Prognosis Southeast Interior (SEI 2.0)
Geographic Variant Description

British Columbia Ministry of Forests

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Prepared for

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We thank Bruce Mackenzie at the BC Ministry of Environment, Lands and Parks and Kathleen McGuiness at the BC Ministry of Forests Nelson Regional office, for help in locating GIS coverage for the provincial forest regions.

Many tables in this document are derived from Wykoff et al. 1982.

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1 Introduction

Prognosis is an individual tree, distance independent growth and yield model (Stage 1973, Wykoff *et al.* 1982, Wykoff 1986, Crookston 1990), originally developed for use in the Inland Empire area of Idaho and Montana. New variants of Prognosis result when the model is calibrated for different geographic areas. Geographic variants of Prognosis (renamed Forest Vegetation Simulator – FVS – in the United States) have been developed for many areas in the United States.

Over the past four years the Inland Empire variant – more commonly called the Northern Idaho (NI) variant – has been modified for use within the Southern Interior region of British Columbia, creating the Southeast Interior (SEI) geographic variant. Coverage now extends over much of the Nelson, Kamloops and Cariboo Forest Regions, including many subzones and site series of the IDF, ICH, MS and ESSF biogeoclimatic zones.

While much progress has been made, the model refit is not yet complete. Adaptation and geographic localisation of the model currently includes:

- metrification of inputs and outputs for the base model keywords and tree lists;
- metrification of inputs and outputs for the Event Monitor (Crookston 1990), the Regeneration Establishment model version 2.0 (Ferguson and Crookston 1991), and the Western Root Disease version 3.0 extension (Frankel 1998);
- inclusion of volume calculation algorithms (Kozak 1988) and default diameter limits;
- modification of trees species character codes;
- calibration of large-tree diameter growth model for many BEC subzones and site series;
- calibration of the height-dubbing model for many BEC subzones;
- tapering of diameter and height growth for old trees;
- preliminary calibration of the large-tree height growth model for many BEC subzones; and
- improved estimates of site carrying capacity, resulting in a preliminary calibration of the mortality model for many BEC subzones.

Like the NI variant, The SEI variant is applicable for the projection of a variety of species, forest types, and stand structures. Species include western white pine, western larch, Douglas-fir, grand fir, western hemlock, western redcedar, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine and mountain hemlock. Since Prognosis is an individual tree model, a wide variety of forest types can be accommodated, as can any stand structure ranging from even-aged to uneven-aged.

2 Constraints to Model Use

Potential users of the SEI variant should be aware of certain challenges that await them as a result of the as-yet-incomplete nature of the variant. Users of the Prognosis^{BC} interface to the SEI variant do not have to contend with many of these issues, since the interface programme automatically makes the most appropriate settings for a run.

2.1 Forest Habitat & Biogeoclimatic Classification Systems

The NI variant uses the concept of forest habitat type (Daubenmire and Daubenmire 1968) as a method of stratifying the landscape by climax overstorey/understorey plant associations. This stratification system underlies many of the regression equations in the NI and SEI variants, and thus influences model behaviour in many ways. In British Columbia the biogeoclimatic classification (BEC) system (Pojar *et al.* 1987) serves an analogous function, but there are differences between the approach and resolution of the two methods.

In Section 3, Tables 3.1 and 3.2 give the best mapping between a large subset of the BEC site series in the Kamloops and Nelson Regions and the ecological forest habitat groups (Habitat Codes) of the NI variant. This mapping is based on Mackenzie *et al.* (1990, p. 17-30). Users who employ the Prognosis^{BC} graphical interface have the benefit of automatically making use of the relationships shown in these tables. Users who do not make use of the graphical interface and who wish to evaluate the model in subzones or site series that are not yet calibrated should make use of Table 3.3 to select the most applicable Habitat Code.

2.2 Hardwood Species

Hardwood species are common in many stands of the southern interior of B.C., particularly in early seral stages. The SEI variant is not yet calibrated for any deciduous species, and will treat any unrecognised two-character species codes as mountain hemlock. In some cases it may be possible to emulate the behaviour of a deciduous species by using an absent coniferous species as a surrogate, modifying its growth with the appropriate keywords and Event Monitor directives. Plans are now under way to allow a single hardwood species to be included in projections. This feature should become available by 2001.

2.3 Regeneration Establishment Model

By default, the NI variant automatically plants seedlings under certain stand conditions, using the Regeneration Establishment model (Ferguson and Crookston 1991). A comparative analysis of ISIS regeneration surveys and the Regeneration model (Robinson and Kurz 1998) showed that the NI variant is currently unable to reliably reproduce the mixture of species and density observed in the surveys. Model users may deactivate this component of the model or modify its behaviour using the Regeneration Establishment keywords.

3 Data Base

3.1 Recalibration of the Large-tree Diameter Growth Model

The adjusted large-tree diameter increment model (Section 4.9) depends on the relationships illustrated in Tables 3.1and 3.2. These tables show the best mapping between a substantial subset of the BEC site series in the Kamloops and Nelson Regions and the ecological forest habitat groups (Habitat Codes) of the NI variant. The choice of Habitat Code plays a very important role in the model's behaviour in general, and in the current recalibration work specifically. This mapping is based Mackenzie *et al.* (1990, p. 17-30).

The actual set of site series available for recalibration is a subset of the site series shown in Tables 3.1 and 3.2. The available subset is based on the availability of PSP data to estimate an adjusted diameter growth model. These PSP data are summarised in Table 3.4 (Abdel-Azim Zumrawi, *pers. comm.*), and their geographic extent is shown Section 3.2.

Users who employ the Prognosis^{BC} graphical interface have the benefit of automatically making use of the relationships shown in Table 3.1 and 3.2. Users who do not make use of the graphical interface and who wish to evaluate the model in subzones or site series that are not yet calibrated may wish to make use of Table 3.3 to evaluate the best possible choice of Habitat Code. Table 3.3 is based in part on Table 13 of Wykoff (1986).

Table 3.1: Shaded cells show the correspondence between each indicated site series in the **Nelson Region** and the NI variant Daubenmire Habitat Code (see text for details). Those site series that have regional PSP data are shaded dark. Within the shaded cells, model reliability is denoted by H, M, P or L (High > Medium > Poor > Low) and is based on the number of sample plots used in the recalibration (Anonymous 2000). Those series that have a plausible Habitat Code mapping but no regional data with which to recalibrate the diameter increment model are lightly shaded and are usually assigned a Low Reliability. The site series columns have been ordered to show the moisture gradient from driest (02) to wettest (07); the mesic series is marked to aid legibility. Table 3.4 contains further information about the PSP data.

BEC variant		Site Series							Habitat Code
		2	3	4	1	5	6	7	
ESSF	dc		░						730
	dk			M	M				670
	wc1	░							640
	wc4	P	P						670
	wm	L	P						670
				P	M				620
ICH	dw			L	H				570
	mk1		H						250
				H					640
					H	P			530
	mw1				▓				570
						L	L		550
	mw2		H						250
				H	H				570
						P	L		550
	mw3		P						250
				M					530
					M				570
						M			530
								P	550
	vk1				░				550
	wk1			P	L				570
						L			550

BEC variant		Site Series							Habitat Code
		2	3	4	1	5	6	7	
IDF	dk1			░	░				320
	dk2		░						320
					░				250
	dm1			M	M				320
						L			640
	dm2			M					420
					M				350
						L			420
	mw1					░			250
	xh1			P	P				320
	xh2					░	░		320
								░	310
MS	dk		M						470
				H					250
					H				660
						L			420
	dm1	L							320
			L						730
				M					250
					L				620
	xk					░			320
PP	dh1				▓				130
	dh2				P				130
	xh1			░	░				130
							░	░	310
	xh2		░						130

Table 3.2: Shaded cells show the correspondence between each indicated site series in the **Kamloops Region** and the NI variant Daubenmire Habitat Code (see text for details). Those site series that have regional PSP data are shaded dark. Within the shaded cells, model reliability in the Nelson Region is denoted by H, M, P or L (High > Medium > Poor > Low) and is based on the number of sample plots used in the recalibration (Anonymous 2000). Those series that have a plausible Habitat Code mapping but no regional data with which to recalibrate the diameter increment model are lightly shaded and are usually assigned a Low Reliability. The site series columns have been ordered to show the moisture gradient from driest (02) to wettest (07); the mesic series is marked to aid legibility. Table 3.4 contains further information about the PSP data.

BEC variant		**Site Series**							**Habitat Code**
		2	**3**	**4**	**1**	**5**	**6**	**7**	
ESSF	dc		▨						730
	dk			▨	▨				670
	wc1	▨							640
	wc4	▨	▨						670
	wm	▨	▨						670
				▨	▨				620
ICH	dw			▨	▨				570
	mk1		M						250
				P					640
					▨	▨			530
	mw1				▨				570
						▨	▨		550
	mw2		▨						250
				P	M				570
						P	L		550
	mw3		P						250
				▨					530
					M				570
						▨			530
								P	550
	vk1				▨				550
	wk1			▨	▨				570
						▨			550
IDF	dk1			M	M				320
	dk2		M						320
					M				250
	dk3			■	■		■		320
	dm1			■	■				320
						▨			640
	dm2			▨					420
					▨				350
						▨			420
	mw1			■					250
	xh1			P	M				320
	xh2					P	P		320
								▨	310
MS	dk		▨						470
				▨					250
					▨				660
						▨			420
	dm1	▨							320
			▨						730
				■					250
					L				620
	xk					▨			320
PP	dh1				▨				130
	dh2				▨				130
	xh1			▨	▨				130
							▨	▨	310
	xh2		P						130

Table 3.3: Habitat codes and plant associations used by the NI variant (abstracted from Table 13, Wykoff (1986).

