	11
SP	5	PY	11
WP	5	DG	14
PP	6	HT	14
DF	7	CH	14
RW	11	WI	14
RC	8	OT	14
WH	9		
MH	10		

Table 4.7.1.2 Coefficients (b_2 - b_{18}) for species with a species index 1-9 for equation {4.7.1.1} in the PN variant.

Coefficient	Species Index								
	1	2	3	4	5	6	7	8	9
b_2	-0.023858	-0.003051	-0.003773	-0.069045	-0.023376	-0.003784	-0.009845	-0.009564	-0.018444
b_3	0	0	0	0.000608	0	0.0000666	0	0	0
b_4	0.541881	0.318254	0.349888	0.684939	0.40401	1.011504	0.495162	0.708166	0.634098
b_5	0.096326	0	0.02216	-0.207659	0	0	0.003263	-0.10602	0.061254
b_6	-0.217205	0	-0.782418	-0.374512	0	0	0.014165	-0.106936	-0.056608
b_7	-0.265612	0	0.319956	0.400223	0	0	-0.340401	-0.30349	0.736143
b_8	0	0	0	0	0	0	0	0	-1.082191
b_9	0.919402	0.905119	0.993986	0.904253	0.84469	0.73875	0.802905	0.744005	0.641956
b_{10}	1.290568	1.754811	1.522401	4.123101	1.59725	3.454857	1.936912	0.771395	1.471926
b_{11}	0.125823	0	0	-2.68934	0	-1.773805	0	0	0
b_{12}^*									
b_{13}	-0.002133	-0.005355	-0.002979	-0.006368	-0.003726	-0.013091	-0.001827	-0.01624	-0.012589
b_{14}	0	0	0	-0.000471	-0.000257	-0.000593	0	0	0
b_{15}	0	-0.000661	0	0	0	0	0	0	0
b_{16}	-0.136818	0	0	0	0	-0.131185	-0.129474	-0.130036	-0.085525

Coefficient	Species Index								
	1	2	3	4	5	6	7	8	9
b ₁₇	0	0	0	0	0	0	-0.001689	0.003883	0.002385
b ₁₈	0	0	-0.000137	0	0	0	0	0	0

*See table 4.7.1.4 for b₁₂ values

Table 4.7.1.2 (continued) Coefficients (b₂- b₁₈) for species with a species index 10-19 for equation {4.7.1.1} in the PN variant.

Coefficient	Species Index							
	10	11	12	14	15	16	18	19
b ₂	-0.003809	0	-0.012111	-0.075986	0	-0.005414	0.007009	0
b ₃	0	0	0	0.001193	0	0	0	0
b ₄	0.20804	0.252853	1.965888	0.227307	0.244694	0.391327	0	0.14995
b ₅	-0.12613	0	0	-0.86398	0.679903	0.37886	0.100081	0
b ₆	-0.104495	0	0	0.085958	-0.023186	0.207853	-0.221095	0
b ₇	0.411602	0	0	0	0	-0.06644	-0.169141	0
b ₈	0	0	0	0	0	0	0	0
b ₉	0.857131	0.879338	1.024186	0.889596	0.81688	0.478504	1.049845	1.66609
b ₁₀	1.505513	1.970052	0.459387	1.732535	2.471226	1.905011	1.632468	0
b ₁₁	0	0	0	0	0	0	0	0
b ₁₂ *								
b ₁₃	-0.004101	-0.004215	-0.010222	-0.001265	-0.00595	-0.004706	-0.000086	0
b ₁₄	-0.000201	0	-0.000757	0	0	0	0	0
b ₁₅	0	0	0	0	0	0	0	0
b ₁₆	0	0	0	0	0	0	-0.198636	0
b ₁₇	0	0	0	0	0	0	-0.002319	-0.00326
b ₁₈	0	-0.000173	0	-0.000981	-0.000147	-0.000114	0	-0.00204

*See table 4.7.1.4 for b₁₂ values

Table 4.7.1.3 b₁ values by location class for species that have a species index 1 – 9 for equation {4.7.1.1} in the PN variant.

Location Class	Species Index								
	1	2	3	4	5	6	7	8	9
1	-0.627531	-0.64392	-1.888949	-1.401865	-0.58957	-2.922255	-0.739354	-0.68825	-0.59446
2	0	0	0	-1.127977	-0.909553	0	-0.1992	-0.40559	-0.522658
3	0	0	0	0	0	0	0	0	0

Table 4.7.1.3 (continued) b₁ values by location class for species that have a species index 10 – 19 for equation {4.7.1.1} in the PN variant.

Location Class	Species Index							
	10	11	12	14	15	16	18	19
1	-1.052161	-1.310067	-7.753469	-0.107648	-1.277664	-0.524624	2.075598	-1.33299
2	0	-1.432659	-8.279266	-0.098335	-1.178041	-0.803095	2.100904	0
3	0	0	0	0	0	0	0	0

Table 4.7.1.4 Location class by species index and location code in the PN variant.

Location Code	Species Index																	
	1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	18	19	
609 – Olympic	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
612 – Siuslaw	1	1	1	2	2	1	2	2	2	1	2	2	2	2	2	2	1	
800 – Quinalt Indian Res.	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	
708 – BLM Salem	1	1	1	2	2	1	2	2	2	1	2	2	2	2	2	2	1	
709 – BLM Eugene	1	1	1	2	2	1	2	2	2	1	2	2	2	2	2	2	1	
712 – BLM Coos Bay	1	1	1	2	2	1	2	2	2	1	2	2	2	2	2	2	1	

Table 4.7.1.5 b_{12} values by location class for species that have a species index 1 – 9 for equation {4.7.1.1} in the PN variant.

Location Class	Species Index								
	1	2	3	4	5	6	7	8	9
1	-0.0002641	-0.0003137	-0.0002621	-0.0003996	-0.0000596	-0.0004708	-0.0000896	-0.0000572	-0.0001736
2	0	0	0	0	0	0	-0.0000641	-0.0000862	-0.000104

Table 4.7.1.5 (continued) b_{12} values by location class for species that have a species index 10 – 19 for equation {4.7.1.1} in the PN variant.

Location Class	Species Index							
	10	11	12	14	15	16	18	19
1	-0.0002214	-0.0001323	-0.0001737	0	-0.0002536	0	-0.0002123	-0.00154
2	0	0	0	0	0	0	-0.0001361	0

Table 4.7.1.6 Location class by species index and location code in the PN variant.

Location Code	Species Index																	
	1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	18	19	
609 – Olympic	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
612 – Siuslaw	1	1	1	1	1	1	2	2	2	1	1	1	1	1	1	2	1	
800 – Quinalt Indian Res.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
708 – BLM Salem	1	1	1	1	1	1	2	2	2	1	1	1	1	1	1	2	1	
709 – BLM Eugene	1	1	1	1	1	1	2	2	2	1	1	1	1	1	1	2	1	
Location Code	Species Index																	
	1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	18	19	

712 – BLM Coos Bay	1	1	1	1	1	1	2	2	2	1	1	1	1	1	2	1
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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

$$DBH \leq 18.0'': DG = CON - (0.166496 * DBH) + (0.004618 * DBH^2)$$

$$DBH > 18.0'': DG = CON - (CON / 10) * (DBH - 18)$$

$$CON = (3.2505 - 0.00303 * BA)$$

where:

DG is potential diameter growth
DBH is tree diameter at breast height
BA is stand basal area

Diameter growth for redwood is predicted using equation {4.7.1.3}.

$$\begin{aligned} \{4.7.1.3\} DI = & \exp(-3.502444 + (0.185911 * \ln(DBH)) + (-0.000073 * DBH^2) + (-0.001796 * PBAL) \\ & + (-0.42078 * PRD) + (0.589318 * \ln(CR)) + (0.415435 * \ln(SI)) + (-0.000926 * SL) \\ & + (-0.002203 * (SL * \cos(ASP))) \end{aligned}$$

where:

DI is 10-year outside bark diameter growth increment
SI is species site index
ASP is stand aspect
SL is stand slope
CR is crown ratio expressed as a proportion
DBH is tree diameter at breast height
PBAL is point basal area in trees larger than the subject tree
PRD is relative density of the inventory point (point Zeide SDI / point SDI max)

For all species except redwood, diameter growth is checked to make sure diameter growth is between zero and a maximum allowed value, set by equation {4.7.1.4}. If diameter growth exceeds the estimate in equation {4.7.1.4}, diameter growth is set to the maximum growth allowed.

$$\{4.7.1.4\} DGMax = (7.92 * \exp(-0.03 * DBH))$$

where:

DGMax is maximum diameter growth allowed
DBH is tree diameter at breast height

4.7.2 Large Tree Height Growth

For all species except white oak and redwood, height growth equations used in the PN variant are based on site index curves shown in section 3.4. Species differences in height growth are accounted for by entering the appropriate curve with the species specific site index value (see section 3.4).

In the PN variant, each species is mapped into a species index as shown in table 4.7.2.1. The coefficients and equations used for each species will depend on the species index of the subject species.

Table 4.7.2.1 Mapped species index for each species for height growth in the PN variant.

Species Code	Species Index	Species Code	Species Index
SF	1	BM	6
WF	2	RA	12
GF	2	WA	6
AF	3	PB	6
RF	4	GC	6
SS	15	AS	6
NF	5	CW	6
YC	6	WO	
IC	7	WJ	6
ES	3	LL	13
LP	8	WB	6
JP	7	KP	6
SP	9	PY	6
WP	9	DG	6
PP	7	HT	6
DF	14	CH	6
RW		WI	6
RC	15	OT	6
WH	10		
MH	11		

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, maximum species heights are computed using equations {4.7.2.1 – 4.7.2.2}.

$$\{4.7.2.1\} HTMAX = a_0 + a_1 * DBH$$

$$\{4.7.2.2\} HTMAX2 = a_0 + a_1 * (DBH + (DG/BARK))$$

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
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 4.7.2.2

Table 4.7.2.2 Coefficients for equations {4.7.2.1} and {4.7.2.2} and maximum age in the PN variant.

