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Pacific Northwest Coast (PN) Variant Overview

Forest Vegetation Simulator

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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 June 29, 2021). 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. 67p.

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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 Species
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 Species
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	1/300th Acre	
Breakpoint DBH	5.0 inches	

1.0 Introduction

The Forest Vegetation Simulator (FVS) is an individual tree, distance independent growth and yield model with linkable modules called extensions, which simulate various insect and pathogen impacts, fire effects, fuel loading, snag dynamics, and development of understory tree vegetation. FVS can simulate a wide variety of forest types, stand structures, and pure or mixed species stands.

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

The 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 Quinault Indian Reservation. In 2013, new small tree growth equations from Gould and Harrington (2012) were embedded in the WC variant.

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.

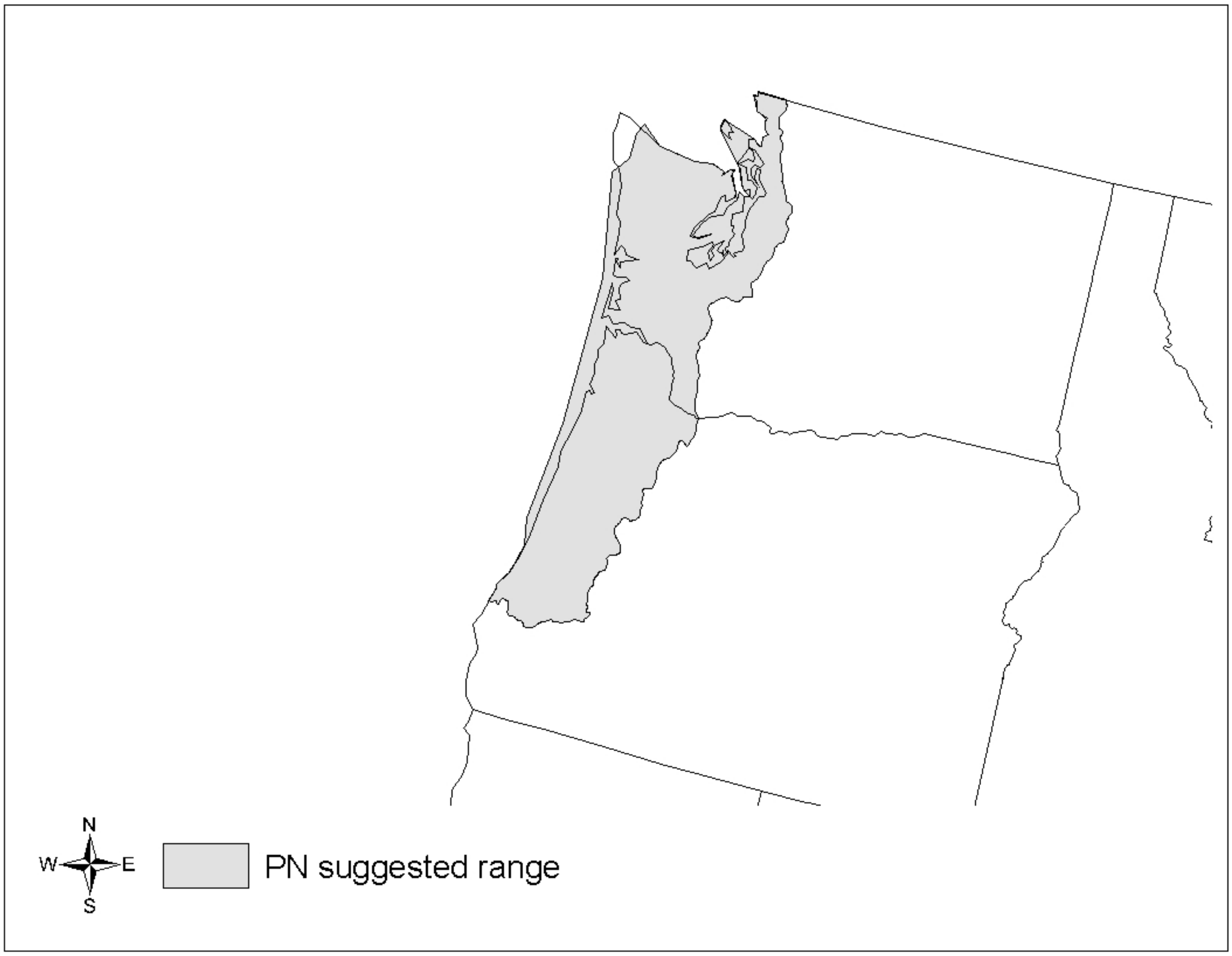

Figure 2.0.1 Suggested geographic range of use for the PN variant.