Habitat Code	Abbreviation	Plant Association
130	PIPO/AGSP	*Pinus ponderosa/Agropyron spicatum*
170	PIPO/SYAL	*Pinus ponderosa/Symphoricarpos albus*
250	PSME/VACA	*Pseudotsuga menziesii/Vaccinium caespitosum*
260	PSME/PHMA	*Pseudotsuga menziesii/Physocarpus malvaceus*
280	PSME/VAGL	*Pseudotsuga menziesii/Vaccinium globulare*
290	PSME/LIBO	*Pseudotsuga menziesii/Linnaea borealis*
310	PSME/SYAL	*Pseudotsuga menziesii/Symphoricarpos albus*
320	PSME/CARU	*Pseudotsuga menziesii/Calamagrostis rubescens*
330	PSME/CAGE	*Pseudotsuga menziesii/Carex geyeri*
420	PICEA/CLUN	*Picea/Clintonia uniflora*
470	PICEA/LIBO	*Picea/Linnaea borealis*
510	ABGR/XETE	*Abies grandis/Xerophyllum tenax*
520	ABGR/CLUN	*Abies grandis/Clintonia uniflora*
530	THPL/CLUN	*Thuja plicata/Clintonia uniflora*
540	THPL/ATFI	*Thuja plicata/Athyrium filix-femina*
550	THPL/OPHO	*Thuja plicata/Oplopanax horridum*
570	TSHE/CLUN	*Tsuga heterophylla/Clintonia uniflora*
610	ABLA/OPHO	*Abies lasiocarpa/Oplopanax horridum*
620	ABLA/CLUN	*Abies lasiocarpa/Clintonia uniflora*
640	ABLA/VACA	*Abies lasiocarpa/Vaccinium caespitosum*
660	ABLA/LIBO	*Abies lasiocarpa/Linnaea borealis*
670	ABLA/MEFE	*Abies lasiocarpa/Menziesia ferruginea*
680	TSME/MEFE	*Tsuga mertensiana/Menziesia ferruginea*
690	ABLA/XETE	*Abies lasiocarpa/Xerophyllum tenax*
710	TSME/XETE	*Tsuga mertensiana/Xerophyllum tenax*
720	ABLA/VAGL	*Abies lasiocarpa/Vaccinium globulare*
730	ABLA/VASC	*Abies lasiocarpa/Vaccinium scoparium*
830	ABLA/LUHI	*Abies lasiocarpa/Luzula hitchcockii*
850	PIAL/ABLA	*Pinus albicaulis/Abies lasiocarpa*
999	OTHER	

Table 3.4: Summary of PSP data from the Kamloops and Nelson regions (including some PSPS from the Cariboo region applied to the Kamloops recalibration). Records shown here correspond to the heavily shaded cells of Tables 3.1 and 3.2. The first value shows the number, *n*, of plots used in the calibration. The second value, *x*, shows the average number of trees/plot for measurements used in the calibration (Abdel Azim Zumrawi, *pers. comm.*). These data were used to calibrate the large-tree diameter growth model adjustment. The site series columns have been ordered to show the moisture gradient from driest (02) to wettest (07); the mesic series is marked to aid legibility.

BEC variant		Site Series													
		2		3		4		1		5		6		7	
		n	*x*	*n*	*x*	*n*	*x*	*n*	*x*	*n*	*x*	*n*	*x*	*n*	*x*
Nelson Region															
ESSF	dk					9	48	11	29						
	wc4	4	49	3	78										
	wm			3	38	1	29	9	29						
ICH	dw							45	44						
	mk1			30	57	15	55	25	71	2	65				
	mw1							1	110						
	mw2			82	61	69	41	22	36	2	45				
	mw3			2	43	6	26	6	25	8	30			1	26
	wk1					1	31								
IDF	dm1					12	32	25	30						
	dm2					13	48	43	62						
MS	dk			5	51	49	83	15	43						
	dm1					2	23								
PP	dh2							5	59						
Kamloops Region															
ICH	mk1			7	65	4	42								
	mw2					1	14	47	43	2	21				
	mw3							24	40						
IDF	dk1					17	53	18	53						
	dk2			20	50			37	66						
	dm1					2	55	1	24						
	mw1					3	62								
	xh1					2	53	8	63						
	xh2									4	74	2	78		
MS	dm1					5	27								
PP	xh2			3	27										
Cariboo Region															
IDF	dk3					6	54	32	53			11	49		

3.2 Geographic Scope of the Model

The area for which the SEI variant is calibrated includes a substantial portion of the commercially important areas of the Kamloops and Nelson regions (Barry Snowdon, *pers. comm.*).[1] The geographic extent of the calibration is shown in Figure 3.1.

Table 3.5: Summary of harvesting activity in the Kamloops and Nelson regions. Applicable Area refers to the areal proportion of the subzone/variant's site series that are projectable by the SEI variant.

BEC Subzone/ Variant	Active Area (ha)	Area Partially Cut (%)	Area Covered by Model (%)
ICHmw2	49670	22	98
ICHmk1	29928	24	97
MSdk	28958	52	100
ESSFwc2	28540	16	0
MSdm2	28134	8	0
MSxk	27294	5	0
MSdm1	26708	34	83
IDFdm2	22523	68	94
IDFdk1	21900	49	87
ICHmw3	18902	12	92
ESSFdk	18574	10	56
ICHwk1	17088	10	87
IDFdk2	16061	37	83
ESSFwc4	14477	17	15
ESSFdc2	14194	6	0
ESSFdc1	11254	16	0
ESSFxc	9761	2	0
IDFdm1	9164	79	91
ICHvk1	8155	7	0
ICHdw	7312	38	82
IDFmw2	7195	34	0
ICHmw1	7080	16	8
ESSFwm	6980	4	93
SBSmm	5853	2	0
ESSFmw	5109	2	0
ESSFvc	4868	7	0
ESSFwc1	4518	21	0
ICHmk2	3435	14	0
IDFxh2	3239	83	14
IDFmw1	2972	55	0
ESSFdv	2176	1	0
ESSFvv	1844	49	0
MSdc	1817	2	0
PPdh2	1404	84	85
IDFxh1	845	85	68
PPxh2	179	100	26
ICHxw	70	46	0
IDFun	52	0	0
PPxh1	18	100	0

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[1] The ISIS database provided information from the Kamloops and Nelson Forest Regions by BEC site series for the total area harvested and total area partial cut between January 1, 1988 and September 15, 1999. The two forest regions were not delineated in the query.

As Table 3.5 shows, the model applies to 19 of the 40 forested subzone/variants (ecological site units) that occur in the two regions; 39 of which report some harvesting activity. However, it is applicable to seven of the 10 most commercially important subzone/variants (shaded below) and is typically applicable to the projection of 90% of the area in those categories. Overall, the variant can project stands in 66% of the total area in these 10 zones.

The three “top 10” subzone/variants with no coverage were the ESSFwc2, MSdm2 and MSxk. Historically, 84% of the ESSFwc2, 92% of the MSdm2 and 95% of the MSxk subzones/variants have been harvested using clearcut systems, and can therefore be adequately handled by VDYP and TIPSY.

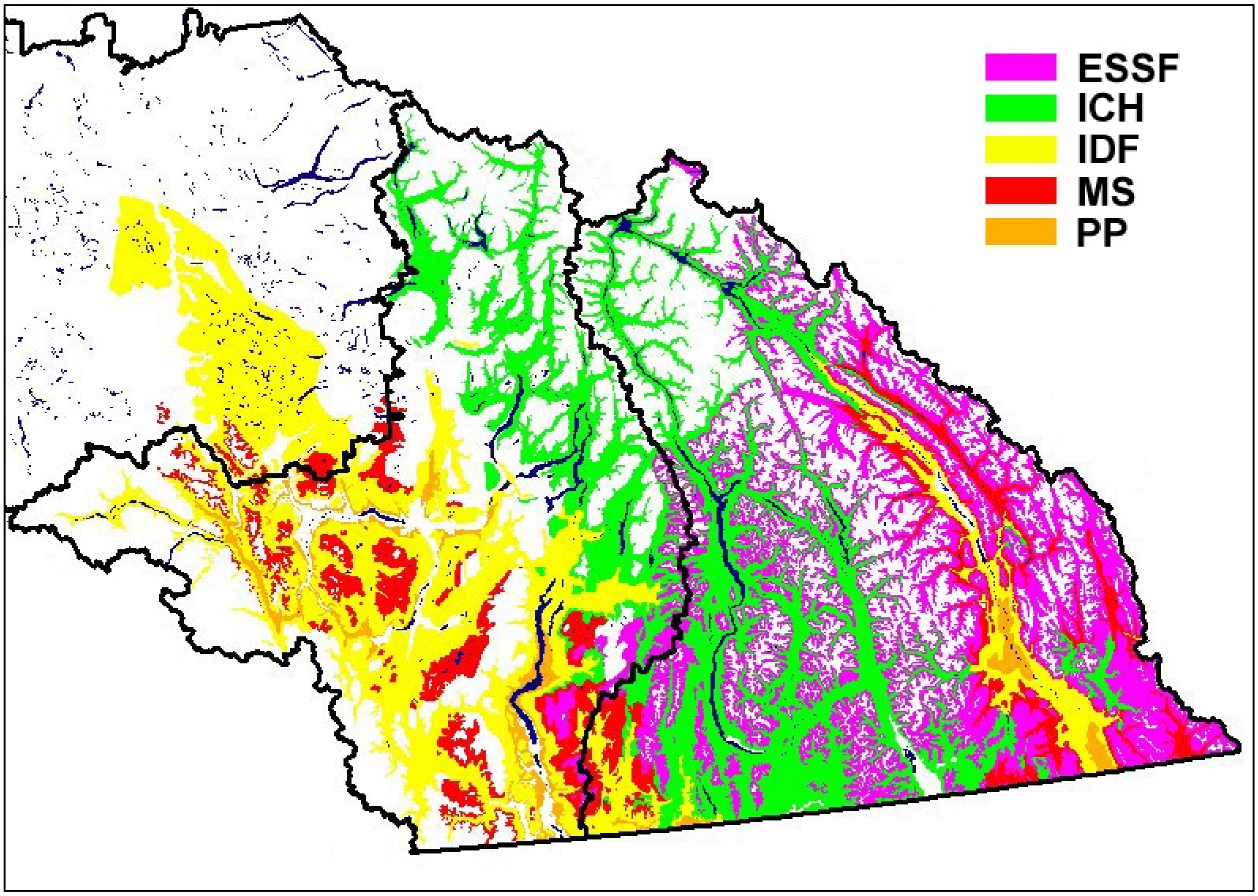

Figure 3.1: The large-tree growth model is calibrated for the BEC variants mapped here[2]. Heavy outlines show the administrative boundaries of the Nelson, Kamloops and Cariboo Forest regions[3] in the lower right, centre and upper left portions of the figure, respectively. The inset map shows the location of the locations of the three zones within the province. Map needs inset of entire province << work here for Don.

3.3 Data Codes and Conversions

The SEI variant supports the simulation of stands with the eleven species shown below in Table 3.6. With the exception of two cases described in the following paragraph, they may be referred to by a two-letter alphabetic code or by an equivalent numeric code. If an unrecognised code is encountered while processing the input tree list, it is assigned to the eleventh species category and is subsequently modelled as mountain hemlock. Unrecognised tree species encountered while processing keywords cause the entire keyword to be ignored. As already noted, no hardwood species are yet included in the variant.

There are two exceptions to the system of two-letter alphabetic codes. The first of these is due to the presence of non-standard species codes in some tree lists. To allow for these treelists, alphabetic codes for

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[2] These include the subzones found in Tables 3.1 and 3.2. Map data are derived from BC Ministry of Forests Version 1.2 of the Provincial Digital Biogeoclimatic Subzone/Variant Mapping: http://www.for.gov.bc.ca/research/becmaps/becmaps.htm.

[3] Regional boundaries are based on a draft digital coverage provided by the BC Ministry of Forests, Nelson Regional Office. The finalized boundaries may vary slightly, but any final changes would not be visible at the scale at which this map is rendered.

western larch and Engelmann spruce in the input tree list are recognised by their first letter only: the second letter is ignored. In the case of Douglas-fir, western redcedar and subalpine fir, a one-letter code may be used. However, when used in keywords, the two-letter form or the numeric code must be used. The second exception occurs when species codes are used in the PARMS statements of the Event Monitor. In this context, the numeric code must be used and alphabetic codes will result in an error.

Table 3.6: Tree species and codes used by the SEI variant.