Species Code	a_0	a_1	Maximum Age
SF	43.9957174	4.3396271	200
WF	43.9957174	4.3396271	200
GF	43.9957174	4.3396271	200
AF	39.6317079	4.3149844	200
RF	39.6317079	4.3149844	200
SS	16.2223589	6.3657425	200
NF	39.6317079	4.3149844	200
YC	62.7139427	3.2412923	200
IC	62.7139427	3.2412923	200
ES	39.6317079	4.3149844	200
LP	65.7622908	2.3475244	200
JP	18.6043842	5.5324838	200
SP	18.6043842	5.5324838	200
WP	18.6043842	5.5324838	200
PP	18.6043842	5.5324838	200
DF	16.2223589	6.3657425	200
RC	62.7139427	3.2412923	200
WH	51.9732476	4.0156013	200
MH	51.9732476	4.0156013	200
BM	59.3370816	3.9033821	200
RA	59.3370816	3.9033821	200
WA	59.3370816	3.9033821	200
PB	59.3370816	3.9033821	200
GC	59.3370816	3.9033821	200
AS	59.3370816	3.9033821	200
CW	59.3370816	3.9033821	200
WO	59.3370816	3.9033821	200
WJ	62.7139427	3.2412923	200
LL	62.7139427	3.2412923	200
WB	62.7139427	3.2412923	200
KP	62.7139427	3.2412923	200
PY	62.7139427	3.2412923	200
DG	59.3370816	3.9033821	200
HT	59.3370816	3.9033821	200
CH	59.3370816	3.9033821	200
WI	59.3370816	3.9033821	200
OT	16.2223589	6.3657425	200

For all species, if tree height at the beginning of the projection cycle is greater than the maximum species height (*HTMAX*), then tree height at the beginning of the projection cycle is compared to the estimated tree height at the end of the projection cycle (*HTMAX2*). If beginning of the cycle height is less than *HTMAX2*, height growth is computed using equation {4.7.2.3}; if beginning of the cycle height is greater than or equal to *HTMAX2*, height growth is set using equation {4.7.2.3} or {4.7.2.4} whichever is larger.

If tree height at the beginning of the projection cycle is less than or equal to the maximum species height (*HTMAX*), then height growth is obtained by estimating a tree's potential height growth and adjusting the estimate using a height growth modifier based on the tree's crown ratio and height relative to other trees in the stand, equation {4.7.2.5}.

$$\{4.7.2.3\} HTG = 0.1$$

$$\{4.7.2.4\} HTG = 0.5 * DG$$

$$\{4.7.2.5\} HTG = POTHTG * HTGMOD$$

where:

HTG is estimated 10-year tree height growth (bounded $0.1 \leq HTG$)

DG is species estimated 10-year diameter growth

POTHTG is potential height growth

HTGMOD is a weighted height growth modifier

If estimated tree age at the beginning of the projection cycle is greater than or equal to the species maximum age, potential height growth is calculated using equation {4.7.2.6}.

$$\{4.7.2.6\} POTHTG = 0.1$$

where:

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

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.

For all species except Oregon white oak, 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.

{4.7.2.7} Used for species index 1: Pacific silver fir

$$H = ([1 - \exp((-1 * (b_0 + b_1 * SM45)) * A)]^{b_2} / [1 - \exp((-1 * (b_0 + b_1 * SM45)) * 100)]^{b_2}) * SM45 + 4.5$$

$$SM45 = SI - 4.5$$

{4.7.2.8} Used for species index 2: white fir, grand fir

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

{4.7.2.9} Used for species index 3: subalpine fir, Engelmann spruce

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

{4.7.2.10} Used for species index 4: California red fir

$$H = [(SI - 4.5) * (1 - \exp(-X * A^{b_1}))] / [1 - \exp(-Y * 50^{b_1})] + 4.5$$

$$X = (SI * TERM) + (b_4 * TERM^2) + b_5$$

$$TERM = A * b_2 * \exp(A * b_3)$$

$$Y = (SI * TERM^2) + (b_4 * TERM^2^2) + b_5$$

$$TERM^2 = 50 * b_2 * \exp(50 * b_3)$$

{4.7.2.11} Used for species index 5: noble fir

$$H = 4.5 + [(SI - 4.5) / (X_1 * (1 / A)^2 + X_2 * (1 / A) + 1 - (X_1 * 0.0001) - (X_2 * 0.01))]]$$

$$X_1 = b_0 + (b_1 * (SI - 4.5)) - (b_2 * (SI - 4.5)^2)$$

$$X_2 = b_3 + (b_4 * 1 / (SI - 4.5)) - (b_5 * (SI - 4.5)^{-2})$$

{4.7.2.12} Used for species index 6: Alaska cedar, bigleaf maple, white alder, paper birch, giant chinquapin, quaking aspen, black cottonwood, western juniper, whitebark pine, knobcone pine, Pacific yew, Pacific dogwood, hawthorn, bitter cherry, willow, other

$$H = [(SI - 4.5) / [b_0 + (b_1 / (SI - 4.5)) + [b_2 + (b_3 / (SI - 4.5))] * A^{-1.4}] + 4.5$$

{4.7.2.13} Used for species index 7: incense cedar, Jeffrey pine, ponderosa pine

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

{4.7.2.14} Used for species index 8: lodgepole pine

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

{4.7.2.15} Used for species index 9: sugar pine, western white pine

$$H = ([1 - \exp(-\exp(b_0 + (b_1 * \ln(A)) + (b_2 / SI)))] / [1 - \exp(-\exp(b_0 + (b_1 * \ln(100)) + (b_2 / SI)))] \\ * (SI - 4.5) + 4.5$$

{4.7.2.16} Used for species index 10: western hemlock

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

{4.7.2.17} Used for species index 11: mountain hemlock

$$H = [(b_0 + b_1 * SI) * (1 - \exp(b_2 * SI^{0.5} * A))^{(b_4 + b_5/SI) + 1.37}] * 3.281$$

{4.7.2.18} Used for species index 12: red alder

$$H = SI + (b_0 + (b_1 * SI)) * (1 - \exp(b_2 + (b_3 * SI) * A))^{b_4} - (b_0 + (b_1 * SI)) * (1 - \exp(b_2 + (b_3 * \\ SI) * 20))^{b_4}$$

{4.7.2.19} Used for species index 13: subalpine larch

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

{4.7.2.20} Used for species index 14: Douglas-fir

$$H = [A^2 / (b_0 + (b_1 * Z) + ((b_2 + (b_3 * Z)) * A) + ((b_4 + (b_5 * Z)) * A^2))] + 4.5$$

$$Z = 2500 / (SI - 4.5)$$

{4.7.2.21} Used for species index 15: Sitka spruce, western redcedar

$$H = 4.5 + \exp [b_0 + b_1 * \ln(A) + b_2 * (\ln(A))^3 + b_3 * (\ln(A))^5 + b_4 * (\ln(A))^30] + ((SI - 4.5) + b_{11}) * [\exp [b_5 + b_6 * \ln(A) + b_7 * (\ln(A))^2 + b_8 * (\ln(A))^5 + b_9 * (\ln(A))^16 + b_{10} * (\ln(A))^36]$$

where:

H is estimated height of the tree

SI is species site index

A is estimated tree age

$b_0 - b_{13}$ are species-specific coefficients shown in table 4.7.2.3

Table 4.7.2.3 Coefficients (b_0 - b_{13}) for height-growth equations in the PN variant.

Coefficient	Species Index							
	1	2	3	4	5	6	7	8
b_0	0.0071839	-0.30935	2.7578	0	-564.38	0.6192	128.89522	-0.0968
b_1	0.0000571	1.2383	0.83312	1.51744	22.25	-5.3394	-0.016959	0.02679
b_2	1.39005	0.001762	0.015701	1.42E-06	0.04995	240.29	1.23114	-9.31E-05
b_3	0	-5.40E-06	22.71944	-0.044085	6.8	3368.9	-0.7864	0
b_4	0	2.05E-07	-0.63557	-3.05E+06	2843.21	0	2.49717	0
b_5	0	-4.04E-13	0	5.72E-04	34735.54	0	-0.004504	0
b_6	0	-6.2056	0	0	0	0	0.33022	0
b_7	0	2.097	0	0	0	0	100.43	0
b_8	0	-0.09411	0	0	0	0	0	0
b_9	0	-4.38E-05	0	0	0	0	0	0
b_{10}	0	2.01E-11	0	0	0	0	0	0
b_{11}	0	-2.05E-17	0	0	0	0	0	0
b_{12}	0	-84.93	0	0	0	0	0	0
b_{13}	0	0	0	0	0	0	0	0

Table 4.7.2.3 (continued) Coefficients (b₀- b₁₃) for height-growth equations in the PN variant.

Coefficient	Species Index						
	9	10	11	12	13	14	15
b ₀	-4.62536	-1.7307	22.8741	59.5864	0	-0.954038	-0.2050542
b ₁	1.346399	0.1394	0.950234	0.7953	1.46897	0.109757	1.449615
b ₂	-135.3545	-0.0616	-0.002065	0.00194	0.0092466	0.0558178	-0.01780992
b ₃	0	0.0137	0	-0.00074	-2.40E-04	0.00792236	6.51975E-05
b ₄	0	0.00192	1.365566	0.9198	1.11E-06	-0.000733819	-1.09559E-23
b ₅	0	0.00007	2.045963	0	-0.12528	0.000197693	-5.611879
b ₆	0	0	0	0	0.039636	0	2.418604
b ₇	0	0	0	0	-4.28E-04	0	-0.259311
b ₈	0	0	0	0	1.70E-06	0	0.000135145
b ₉	0	0	0	0	73.57	0	-1.70114E-12
b ₁₀	0	0	0	0	-0.12528	0	7.9642E-27
b ₁₁	0	0	0	0	0.039636	0	-86.43
b ₁₂	0	0	0	0	-4.28E-04	0	0
b ₁₃	0	0	0	0	1.70E-06	0	0

For all species except Oregon white oak, potential height growth is estimated using equation {4.7.2.22}.

$$\{4.7.2.22\} POTHTG = H10 - ECH$$

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

For Oregon white oak, potential 10-year height growth is calculated using equation {4.7.2.23}.

$$\{4.7.2.23\} POTHTG = [4.5 + \{(114.24569(1 - \exp(-.02659 * SIKing))^2.25993\} - 18.602 / \ln(2.71 * BA)] * \{1 - \exp(-.13743 * DBH2)\}^{1.38994} - [4.5 + \{(114.24569(1 - \exp(-.02659 * SIKing))^2.25993\} - 18.602 / \ln(2.71 * BA)] * \{1 - \exp(-.13743 * DBH1)\}^{1.38994}$$

where:

POTHTG is potential 10-year height growth

BA is stand basal area

SIking is Site Index based on King (1966)

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 applied to the height growth based upon a tree's crown ratio (equation {4.7.2.24}), and relative height and shade tolerance (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 {4.7.2.5} as a product of the

modifier and potential height growth. The final height growth is then adjusted to the length of the cycle.