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 38 species. 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 codes identifying species not recognized by the variant will be mapped to the most similar species in the variant. The species mapping crosswalk is available on the variant documentation webpage of the FVS website. Any non-valid species code will default to the "other species" 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.

Table 3.2.1 Species codes used in the PN variant.

Species Number	Species Code	Common Name	FIA Code	PLANTS Symbol	Scientific Name
1	SF	Pacific silver fir	011	ABAM	Abies amabilis
2	WF	white fir	015	ABCO	Abies concolor
3	GF	grand fir	017	ABGR	Abies grandis
4	AF	subalpine fir	019	ABLA	Abies lasiocarpa
5	RF	California red fir / Shasta red fir	020	ABMA	Abies magnifica
6	SS	Sitka spruce	098	PISI	Picea sitchensis
7	NF	noble fir	022	ABPR	Abies procera
8	YC	Alaska cedar / western larch	042	CANO9	Callitropsis nootkatensis
9	IC	incense-cedar	081	CADE27	Libocedrus decurrens
10	ES	Engelmann spruce	093	PIEN	Picea engelmannii
11	LP	lodgepole pine	108	PICO	Pinus contorta
12	JP	Jeffrey pine	116	PIJE	Pinus jeffreyi
13	SP	sugar pine	117	PILA	Pinus lambertiana
14	WP	western white pine	119	PIMO3	Pinus monticola
15	PP	ponderosa pine	122	PIPO	Pinus ponderosa
16	DF	Douglas-fir	202	PSME	Pseudotsuga menziesii
17	RW	coast redwood	211	SESE3	Sequoia sempervirens
18	RC	western redcedar	242	THPL	Thuja plicata
19	WH	western hemlock	263	TSHE	Tsuga heterophylla

Species Number	Species Code	Common Name	FIA Code	PLANTS Symbol	Scientific Name
20	MH	mountain hemlock	264	TSME	Tsuga mertensiana
21	BM	bigleaf maple	312	ACMA3	Acer macrophyllum
22	RA	red alder	351	ALRU2	Alnus rubra
23	WA	white alder / Pacific madrone	352	ALRH2	Alnus rhombifolia
24	PB	paper birch	375	BEPA	Betula papyrifera var. commutata
25	GC	giant chinquapin / tanoak	431	CHCHC4	Chrysolepis chrysophylla
26	AS	quaking aspen	746	POTR5	Populus tremuloides
27	CW	black cottonwood	747	POBAT	Populus trichocarpa
28	WO	Oregon white oak / California black oak	815	QUGA4	Quercus garryana
29	WJ	western juniper	064	JUOC	Juniperus occidentalis
30	LL	subalpine larch	072	LALY	Larix lyallii
31	WB	whitebark pine	101	PIAL	Pinus albicaulis
32	KP	knobcone pine	103	PIAT	Pinus attenuata
33	PY	Pacific yew	231	TABR2	Taxus brevifolia
34	DG	Pacific dogwood	492	CONU4	Cornus nuttallii
35	HT	hawthorn species	500	CRATA	Crataegus spp.
36	CH	bitter cherry	768	PREM	Prunus emarginata
37	WI	willow species	920	SALIX	Salix spp.
38					
39	OT	other species	999	2TREE	

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

[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, coast redwood, bigleaf maple, white alder, paper birch, giant chinquapin, quaking aspen, black cottonwood, western juniper, whitebark pine, knobcone pine, Pacific yew, Pacific dogwood, hawthorn species, bitter cherry, willow species.