Common Name	Numeric Code	Alphabetic Code	Scientific Name
western white pine	1	PW	Pinus monticola
western larch	2	LW, L*c*[1]	*Larix occidentalis*
Douglas-fir	3	FD, F	*Pseudotsuga menziesii*
grand fir	4	BG	*Abies grandis*
western hemlock	5	HW	*Tsuga heterophylla*
western redcedar	6	CW, C	*Thuja plicata*
lodgepole pine	7	PL	*Pinus contorta*
Engelmann spruce	8	SE, S*c*[1]	*Picea engelmannii*
subalpine fir	9	BL, B	*Abies lasiocarpa*
ponderosa pine	10	PY	*Pinus ponderosa*
mountain hemlock, all others	11	HM	*Tsuga mertensiana*
all others	11	No match	

[1] For these species Prognosis only examines the first letter of the alphabetic code in the input tree list. The second letter ‘c’ may be absent or may be any other character.

3.4 National Forest Codes

National Forest codes are used by the NI variant to fine tune growth projections to geographic locales. The SEI large-tree diameter model was calibrated using an assigned National Forest code of 106 (Coeur d’Alene), and this is therefore the default code.

This section is included here simply to provide updated and corrected documentation for Wykoff *et al.* (1982). If a forest code is not provided in the keyword set, the Coeur d’Alene National Forest is used.

Table 3.7: National Forests and codes used by the NI variant. The default value is shaded.

National Forest	Forest Code
Bitterroot	103
Idaho Panhandle	104
Clearwater	105
Coeur d’Alene	106
Colville	621
Flathead	110
Kaniksu	113
Kootenai	114
Lolo	116
Nezperce	117
St. Joe	118

4 Functional Relationships

Most of the SEI variant is based upon the functional relationships used in version 6.1 of the NI variant. Until such time as the model is fully calibrated with British Columbia data, this section serves to document the existing relationships described in Wykoff *et al.* (1982), and Wykoff *et al.* (1991). This section draws extensively from those two documents, as well as from the unpublished *"Inland Empire Prognosis Geographic Variant of the Forest Vegetation Simulator"* (G. Dixon, pers. com.). In all cases, model coefficients have been checked for accuracy against the source code and the values used in this document take precedence over other published values.

The units shown in this section are typically imperial. The metrification of the model involves conversion of the model inputs and outputs and not the internal equations themselves, except as noted in the text for specific equations.

The original model description documents may contain further information on the methodology or the rationale that motivated the choice of a particular model form for the component relationships. To provide links to this earlier documentation, additional references are also provided in most subsections. These are noted by their USDA Forest Service publication number and are referenced in Section 5.

GTR INT-133	Wykoff *et al.* 1982
GTR INT-196	Crookston 1985
GTR INT-208	Wykoff 1986
GTR INT-211	Horn *et al.* 1986
GTR INT-275	Crookston 1990
GTR INT-279	Ferguson and Crookston 1991
GTR INT-394	Hamilton 1991

4.1 Large and Small-tree Models

Many of the Prognosis submodels are implemented in two forms; one form for smaller trees and another form for larger trees. These are summarised in Figure 4.1. The predictions of the diameter- and height-growth models are combined by a diameter-dependent weighting system over a range of tree diameter, and the two weighted predictions combined so that the predictions undergo a smooth transition from the smaller tree model form to the larger tree model form.

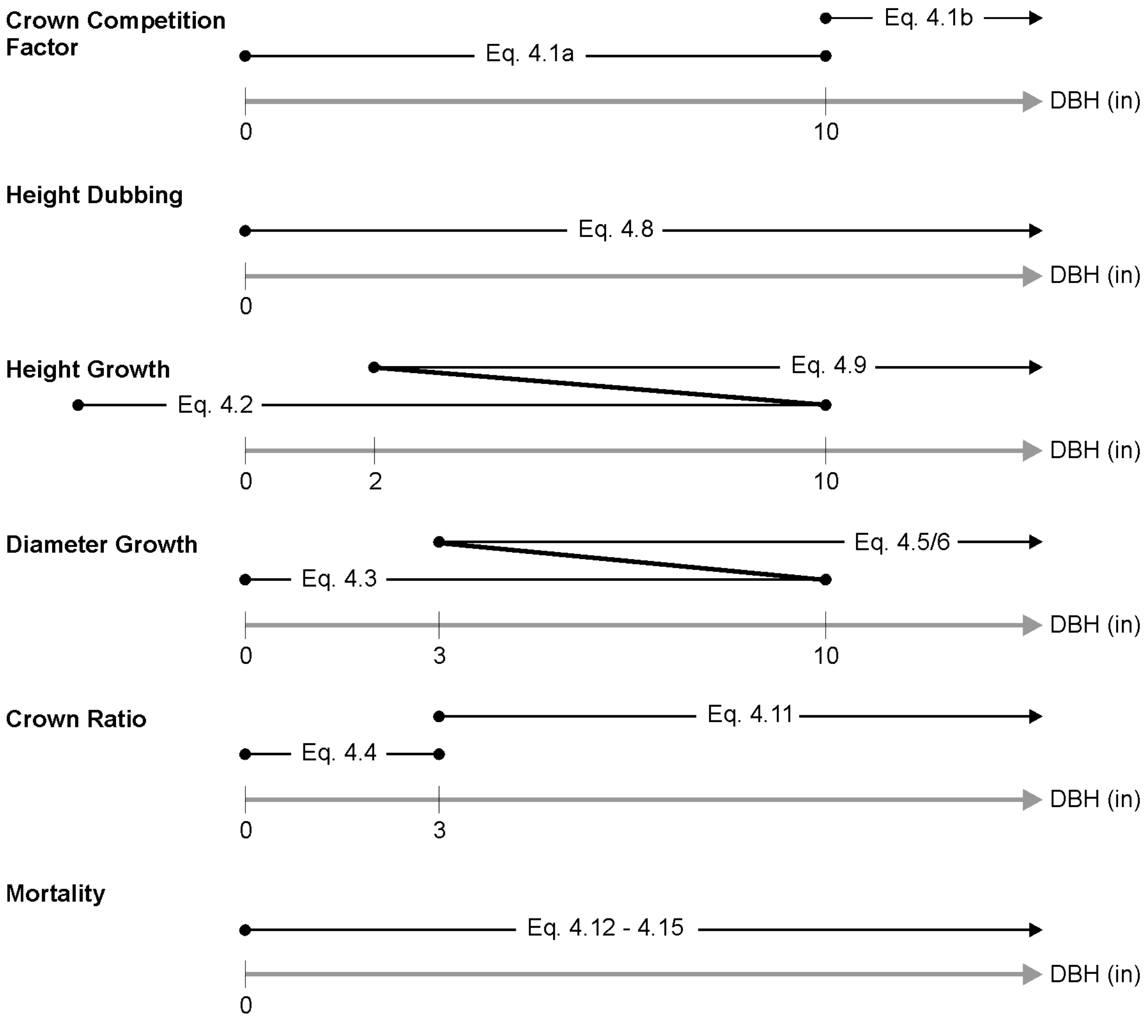

Figure 4.1: Large- and small-tree forms exist for most of the submodels. With the exception of the mortality model, all submodels switch between model forms based on dbh, as indicated by the marked breakpoints[4]. Diameter- and height-growth submodels employ a combination of large- and small-tree forms over part of the diameter range. Relevant equation numbers are shown on the height or diameter line, depending upon whether height or diameter is being predicted. Tree characteristics that play no role for a particular submodel are greyed-out.

4.2 Model Execution Sequence

Figure 4.2 provides a simplified overview of the sequence of model steps.

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[4] The breakpoints shown in the figure are the same for all species except lodgepole pine, which uses breakpoints of 1 and 5 inches for the diameter- and height-growth submodels.

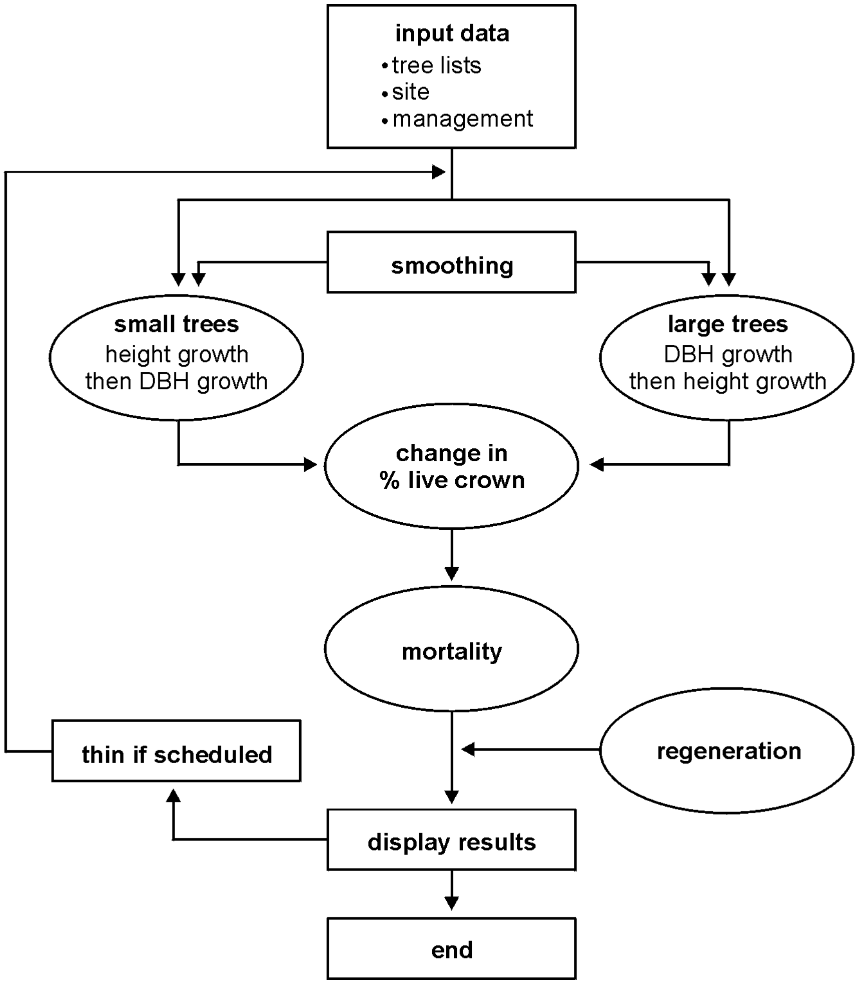

Figure 4.2: A simplified model execution sequence. The 'smoothing' step refers to the diameter-dependent combination of small- and large-tree submodels.

4.3 Regeneration Establishment Submodel

Additional reference: GTR INT-279 (Ferguson and Crookston 1991)

A comparative analysis of ISIS regeneration surveys and the Regeneration model (Robinson and Kurz 1998) showed that the SEI variant is currently unable to reliably reproduce the mixture of species and density observed in the surveys. Prognosis users may deactivate this component of the model or modify its behaviour using the Regeneration Establishment keywords described by Ferguson and Crookston (1991) and in more recent Prognosis documentation.

Users are advised that the Regeneration Establishment model is recommended only if its activities are explicitly controlled and scheduled by the user.