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

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

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

*if $HTGMOD \leq 0.0$, then $HTGMOD = 0.1$

where:

<i>POTHTG</i>	is potential height growth
<i>H10</i>	is estimated height of the tree in ten years
<i>HT</i>	is height of the tree at the beginning of the cycle
<i>BA</i>	is stand basal area
<i>Siking</i>	is Site Index based on King (1966)
<i>DBH1</i>	is diameter of the tree at the beginning of the cycle
<i>DBH2</i>	is estimated diameter of the tree at the end of the cycle
<i>HGMDCR</i>	is a height growth modifier based on crown ratio
<i>HGMDRH</i>	is a height growth modifier based on relative height and shade tolerance
<i>HTGMOD</i>	is a weighted height growth modifier
<i>CR</i>	is crown ratio expressed as a percent
<i>RELHT</i>	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 4.7.2.4

Table 4.7.2.4 Coefficients ($b_1 - b_4$) for equation 4.7.2.25 in the PN variant.

Species Code	b_1	b_2	b_3	b_4
SF	0.15	1.1	16	-1.2
WF	0.15	1.1	16	-1.2
GF	0.15	1.1	16	-1.2
AF	0.2	1.1	20	-1.1
RF	0.15	1.1	16	-1.2
SS	0.15	1.1	16	-1.2
NF	0.1	1.1	15	-1.45
YC	0.15	1.1	16	-1.2
IC	0.2	1.1	20	-1.1
ES	0.15	1.1	16	-1.2
LP	0.01	1.1	12	-1.6
JP	0.05	1.1	13	-1.6
SP	0.1	1.1	15	-1.45
WP	0.15	1.1	15	-1.45
PP	0.05	1.1	13	-1.6
DF	0.1	1.1	15	-1.45

Species Code	b ₁	b ₂	b ₃	b ₄
RC	0.2	1.1	20	-1.1
WH	0.2	1.1	20	-1.1
MH	0.2	1.1	20	-1.1
BM	0.2	1.1	20	-1.1
RA	0.05	1.1	13	-1.6
WA	0.05	1.1	13	-1.6
PB	0.05	1.1	13	-1.6
GC	0.1	1.1	15	-1.45
AS	0.01	1.1	12	-1.6
CW	0.01	1.1	12	-1.6
WO	0.1	1.1	15	-1.45
WJ	0.05	1.1	13	-1.6
LL	0.01	1.1	12	-1.6
WB	0.1	1.1	15	0.1
KP	0.01	1.1	12	-1.6
PY	0.2	1.1	20	-1.1
DG	0.2	1.1	20	-1.1
HT	0.01	1.1	12	-1.6
CH	0.05	1.1	13	-1.6
WI	0.01	1.1	12	-1.6
OT	0.1	1.1	15	-1.45

One 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 equation {4.7.2.27}. Species-specific coefficients for this equation are shown in Table 4.7.2.2.

$$\{4.7.2.27\} HT_{\max} = a_0 + a_1 * DBH$$

where:

$HT_{\max}$ is the maximum height for a given diameter

DBH is tree diameter at breast height

a_0, a_1 are species-specific coefficients shown in table 4.7.2.2

Equation {4.7.2.28} is used to predict 10-year height increment for redwood. The final height growth is then adjusted to the length of the cycle.

$$\{4.7.2.28\} HTG = \exp(1.412947 + (-0.000204 * DBH^2) + (0.31971 * \ln(DBH)) + (0.394005 * \ln(SI)) + (-0.399888 * (\ln(DG10)) + (-0.451708 * \ln(HT)))$$

where:

HTG is 10-year height growth increment

DBH is diameter at breast height

SI is species site index

DG10 is 10-year outside bark diameter growth increment
HT is total tree height

A height growth bounding function is used to ensure tree heights do not exceed the height maximum of redwood. The bounding function is applied using the following concepts. For a tree with height less than the lower height-bounding limit, the height growth modifier is set to 1.0. For a tree with a height greater than or equal to the lower height-bounding limit and less than the upper height-bounding limit, a height growth modifier is computed using equation {4.7.2.29}. For a tree with a height greater than the upper height-bounding limit, the height growth modifier is set to 0.1. The lower bounding limit was determined from the height growth fitting data and the upper bounding limit was determined from literature. The final height increment estimate is multiplied by the bounding function, equation {4.7.2.30}.

$$\{4.7.2.29\} HGBND = 1.0 - ((HT - HTLO) / (HTHI - HTLO))$$

$$\{4.7.2.30\} HTG = HTG * HGBND$$

where:

HGBND is height growth bounding modifier, limited to $0.1 \leq HGBND \leq 1.0$
HT is total tree height (ft)
HTLO is the lower height-bounding limit (217 ft)
HTHI is the upper height-bounding limit (380 ft)

5.0 Mortality Model

All species in the PN variant use individual tree mortality equations. The large tree equations except for Oregon white oak, were developed by Hann et al 2003 and Hann and Hanus 2001. The small tree equations were developed by Gould and Harrington 2013. The equation for redwood was developed by Castle 2021.

The annual mortality rate estimates, RA , predicts individual tree mortality based on trees size, stand density and other tree and stand attributes. The equations used to calculate the annual mortality rate is shown in equations {5.0.1} – {5.0.4}.

{5.0.1} Hann Mortality Equations:

$$DBH \geq 3.0'': RA = 1 - [((1 - (1/(1 + \exp(-Z))))^{0.2}) * CRADJ]$$

$$\text{group 1 species: } Z = d_0 + d_1 * DBH^{-5} + d_3 * CR^{0.25} + d_4 * (XSITE1 + 4.5) + d_5 * BAL$$

$$\text{group 2 species: } Z = d_0 + d_1 * DBH + d_4 * (XSITE1 + 4.5) + d_5 * (BAL / DBH)$$

$$\text{group 3 species: } Z = d_0 + d_1 * DBH + d_2 * DBH^2 + d_3 * CR + d_4 * (XSITE2 + 4.5) + d_5 * BAL$$

$$\text{group 4 species: } Z = d_0 + d_1 * DBH + d_2 * DBH^2 + d_3 * CR + (XSITE1 + 4.5) + d_5 * BAL$$

{5.0.2} Gould and Harrington (2009) Mortality Equation for Oregon white oak

$$DBH \geq 3.0'': RA = 1 - [1 / (1 + \exp(-6.6707 + 0.5105 * \ln(5 + BA) - 1.3183 * RELHT)))] * RADJ$$

{5.0.3} Gould and Harrington (2013) Mortality for small trees

$$DBH < 3'': RA = 1 - [1 / (1 + \exp(-4.4384 + 0.0053 * PBAL * MCLASS / (DBHA + 1)^{0.5} + -0.6001 * RELHT^{0.5})]$$

$$HT < 4.5: DBHA = DBH + HT * a_1$$

$$HT \geq 4.5: DBHA = DBH + 4.5 * a_1$$

{5.0.4} Redwood mortality equation

$$RA = [1 / (1 + \exp(2.901447 + 0.578694 * DBH - 0.001793 * PBAL)))]$$

where:

RA	is the estimated annual mortality rate (bound to minimum value of 0.001)
DBH	is tree diameter at breast height
BA	is total stand basal area
BAL	is total basal area in trees larger
$RELHT$	is tree height divided by average height of the 40 largest diameter trees in the stand
CR	is crown ratio
$CRADJ$	$crown\ adjustment = 1.0 - \exp(-(25.0 * CR)^2)$
$XSITE1$	Douglas-fir site index
$XSITE2$	Western hemlock site index
$PBAL$	is basal area of trees larger than the subject tree on the inventory point

MCLASS Mortality class based on shade tolerance table 5.0.1
HT is tree height
d₀₋₅ are species-specific coefficients shown in table 5.0.1
a_i is a species-specific coefficient from table 4.6.1.1

Table 5.0.1 values used in the individual tree mortality equation {5.0.1, 5.0.3} in the PN variant.