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

Species	Base Age
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} $SI_{wo} = 114.24569[1-\exp(-.02659*SI_{site})]^{2.25993}$

where:

SI_{wo} site index estimate of Oregon white oak
SI_{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:

$SDIMAX_i$ is species-specific SDI maximum
$BAMAX$ is the user-specified stand basal area maximum
$SDIU$ 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 Quinalt 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

$DBH \geq 3.0''$: $HT = 4.5 + P_2 * \exp[-P_3 * DBH^{\wedge}P_4]$
$DBH < 3.0''$: $HT = [(4.5 + P_2 * \exp[-P_3 * 3.0^{\wedge}P_4] - 4.51) * (DBH - 0.3) / 2.7] + 4.51$
For Douglas-fir at locations 612, 708, and 712 where $DBH \geq 5.0''$: $HT = 4.5 + P_2 * \exp[-P_3 * DBH^{\wedge}P_4]$
For Douglas-fir at locations 612, 708, and 712 where $DBH < 5.0''$: $HT = [(4.5 + P_2 * \exp[-P_3 * 5.0^{\wedge}P_4] - 4.51) * (DBH - 0.3) / 4.7] + 4.51$

{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, 17, 20, 30 or 33

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

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

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

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 - Quinalt	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
	P_4	-0.8281	-0.8281	-0.8281	-0.8281

Species Code	Coefficient	609 - Olympic, 800 - Quinalt	612 – Siuslaw, 712 – BLM Coos	708 – BLM Salem	709 – BLM Eugene
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	409.8811	409.8811	409.8811	409.8811
	P_3	6.8908	6.8908	6.8908	6.8908
	P_4	-0.5611	-0.5611	-0.5611	-0.5611
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
PB	P_2	1709.723	1709.723	1709.723	1709.723

Species Code	Coefficient	609 - Olympic, 800 - Quinalt	612 – Siuslaw, 712 – BLM Coos	708 – BLM Salem	709 – BLM Eugene
	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
	P_3	2.4231	2.4231	2.4231	2.4231

Species Code	Coefficient	609 - Olympic, 800 - Quinalt	612 – Siuslaw, 712 – BLM Coos	708 – BLM Salem	709 – BLM Eugene
	P_4	-0.18	-0.18	-0.18	-0.18
OT	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	5.188	-13.801	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
PY	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
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 (b_1 and b_2) and equation reference for each species are shown in table 4.2.1.

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

{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 $0.80 \le BRATIO \le 0.99$)
DBH is tree diameter at breast height
DIB is tree diameter inside bark at breast height
b_1, b_2 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
DF	0.903563	0.989388	{4.2.1}	Larsen and Hann, 1985

Species Code	b_1	b_2	Equation Used	Equation Source
RW	0.837291	1.0	{4.2.1}	Larsen and Hann, 1985
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. 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
RW	7.558538	-0.015637	-0.009064	1.9658
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

a_0, b_{0-1}, c_{0-1}, and d_{0-1} 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

Species Code	Species Index Number
SF	1
WF	2
GF	2
AF	3
RF	3
SS	17
NF	4
YC	15
IC	11
ES	11
LP	16
JP	6
SP	5
WP	5
PP	6
DF	7
RW	11
RC	8
WH	9
MH	10

Species Code	Species Index Number
BM	12
RA	13
WA	14
PB	14
GC	14
AS	14
CW	14
WO	14
WJ	14
LL	11
WB	11
KP	11
PY	11
DG	14
HT	14
CH	14
WI	14
OT	14

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

Species Index	a_0	b_0	b_1	c_0	c_1	d_0	d_1
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

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}. 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:

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

4.4 Crown Width Relationships

The 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)

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

$5.0 \le HT < 15.0$: $CW = 0.8 * HT * MAX(0.5, CR * 0.01)$

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

{4.4.3} Crookston (2003); Equation 03

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

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

{4.4.4} Crookston (2005); Equation 04

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

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

{4.4.5} Crookston (2005); Equation 05

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

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

{4.4.6} Donnelly (1996); Equation 06

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

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

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

Species Code	Equation Number*	a_1	a_2	a_3	a_4	a_5	a_6
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
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
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	Model Coefficients		
	R_1	R_2	R_3

Species Code	Model Coefficients		
	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
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

As stated previously, 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

Species Code	a_1
DF	0.1635
RW	0.1727
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
OT	0.1635

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 {4.6.1.2}, and applied as shown in equation {4.6.1.3}. The range of diameters for each species is shown in table 4.6.1.2.