4.4 Bark Thickness

Additional reference: GTR INT-133, pp 48-50 (Wykoff et al. 1982)

Estimated diameter increment is based on the growth of bark plus wood. The multipliers given in Table 4.1 are used to predict total diameter increment, given the predicted wood increment only. A recent study (Abdel-Azim Zumrawi, *pers. comm.*) examined the set of coefficients in Table 4.1, and found that they were unbiased for the species found in the Kamloops and Nelson regions.

Table 4.1: Bark thickness adjustment factors.

Species	Adjustment Factor
western white pine	1.037
western larch	1.175
Douglas-fir	1.153
grand fir	1.093
western hemlock	1.071
western redcedar	1.053
lodgepole pine	1.032
Engelmann spruce	1.046
subalpine fir	1.067
ponderosa pine	1.124
mountain hemlock	1.071

4.5 Crown Competition Factor

Additional reference: GTR INT-133, pp 49-51 (Wykoff et al. 1982)

Crown competition factor (CCF) of individual trees is estimated by Equation 4.1: a quadratic expression for trees of at least 10 inches DBH and an exponential relationship for smaller trees. Stand CCF is the summation of the individual tree estimates. Model coefficients are found in Table 4.2.

$$CCF_{dbh \geq 10} = D(a_0 + a_1 DBH + a_2 DBH^2)$$
$$CCF_{dbh < 10} = D(b_0 DBH^{b_1})$$

Equation 4.1

where:

D = density (ac^{-1}) of individual trees
DBH = diameter (in) at breast height (4.5 ft)

Table 4.2: Coefficients for the model used to predict CCF. The *b* coefficients apply to the model for trees less than 10 inches DBH; the *a* coefficients apply to all larger trees (see Equation 4.1).

Species	DBH < 10 in		DBH ≥ 10 in		
	b_0	b_1	a_0	a_1	a_2
western white pine	0.00988	1.6667	0.030	0.0167	0.00230
western larch	0.00724	1.8182	0.020	0.0148	0.00338
Douglas-fir	0.01730	1.5571	0.110	0.0333	0.00259
grand fir	0.01525	1.7333	0.040	0.0270	0.00405
western hemlock	0.01111	1.7250	0.030	0.0215	0.00363
western redcedar	0.00892	1.7800	0.030	0.0238	0.00490
lodgepole pine	0.00919	1.7600	0.019	0.0168	0.00365
Engelmann spruce	0.00788	1.7360	0.030	0.0173	0.00259
subalpine fir	0.01140	1.7560	0.030	0.0216	0.00405
ponderosa pine	0.00781	1.7680	0.030	0.0180	0.00281
mountain hemlock	0.01111	1.7250	0.030	0.0215	0.00363

4.6 Height Growth of Small Trees

Additional reference: GTR INT-133, pp 66-69 (Wykoff et al. 1982)

Height growth for trees with DBH < 2 inches is estimated with the regression shown in Equation 4.2 below. When diameter falls between two and ten inches DBH (one and five inches for lodgepole pine) diameter-weighted estimates obtained from this regression are combined with diameter-weighted estimates of large tree height growth so that height increment predictions gradually shift from the small-tree to the large-tree equation. Equation 4.2 is also used to estimate height growth of trees in the Regeneration Establishment model, without incorporating the large tree component of the estimate. Until a full recalibration is made, height growth of small trees is adjusted using site adjustments derived from the large-tree diameter growth adjustment (see Equation 4.7).

$$\begin{aligned}\ln(HTG) = {} & HAB + LOC \\ & + 0.2216 \times SL\cos(ASP) - 0.1243 \times SL\sin(ASP) \\ & - 0.1099 \times SL + b_1\ln(HT) + b_2\,CCF + b_3\,(BAL/100) \\ & + CAL + USR \\ & + SEIADJ\end{aligned}$$

Equation 4.2

where:

HTG = 5-year change in height (ft)
HAB = habitat-type dependent intercept term (see Table 4.3)
LOC = location dependent intercept term (see Table 4.3)
ASP = stand aspect (degrees)
SL = stand slope ratio (%/100)
HT = tree height (ft)
CCF = crown competition factor
BAL = basal area in larger trees (ft_2 ac^{-1})

b_1-b_3 = species dependent regression coefficients (see Table 4.3)
CAL = species self-calibration adjustment
USR = user-supplied species adjustment
SEIADJ = adjustment based on SEI calibration of large-tree diameter growth (see Equation 4.9)

Table 4.3: Coefficients for the small-tree height increment model (see Equation 4.2).

Variable		**Species**										
		PW	**LW**	**FD**	**BG**	**HW**	**CW**	**PL**	**SE**	**BL**	**PY**	**HM**
ln(HT)	b_1	0.4214	0.2716	0.3907	0.3487	0.3417	0.2354	0.5843	0.2827	0.3740	0.4485	0.2354
CCF	b_2	–0.0059	–0.0065	–0.0059	–0.0039	–0.0039	–0.0039	–0.0065	–0.0039	–0.0039	–0.0065	–0.0039
BAL/100	b_3	–0.3720	–0.4153	–0.4004	–0.2536	–0.3469	–0.1201	–0.2417	–0.2530	–0.2296	–0.4730	–0.2535
HAB[1]	1	1.2554	1.4058	1.2786	0.7835	0.8056	0.6807	1.0190	0.8818	0.8521	1.5165	0.6807
Habitat	2	1.3759	1.5263	1.3991	0.9040	0.9261	0.8012	1.1395	1.0023	0.9726	1.6370	0.8012
Class	3	1.1559	1.2908	0.9531	0.7205	1.0202	0.8953	0.9852	0.7533	0.5751	1.2966	0.5215
Constants	4	1.4700	1.6204	1.0984	0.9981			0.7202	1.0964	0.7085	1.7311	0.8953
	5			1.4932				0.8841		1.0667		
	6							1.2336				
		Location Class[2]										
		1	**2**	**3**								
LOC		0.0	–0.0480	–0.2785								

[1] The 6 habitat classes are defined in Table 4.4

[2] The 3 location classes are:
1 Clearwater and Nezperce National Forests
2 St. Joe and Coeur d'Alene National Forests
3 All other forests

Table 4.4: Index by species to the habitat class constants (variable HAB) used in the small-tree height increment model (see Table 4.3 and Equation 4.2). The SEI variant uses BEC/ss to infer the best choice of Habitat Code, as shown in Tables 3.1 and 3.2.

Habitat Code	Species										
	PW	LW	FD	BG	HW	CW	PL	SE	BL	PY	HM
130	3	3	4	3	1	1	5	1	4	1	3
170	3	3	4	3	1	1	5	1	4	1	3
250	3	3	4	3	1	1	5	1	4	1	3
260	3	3	4	3	1	1	5	1	4	3	3
280	3	3	4	3	1	1	1	1	4	3	3
290	3	3	4	3	1	1	1	1	4	1	3
310	3	3	4	3	1	1	1	1	4	1	3
320	3	3	1	3	1	1	5	1	4	3	3
330	3	3	4	3	1	1	5	1	4	3	3
420	3	1	4	3	1	1	5	1	4	3	3
470	3	1	4	3	1	1	5	1	4	3	3
510	3	1	1	3	1	1	4	1	4	1	3
520	1	1	1	1	1	1	4	1	3	1	1
530	2	2	2	2	2	2	2	2	2	2	2
540	4	4	5	4	3	3	6	4	5	4	4
550	4	4	5	4	3	3	6	4	5	4	4
570	4	4	5	4	3	3	6	4	5	4	4
610	4	4	5	4	3	3	6	4	5	4	4
620	1	1	1	1	1	1	6	1	1	1	1
640	3	3	4	3	1	1	4	1	4	3	3
660	3	3	3	3	1	1	4	1	4	3	3
670	3	3	4	1	1	1	3	1	4	3	2
680	3	3	4	1	1	1	4	1	4	3	3
690	3	3	4	3	1	1	5	1	4	3	3
710	3	3	4	3	1	1	5	1	4	3	3
720	3	3	4	3	1	1	5	1	4	3	3
730	3	3	4	3	1	1	4	1	1	3	3
830	3	3	3	3	1	1	4	3	3	3	3
850	3	3	4	3	1	1	5	1	3	3	3
999	3	3	4	3	1	1	5	1	4	3	3

4.7 Diameter Growth of Small Trees

Additional reference: GTR INT-208, pp 2-3 (Wykoff 1986)

Diameter of trees with DBH < 3 inches is modelled with the following height-based allometric function, using the b_0 and b_1 coefficients shown in Table 4.5. Diameter growth of these small trees is then estimated by subtraction between model timesteps. Equation 4.3 is also used to estimate diameter growth in the Regeneration Establishment model.

$$DBH = b_0\,(HT - 4.5)^{b_1} + \left[\frac{AVH}{36}\,(0.01232 \times CCF - 1.75)\;RELH\right](RELH - 2.0) + 0.65$$

Equation 4.3

where:

DBH = diameter (in) at breast height (4.5 ft)
b_0-b_1 = species dependent regression coefficients (see Table 4.5)
HT = tree height (ft)
AVH = average height (ft) of the 40 trees per acre with the largest DBH (top height)
CCF = crown competition factor
RELH = relative height: (HT – 4.5) / (AVH – 4.5) ($0.0 \le RELH \le 1.0$)

Table 4.5: Coefficients for the model used to predict DBH (in) for small trees (see Equation 4.3).

Species	Coefficients	
	b_0	b_1
western white pine	0.0781	1.1645
western larch	0.0751	1.1176
Douglas-fir	0.0828	1.1713
grand fir	0.1155	1.0688
western hemlock	0.0729	1.1988
western redcedar	0.0730	1.2343
lodgepole pine	0.0988	1.0807
Engelmann spruce	0.0658	1.3817
subalpine fir	0.0658	1.3817
ponderosa pine	0.2160	1.0049
mountain hemlock	0.0729	1.1988

4.8 Crown Ratio of Small Trees

Additional reference: GTR INT-208, pp 3-4 (Wykoff 1986)

Crown ratio of trees with DBH < 3 inches is estimated by the logistic function shown in Equation 4.4. Crown ratio is assumed to remain constant for small trees.

$$CR = \frac{1}{1 + e^{b_0 + b_1\,DBH + b_2\,HT + b_3\,BA}} \qquad \textbf{Equation 4.4}$$

where:

CR = ratio of crown length to total tree height
b_0-b_3 = species-dependent regression coefficients (see Table 4.6)
DBH = diameter (in) at breast height (4.5 ft)
HT = tree height (ft)
BA = stand basal area ($ft^2\ ac^{-1}$)

Table 4.6: Coefficients for the model used to assign crown ratio to small trees (see Equation 4.4).