Species Code	Coefficients							
	group	d ₀	d ₁	d ₂	d ₃	d ₄	d ₅	MCLASS
SF	2	-7.60159	-0.20052	0	0	0.044133	0.000638	1
WF	2	-7.60159	-0.20052	0	0	0.044133	0.000638	1.5
GF	2	-7.60159	-0.20052	0	0	0.044133	0.000638	1.5
AF	2	-7.60159	-0.20052	0	0	0.044133	0.000638	1.5
RF	2	-7.60159	-0.20052	0	0	0.044133	0.000638	1.5
SS	2	-7.60159	-0.20052	0	0	0.044133	0.000638	1.5
NF	2	-7.60159	-0.20052	0	0	0.044133	0.000638	2.25
YC	4	-1.92269	-0.13608	0.00248	-3.17812	0	0.004684	1.5
IC	4	-1.92269	-0.13608	0.00248	-3.17812	0	0.004684	2.25
ES	2	-7.60159	-0.20052	0	0	0.044133	0.000638	1.5
LP	4	-1.05	-0.19436	0.003803	-3.5573	0.003972	0.005574	3.375
JP	4	-1.05	-0.19436	0.003803	-3.5573	0.003972	0.005574	3.375
SP	4	-1.05	-0.19436	0.003803	-3.5573	0.003972	0.005574	2.25
WP	4	-1.05	-0.19436	0.003803	-3.5573	0.003972	0.005574	2.25
PP	4	-1.05	-0.19436	0.003803	-3.5573	0.003972	0.005574	3.375
DF	1	-4.13142	-1.13736	0	-0.82331	0.030775	0.00991	2.25
RC	3	-0.76161	-0.52937	0	-4.74019	0.011959	0.007564	1
WH	3	-0.76161	-0.52937	0	-4.74019	0.011959	0.007564	1
MH	3	-0.76161	-0.52937	0	-4.74019	0.011959	0.007564	1
BM	4	-2.97682	0	0	-6.22325	0	0	1
RA	4	-2	-0.5	0.015	-3	0.015	0.01	3.375
WA	4	-2	-0.5	0.015	-3	0.015	0.01	2.25
PB	4	-2	-0.5	0.015	-3	0.015	0.01	3.375
GC	4	-4.13175	-0.0577	0	0	0.004861	0.009981	2.25
AS	4	-2	-0.5	0.015	-3	0.015	0.01	5.062
CW	4	-2	-0.5	0.015	-3	0.015	0.01	5.062
WO	5	0	0	0	0	0	0	5.062

Species Code	Coefficients							
	group	d ₀	d ₁	d ₂	d ₃	d ₄	d ₅	MCLASS
WJ	4	-1.05	-0.19436	0.003803	-3.5573	0.003972	0.005574	5.062
LL	4	-1.05	-0.19436	0.003803	-3.5573	0.003972	0.005574	3.375
WB	4	-1.05	-0.19436	0.003803	-3.5573	0.003972	0.005574	3.375
KP	4	-1.05	-0.19436	0.003803	-3.5573	0.003972	0.005574	5.062
PY	4	-4.07278	-0.17643	0	-1.72945	0	0.012526	1
DG	4	-3.02035	0	0	-8.46788	0.013966	0.009462	1
HT	4	-3.02035	0	0	-8.46788	0.013966	0.009462	2.25
CH	4	-3.02035	0	0	-8.46788	0.013966	0.009462	2.25
WI	4	-2	-0.5	0.015	-3	0.015	0.01	5.062
WI	1	-4.13142	-1.13736	0	-0.82331	0.030775	0.00991	1
OT	1	-4.13412	-1.13736	0	-0.82331	0.030775	0.00991	5.062

The annual mortality rates are adjusted for the length of cycle using a compound interest formula (Hamilton 1976), and then applied to each tree record. After the rate is applied to each tree, if the stand density is above the maximum stand density index (or a basal area of 550ft²/acre) the stand will reapply the mortality rate to each tree record again until the stand is below the maximum density.

$$\{5.0.4\} \quad RT = 1 - (1 - RA)^Y$$

where:

RT is the mortality rate applied to an individual tree record for the growth period

RA is the annual mortality rate for the tree record

Y is length of the current projection cycle in years

6.0 Regeneration

The PN 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 PN variant.

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
SF	No	0.3	1.0	20.0
WF	No	0.3	1.5	20.0
GF	No	0.3	1.5	20.0
AF	No	0.3	1.0	20.0
RF	No	0.3	1.0	20.0
SS	No	0.3	1.0	20.0
NF	No	0.3	1.0	20.0
YC	No	0.2	1.0	20.0
IC	No	0.2	1.0	20.0
ES	No	0.3	1.0	20.0
LP	No	0.4	1.4	20.0
JP	No	0.4	1.0	20.0
SP	No	0.4	1.0	20.0
WP	No	0.4	1.0	20.0
PP	No	0.5	1.3	20.0
DF	No	0.3	1.5	20.0
RW	Yes	0.2	2.0	20.0
RC	No	0.2	1.0	20.0
WH	No	0.2	1.0	20.0
MH	No	0.2	1.0	20.0
BM	Yes	0.2	1.0	20.0
RA	Yes	0.2	1.0	50.0
WA	Yes	0.2	1.0	20.0
PB	Yes	0.2	1.0	20.0
GC	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
WJ	No	0.2	1.0	20.0

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
LL	No	0.3	1.5	20.0
WB	No	0.4	1.0	20.0
KP	No	0.4	1.0	20.0
PY	Yes	0.2	1.0	20.0
DG	Yes	0.2	1.0	20.0
HT	Yes	0.2	1.0	20.0
CH	Yes	0.2	1.0	20.0
WI	Yes	0.2	1.0	20.0
OT	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

$$DSTMP_i \leq 5: NUMSPRC = 1$$

$$5 < DSTMP_i \leq 10: NUMSPRC = NINT(0.2 * DSTMP_i)$$

$$DSTMP_i > 10: NUMSPRC = 2$$

{6.0.2} For root suckering hardwood species

$$DSTMP_i \leq 5: NUMSPRC = 1$$

$$5 < DSTMP_i \leq 10: NUMSPRC = NINT(-1.0 + 0.4 * DSTMP_i)$$

$$DSTMP_i > 10: NUMSPRC = 3$$

$$\{6.0.3\} TPA_s = TPA_i * PS$$

$$\{6.0.4\} PS = ((93.2669 - 0.4303 * DSTMP_i) / 100)$$

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

$$\{6.0.6\} PS = (TPA_i / (ASTPAR * 2)) * ((ASBAR / 198) * (40100.45 - 3574.02 * RSHAG^2 + 554.02 * RSHAG^3 - 3.5208 * RSHAG^5 + 0.011797 * RSHAG^7))$$

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 PN variant.

Species Code	Sprouting Probability	Number of Sprout Records	Source
RW	{6.0.4}	{6.0.2}	Neal 1967 Boe 1975 Griffith 1992
BM	0.9	{6.0.2}	Roy 1955 Tappenier et al. 1996 Ag. Handbook 654
RA	{6.0.5}	{6.0.2}	Harrington 1984 Uchytel 1989
WA	0.9	{6.0.2}	See red alder (MA)
PB	0.7	1	Hutnik and Cunningham 1965 Bjorkbom 1972
GC	0.9	{6.0.2}	Harrington et al. 1992 Wilkinson et al. 1997 Fryer 2008
AS	{6.0.6}	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
PY	0.4	1	Minore 1996 Ag. Handbook 654
DG	0.9	{6.0.1}	Gucker 2005
HT	No info available-- default to 0.7	1	n/a
CH	0.9	{6.0.2}	Mueggler 1965 Leedge and Hickey 1971 Morgan and Neuenschwander 1988
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

Volume is calculated for four merchantability standards: total stem cubic feet, merchantable stem cubic feet, sawlog stem cubic feet, and merchantable stem board feet (Scribner). Sawlog cubic foot volume is only reported when the FIAVBC keyword is in use. 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 PN variant are shown in tables 7.0.1-7.0.4.

Volume computation methods used by the Forest Inventory and Analysis (FIA) program can be requested with the FIAVBC keyword. This keyword encompasses the National Scale Volume and Biomass estimators (NSVB; Westfall et al. 2024) and regional equations used for woodland species (Burrill et al. 2024). More information about the FIAVBC keyword and required input variables can be found in the Essential FVS Guide (Dixon 2002).

Table 7.0.1 Volume merchantability standards for the PN variant.

Merchantable Cubic Foot Volume Specifications:		
Minimum DBH / Top Diameter	LP	All Other
708 – BLM Salem; 709 BLM Eugene; 712 – BLM Coos Bay	7.0 / 5.0 inches	7.0 / 5.0 inches
All other 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
708 – BLM Salem; 709 BLM Eugene; 712 – BLM Coos Bay	7.0 / 5.0 inches	7.0 / 5.0 inches
All other 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	Model Name
Pacific silver fir	609, 612, 800	616BEHW011	Behre's Hyperbola
Pacific silver fir	708, 709, 712	B00BEHW011	Behre's Hyperbola
white fir	609, 612, 800	616BEHW015	Behre's Hyperbola
white fir	708, 709, 712	B00BEHW015	Behre's Hyperbola
grand fir	609, 612, 800	616BEHW017	Behre's Hyperbola
grand fir	708, 709, 712	B00BEHW017	Behre's Hyperbola
subalpine fir	609, 612, 800	616BEHW019	Behre's Hyperbola
subalpine fir	708, 709, 712	B00BEHW015	Behre's Hyperbola
California red fir	609, 612, 800	616BEHW020	Behre's Hyperbola

Common Name	Location Code	Equation Number	Model Name
California red fir	708, 709, 712	B00BEHW021	Behre's Hyperbola
Sitka spruce	609, 800	F03FW2W263	Flewelling's 2-Point Profile Model
Sitka spruce	612	616BEHW098	Behre's Hyperbola
Sitka spruce	708, 709, 712	B00BEHW098	Behre's Hyperbola
noble fir	609, 612, 800	616BEHW022	Behre's Hyperbola
noble fir	708, 709, 712	B00BEHW022	Behre's Hyperbola
Alaska cedar	609, 612, 800	616BEHW042	Behre's Hyperbola
Alaska cedar	708, 709, 712	B00BEHW042	Behre's Hyperbola
incense cedar	609, 612, 800	616BEHW081	Behre's Hyperbola
incense cedar	708, 709, 712	B00BEHW081	Behre's Hyperbola
Engelmann spruce	609, 612, 800	616BEHW093	Behre's Hyperbola
Engelmann spruce	708, 709, 712	B00BEHW093	Behre's Hyperbola
lodgepole pine	609, 612, 800	616BEHW108	Behre's Hyperbola
lodgepole pine	708, 709, 712	B00BEHW108	Behre's Hyperbola
Jeffrey pine	609, 612, 800	616BEHW116	Behre's Hyperbola
Jeffrey pine	708, 709, 712	B00BEHW116	Behre's Hyperbola
sugar pine	609, 612, 800	616BEHW117	Behre's Hyperbola
sugar pine	708, 709, 712	B00BEHW117	Behre's Hyperbola
western white pine	609, 612, 800	616BEHW119	Behre's Hyperbola
western white pine	708, 709, 712	B00BEHW119	Behre's Hyperbola
ponderosa pine	609, 612, 800	616BEHW122	Behre's Hyperbola
ponderosa pine	708, 709, 712	B00BEHW122	Behre's Hyperbola
Douglas-fir	609, 800	F03FW2W202	Flewelling's 2-Point Profile Model
Douglas-fir	612	F00FW2W202	Flewelling's 2-Point Profile Model
Douglas-fir	708, 709	B01BEHW202	Behre's Hyperbola
Douglas-fir	712	B02BEHW202	Behre's Hyperbola
redwood	609, 612, 800	616BEHW211	Behre's Hyperbola
redwood	708, 709, 712	B00BEHW211	Behre's Hyperbola
western redcedar	609, 612, 800	616BEHW242	Behre's Hyperbola
western redcedar	708, 709, 712	B00BEHW242	Behre's Hyperbola
western hemlock	612	F03FW2W263	Flewelling's 2-Point Profile Model
western hemlock	609, 800	F00FW2W263	Flewelling's 2-Point Profile Model
western hemlock	708, 709, 712	B00BEHW263	Behre's Hyperbola