{4.6.1.2}

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

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

where:

XWT	is the weight applied to the growth estimates
DBH	is tree diameter at breast height
Xmax	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	4.0	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. 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
DBH	is tree diameter at breast height
D5	is 5-yr diameter increment (in)
DMAX	is maximum diameter increment for the species (in).
OPEN	is an adjustment for open grown conditions
PTBA	is basal area (sq. ft. /ac.) on the inventory point where the tree is located
PTBA2	is the transformation of *PTBA*: log(*PTBA* + 2.71)
PTBAL	is basal area of trees larger than the subject tree (ft2/acre) on the inventory point Where the tree is located
PTBAL2	is the transformation of PTBAL: log(*PTBAL* + 2.71)
CR	is crown ratio expressed as a proportion
RELHT	is tree height / height of 40 largest trees/acre, measured at the stand level (proportion, bound between 0 and 1.5)
RELHT2	is *RELHT*^0.5
SI	is species site index
c_0-c_9	are species-specific coefficients in table 4.6.2.1
a_1	are species-specific coefficients in table 4.6.1.1

Table 4.6.1.1 Coefficients ($c_0 - c_9$) and equation reference for small-tree diameter increment equations {4.6.1.1} in the PN variant.

Species Code	*DMAX*	Model Coefficients									
		c_0	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9
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
RW	2.8489	2.9527	0	0	0.0066	0	0	-0.4734	0	-0.7394	-0.0207
RC	2.7899	1.6815	0	0	0.0068	0	0	0	0	-0.6049	-0.0121

Species Code	*DMAX*	Model Coefficients									
		c_0	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9
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
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

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. Coefficients for this equation are shown in tables 4.7.1.1 – 4.7.1.6. Diameter growth for red alder in the PN variant is shown later in this section.

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:

DDS	is the square of the diameter growth increment
EL	is stand elevation in hundreds of feet (if species index 14, $EL \leq 30$)
SI	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)
ASP	is stand aspect
SL	is stand slope
DBH	is tree diameter at breast height
BAL	is total basal area in trees larger than the subject tree
CR	is crown ratio expressed as a proportion
PCCF	is crown competition factor on the inventory point where the tree is established
RELHT	is tree height divided by average height of the 40 largest diameter trees in the stand bounded to $RELHT \leq 1.5$)
BA	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
SF	1
WF	2
GF	2
AF	3
RF	4
SS	18
NF	4
YC	15
IC	11
ES	11
LP	16
JP	6
SP	5
WP	5
PP	6
DF	7
RW	11
RC	8
WH	9

Species Code	Species Index
BM	12
RA	13
WA	14
PB	14
GC	14
AS	14
CW	14
WO	19
WJ	14
LL	11
WB	11
KP	11
PY	11
DG	14
HT	14
CH	14
WI	14
OT	14

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
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 b_{12} values

Table 4.7.1.2 (continued) Coefficients (b_2- b_{18}) 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 b_{12} values

Table 4.7.1.3 b_1 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) b_1 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.

	Species Index																
Location Code	**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
712 – BLM Coos Bay	1	1	1	1	1	1	2	2	2	1	1	1	1	1	1	2	1

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

For all trees, diameter growth is checked to make sure diameter growth is between zero and a maximum allowed value, set by equation {4.7.1.3}. If diameter growth exceeds the estimate in equation {4.7.1.3}, diameter growth is set to the maximum growth allowed.

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

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, 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
SF	1
WF	2
GF	2
AF	3
RF	4
SS	15
NF	5
YC	6
IC	7
ES	3
LP	8
JP	7
SP	9
WP	9
PP	7
DF	14
RW	6
RC	15
WH	10
MH	11

Species Code	Species Index
BM	6
RA	12
WA	6
PB	6
GC	6
AS	6
CW	6
WO	
WJ	6
LL	13
WB	6
KP	6
PY	6
DG	6
HT	6
CH	6
WI	6
OT	6

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

Species Code	a_0	a_1	Maximum Age
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
RW	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

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

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

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

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

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

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

$H = [(SI - 4.5) * (1 - \exp(-X * A\text{^}b_1))] / [1 - \exp(-Y * 50\text{^}b_1)] + 4.5$
X = (SI * TERM) + (b4 * TERM^2) + b5
TERM = A * b2* exp (A * b3)
Y = (SI * TERM2) + (b4* TERM2^2) + b5
TERM2 = 50 * b2 * exp (50 * b3)

{4.7.2.11} Used for species index 5: noble fir

$H = 4.5 + [(SI - 4.5) / (X_1 * (1 / A)\text{^}2 + X_2 * (1 / A) + 1 - (X_1 * 0.0001) - (X_2 * 0.01))]$
$X_1 = b_0 + (b_1 * (SI - 4.5)) - (b_2 * (SI - 4.5)\text{^}2)$
$X_2 = b_3 + (b_4 * 1 / (SI - 4.5)) - (b_5 * (SI - 4.5)\text{^-}2)$