Species	Coefficients			
	b_0	b_1	b_2	b_3
western white pine	–0.4432	–0.4845	0.0582	0.0051
western larch	–0.8396	–0.1611	0.0416	0.0060
Douglas-fir	–0.8912	–0.1808	0.0519	0.0045
grand fir	–0.6265	–0.0614	0.0236	0.0050
western hemlock	–0.4955	–0.0001	0.0036	0.0046
western redcedar	–0.1185	–0.3931	0.0278	0.0063
lodgepole pine	–0.3247	–0.2011	0.0422	0.0044
Engelmann spruce	–0.9201	–0.2245	0.0325	0.0062
subalpine fir	–0.8901	–0.1803	0.0223	0.0061
ponderosa pine	–0.1756	–0.3385	0.0570	0.0069
mountain hemlock	–0.4955	–0.0001	0.0036	0.0046

4.9 Diameter Growth of Large Trees

Additional references: GTR INT-133, pp 53-65 (Wykoff et al. 1982)
GTR INT-208, pp 5-8 (Wykoff 1986)

Diameter increment of large trees (□ 3 inches DBH) in the NI variant is computed by Equation 4.5, and estimates the natural logarithm of the squared change in diameter growth. The same equation is used in the SEI when no recalibration is available for a stand's site series.

When a stand is in a site series for which recalibration data is available, a modified form of Equation 4.5 is used (Zumrawi *et al.* 2000). This modified large-tree equation, Equation 4.6, begins with the average contribution of slope, aspect and elevation in the NI calibration, then adds SEI-specific coefficients for these topographic parameters, as well as site-series terms through the SEILOC variable. Since Equation 4.6 continues to make use of the HAB and LOC variables, part of the role of the SEILOC variable is to compensate for differences between the mapping between the most appropriate NI Habitat Code (see Tables 3.1 and 3.2) and the actual conditions of the site series.

$$\begin{aligned} \ln(DDS) = {} & HAB + LOC \\ & + b_1\, SL\cos(ASP) + b_2\, SL\sin(ASP) + b_3\, SL + b_4\, SL^2 + b_5\, EL + b_6\, EL^2 \\ & + b_7 \ln(DBH) + b_8\, CR + b_9\, CR^2 + b_{10}\,(BAL/100) + b_{11}\,(BAL/\ln(DBH+1)) \\ & + b_{12}\, DBH^2 + b_{13}\,(CCF/100) + CAL + USR \end{aligned}$$

Equation 4.5

where:

DDS = 10-year change in DBH^2
HAB = habitat-type dependent intercept term (see Tables 4.7 and 4.8)
LOC = location dependent intercept term (see Tables 4.7 and 4.9)
SL = stand slope ratio (%/100)
ASP = stand aspect (degrees)
EL = stand elevation (in hundreds of feet)
DBH = diameter (in) at breast height (4.5 ft)
CR = ratio of crown length to total tree height
BAL = basal area in larger trees ($ft^2\ ac^{-1}$)
CCF = crown competition factor
b_1-b_{11} = species dependent coefficients (see Table 4.7)
b_{12} = location dependent DBH^2 coefficient (see Tables 4.7 and 4.10)
b_{13} = habitat-type dependent CCF coefficient (see Tables 4.7 and 4.11)
CAL = species self-calibration adjustment
USR = user-supplied species adjustment

Table 4.7: Coefficients for the large-tree diameter increment model (see Equation 4.5).

Variable		**Species**										
		PW	**LW**	**FD**	**BG**	**HW**	**CW**	**PL**	**SE**	**BL**	**PY**	**HM**
HAB	1	1.1558	0.3834	0.4778	0.6676	0.4526	1.6145	0.7740	–0.5884	–0.9639	1.1623	–1.6803
Habitat Class	2	1.0564	0.5129	0.1523	0.6045		1.3177	0.6783	–0.2124	–0.7242	0.7341	–1.5211
constants[1]	3		0.4538	0.2976				0.6445	–0.7163	–0.5731	0.5142	
	4		0.7132					0.3794	–0.5395	–0.8222		
	5		0.2684					0.5434		–1.2409		
	6									–1.1075		
LOC	1	0.1692	0.2000	0.5036	0.4344	0.1067	0.5007	0.4374	0.2626	0.4206	0.2459	0.1252
Location Class	2		0.0766	0.3492	0.2834	0.4436	0.1765	0.2111	–0.1587	0.1407	0.5696	0.4808
constants[2]	3		0.0819	0.2196	–0.1483		0.3174	0.1481		–0.1300	0.4279	
	4		0.3038	0.6181	0.2020							
	5				0.5776							
SL·cos(ASP)	b_1	0.0982	–0.2134	–0.0456	–0.0122	0.0828	–0.0662	0.0032	–0.1309	–0.1247	–0.0998	0.1794
SL·sin(ASP)	b_2	0.0388	0.0343	0.0629	–0.0460	0.1099	0.0553	0.1299	–0.0604	–0.0686	0.0119	0.1336
SL	b_3	–0.1789	0.3352	0.7818	1.1702	0.0497	0.1193	0.4655	0.6562	0.3007	–0.0664	0.0763
SL^2	b_4	0.0	–0.7022	–1.1238	–1.5201	0.0	0.0	–0.5801	–0.9014	–0.6222	–0.4372	0.0
EL	b_5	0.0352	0.0373	0.0259	0.0092	0.0286	–0.0018	–0.0048	0.0626	0.0631	0.0323	0.0852
EL^2	b_6	–0.00047	–0.00043	–0.00038	–0.00012	–0.00042	–0.00007	–0.00006	–0.00071	–0.00068	–0.00042	–0.00094
ln(DBH)	b_7	0.5644	0.5414	0.5689	0.6881	0.6871	0.5870	0.8950	0.7304	0.8624	0.6610	0.8978
CR	b_8	1.0834	1.0348	2.0685	1.9397	1.6413	1.2936	1.8556	1.5464	0.5204	1.3162	1.2840
CR^2	b_9	0.0	0.0751	–0.6236	–0.7826	–0.2724	0.0	–0.3639	–0.2664	0.8624	0.0	0.0
BAL/100	b_{10}	0.4211	0.4364	0.5020	0.4514	0.0	0.7460	–0.0366	0.2564	0.0	0.0	0.0
BAL/ln(DBH+1)	b_{11}	–2.0827	–2.0326	–2.1159	–1.7681	–0.8092	–2.2838	–0.4333	–1.1822	–0.5127	–1.2588	–0.6611
DBH^2 classes[3]	1	–0.00044	–0.00031	–0.00025	–0.00027	–0.00022	0.0	–0.00126	–0.00013	–0.00028	–0.00041	–0.00048
(b_{12})	2	0.0	–0.00057	–0.00037	–0.00009	–0.00022		–0.00217	–0.00029	–0.00078	–0.00044	–0.00031
	3			–0.00050	–0.00064	–0.00043		–0.00189	–0.00043		–0.00014	
	4			–0.00057				–0.00087				
CCF classes[4]	1	–0.0243	–0.1014	–0.0905	–0.0962	0.0	–0.0505	–0.0558	–0.0155	–0.0160	–0.1042	–0.1074
(b_{13})	2	–0.2489	–0.1479	–0.1188	–0.1954		–0.1536	–0.1492	–0.3839	–0.0448	–0.8881	
	3	–0.0108	–0.0544	–0.0553	–0.0512		–0.0940	–0.4064	–0.0537	–0.0739	–0.2594	
	4			–0.0218				–0.1140	–0.1516		–0.1473	

[1] Habitat classes are defined in Table 4.8
[2] Location classes are defined in Table 4.9
[3] DBH^2 classes are defined in Table 4.10
[4] CCF classes are defined in Table 4.11

Table 4.8: Index by species to the habitat class constants (variable HAB) used by the large-tree diameter increment model (see Equation 4.5). The SEI variant uses BEC/ss to infer the best choice of Habitat Code, as shown in Tables 3.1 and 3.2.

Habitat Code	Species										
	PW	LW	FD	BG	HW	CW	PL	SE	BL	PY	HM
130	2	5	3	2	1	2	5	4	6	1	2
170	2	5	3	2	1	2	5	4	6	1	2
250	2	5	3	2	1	2	5	4	6	2	2
260	2	5	3	2	1	2	5	4	6	3	2
280	2	5	3	2	1	2	1	4	6	3	2
290	2	5	3	2	1	2	2	4	6	2	2
310	2	5	3	2	1	2	1	4	6	2	2
320	2	5	1	2	1	2	5	4	6	3	2
330	2	5	3	2	1	2	5	4	6	3	2
420	2	1	3	2	1	2	5	4	6	3	2
470	2	1	3	2	1	2	5	4	6	3	2
510	2	2	1	2	1	2	2	1	6	2	2
520	1	1	1	1	1	2	2	1	1	2	2
530	1	2	1	2	1	2	3	4	2	2	2
540	1	2	1	2	1	1	3	2	3	3	2
550	1	2	1	2	1	1	3	2	3	3	2
570	1	3	1	2	1	2	3	4	4	3	2
610	1	3	1	2	1	2	3	2	3	3	2
620	1	2	1	2	1	2	3	1	1	2	2
640	2	5	3	2	1	2	4	4	6	3	2
660	2	2	2	2	1	2	4	4	6	3	2
670	1	1	3	1	1	2	3	4	6	3	1
680	1	1	3	2	1	2	4	4	6	3	2
690	2	1	3	2	1	2	5	4	6	3	2
710	2	5	3	1	1	2	5	4	6	3	2
720	2	5	3	2	1	2	5	4	6	3	2
730	2	4	3	2	1	2	4	4	1	3	2
830	2	5	2	2	1	2	4	3	5	3	2
850	2	5	3	2	1	2	5	4	5	3	2
999[1]	2	5	3	2	1	2	5	4	6	3	2

[1] Types grouped with 999 were included in the overall mean for the species.

Table 4.9: Index by species for the location class constants (variable LOC) used by the large-tree diameter increment model (see Equation 4.5). The SEI variant uses the shaded National Forest by default.

National Forest	Species										
	PW	LW	FD	BG	HW	CW	PL	SE	BL	PY	HM
Bitterroot	2	1	5	6	3	4	4	3	4	1	3
Idaho Panhandle	1	1	4	5	2	1	2	1	1	2	2
Clearwater	2	1	1	1	3	1	1	1	1	2	1
Coeur d'Alene	2	2	2	2	1	1	1	1	2	2	1
Colville	2	3	3	2	3	2	2	3	2	1	3
Flathead	2	3	3	3	3	2	4	2	3	4	3
Kaniksu	2	2	2	2	3	3	3	3	3	3	3
Kootenai	2	5	3	4	3	4	3	3	4	1	3
Lolo	2	5	5	6	3	2	4	3	4	4	1
Nezperce	2	4	1	2	3	1	2	1	2	3	3
St. Joe	1	1	4	5	2	1	2	1	1	2	2

Table 4.10: Index by species of the location-dependent DBH^2 coefficients (variable b_{12}) in the large-tree diameter increment model (see Equation 4.5). The SEI variant uses the shaded National Forest by default.

National Forest	Species										
	PW	LW	FD	BG	HW	CW	PL	SE	BL	PY	HM
Bitterroot	1	1	1	1	1	1	1	1	1	1	1
Idaho Panhandle	2	2	4	1	3	1	1	1	2	2	2
Clearwater	2	1	2	1	1	2	2	2	2	2	1
Coeur d'Alene	2	1	2	1	2	1	2	1	1	2	1
Colville	2	1	2	1	3	1	1	1	2	2	1
Flathead	1	1	3	2	1	1	1	1	1	3	1
Kaniksu	2	1	1	2	1	1	2	3	1	3	1
Kootenai	1	1	4	3	1	2	3	2	2	2	1
Lolo	1	1	1	1	1	1	1	1	1	1	2
Nezperce	1	1	1	2	1	2	4	1	1	1	1
St. Joe	2	2	4	1	3	1	1	1	2	2	2

Table 4.11: Index by species for the habitat-dependent CCF coefficients (variable b_{13}) in the large-tree diameter increment model (see Equation 4.5). The SEI variant uses BEC/ss to infer the best choice of Habitat Code, as shown in Tables 3.1 and 3.2.