Common Name	Location Code	Equation Number	Model Name
mountain hemlock	609, 612, 800	616BEHW264	Behre's Hyperbola
mountain hemlock	708, 709, 712	B00BEHW260	Behre's Hyperbola
bigleaf maple	609, 612, 800	616BEHW312	Behre's Hyperbola
bigleaf maple	708, 709, 712	B00BEHW312	Behre's Hyperbola
red alder	609, 612, 800	616BEHW351	Behre's Hyperbola
red alder	708, 709, 712	B00BEHW351	Behre's Hyperbola
white alder	609, 612, 800	616BEHW352	Behre's Hyperbola
white alder	708, 709, 712	B00BEHW361	Behre's Hyperbola
paper birch	609, 612, 800	616BEHW375	Behre's Hyperbola
paper birch	708, 709, 712	B00BEHW999	Behre's Hyperbola
giant chinquapin	609, 612, 800	616BEHW431	Behre's Hyperbola
giant chinquapin	708, 709, 712	B00BEHW431	Behre's Hyperbola
quaking aspen	609, 612, 800	616BEHW746	Behre's Hyperbola
quaking aspen	708, 709, 712	B00BEHW999	Behre's Hyperbola
black cottonwood	609, 612, 800	616BEHW747	Behre's Hyperbola
black cottonwood	708, 709, 712	B00BEHW747	Behre's Hyperbola
Oregon white oak	609, 612, 800	616BEHW815	Behre's Hyperbola
Oregon white oak	708, 709, 712	B00BEHW800	Behre's Hyperbola
western juniper	609, 612, 800	616BEHW064	Behre's Hyperbola
western juniper	708, 709, 712	B00BEHW242	Behre's Hyperbola
subalpine larch	609, 612, 800	616BEHW072	Behre's Hyperbola
subalpine larch	708, 709, 712	B00BEHW073	Behre's Hyperbola
whitebark pine	609, 612, 800	616BEHW101	Behre's Hyperbola
whitebark pine	708, 709, 712	B00BEHW119	Behre's Hyperbola
knobcone pine	609, 612, 800	616BEHW103	Behre's Hyperbola
knobcone pine	708, 709, 712	B00BEHW108	Behre's Hyperbola
Pacific yew	609, 612, 800	616BEHW231	Behre's Hyperbola
Pacific yew	708, 709, 712	B00BEHW231	Behre's Hyperbola
Pacific dogwood	609, 612, 800	616BEHW492	Behre's Hyperbola
Pacific dogwood	708, 709, 712	B00BEHW999	Behre's Hyperbola
hawthorn	609, 612, 800	616BEHW500	Behre's Hyperbola
hawthorn	708, 709, 712	B00BEHW999	Behre's Hyperbola
bitter cherry	609, 612, 800	616BEHW768	Behre's Hyperbola
bitter cherry	708, 709, 712	B00BEHW999	Behre's Hyperbola
willow	609, 612, 800	616BEHW920	Behre's Hyperbola
willow	708, 709, 712	B00BEHW999	Behre's Hyperbola
other	609, 612, 800	616BEHW999	Behre's Hyperbola
other	708, 709, 712	B00BEHW999	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 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.

Table 7.0.4 Species-specific default form class values for the PN variant.

Species Code	Behr's Hyperbola Equation Number	Form Class				
		0<DBH<11	11<=DBH<21	21<=DBH<31	31<=DBH<41	DBH>=41
Olympic NF (609)						
SF	616BEHW011	97	97	91	90	90
WF	616BEHW015	97	97	93	91	91
GF	616BEHW017	86	86	83	82	82
AF	616BEHW019	97	97	97	95	95
RF	616BEHW020	83	83	80	80	79
SS*	616BEHW098	89	89	86	84	84
NF	616BEHW022	88	88	84	82	82
YC	616BEHW042	99	99	88	87	86
IC	616BEHW081	81	81	72	71	70
ES	616BEHW093	90	90	86	85	85
LP	616BEHW108	96	96	96	93	93
JP	616BEHW116	92	92	82	80	79
SP	616BEHW117	79	79	76	76	75
WP	616BEHW119	95	95	91	90	90
PP	616BEHW122	89	89	82	80	80
DF*	616BEHW202	82	82	79	78	78
RW	616BEHW211	82	82	79	78	78
RC	616BEHW242	93	93	87	86	86
WH*	616BEHW263	96	96	93	91	91
MH	616BEHW264	98	98	95	94	93
BM	616BEHW312	86	86	84	82	82
RA	616BEHW351	84	84	81	80	79
WA	616BEHW352	79	79	76	76	75
PB	616BEHW375	79	79	76	74	74
GC	616BEHW431	87	87	81	79	79
AS	616BEHW746	85	85	81	80	79

Species Code	Behr's Hyperbola Equation Number	Form Class				
		0<DBH<11	11<=DBH<21	21<=DBH<31	31<=DBH<41	DBH>=41
CW	616BEHW747	82	82	80	79	79
WO	616BEHW815	95	95	82	82	82
WJ	616BEHW064	81	81	81	81	74
LL	616BEHW072	92	92	92	92	92
WB	616BEHW101	96	96	96	96	96
KP	616BEHW103	96	96	89	87	86
PY	616BEHW231	76	76	69	65	65
DG	616BEHW492	95	95	86	82	82
HT	616BEHW500	95	95	95	95	95
CH	616BEHW768	86	86	86	84	84
WI	616BEHW920	92	92	92	92	92
OT	616BEHW999	84	84	80	79	78
Siuslaw NF (612)						
SF	616BEHW011	95	95	89	88	88
WF	616BEHW015	97	97	93	91	91
GF	616BEHW017	86	86	83	82	82
AF	616BEHW019	96	96	93	91	91
RF	616BEHW020	83	83	80	80	79
SS	616BEHW098	89	89	86	84	84
NF	616BEHW022	88	88	84	82	82
YC	616BEHW042	88	88	79	77	76
IC	616BEHW081	81	81	72	71	70
ES	616BEHW093	90	90	86	85	85
LP	616BEHW108	98	98	93	90	90
JP	616BEHW116	92	92	82	80	79
SP	616BEHW117	79	79	76	76	75
WP	616BEHW119	93	93	89	88	88
PP	616BEHW122	89	89	82	80	80
DF	616BEHW202	73	73	71	70	70
RW	616BEHW211	82	82	79	78	78
RC	616BEHW242	68	68	63	63	62
WH	616BEHW263	75	75	72	71	71
MH	616BEHW264	89	89	83	82	81
BM	616BEHW312	86	86	84	82	82
RA	616BEHW351	84	84	81	80	79

Species Code	Behr's Hyperbola Equation Number	Form Class				
		0<DBH<11	11<=DBH<21	21<=DBH<31	31<=DBH<41	DBH>=41
WA	616BEHW352	79	79	76	76	75
PB	616BEHW375	79	79	76	74	74
GC	616BEHW431	87	87	81	79	79
AS	616BEHW746	85	85	81	80	79
CW	616BEHW747	82	82	80	79	79
WO	616BEHW815	95	95	82	82	82
WJ	616BEHW064	81	81	81	81	74
LL	616BEHW072	92	92	92	92	92
WB	616BEHW101	96	96	96	96	96
KP	616BEHW103	96	96	89	87	86
PY	616BEHW231	76	76	69	65	65
DG	616BEHW492	95	95	86	82	82
HT	616BEHW500	95	95	95	95	95
CH	616BEHW768	86	86	86	84	84
WI	616BEHW920	92	92	92	92	92
OT	616BEHW999	84	84	80	79	78

*Species whose default volume equation at this location code is not Behre's Hyperbola (see Table 7.0.2).

Species Code	Behr's Hyperbola Equation Number	708	709	712
SF	B00BEHW011	84	82	80
WF	B00BEHW015	86	78	84
GF	B00BEHW017	84	82	86
AF	B00BEHW015	82	78	80
RF	B00BEHW021	75	78	75
SS	B00BEHW098	80	78	80
NF	B00BEHW022	84	78	78
YC	B00BEHW042	73	78	70
IC	B00BEHW081	73	70	70
ES	B00BEHW093	77	78	72
LP	B00BEHW108	68	78	80
JP	B00BEHW116	75	78	75
SP	B00BEHW117	75	72	76
WP	B00BEHW119	76	78	80
PP	B00BEHW122	82	70	80
DF	B01BEHW202	80	78	74

Species Code	Behr's Hyperbola Equation Number	708	709	712
RW	B00BEHW211	75	78	75
RC	B00BEHW242	76	72	70
WH	B00BEHW260	88	80	84
MH	B00BEHW260	72	78	72
BM	B00BEHW312	84	78	82
RA	B00BEHW351	88	80	82
WA	B00BEHW361	70	78	82
PB	B00BEHW999	70	78	70
GC	B00BEHW431	75	80	82
AS	B00BEHW999	75	78	75
CW	B00BEHW747	74	82	74
WO	B00BEHW800	70	78	70
WJ	B00BEHW242	60	78	60
LL	B00BEHW073	75	78	75
WB	B00BEHW119	82	78	82
KP	B00BEHW108	82	78	82
PY	B00BEHW231	60	78	82
DG	B00BEHW999	70	78	70
HT	B00BEHW999	70	78	70
CH	B00BEHW999	75	78	86
WI	B00BEHW999	75	78	75
OT	B00BEHW999	74	78	74

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 PN 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 PN 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).