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

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

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

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

{4.7.2.14} Used for species index 8: lodgepole pine

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

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

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

{4.7.2.16} Used for species index 10: western hemlock

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

{4.7.2.17} Used for species index 11: mountain hemlock

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

{4.7.2.18} Used for species index 12: red alder

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

{4.7.2.19} Used for species index 13: subalpine larch

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

{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 (b_0- b_{13}) 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} $POTHTG = [4.5+\{(114.24569(1-\exp(-.02659*SIKing))\text{^}2.25993)-18.602 / \ln(2.71*BA)\}*\{1-\exp(-.13743*DBH2)\}\text{^}1.38994] – [4.5+\{(114.24569(1-\exp(-.02659*SIKing))\text{^}2.25993)-18.602 / \ln(2.71*BA)\}*\{1-\exp(-.13743*DBH1)\}\text{^}1.38994]$

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

For all species, 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} $HGMDCR = (100 * (CR / 100)^3) * \exp(-5 * (CR / 100))$ bounded $HGMDCR \leq 1.0$

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

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

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

where:

POTHTG	is potential height growth
H10	is estimated height of the tree in ten years
HT	is height of the tree at the beginning of the cycle
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
HGMDCR	is a height growth modifier based on crown ratio
HGMDRH	is a height growth modifier based on relative height and shade tolerance
HTGMOD	is a weighted height growth modifier
CR	is crown ratio expressed as a percent
RELHT	is tree height divided by average height of the 40 largest diameter trees in the stand
$b_1 - b_4$	are species-specific coefficients shown in table 4.7.2.4

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

Species Code	Coefficients			
	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
RW	0.2	1.1	20	-1.1
RC	0.2	1.1	20	-1.1
WH	0.2	1.1	20	-1.1

Species Code	Coefficients			
	b_1	b_2	b_3	b_4
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

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 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, 5.0.2 and 5.0.3.

{5.0.1} Hann Mortality Equations:

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

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

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

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

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

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

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

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

where:

RA	is the estimated annual mortality rate
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
d_{0-5}	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
RW	1	-4.13142	-1.13736	0	-0.82331	0.030775	0.00991	1
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
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

Species Code	Coefficients							
	group	d_0	d_1	d_2	d_3	d_4	d_5	MCLASS
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 550ft^2/acre) the stand will reapply the mortality rate to each tree record again until the stand is below the maximum density.

{5.0.4} $RT = 1 – (1 – RA)^Y$

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*RT* is the mortality rate applied to an individual tree record for the growth period
RC is the combined estimate of 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	1.0	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

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

{6.0.2} For root suckering hardwood species

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

{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 Uchytil 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 three merchantability standards: total stem cubic feet, merchantable stem cubic feet, and merchantable stem board feet (Scribner). Volume estimation is based on methods contained in the National Volume Estimator Library maintained by the Forest Products Measurements group in the Forest Management Service Center (Volume Estimator Library Equations 2009). The default volume merchantability standards and equation numbers for the PN variant are shown in tables 7.0.1-7.0.4.

Table 7.0.1 Volume merchantability standards for the PN variant.

Merchantable Cubic Foot Volume Specifications:		
Minimum DBH / Top Diameter	LP	All Other Species
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 Species
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 / Shasta red fir	609, 612, 800	616BEHW020	Behre's Hyperbola
California red fir / Shasta 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

Common Name	Location Code	Equation Number	Model Name
Alaska cedar / western larch	609, 612, 800	616BEHW042	Behre's Hyperbola
Alaska cedar / western larch	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
coast redwood	609, 612, 800	616BEHW211	Behre's Hyperbola
coast 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
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 / Pacific madrone	609, 612, 800	616BEHW352	Behre's Hyperbola

Common Name	Location Code	Equation Number	Model Name
white alder / Pacific madrone	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 / tanoak	609, 612, 800	616BEHW431	Behre's Hyperbola
giant chinquapin / tanoak	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 / California black oak	609, 612, 800	616BEHW815	Behre's Hyperbola
Oregon white oak / California black 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 species	609, 612, 800	616BEHW500	Behre's Hyperbola
hawthorn species	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 species	609, 612, 800	616BEHW920	Behre's Hyperbola
willow species	708, 709, 712	B00BEHW999	Behre's Hyperbola
other species	609, 612, 800	616BEHW999	Behre's Hyperbola
other species	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).**

BLM Locations:		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
RW	B00BEHW211	75	78	75
RC	B00BEHW242	76	72	70

BLM Locations:		708	709	712
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).