Habitat Code	Species										
	PW	LW	FD	BG	HW	CW	PL	SE	BL	PY	HM
130	3	3	4	3	1	3	4	4	3	2	1
170	3	3	4	3	1	3	4	4	3	2	1
250	3	3	4	3	1	3	1	4	3	3	1
260	3	3	4	3	1	3	4	4	3	1	1
280	3	3	4	3	1	3	3	4	3	4	1
290	3	3	4	3	1	3	4	4	3	3	1
310	3	3	1	3	1	3	2	4	3	3	1
320	3	3	2	3	1	3	1	4	3	1	1
330	3	3	4	3	1	3	4	4	3	2	1
420	3	3	4	3	1	3	1	4	3	4	1
470	3	3	4	3	1	3	4	4	3	4	1
510	3	1	2	3	1	3	4	3	3	1	1
520	1	3	1	1	1	3	4	3	1	4	1
530	3	3	4	3	1	1	2	1	1	4	1
540	3	3	4	3	1	2	2	1	1	4	1
550	3	3	4	3	1	2	2	1	1	4	1
570	1	3	3	3	1	3	2	3	1	1	1
610	3	3	4	3	1	3	2	3	1	4	1
620	3	2	4	3	1	2	2	1	1	4	1
640	3	3	4	3	1	3	4	4	3	4	1
660	3	1	1	3	1	3	1	2	1	4	1
670	2	3	3	3	1	1	4	4	1	4	1
680	2	3	2	2	1	3	1	1	2	4	1
690	3	1	4	2	1	3	4	4	2	4	1
710	3	3	4	3	1	3	4	4	1	4	1
720	3	3	4	3	1	3	4	4	3	4	1
730	3	3	4	3	1	3	1	1	1	4	1
830	3	3	2	3	1	3	4	4	1	4	1
850	3	3	4	3	1	3	4	4	3	4	1
999[1]	3	3	4	3	1	3	4	4	3	4	1

[1] Types grouped with 999 were included in the overall mean for the species.

In the adjusted large-tree diameter growth equation (Equation 4.6), the contribution of average slope, aspect and elevation used to fit the NI variant Equation 4.5 – 37% slope, 225° aspect, 1275 feet elevation – is first computed. The mean contributions of these NI topographic effects use the same b_1-b_6 coefficients as Equation 4.5. Next, analogous SEI coefficients are applied using the actual topographic conditions for the stand (coefficients c_1-c_5), adjusting the prediction for the SEI topographic conditions. Finally, individual tree and stand effects are added, using the NI variant terms. The CCF coefficient (b_{13}) of the NI variant is augmented by an SEI-based coefficient (c_{13}).

$$
\begin{aligned}
\ln(DDS) = {} & HAB + LOC \\
& + b_1 \frac{37}{100}\cos(225\times\frac{\pi}{2}) + b_2 \frac{37}{100}\sin(225\times\frac{\pi}{2}) + b_3 \frac{37}{100} + b_4 \left(\frac{37}{100}\right)^2 + b_5 \times 1276 + b_6\,(1276)^2 \\
& + SEICON + SEILOC \\
& + c_1\,SL\cos(ASP) + c_2\,SL\sin(ASP) + c_3\,SL + c_4 EL + c_5 EL^2 \\
& + b_7 \ln(DBH) + b_8\,CR + b_9\,CR^2 + b_{10}\,(BAL/100) + b_{11}\,(BAL/\ln(DBH+1)) \\
& + b_{12}\,DBH^2 + (b_{13} + c_{13})\,(CCF/100) \\
& + CAL + USR
\end{aligned}
$$

Equation 4.6

where:

DDS = 10-year change in DBH^2
HAB = habitat-type dependent intercept term (see Tables 4.7 and 4.8)
LOC = location dependent intercept term (see Tables 4.7 and 4.9)
SEICON = species-dependent intercept term (see Table 4.12)
SEILOC = BEC/ss-dependent intercept term (see Table 4.13)
SL = stand slope ratio (%/100)
ASP = stand aspect (degrees)
EL = stand elevation (in hundreds of feet)
DBH = diameter (in) at breast height (4.5 ft)
CR = ratio of crown length to total tree height
BAL = basal area in larger trees ($ft^2\ ac^{-1}$)
CCF = crown competition factor
b_1-b_{11} = species dependent coefficients (see Table 4.7)
b_{12} = location dependent DBH^2 coefficient (see Tables 4.7 and 4.10)
b_{13} = habitat-type dependent CCF coefficient (see Tables 4.7 and 4.11)
c_1-c_5 = species dependent SEI coefficients (see Table 4.12)
c_{13} = species-dependent CCF coefficient (see Table 4.12)
CAL = species self-calibration adjustment
USR = user-supplied species adjustment

The small-tree growth model and mortality models (Sections 4.6and 4.13) both make use of estimates of some of the adjustment term in the large-tree increment model. These are summarised in Equation 4.7:

$$\begin{aligned} SEIADJ &= SEICON + SEILOC \\ &\quad + c_1\, SL\cos(ASP) + c_2\, SL\sin(ASP) + c_3\, SL + c_4 EL + c_5 EL^2 \end{aligned}$$

Equation 4.7

Table 4.12: Coefficients for the SEI recalibration of the large-tree diameter increment model (see Equations 4.6 and 4.7). Empty cells are zero.

		Species										
Variable		**PW**	**LW**	**FD**	**BG**	**HW**	**CW**	**PL**	**SE**	**BL**	**PY**	**HM**
SEICON		−1.20012	0.03164	−0.33768	−0.35409	−0.53158	0.30382	−0.57696	−1.46710	−0.65511	−2.01572	
SEILOC		*see Table 4.13*										
SL·cos(ASP)	c_1			0.00083							−1.11471	
SL·sin(ASP)	c_2				−0.40671			−0.08531		−0.74662		
SL	c_3								−0.82000			
EL	c_4	0.01724		0.01048	0.05738	0.04685		0.01065	0.07223	0.07129	0.06151	
EL^2	c_5				−0.00085	−0.00068			−0.00090	−0.00099		
CCF	c_{13}			−0.07463				−0.16348				

Finally, diameter growth of large trees is modified using a simple linear interpolation scheme to reduce diameter growth after an individual tree's dbh passes the 90th percentile for the species and subzone. As dbh approaches the 100th percentile, the adjusted prediction of diameter growth approaches zero. Tree diameter is therefore constrained to not exceed the maximum diameter observed in the subzone, based on diameter data in inventory audit programme.[5] (Barry Snowdon, pers. comm.).

Equation 4.10 and Figure 4.3 describe how the same adjustment method is carried out for the large-tree height growth submodel. Coefficients for the relationship are found in Table 4.14. Species that do not occur in the subzone have very low limits applied to them, which has the effect of killing them very quickly.

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[5] Further information about the inventory audit programme is found at http://www.for.gov.bc.ca/resinv/audits/tudor.htm.

Table 4.13: Coefficients for the SEILOC coefficients of the SEI large-tree diameter increment model (Equation 4.6). Site series columns have been ordered to show the moisture gradient from driest (02) to wettest (07); the mesic series is marked to aid legibility. Rows with more than one site series indicate data pooling across site series. In one case (Douglas-fir, IDFxh01/02) data were pooled across subzone variants. The coefficients include an adjustment for lack of fit between the most appropriate Habitat Code and site series, as well as real site differences.

BEC variant		Site Series							SEILOC
		2	3	4	1	5	6	7	
western white pine									
ICH	dw			■	■				0.97080
	mw2		■	■	■	■	■		0.55088
	mw3				■				0.54472
						■			1.57930
western larch									
ICH	mw2			■					–0.11546
					■				–0.24679
	mk1				■				–0.45001
IDF	dm1			■	■	■			0.16060
	dm2			■		■			–0.83091
					■				–0.53506
	mw1			■					–0.28032
MS	dk1		■		■				–0.47719
				■		■			–0.13477
Douglas-fir									
ICH	dw			■	■				0.22398
	mk1		■						0.15358
	mw2		■						0.26506
					■				0.12485
	mw3		■						0.52539
				■					0.16271
					■				0.37126
	wk1			■	■	■			0.29088
IDF	dk1				■				0.13588
	dk2				■				0.28110
	dk3			■					–0.73119
					■				–0.17949
							■		–0.18901
	dm1			■					0.11163
					■	■			0. 31994
	dm2			■	■	■			0.14139
	mw1			■					0.35498
	xh1			■	■			■	–0.20460
	xh2					■	■		
MS	dk		■	■	■	■			0.22099
grand fir									
ESSF	wc4	■	■						–0.68074
	wm1	■	■	■	■				0.26881
ICH	dw			■	■				–1.32980
	mk1		■	■	■	■			–0.99113
	mw2		■	■	■	■	■		–1.08111
	mw3		■	■	■	■		■	–0.74432
MS	dk		■	■	■	■			–0.49646
Western hemlock									
ICH	mw2		■						–0.33966
				■					–0.38468
					■	■	■		–0.32891
	mw3		■						–0.35852
					■				–0.34059
								■	–0.33842
Western redcedar									
ICH	mk1		■	■	■	■			–0.67998
	mw2		■						–0.53091
				■					–0.45763
					■				–0.24884
	mw3		■						–0.94850
				■					–0.36550
					■				–0.26425
						■			–0.74451
								■	–0.50328
	wk1			■	■	■			–0.85966
IDF	dm2			■	■	■			–0.93040
lodgepole pine									
ICH	dw			■	■				0.14517
	mk1			■					0.21038
	mw2		■						0.10317
					■				0.24878
IDF	dk2		■						–0.29809
	dk3			■					–0.53275
					■				–0.44302
							■		–0.38840
	dm2				■				–0.31680
Engelmann spruce									
ESSF	dk				■				0.26510
	wm	■	■	■	■				0.72027
ICH	dw			■	■				0.30629
	mk1		■	■	■	■			–0.21132
subalpine fir									
ESSF	wc4	■	■						–0.68074
	wm	■	■	■	■				0.26881
ICH	dw			■	■				–1.32980
	mk1		■	■	■	■			–0.99113
	mw2		■	■	■	■	■		–1.08110
	mw3		■	■	■	■		■	–0.77432
MS	dk		■	■	■	■			–0.49646
ponderosa pine									
IDF	dm2			■	■	■			–0.44823
	xh1			■	■			■	–0.41938
	xh2					■	■		–0.68892
PP	xh2		■						–0.59717

Table 4.14: Diameter breakpoints used to adjust diameter growth predictions, by species. The D_{90} and D_{100} terms correspond to the H_{90} and H_{100} terms used in Equation 4.10.