10.0 Literature Cited

- Alexander, R.R., Tackle, D., and Dahms, W.G. 1967. Site Indices for Engelmann Spruce. Res. Pap. RM-32. Forest Service, Rocky Mountain Research Station.
- Arney, J. D. 1985. A modeling strategy for the growth projection of managed stands. Canadian Journal of Forest Research. 15(3):511-518.
- Barrett, James W. 1978. Height growth and site index curves for managed, even-aged stands of ponderosa pine in the Pacific Northwest. Res. Pap. PNW-232. Portland, OR: Forest Service, Pacific Northwest Forest and Range Experiment Station. 14 p.
- Bechtold, William A. 2004. Largest-crown-diameter Prediction Models for 53 Species in the Western United States. WJAF. Forest Service. 19(4): pp 241-245.
- Bjorkbom, John C. 1972. Stand changes in the first 10 years after seedbed preparation for paper birch. USDA Forest Service, Research Paper NE-238. Northeastern Forest Experiment Station, Upper Darby, PA. 10 p.
- Boe, Kenneth N. 1975. Natural seedlings and sprouts after regeneration cuttings in old-growth redwood. PSW-111. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 17 p.
- Burns, R. M., & Honkala, B. H. 1990. Silvics of North America: 1. Conifers; 2. Hardwoods Agriculture Handbook 654. US Department of Agriculture, Forest Service, Washington, DC.
- Burrill, Elizabeth A.; DiTommaso, Andrea M.; Turner, Jeffery A.; Pugh, Scott A.; Christensen, Glenn; Kralicek, Karin M.; Perry, Carol J.; Lepine, Lucie C.; Walker, David M.; Conkling, Barbara L. 2024. The Forest Inventory and Analysis Database, FIADB user guides, volume: database description (version 9.3), nationwide forest inventory (NFI). U.S. Department of Agriculture, Forest Service. 1026 p. [Online].
- Cochran, P.H. 1979. Site index and height growth curves for managed, even-aged stands of white or grand fir east of the Cascades in Oregon and Washington. Res. Pap. PNW-251. Portland, OR: Forest Service, Pacific Northwest Forest and Range Experiment Station. 16 p.
- Cochran, P.H. 1979. Site index and height growth curves for managed, even-aged stands of white or grand fir east of the Cascades in Oregon and Washington. Res. Pap. PNW-252. Portland, OR: Forest Service, Pacific Northwest Forest and Range Experiment Station. 13 p.
- Cochran, P. H. 1985. Site index, height growth, normal yields, and stocking levels for larch in Oregon and Washington. Res. Note PNW-424. Portland, OR: Forest Service, Pacific Northwest Forest and Range Experiment Station. 13 p.
- Cole, D. M.; Stage, A. R. 1972. Estimating future diameters of lodgepole pine. Res. Pap. INT-131. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 20p.

- Crookston, Nicholas L. 2003. Internal document on file. Data provided from Region 1. Moscow, ID: Forest Service.
- Crookston, Nicholas L. 2005. Draft: Allometric Crown Width Equations for 34 Northwest United States Tree Species Estimated Using Generalized Linear Mixed Effects Models.
- Crookston, Nicholas L. 2008. Internal Report.
- Curtis, Robert O. 1967. Height-diameter and height-diameter-age equations for second-growth Douglas-fir. *Forest Science* 13(4):365-375.
- Curtis, Robert O.; Herman, Francis R.; DeMars, Donald J. 1974. Height growth and site index for Douglas-fir in high-elevation forests of the Oregon-Washington Cascades. *Forest Science* 20(4):307-316.
- Curtis, Robert O.; Diaz, Nancy M.; Clendenen, Gary W. 1990. Height growth and site index curves for western white pine in the Cascade Range of Washington and Oregon. Res. Pap. PNW-423. Portland, OR: Forest Service, Pacific Northwest Forest and Range Experiment Station. 14 p.
- Dahms, Walter. 1964. Gross and net yield tables for lodgepole pine. Res. Pap. PNW-8. Portland, OR: Pacific Northwest Forest and Range Experiment Station. 14 p.
- Dixon, G. E. 1985. Crown ratio modeling using stand density index and the Weibull distribution. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 13p.
- Dixon, Gary E. comp. 2002 (revised frequently). Essential FVS: A user's guide to the Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Management Service Center.
- Dolph, K. Leroy. 1991. Polymorphic site index curves for red fir in California and southern Oregon. Res. Paper PSW-206. Berkeley, CA: Forest Service, Pacific Southwest Forest and Range Experiment Station. 18p.
- Donnelly, Dennis M., Betters, David R., Turner, Matthew T., and Gaines, Robert E. 1992. Thinning even-aged forest stands: Behavior of singular path solutions in optimal control analyses. Res. Pap. RM-307. Fort Collins, CO: Forest Service. Rocky Mountain Forest and Range Experiment Station. 12 p.
- Donnelly, Dennis. 1996. Internal document on file. Data provided from Region 6. Fort Collins, CO: Forest Service.
- Farr, Wilbur A. 1984. Site index and height growth curves for unmanaged even-aged stands of western hemlock and Sitka spruce in southeast Alaska. Res. Pap. PNW-326. Portland, OR: Forest Service, Pacific Northwest Forest and Range Experiment Station. 26 p.

- 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.
- Fryer, Janet L. 2008. *Lithocarpus densiflorus*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer).
- Gom, L. A., & Rood, S. B. (2000). Fire induces clonal sprouting of riparian cottonwoods. *Canadian Journal of Botany*, 77(11), 1604-1616.
- Gould, Peter and Harrington, Constance. 2009. Draft - Revising the Pacific Northwest Coast Variant of the Forest Vegetation Simulator (FVS-PN) for Oregon White Oak. USDA Forest Service, Pacific Northwest Research Station. 25 p.
- Gould, Peter J.; Harrington, Constance A. 2013. Making the little things count: modeling the development of understory trees in complex stands. In: Anderson, Paul D.; Ronnenberg, Kathryn L., eds. *Density management for the 21st century: west side story*. Gen. Tech. Rep. PNW-GTR-880. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 59–70.
- Griffith, Randy Scott. 1992. *Sequoia sempervirens*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer).
- Gucker, Corey L. 2005. *Cornus nuttallii*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer).
- Gucker, Corey L. 2007. *Quercus garryana*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer).
- Hall, Frederick C. 1983. Growth basal area: a field method for appraising forest site productivity for stockability. *Can. J. For. Res.* 13:70-77.
- Hamilton, D. A., Jr. 1986. A logistic model of mortality in thinned and unthinned mixed conifer stands of northern Idaho. *Forest Science* 32(4): 989-1000.
- Harlow, William M.; Harrar, Ellwood S. 1968. *Textbook of Dendrology*. McGraw-Hill Book Co. New York. 512 p.
- Harrington, Constance A. 1984. Factors influencing initial sprouting of red alder. *Canadian Journal of Forest Research*. 14: 357-361.
- Harrington, Constance A.; Curtis, Robert O. 1986. Height growth and site index curves for red alder. Res. Pap. PNW-358. Portland, OR: Forest Service, Pacific Northwest Forest and Range Experiment Station. 14 p.

- Harrington, T. B., Tappeiner, I. I., John, C., & Warbington, R. 1992. Predicting crown sizes and diameter distributions of tanoak, Pacific madrone, and giant chinkapin sprout clumps. *Western Journal of Applied Forestry*, 7(4), 103-108.
- Herman, Francis R.; Curtis, Robert O.; DeMars, Donald J. 1978. Height growth and site index estimates for noble fir in high-elevation forests of the Oregon-Washington Cascades. Res. Pap. PNW-243. Portland, OR: Forest Service, Pacific Northwest Forest and Range Experiment Station. 15 p.
- Hoyer, Gerald E.; Herman, Francis R. 1989. Height-age and site index curves for Pacific silver fir in the Pacific Northwest. Res. Pap. PNW-418. Portland, OR: Forest Service, Pacific Northwest Forest and Range Experiment Station. 33 p.
- Hutnik, Russell J., and Frank E. Cunningham. 1965. Paper birch (*Betula papyrifera* Marsh.). In *Silvics of forest trees of the United States*. p. 93-98. H. A. Fowells, comp. U.S. Department of Agriculture, Agriculture Handbook 271. Washington, DC.
- Keyser, C.E. 2001. Quaking Aspen Sprouting in Western FVS Variants: A New Approach. Unpublished Manuscript.
- King, James E. 1966. Site index curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser Forestry Paper No. 8. Centralia, WA. Weyerhaeuser Forestry Research Center. 49p.
- Krajicek, J.; Brinkman, K.; Gingrich, S. 1961. Crown competition – a measure of density. *Forest Science*. 7(1):35-42
- Krumland, B. and Eng, H., 2005. Site Index Systems for Major Young-Growth Forest and Woodland Species in Northern California. California Forestry Report 4.
- Larsen, D.R. and D.W. Hann. 1985. Equations for predicting diameter and squared diameter inside bark at breast height for six major conifers of southwest Oregon. Res. Note 77. Corvallis, OR: Oregon State University, Forest Research Laboratory. 4p.
- Leedge, T. A., & Hickey, W. O. 1971. Sprouting of northern Idaho shrubs after prescribed burning. *The Journal of Wildlife Management*, 508-515.
- Means, J.F., M.H. Campbell, and G.P. Johnson. 1986. Preliminary height growth and site index curves for mountain hemlock. FIR Report, Vol 10, No.1. Corvallis, OR: Oregon State University.
- Minore, D., & Weatherly, H. G. (1996). Stump sprouting of Pacific yew. General Technical Report. PNW-GTR-378. Portland, Or.: U.S. Dept. of Agriculture, Pacific Northwest Research Station.
- Morgan, P., & Neuenschwander, L. F. 1988. Shrub response to high and low severity burns following clearcutting in northern Idaho. *Western Journal of Applied Forestry*, 3(1), 5-9.
- Mueggler, W. F. 1965. Ecology of seral shrub communities in the cedar-hemlock zone of northern Idaho. *Ecological Monographs*, 165-185.