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11.0 Appendices

11.1 Appendix A: Distribution of Data Samples

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

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

	National Forest					
Species	Siuslaw NF Inventory 1973	Olympic NF Inventory 1974	Siuslaw NF Managed Stand Survey 1987	BLM Oregon Inventory	BIA Quinalt Indian Reservation Inventory 1992	Total Number of Observations
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
coast 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 species		

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 species 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-036-92 p. 37
2 = PSME/GASH Douglas-fir/salal	CDS255	DF	62	955	C	R6 E TP-036-92 p. 93
3 = PSME/ARUV Douglas-fir/kinnikinnick	CDS651	DF	33	600	C	R6 E TP-036-92 p. 91
4 = ABLA2/LULA Subalpine fir/subalpine lupine	CEF321	AF	50	367	H	R6 E TP-255-86 p. 93
5 = ABLA2/RHAL-OLY Subalpine fir/white rhododendron (Olympic)	CES212	AF	65	535	H	R6 E TP-036-92 p. 85
6 = ABLA2/VAME-OLY Subalpine fir/big huckleberry (Olympic)	CES321	AF	91	955	H	R6 E TP-255-86 p. 358
7 = ABLA2/JUCO4 Subalpine fir/common juniper	CES621	AF	31	560	C	R6 E TP-255-86 p. 365
8 = ABAM/OXOR-OLY Silver fir/oxalis (Olympic)	CFF111	SF	150	1050	C	R6 E TP-036-92 p. 87
9 = ABAM/ACTR-TIUN Silver fir/vanillaleaf-foamflower	CFF211	DF	84	950	C	R6 E TP-255-86 p. 352
10 = ABAM/XETE Silver fir/beargrass	CFF311	SF	83	1093	H	R6 E TP-036-92 p. 83
11 = ABAM/POMU Silver fir/swordfern	CFF611	SF	145	995	C	R6 E TP-255-86 p. 339
12 = ABAM/POMU-OXOR Silver fir/swordfern-oxalis	CFF612	SF	154	845	C	R6 E TP-036-92 p. 81
13 = ABAM/Dep. Silver fir/depauperate	CFF911	DF	84	861	H	R6 E TP-255-86 p. 268
14 = ABAM/GASH/OXOR Silver fir/salal/oxalis	CFS156	SF	149	1015	C	R6 E TP-255-86 p. 275
15 = ABAM/VAME/XETE-OLY Silver fir/big huckleberry/beargrass (Olympic)	CFS211	SF	83	1050	C	R6 E TP-036-92 p. 25
16 = ABAM/VAAL-OLY Silver fir/Alaska huckleberry (Olympic)	CFS212	SF	127	1090	C	R6 E TP-279-87 p. 55
17 = ABAM/VAAL/ERMO Silver fir/Alaska huckleberry/avalanche lily	CFS213	SF	108	835	C	R6 E TP-279-87 p. 57
18 = ABAM/VAAL/XETE Silver fir/Alaska huckleberry/beargrass	CFS214	DF	84	1090	C	R6 E Tp-279-87 p. 49
19 = ABAM/VAAL/TIUN Silver fir/Alaska huckleberry/foamflower	CFS215	SF	101	1101	H	R6 E TP-004-88 p. 59
20 = ABAM/VAAL/OXOR Silver fir/Alaska huckleberry/oxalis	CFS217	SF	136	1055	C	R6 E TP-006-88 p. 45
21 = ABAM/VAAL/CLUN Silver fir/Alaska huckleberry/queen's cup	CFS218	SF	111	1080	C	R6 E TP-255-86 p. 262
22 = ABAM/VAAL/LIBO2 Silver fir/Alaska huckleberry/twinflower	CFS219	SF	115	955	C	R6 E TP-255-86 p. 238
23 = ABAM/OPHO-OLY Silver fir/devil's club (Olympic)	CFS311	SF	118	920	C	R6 E TP-036-92 p. 33
24 = ABAM/RHMA-OLY Silver fir/rhododendron (Olympic)	CFS611	SF	107	996	H	R6 E TP-036-92 p. 27
25 = ABAM/RHMA-VAAL Silver fir/rhododendron-Alaska huckleberry	CFS612	SF	96	470	C	R6 E TP-255-86 p. 253