BEC Variant		DBH (cm)	
		D_{90}	D_{100}
western white pine			
ESSF	wm	70	90
ICH	dw	55	61
	mw2	50	75
	mw3	53	88
	wk1	92	125
western larch			
ESSF	dk	61	70
	wm	58	73
ICH	dw	51	92
	mk1	53	81
	mw2	60	117
	mw3	70	121
	wk1	83	125
IDF	dk2	62	155
	dm1	64	104
	dm2	45	60
	mw1	64	119
MS	dk	63	94
	dm1	70	89
PP	dh2	51	65
Douglas-fir			
ESSF	dk	59	126
	wm	70	90
ICH	dw	59	110
	mk1	55	78
	mw2	60	109
	mw3	65	165
	wk1	75	114
	dk1	64	157
	dk2	62	155
	dk3	75	123
	dm1	62	102
	dm2	46	70
	mw1	51	90
	xh1	65	96
	xh2	58	154
MS	dk	60	67
	dm1	57	102
PP	dh2	51	65
	xh2	65	95
grand fir			
ICH	dw	45	63
western hemlock			
ESSF	wm	65	125
ICH	dw	59	62
	mw2	65	115
	mw3	70	115
	wk1	85	170
western redcedar			
ICH	dw	80	217
	mk1	87	102
	mw2	70	183
	mw3	97	239
	wk1	130	211
IDF	dk2	62	88
	mw1	36	53
lodgepole pine			
ESSF	dk	31	50
	wc4	37	50
	wm	31	50
ICH	dw	32	44
	mk1	33	46
	mw2	38	58
	mw3	35	126
IDF	dk1	30	41
	dk2	35	60
	dk3	30	60
	dm1	28	58
	dm2	25	36
	mw1	28	45
MS	dk	31	51
	dm1	28	51
PP	dh2	51	65
Engelmann spruce			
ESSF	dk	49	113
	wc4	71	140
	wm	65	125
ICH	dw	59	62
	mk1	54	75
	mw2	65	115
	w3	70	115
	wk1	85	170
IDF	dk1	38	50
	dk2	62	88
	dk3	50	70
	dm1	48	50
	dm2	48	50
	mw1	48	50
	xh1	50	60
	xh2	50	60
MS	dk	53	74
	dm1	48	66
PP	dh2	51	65
subalpine fir			
ESSF	dk	39	57
	wc4	47	86
	wm	50	85
ICH	mk1	43	55
	mw2	41	85
	mw3	45	65
	wk1	55	92
	dk1	38	50
	dk2	50	80
	dm1	48	50
	mw1	48	50
MS	dk	38	54
	dm1	42	73
ponderosa pine			
ICH	dw	85	115
	mk1	55	78
IDF	dk1	64	80
	dk2	90	95
	dm1	70	93
	dm2	46	70
	mw1	51	90
	xh1	80	96
	xh2	53	87
PP	Dh2	62	63
	xh2	66	80
mountain hemlock			
ESSF	dk	41	71
	wc4	41	71
	wm	41	71
ICH	dw	32	41
	mk1	41	71
	mw2	41	71
	mw3	41	71
	wk1	41	71
IDF	dk1	33	39
	dk2	33	39
	dk3	45	59
	dm1	33	39
	dm2	33	39
	mw1	33	39
	xh1	33	39
	xh2	33	39
MS	dk	33	39
	dm1	33	39
PP	dh2	33	39
	xh2	33	39

4.10 Initial Height of Large Trees

Additional reference: GTR INT-133, pp 51-52 (Wykoff et al. 1982)

The initial height of trees taller than 4.5 feet (sometimes referred to as height dubbing) is estimated from Equation 4.8. The coefficients of Table 4.15 are based on Temesgen & LeMay (1999) for the named BEC subzones. In cases where there were not sufficient data to re-estimate the allometric relationship, the NI variant coefficients are used. When three or more heights for a species are provided in the input treelist, the intercept term c_0 is re-computed.

$$HT = e^{c_0 + \frac{c_1}{DBH+1}} + 4.5$$

Equation 4.8

where:

HT = tree height (ft)
DBH = diameter (in) at breast height (4.5 ft)
c_0-c_1 = species- and subzone-dependent coefficients (see Table 4.15)

Table 4.15: Coefficients used to assign missing heights to large trees (see Equation 4.8).

Zone	Subzone	Coefficients	
		c_0	c_1
western white pine			
ICH	mw	5.1939	–9.1411
	wk	4.9835	–6.8249
all others		5.1999	–9.2672
western larch			
ICH	dw mk	5.1429	–9.8217
	mw	4.9879	–6.3027
IDF	dm xh	5.1274	–8.5554
MS ESSF	dk	5.1659	–9.2489
all others		4.9741	–6.7835
Douglas-fir			
ICH ESSF	dk mk	5.1619	–11.2213
	mw	5.1403	–8.7176
	wk	5.3281	–12.4620
	dw	5.0413	–10.0333
IDF	dk mw xm	4.9200	–9.9590
	dm ww	5.0091	–10.1147
	xh	4.8550	–8.1272
PP	dh xh	4.8169	–9.6455
MS	dk	5.1135	–11.0179
all others		4.8152	–7.2931
grand fir			
all		5.0023	–8.1936
western hemlock			
ICH	vc vk	5.1829	–12.9844
	mw wk	5.1723	–11.3757
	mc	5.0314	–9.2156
IDF ESSF	mm	5.2629	–11.5864
	wv ww wc	5.3234	–13.4049
all others		4.9733	–8.1973
western redcedar			
ICH	mw	5.0713	–11.1453
	mm vk	5.3259	–17.3369
	wk mc mk	5.1541	–12.9964
IDF	dm	4.5231	–5.0204
	ww	5.2649	–15.5587
ESSF MS	wc	5.2127	–13.6008
	dk wk	5.1002	–12.1830
all others		4.8956	–8.3906
lodgepole pine			
ICH	mk mw mc	5.0826	–8.3420
IDF	xh dm	4.8777	–6.6367
	Dk	4.3366	–3.7890
ESSF MS	dk dc dm	4.8819	–6.5269
	wk dc dm	4.9783	–8.3323
	xv mv	4.4564	–5.2739
all others		4.6217	–5.3248
Engelmann spruce			
ICH IDF	dk	4.9229	–8.4108
	dm mk mc	5.2396	–11.0095
	mw mc	5.2029	–10.0429
	wk	5.3430	–12.5309
ESSF	dk mw wc mv	5.1209	–9.5772
	dc	5.2309	–11.4880
	wk mc	4.9348	–10.2506
MS	dk	5.2832	–11.2074
	dm	5.3422	–12.4948
all others		4.9219	–8.3029
subalpine fir			
ICH IDF	mk vk dk	5.0010	–9.1004
	mw wk mc	5.1893	–10.5923
ESSF MS	dk wc mc mk mv	4.9735	–9.5213
	mw dc	5.3607	–14.0449
	wk	4.9056	–10.2126
all others		4.7654	–7.6106
ponderosa pine			
ICH	dw	5.2244	–11.5008
	mk	4.9967	–12.4568
IDF	xh dm	5.0282	–11.8080
	dk	5.0334	–12.8709
PP	dh	5.1168	–15.0042
	xh	4.8643	–13.6723
all others		4.9288	–9.3280
mountain hemlock			
all		4.7795	–9.3174

4.11 Height Growth of Large Trees

Additional reference: GTR INT-133, pp 65-66 (Wykoff et al. 1982)

Height growth of large trees is predicted using Equation 4.9. The predictions are blended with the predictions of the small-tree height growth equation over the 3-5 inch DBH range for lodgepole pine and the 3-10 inch DBH range for all other species. Height growth estimates for the SEI variant are modified using the simple linear interpolation scheme shown in Equation 4.10 and graphed in Figure 4.3. Coefficients for the relationship are found in Table 4.18. The equation reduces height growth after an individual tree's height passes the 90th percentile for the species and subzone. As height approaches the 100th percentile, the adjusted prediction of height growth approaches zero. Tree height is therefore constrained to not exceed the maximum height observed in the subzone, based on height data in inventory audit programme.[6] (Barry Snowdon, pers. comm.). Species that do not occur in the subzone have very low limits applied to them, which has the effect of killing them very quickly.

The height growth of intermediate-size smaller trees is estimated using a weighted combination of the predictions made by Equations 4.9 and Equation 4.2, as described more fully in Section 4.6.

$$\begin{aligned} \ln(HTG) &= HAB + SPP \\ &\quad + 0.232\ln(HT) + b_2 \ln(DBH) + b_3 \ln(DG) + b_4\, HT^2 \\ &\quad + USR \end{aligned} \qquad \textbf{Equation 4.9}$$

where:

HTG = 10-year change in height (ft)
HAB = habitat-type dependent intercept term (see Tables 4.16 and 4.17)
SPP = species dependent intercept term (see Table 4.16)
HT = tree height (ft)
DBH = diameter (in) at breast height (4.5 ft)
DG = predicted 10-year DBH increment (in)
b_2-b_4 = species dependent coefficients (see Table 4.16)
USR = user-supplied species adjustment

Table 4.16: Coefficients for the large-tree height increment model (see Equation 4.9).

Variable		Species										
		PW	**LW**	**FD**	**BG**	**HW**	**CW**	**PL**	**SE**	**BL**	**PY**	**HM**
SPP		–0.5342	0.1433	0.1641	–0.6458	–0.6959	–0.9941	–0.6004	0.2089	–0.5478	0.7316	–0.9941
ln(DBH)	b_2	–0.0494	–0.3899	–0.4574	–0.0978	–0.1555	–0.1219	–0.2454	–0.5720	–0.1997	–0.5657	–0.1219
		Habitat Class[1]										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**			
HAB		2.0304	1.7222	1.1973	1.8176	2.1478	1.7700	2.2110	1.7409			
ln(DG)	b_3	0.6214	1.0237	0.8549	0.7576	0.4624	0.4964	0.3704	0.3400			
HT^2 (x 10^{-4})	b_4	–1.3358	–0.3809	–0.3715	–0.2607	–0.5200	–0.1605	–0.3631	–0.4460			

[1] Habitat classes are defined in Table 4.15

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[6] Further information about the inventory audit programme is found at http://www.for.gov.bc.ca/resinv/audits/tudor.htm.

Table 4.17: Index to the habitat class constants used by the large-tree height growth model (see Equation 4.9). The SEI variant uses BEC/ss to infer the best choice of Habitat Code, as shown in Tables 3.1 and 3.2.