- Neal, Robert L., Jr. 1967. Sprouting of old-growth redwood stumps--first year after logging. USDA Forest Service, Research Note PSW-137. Pacific Southwest Forest and Range Experiment Station, Berkeley, CA. 8 p.
- Paine, D.P., and Hann, D.W. 1982. Maximum Crown Width Equations for Southwestern Oregon Tree Species. Res. Pap. 46. Corvallis, OR: Oregon State University, Forest Research Laboratory. 20 p.
- Pillsbury, Norman H.; Kirkley, Michael L. 1984. Equations for total, wood, and saw-log volume for thirteen California hardwoods. Res. Note PNW-414. Portland, OR: Forest Service, Pacific Northwest Forest and Range Experiment Station. 52 p.
- Rebain, Stephanie A. comp. 2010 (revised frequently). The Fire and Fuels Extension to the Forest Vegetation Simulator: Updated Model Documentation. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 379 p.
- Reinhardt, Elizabeth; Crookston, Nicholas L. (Technical Editors). 2003. The Fire and Fuels Extension to the Forest Vegetation Simulator. Gen. Tech. Rep. RMRS-GTR-116. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 209 p.
- Roy, D. F. 1955. Hardwood sprout measurements in northwestern California. Forest Research Notes. California Forest and Range Experiment Station, (95).
- Stage, A. R. 1973. Prognosis Model for stand development. Res. Paper INT-137. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32p.
- Steinberg, Peter D. 2001. *Populus balsamifera* subsp. *trichocarpa*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer).
- Tappeiner, I. I., John, C., Zasada, J., Huffman, D., & Maxwell, B. D. 1996. Effects of cutting time, stump height, parent tree characteristics, and harvest variables on development of bigleaf maple sprout clumps. *Western Journal of Applied Forestry*, 11(4), 120-124.
- Uchytel, Ronald J. 1989. *Alnus rubra*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory.
- USFS-R6 Sale Preparation and Valuation Section of Diameter and Volume Procedures - R6 Timber Cruise System. 1978.
- 2009(revised frequently). Volume Estimator Library Equations. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center.
- Walters, David K., Hann, David W., Clyde, Merlise A. 1985. Equations and tables predicting gross total stem volumes in cubic feet for six major conifers of southwest Oregon.

Res. Bull. No. 50. Corvallis, OR: Forest Research Laboratory, College of Forestry, Oregon State University. 36p.

- Westfall, James A.; Coulston, John W.; Gray, Andrew N.; Shaw, John D.; Radtke, Philip J.; Walker, David M.; Weiskittel, Aaron R.; MacFarlane, David W.; Affleck, David L.R.; Zhao, Dehai; Temesgen, Hailemariam; Poudel, Krishna P.; Frank, Jereme M.; Prisley, Stephen P.; Wang, Yingfang; Sánchez Meador, Andrew J.; Auty, David; Domke, Grant M. 2024. A national-scale tree volume, biomass, and carbon modeling system for the United States. Gen. Tech. Rep. WO-104. Washington, DC: U.S. Department of Agriculture, Forest Service. 37 p.
- Wiley, Kenneth N. 1978. Site index tables for western hemlock in the Pacific Northwest. For. Pap. No. 17. Centralia, WA: Weyerhaeuser Forestry Research Center. 28 p.
- Wilkinson, W. H., McDonald, P. M., & Morgan, P. 1997. Tanoak sprout development after cutting and burning in a shade environment. *Western Journal of Applied Forestry*, 12(1), 21-26.
- Wykoff, W. R. 1990. A basal area increment model for individual conifers in the northern Rocky Mountains. *For. Science* 36(4): 1077-1104.
- Wykoff, William R., Crookston, Nicholas L., and Stage, Albert R. 1982. User's guide to the Stand Prognosis Model. Gen. Tech. Rep. INT-133. Ogden, UT: Forest Service, Intermountain Forest and Range Experiment Station. 112p.

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			BLM Oregon Inventory	BIA Quinault Indian Reservation Inventory 1992	Total Number of Observations
	Siuslaw NF Inventory 1973	Olympic NF Inventory 1974	Siuslaw NF Managed Stand Survey 1987			
Pacific silver fir	0	90	0	1	9	622
Sitka spruce	37	11	26	2	23	412
Douglas-fir	26	13	36	24	1	10098
western redcedar	13	27	2	5	52	1171
western hemlock	9	41	16	6	28	3931
red alder	2	45	0	39	14	1369

*Figures in the "Species Totals" line are completely accurate in terms of number of GST's supporting the large tree diameter growth model. Within the body of the table, the percent of GST's for each species/data source combination are also accurate estimates. An edit feature of the software used to construct the large tree diameter model skips records missing certain data elements. Almost all such skips occurred in data from the Siuslaw Managed Stand Survey.

Table 11.1.2 Species observations used in the PN variant.

Common Name	Number of Observations	Comments (see below)
Pacific silver fir	622	* P
white fir	1044	*
grand fir	504	*
subalpine fir	227	*
California red fir	44	* A
Shasta red fir	515	* a
Sitka spruce	412	* P
noble fir	1555	*
Alaska cedar	112	* B
western larch	74	* b
incense cedar	296	
Engelmann spruce	209	*
lodgepole pine	898	*

Common Name	Number of Observations	Comments (see below)
Jeffrey pine	0	
sugar pine	240	
western white pine	414	*
ponderosa pine	432	*
Douglas-fir	10098	* P
redwood	0	
western redcedar	1171	* P
western hemlock	3931	* P
mountain hemlock	3019	*
bigleaf maple	89	*
red alder	1369	* P
white alder	2	C
Pacific madrone	70	c
paper birch	0	
giant chinquapin	62	D
Tanoak	1	d
quaking aspen	0	
black cottonwood	8	
Oregon white oak	12	E
California black oak	4	e
western juniper	0	
subalpine larch	0	
whitebark pine	2	
knobcone pine	0	
Pacific yew	5	
Pacific dogwood	0	
hawthorn	0	
bitter cherry	0	
willow	0	
other		

A “*” marks a species whose large tree growth relationships were fitted specifically for either the WC or PN variant.

A “P” marks species whose large tree growth relationships were fitted specifically with data from PN coast areas. The number of observations for every other are for the WC variant.

Pairs of letters, for example “A” and “a” indicate two species of the same variety that are combined into one code in the variant. The capital letter marks which species of the two the variant assumes.

11.2 Appendix B: Plant Association Codes

Table 11.2.1 Plant association codes recognized in the PN variant.

FVS Sequence Number = Plant Association Species Type	Alpha Code	Site Species	Site Index*	Max. SDI*	Source*	Reference
1 = PSME/HODI-ROGY Douglas-fir/oceanspray-baldhip rose	CDS221	DF	54	750	C	R6 E TP-001-88 p. 100
2 = PSME/GASH Douglas-fir/salal	CDS255	DF	62	955	C	R6 E TP-001-88 p. 104
3 = PSME/ARUV Douglas-fir/kinnikinnick	CDS651	DF	33	600	C	R6 E TP-001-88 p. 96
4 = ABLA2/LULA Subalpine fir/subalpine lupine	CEF321	AF	50	367	H	R6 E TP-001-88 p. 268
5 = ABLA2/RHAL-OLY Subalpine fir/white rhododendron (Olympic)	CES212	AF	65	535	H	R6 E TP-001-88 p. 272
6 = ABLA2/VAME-OLY Subalpine fir/big huckleberry (Olympic)	CES321	AF	91	955	H	R6 E TP-001-88 p. 260
7 = ABLA2/JUCO4 Subalpine fir/common juniper	CES621	AF	31	560	C	R6 E TP-001-88 p. 264
8 = ABAM/OXOR-OLY Silver fir/oxalis (Olympic)	CFF111	SF	150	1050	C	R6 E TP-001-88 p. 202
9 = ABAM/ACTR-TIUN Silver fir/vanillaleaf-foamflower	CFF211	DF	84	950	C	R6 E TP-001-88 p. 238
10 = ABAM/XETE Silver fir/beargrass	CFF311	SF	83	1093	H	R6 E TP-001-88 p. 186
11 = ABAM/POMU Silver fir/swordfern	CFF611	SF	145	995	C	R6 E TP-001-88 p. 230
12 = ABAM/POMU-OXOR Silver fir/swordfern-oxalis	CFF612	SF	154	845	C	R6 E TP-001-88 p. 234
13 = ABAM/Dep. Silver fir/depauperate	CFF911	DF	84	861	H	R6 E TP-001-88 p. 194
14 = ABAM/GASH/OXOR Silver fir/salal/oxalis	CFS156	SF	149	1015	C	R6 E TP-001-88 p. 222
15 = ABAM/VAME/XETE-OLY Silver fir/big huckleberry/beargrass (Olympic)	CFS211	SF	83	1050	C	R6 E TP-001-88 p. 190
16 = ABAM/VAAL-OLY Silver fir/Alaska huckleberry (Olympic)	CFS212	SF	127	1090	C	R6 E TP-001-88 p. 152
17 = ABAM/VAAL/ERMO Silver fir/Alaska huckleberry/avalanche lily	CFS213	SF	108	835	C	R6 E TP-001-88 p. 156
18 = ABAM/VAAL/XETE Silver fir/Alaska huckleberry/beargrass	CFS214	DF	84	1090	C	R6 E TP-001-88 p. 160
19 = ABAM/VAAL/TIUN Silver fir/Alaska huckleberry/foamflower	CFS215	SF	101	1101	H	R6 E TP-001-88 p. 164
20 = ABAM/VAAL/OXOR Silver fir/Alaska huckleberry/oxalis	CFS217	SF	136	1055	C	R6 E TP-001-88 p. 172
21 = ABAM/VAAL/CLUN Silver fir/Alaska huckleberry/queen's cup	CFS218	SF	111	1080	C	R6 E TP-001-88 p. 176
22 = ABAM/VAAL/LIBO2 Silver fir/Alaska huckleberry/twinflower	CFS219	SF	115	955	C	R6 E TP-001-88 p. 180
23 = ABAM/OPHO-OLY Silver fir/devil's club (Olympic)	CFS311	SF	118	920	C	R6 E TP-001-88 p. 198
24 = ABAM/RHMA-OLY Silver fir/rhododendron (Olympic)	CFS611	SF	107	996	H	R6 E TP-001-88 p. 206
25 = ABAM/RHMA-VAAL Silver fir/rhododendron-Alaska huckleberry	CFS612	SF	96	470	C	R6 E TP-001-88 p. 210