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-036-92 p. 35
27 = TSHE/OXOR-COAST Western hemlock/Oregon oxalis (Coast)	CHF121	WH	110	960	C	R6 E TP-036-92 p. 29
28 = TSHE/POMU-COAST Western hemlock/swordfern (Coast)	CHF122	WH	114	925	C	R6 E TP-255-86 p. 244
29 = TSHE/POMU-OXOR-OLY Western hemlock/swordfern-oxalis (Olympic)	CHF131	WH	94	950	C	R6 E TP-255-86 p. 305
30 = TSHE/POMU-TITR Western hemlock/swordfern-foamflower	CHF132	DF	116	1010	C	R6 AG 3-1-73 p. 34
31 = TSHE/ACTR-OLY Western hemlock/vanillaleaf (Olympic)	CHF211	DF	108	1040	C	R6 E TP-279-87 p. 29
32 = TSHE/XETE-OLY Western hemlock/beargrass (Olympic)	CHF511	WH	50	696	H	R6 E TP-279-87 p. 41
33 = TSHE/Dep. Western hemlock/depauperate	CHF911	WH	105	1165	H	R6 E TP-279-87 p. 43
34 = TSHE/LYAM-OLY Western hemlock/skunkcabbage (Olympic)	CHM111	RA	52	760	C	R6 E TP-279-87 p. 39
35 = TSHE/BENE-COAST Western hemlock/dwarf Oregon grape (Coast)	CHS121	DF	118	985	C	R6 E TP-279-87 p. 33
36 = TSHE/BENE-GASH-COAST Western hemlock/dwarf Oregon grape-salal (Coast)	CHS122	WH	114	820	C	R6 E TP-279-87 p. 35
37 = TSHE/GASH-COAST Western hemlock/salal (Coast)	CHS123	WH	112	1210	C	R6 E TP-279-87 p. 45
38 = TSHE/GASH-OLY Western hemlock/salal (Olympic)	CHS131	WH	78	1050	C	R6 AG 3-1-73 p. 36
39 = TSHE/GASH/XETE Western hemlock/salal/beargrass	CHS132	DF	67	880	C	R6 E TP-255-86 p. 250
40 = TSHE/GASH-VAOV2 Western hemlock/salal-evergreen huckleberry	CHS133	DF	98	1606	H	R6 E TP-036-92 p. 79
41 = TSHE/GASH-HODI Western hemlock/salal-oceanspray	CHS134	DF	78	810	C	R6 AG 3-1-73 p. 35
42 = TSHE/GASH/OXOR Western hemlock/salal/oxalis	CHS136	WH	84	895	C	R6 E TP-255-86 p. 259
43 = TSHE/GASH/POMU Western hemlock/salal/swordfern	CHS137	DF	108	975	C	R6 E TP-255-86 p.230
44 = TSHE/BENE-OLY Western hemlock/Oregongrape(Olympic)	CHS138	DF	71	1095	C	R6 E TP-255-86 p. 230
45 = TSHE/BENE/POMU-OLY Western hemlock/Oregongrape/swordfern (Olympic)	CHS139	DF	119	955	C	R6 E TP-036-92 p. 121
46 = TSHE/ACCI-GASH-COAST Western hemlock/vine maple-salal (Coast)	CHS221	DF	122	825	C	R6 E TP-036-92 p. 119
47 = TSHE/ACCI/POMU-COAST Western hemlock/vine maple/swordfern (Coast)	CHS222	DF	128	875	C	R6 E TP-255-86 p. 378
48 = TSHE/RHMA-BENE-COAST Western hemlock/rhododendron-dwarf OR grape (Coast)	CHS321	WH	98	1107	H	R6 E TP-255-86 p. 383
49 = TSHE/RHMA-GASH-COAST Western hemlock/rhododendron-salal	CHS322	DF	114	840	C	R6 E TP-036-92 p. 107
50 = TSHE/RHMA/POMU-COAST Western hemlock/rhododendron/swordfern (Coast)	CHS323	WH	84	945	C	R6 E TP-036-92 p. 109
51 = TSHE/RHMA/VAOV2-COAST W.hemlock/rhododendron-evergreen huckleberry(Coast)	CHS324	WH	80	865	C	R6 AG 3-1-73 p. 28
52 = TSHE/RHMA-OLY Western hemlock/rhododendron (Olympic)	CHS331	WH	56	1145	C	R6 E TP-036-92 p. 117

FVS Sequence Number = Plant Association Species Type	Alpha Code	Site Species	Site Index*	Max. SDI*	Source*	Reference
53 = TSHE/RHMA/XETE-OLY Western hemlock/rhododendron/beargrass (Olympic)	CHS332	DF	56	610	C	R6 E TP-036-92 p. 111
54 = TSHE/RHMA-BENE-OLY Western hemlock/rhododendron-Oregongrape (Olympic)	CHS333	DF	80	1065	C	R6 E TP-036-92 p. 113
55 = TSHE/RHMA-GASH-OLY Western hemlock/rhododendron-salal (Olympic)	CHS334	DF	66	810	C	R6 E TP-036-92 p. 115
56 = TSHE/RHMA/POMU-OLY Western hemlock/rhododendron/swordfern (Olympic)	CHS335	DF	88	845	C	R6 E TP-036-92 p. 97
57 = TSHE/RUSP-COAST Western hemlock/salmonberry (Coast)	CHS421	WH	110	675	C	R6 E TP-036-92 p. 99
58 = TSHE/RUSP-ACCI-COAST Western hemlock/salmonberry-vine maple (Coast)	CHS422	WH	94	660	C	R6 E TP-036-92 p. 101
59 = TSHE/RUSP-GASH-COAST Western hemlock/salmonberry-salal (Coast)	CHS423	DF	119	600	C	R6 E TP-279-87 p. 27
60 = TSHE/OPHO-OLY Western hemlock/devil's club (Olympic)	CHS512	DF	134	485	C	R6 E TP-255-86 p. 372
61 = TSHE/OPHO-COAST Western hemlock/devil's club (Coast)	CHS521	WH	114	375	C	R6 E TP-255-86 p. 377
62 = TSHE/VAOV2-COAST Western hemlock/evergreen huckleberry (Coast)	CHS610	WH	118	935	C	R6 E TP-036-92 p. 103
63 = TSHE/VAAL Western hemlock/Alaska huckleberry	CHS621	WH	98	1025	C	R6 E TP-036-92 p. 105
64 = TSHE/VAAL/XETE Western hemlock/Alaska huckleberry/beargrass	CHS622	DF	70	610	C	R6 E TP-036-92 p. 51
65 = TSHE/VAAL/OXOR-OLY Western hemlock/Alaska huckleberry/oxalis (Olympic)	CHS623	WH	94	570	C	R6 E TP-036-92 p. 53
66 = TSHE/VAAL-GASH-OLY Western hemlock/Alaska huckleberry-salal (Olympic)	CHS624	WH	92	915	C	R6 E TP-255-86 p. 298
67 = TSME/VAAL/ERMO Mountain hemlock/Alaska huckleberry/avalanche lily	CMS242	MH	14	1021	H	R6 E TP-036-92 p. 59
68 = PISI/POMU-OXOR Sitka spruce/swordfern-oxalis	CSF111	SS	120	930	C	R6 E TP-255-86 p. 279
69 = PISI/POMU-COAST Sitka spruce/swordfern (Coast)	CSF121	SS	115	930	C	R6 E TP-279-87 p. 47
70 = PISI/OXOR-COAST Sitka spruce/Oregon oxalis	CSF321	SS	120	930	C	R6 E TP-036-92 p. 49
71 = PISI/MEFE-VAPA-COAST Sitka spruce/fool's huckleberry-red huckleb (Coast)	CSS221	SS	125	1000	C	R6 E TP-036-92 p. 45
72 = PISI/GASH-COAST Sitka spruce/salal (Coast)	CSS321	SS	117	615	C	R6 E TP-036-92 p. 47
73 = PISI/RUSP-COAST Sitka spruce/salmonberry (Coast)	CSS521	SS	123	545	C	R6 E TP-036-92 p. 73
74 = PISI/RUSP-GASH-COAST Sitka spruce/salmonberry-salal (Coast)	CSS522	SS	111	535	C	R6 E TP-255-86 p. 320
75 = PISI/OPHO-COAST Sitka spruce/devil's club (Coast)	CSS621	SS	121	1000	C	R6 E TP-036-92 p. 71

*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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