FVS Sequence Number = Plant Association Species Type	Alpha Code	Site Species	Site Index*	Max. SDI*	Source*	Reference
26 = TSHE/OXOR-OLY Western hemlock/oxalis (Olympic)	CHF112	WH	104	780	C	R6 E TP-001-88 p. 326
27 = TSHE/OXOR-COAST Western hemlock/Oregon oxalis (Coast)	CHF121	WH	110	960	C	R6 E 220-86a p. 83
28 = TSHE/POMU-COAST Western hemlock/swordfern (Coast)	CHF122	WH	114	925	C	R6 E 220-86a p. 101
29 = TSHE/POMU-OXOR-OLY Western hemlock/swordfern-oxalis (Olympic)	CHF131	WH	94	950	C	R6 E TP-001-88 p. 386
30 = TSHE/POMU-TITR Western hemlock/swordfern-foamflower	CHF132	DF	116	1010	C	R6 E TP-001-88 p. 382
31 = TSHE/ACTR-OLY Western hemlock/vanillaleaf (Olympic)	CHF211	DF	108	1040	C	R6 E TP-001-88 p. 390
32 = TSHE/XETE-OLY Western hemlock/beargrass (Olympic)	CHF511	WH	50	696	H	R6 E TP-001-88 p. 306
33 = TSHE/Dep. Western hemlock/depauperate	CHF911	WH	105	1165	H	R6 E TP-001-88 p. 310
34 = TSHE/LYAM-OLY Western hemlock/skunkcabbage (Olympic)	CHM111	RA	52	760	C	R6 E TP-001-88 p. 378
35 = TSHE/BENE-COAST Western hemlock/dwarf Oregon grape (Coast)	CHS121	DF	118	985	C	R6 E 220-86a p. 77
36 = TSHE/BENE-GASH-COAST Western hemlock/dwarf Oregon grape-salal (Coast)	CHS122	WH	114	820	C	R6 E 220-86a p. 79
37 = TSHE/GASH-COAST Western hemlock/salal (Coast)	CHS123	WH	112	1210	C	R6 E 220-86a p. 93
38 = TSHE/GASH-OLY Western hemlock/salal (Olympic)	CHS131	WH	78	1050	C	R6 E TP-001-88 p. 350
39 = TSHE/GASH/XETE Western hemlock/salal/beargrass	CHS132	DF	67	880	C	R6 E TP-001-88 p. 354
40 = TSHE/GASH-VAOV2 Western hemlock/salal-evergreen huckleberry	CHS133	DF	98	1606	H	R6 E TP-001-88 p. 358
41 = TSHE/GASH-HODI Western hemlock/salal-oceanspray	CHS134	DF	78	810	C	R6 E TP-001-88 p. 362
42 = TSHE/GASH/OXOR Western hemlock/salal/oxalis	CHS136	WH	84	895	C	R6 E TP-001-88 p. 370
43 = TSHE/GASH/POMU Western hemlock/salal/swordfern	CHS137	DF	108	975	C	R6 E TP-001-88 p. 374
44 = TSHE/BENE-OLY Western hemlock/Oregongrape(Olympic)	CHS138	DF	71	1095	C	R6 E TP-001-88 p. 318
45 = TSHE/BENE/POMU-OLY Western hemlock/Oregongrape/swordfern (Olympic)	CHS139	DF	119	955	C	R6 E TP-001-99 p. 322
46 = TSHE/ACCI-GASH-COAST Western hemlock/vine maple-salal (Coast)	CHS221	DF	122	825	C	R6 E 220-86a p. 103
47 = TSHE/ACCI/POMU-COAST Western hemlock/vine maple/swordfern (Coast)	CHS222	DF	128	875	C	R6 E 220-86a p. 105
48 = TSHE/RHMA-BENE-COAST Western hemlock/rhododendron-dwarf OR grape (Coast)	CHS321	WH	98	1107	H	R6 E 220-86a p. 85
49 = TSHE/RHMA-GASH-COAST Western hemlock/rhododendron-salal	CHS322	DF	114	840	C	R6 E 220-86a p. 89
50 = TSHE/RHMA/POMU-COAST Western hemlock/rhododendron/swordfern (Coast)	CHS323	WH	84	945	C	R6 E 220-86a p. 91

FVS Sequence Number = Plant Association Species Type	Alpha Code	Site Species	Site Index*	Max. SDI*	Source*	Reference
51 = TSHE/RHMA/VAOV2-COAST W.hemlock/rhododendron-evergreen huckleberry(Coast)	CHS324	WH	80	865	C	R6 E 220-86a p. 87
52 = TSHE/RHMA-OLY Western hemlock/rhododendron (Olympic)	CHS331	WH	56	1145	C	R6 E TP-001-88 p. 330
53 = TSHE/RHMA/XETE-OLY Western hemlock/rhododendron/beargrass (Olympic)	CHS332	DF	56	610	C	R6 E TP-001-88 p. 334
54 = TSHE/RHMA-BENE-OLY Western hemlock/rhododendron-Oregongrape (Olympic)	CHS333	DF	80	1065	C	R6 E TP-001-88 p. 338
55 = TSHE/RHMA-GASH-OLY Western hemlock/rhododendron-salal (Olympic)	CHS334	DF	66	810	C	R6 E TP-001-88 p. 342
56 = TSHE/RHMA/POMU-OLY Western hemlock/rhododendron/swordfern (Olympic)	CHS335	DF	88	845	C	R6 E TP-001-88 p. 346
57 = TSHE/RUSP-COAST Western hemlock/salmonberry (Coast)	CHS421	WH	110	675	C	R6 E 220-86a p. 95
58 = TSHE/RUSP-ACCI-COAST Western hemlock/salmonberry-vine maple (Coast)	CHS422	WH	94	660	C	R6 E 220-86a p. 99
59 = TSHE/RUSP-GASH-COAST Western hemlock/salmonberry-salal (Coast)	CHS423	DF	119	600	C	R6 E 220-86a p. 97
60 = TSHE/OPHO-OLY Western hemlock/devil's club (Olympic)	CHS512	DF	134	485	C	R6 E TP-001-88 p. 314
61 = TSHE/OPHO-COAST Western hemlock/devil's club (Coast)	CHS521	WH	114	375	C	R6 E 220-86a p. 75
62 = TSHE/VAOV2-COAST Western hemlock/evergreen huckleberry (Coast)	CHS610	WH	118	935	C	R6 E 220-86a p. 81
63 = TSHE/VAAL Western hemlock/Alaska huckleberry	CHS621	WH	98	1025	C	R6 E TP-001-88 p. 290
64 = TSHE/VAAL/XETE Western hemlock/Alaska huckleberry/beargrass	CHS622	DF	70	610	C	R6 E TP-001-88 p. 294
65 = TSHE/VAAL/OXOR-OLY Western hemlock/Alaska huckleberry/oxalis (Olympic)	CHS623	WH	94	570	C	R6 E TP-001-88 p. 298
66 = TSHE/VAAL-GASH-OLY Western hemlock/Alaska huckleberry-salal (Olympic)	CHS624	WH	92	915	C	R6 E TP-001-88 p. 302
67 = TSME/VAAL/ERMO Mountain hemlock/Alaska huckleberry/avalanche lily	CMS242	MH	14	1021	H	R6 E TP-001-88 p. 120
68 = PISI/POMU-OXOR Sitka spruce/swordfern-oxalis	CSF111	SS	120	930	C	R6 E TP-001-88 p. 248
69 = PISI/POMU-COAST Sitka spruce/swordfern (Coast)	CSF121	SS	115	930	C	R6 E 220-86a p. 73
70 = PISI/OXOR-COAST Sitka spruce/Oregon oxalis	CSF321	SS	120	930	C	R6 E 220-86a p. 65
71 = PISI/MEFE-VAPA-COAST Sitka spruce/fool's huckleberry-red huckleb (Coast)	CSS221	SS	125	1000	C	R6 E 220-86a p. 63
72 = PISI/GASH-COAST Sitka spruce/salal (Coast)	CSS321	SS	117	615	C	R6 E 220-86a p. 67
73 = PISI/RUSP-COAST Sitka spruce/salmonberry (Coast)	CSS521	SS	123	545	C	R6 E 220-86a p. 69

FVS Sequence Number = Plant Association Species Type	Alpha Code	Site Species	Site Index*	Max. SDI*	Source*	Reference
74 = PISI/RUSP-GASH-COAST Sitka spruce/salmonberry-salal (Coast)	CSS522	SS	111	535	C	R6 E 220-86a p. 71
75 = PISI/OPHO-COAST Sitka spruce/devil's club (Coast)	CSS621	SS	121	1000	C	R6 E 220-86a p. 61

*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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