Habitat Code	Habitat Class	Habitat Code	Habitat Class	Habitat Code	Habitat Class
130	1	470	3	660	1
170	1	510	4	670	4
250	2	520	5	680	4
260	2	530	6	690	8
280	2	540	7	710	8
290	2	550	7	720	8
310	2	570	7	730	1
320	2	610	7	830	1
330	2	620	4	850	1
420	3	640	4	999	1

$$C = \begin{cases} HT < HT_{90} & 1 \\ HT_{90} <= HT <= HT_{100} & 1 - \dfrac{HT - HT_{90}}{HT_{100} - HT_{90}} \\ HT > HT_{100} & 0 \end{cases}$$

Equation 4.10

where:

C = correction factor for 10-year change in height
HT = current predicted height (m)
H_{90} = 90th percentile of species' height distribution (m) (see Table 4.18)
H_{100} = 100th percentile of species' height distribution (m) (see Table 4.18)

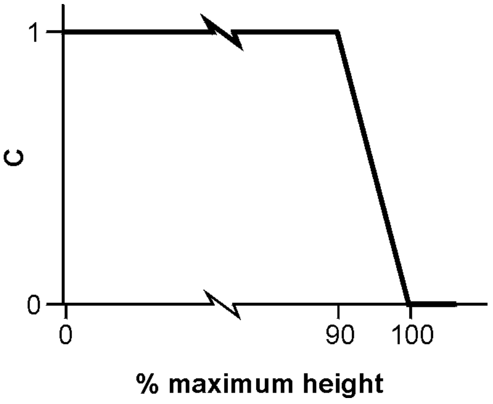

Figure 4.3: Height growth is reduced after reaching the 90th percentile of observed height for the BEC subzone. This relationship is shown in Equation 4.10. See Table 4.18 for parameter values for each BEC subzone.

Table 4.18: Height breakpoints used to adjust height growth predictions (see Equation 4.10), by species.

BEC Variant		Height (m)	
		H_{90}	H_{100}
western white pine			
ESSF	wm	31	35
ICH	dw	34	41
	mw2	33	40
	mw3	38	48
	wk1	39	43
western larch			
ESSF	dk	31	35
	wm	31	35
ICH	dw	38	43
	mk1	40	44
	mw2	38	46
	mw3	38	40
	wk1	40	44
IDF	dk2	32	48
	dm1	34	44
	dm2	29	33
	mw1	33	42
MS	dk	36	41
	dm1	36	45
PP	dh2	24	24
Douglas-fir			
ESSF	Dk	31	35
	Wm	32	36
ICH	Dw	34	41
	Mk1	34	44
	Mw2	35	47
	Mw3	37	50
	Wk1	39	43
	Dk1	27	37
	Dk2	32	48
	Dk3	29	41
	Dm1	30	43
	Dm2	25	28
	Mw1	28	33
	Xh1	31	43
	Xh2	27	47
MS	Dk	27	33
	Dm1	31	37
PP	Dh2	24	24
	Xh2	28	34
grand fir			
ICH	Dw	31	35
western hemlock			
ESSF	wm	35	41
ICH	dw	34	36
	mw2	36	45
	mw3	34	44
	wk1	37	45
western redcedar			
ICH	dw	33	41
	mk1	27	29
	mw2	33	47
	mw3	34	44
	wk1	37	47
IDF	dk2	21	24
	mw1	21	24
lodgepole pine			
ESSF	dk	25	32
	wc4	23	30
	wm	24	27
ICH	dw	27	31
	mk1	26	30
	mw2	29	36
	mw3	29	34
IDF	dk1	23	29
	dk2	25	32
	dk3	20	28
	dm1	24	36
	dm2	21	25
	mw1	24	36
MS	dk	25	30
	dm1	23	29
PP	dh2	24	24
Engelmann spruce			
ESSF	dk	28	37
	wc4	37	49
	wm	35	47
ICH	dw	36	40
	mk1	42	45
	mw2	37	46
	w3	46	50
	wk1	45	53
IDF	dk1	36	46
	dk2	36	46
	dk3	28	29
	dm1	36	46
	dm2	36	46
	mw1	36	46
	xh1	36	46
	xh2	36	46
MS	dk	31	35
	dm1	31	35
PP	dh2	36	46
subalpine fir			
ESSF	dk	26	32
	wc4	29	36
	wm	30	41
ICH	mk1	27	29
	mw2	31	39
	mw3	29	32
	wk1	33	43
	dk1	36	46
	dk2	31	33
	dm1	36	46
	mw1	21	24
MS	dk	31	35
	dm1	28	33
ponderosa pine			
ICH	dw	34	41
	mk1	34	44
IDF	dk1	27	29
	dk2	32	48
	dm1	39	45
	dm2	39	45
	mw1	39	45
	xh1	28	33
	xh2	27	47
PP	dh2	25	31
	xh2	25	31
mountain hemlock			
ESSF	dk	25	32
	wc4	23	30
	wm	24	27
ICH	dw	25	29
	mk1	26	30
	mw2	31	37
	mw3	25	29
	wk1	25	29
IDF	dk1	24	25
	dk2	33	42
	dk3	28	29
	dm1	24	36
	dm2	33	42
	mw1	33	42
	xh1	33	42
	xh2	33	42
MS	dk	25	30
	dm1	23	29
PP	dh2	33	42
	xh2	33	42

4.12 Crown Ratio of Large Trees

Additional reference: GTR INT-133, pp 77-80 (Wykoff et al. 1982)

Crown ratio of large trees is computed at the beginning of a projection and when the diameter of a small tree is at least 3 inches DBH, using the relationship below. Change in crown ratio of large trees is found by subtraction between model timesteps.

$$\begin{aligned}\ln(CR) = HAB + &\\ &+ b_1\, BA + b_2\, BA^2 + b_3 \ln(BA)\\ &+ b_4\, CCF + b_5\, CCF^2 + b_6 \ln(CCF)\\ &+ b_7\, DBH + b_8\, DBH^2 + b_9 \ln(DBH)\\ &+ b_{10}\, HT + b_{11}\, HT^2 + b_{12} \ln(HT)\\ &+ b_{13}\, PCT + b_{14} \ln(PCT)\end{aligned}$$

Equation 4.11

where:

CR = ratio of crown length to total tree height
HAB = habitat-type dependent intercept term (see Tables 4.19 and 4.20)
BA = stand basal area (ft^2 ac^{-1})
CCF = crown competition factor
DBH = diameter (in) at breast height (4.5 ft)
HT = tree height (ft)
PCT = tree basal area percentile (%)
b_1-b_{14} = species dependent coefficients (see Table 4.19)

Table 4.19: Coefficients of the crown ratio equation for large trees (Equation 4.11). Empty cells among the 14 possible Habitat Class Constant coefficients indicate that the species has less than the maximum number of categorical groups; empty cells among the b_1-b_{14} coefficients indicate a value of zero.

Variable		**Species**										
		PW	**LW**	**FD**	**BG**	**HW**	**CW**	**PL**	**SE**	**BL**	**PY**	**HM**
Habitat Class Constants[1] (HAB)	1	0.8884	0.0653	0.8643	-0.2304	-0.2413	-1.6053	-0.3785	0.0535	0.0945	-0.9436	0.4649
	2	0.7309	0.0344	0.7271	-0.5421		-1.7128	-0.4142	-0.0503	-0.0774	-0.8654	0.3211
	3	0.9347	0.2307	0.9840	-0.4343			-0.3985	0.1075	0.0711	-0.8849	0.1970
	4	0.9888	0.1661	0.8127	-0.3759			-0.2987	-0.1872	0.2039	-0.9067	0.2295
	5	0.9945	-0.1253	0.8874	-0.4129			-0.3810	0.0173	0.0618	-0.8783	0.3383
	6	1.1126	-0.0502	0.7055	-0.4879			-0.4087	0.0367	0.1513	-1.0103	0.3450
	7	1.0263	0.1100	0.7708	-0.2674			-0.3577	0.0188	0.0909	-1.0268	
	8		0.0811	0.7849	-0.1941			-0.2994	0.0910	0.1580	-1.0050	
	9		0.1782	0.8038				-0.2486	0.1371	0.0923	-1.0301	
	10		0.0392	0.8742				-0.2863	0.0837	0.0155		
	11		0.2107	0.8232				-0.1968	0.1230			
	12			0.8415				-0.4931	-0.0236			
	13			0.9759				-0.2676				
	14							-0.5625				
BA	b_1		-0.0020		-0.0018				-0.0020	-0.0019	-0.0022	-0.0026
BA^2 (x 10^{-6})	b_2					-1.9020						
ln (BA)	b_3	-0.3457					0.1748					
CCF	b_4						-0.0018					
CCF^2 (x 10^{-6})	b_5											5.1160
ln (CCF)	b_6			-0.1533				-0.1856				
DBH	b_7	0.0388				0.0303	-0.0056					
DBH^2 (x 10^{-6})	b_8	-0.0007				-0.0006						
ln (DBH)	b_9		0.3007	0.3384	0.2429			0.5317	0.2970	0.2337	0.2656	
HT	b_{10}							-0.0299				
HT^2 (x 10^{-6})	b_{11}							0.0001				
ln (HT)	b_{12}	-0.2122	-0.5930	-0.5968	-0.2560	-0.2578			-0.3833	-0.2843	-0.3156	-0.2514
PCT	b_{13}	0.0030						0.0042		0.0019		
ln (PCT)	b_{14}		0.1956	0.1649	0.0726	0.0689	0.1105		0.0992		0.1607	0.0514

[1] Habitat classes are defined in Table 4.20.

Table 4.20: Index by species to the habitat class constants (variable HAB) used by the large-tree crown ratio model (see Equation 4.11). The SEI variant uses BEC/ss to infer the best choice of Habitat Code, as shown in Tables 3.1 and 3.2.

Habitat Code	Species										
	PW	LW	FD	BG	HW	CW	PL	SE	BL	PY	HM
130	2	2	2	2	1	1	2	2	2	2	1
170	2	2	2	2	1	1	2	2	2	2	1
250	2	2	2	2	1	1	2	2	2	4	1
260	2	2	4	2	1	1	2	2	2	1	1
280	2	2	4	2	1	1	2	2	2	1	1
290	2	2	4	2	1	1	2	2	2	1	1
310	2	2	6	2	1	1	4	2	2	5	1
320	2	3	7	2	1	1	5	3	2	6	1
330	2	2	4	2	1	1	5	2	2	1	1
420	2	4	8	1	1	1	2	1	2	1	1
470	2	4	8	1	1	1	2	1	2	1	1
510	2	5	5	2	1	1	6	2	2	8	1
520	3	6	9	3	1	1	7	4	2	7	2
530	4	7	10	4	1	1	8	5	3	9	2
540	4	7	10	4	1	1	8	5	4	9	2
550	4	7	10	4	1	1	8	5	4	9	2
570	5	8	11	5	1	2	9	6	4	3	3
610	5	8	11	5	1	2	9	6	4	3	3
620	5	4	8	6	1	2	10	7	5	3	4
640	6	1	1	1	1	1	11	8	6	1	1
660	6	10	12	7	1	1	11	8	6	1	1
670	1	9	12	7	1	1	12	9	7	1	1
680	6	10	13	7	1	1	11	8	6	1	5
690	1	1	1	1	1	1	1	10	1	1	1
710	7	11	3	8	1	1	13	11	8	1	6
720	1	1	1	1	1	1	1	1	1	1	1
730	6	1	3	7	1	1	14	1	9	1	1
830	6	1	1	1	1	1	3	12	10	1	1
850	6	1	1	1	1	1	3	12	10	1	1
999	6	2	1	1	1	1	11	8	6	1	1

4.13 Mortality

Additional references: GTR INT-133, pp 70-76 (Wykoff et al. 1982)
GTR INT-208, pp 9-11 (Wykoff 1986)

Individual tree mortality estimates are based on a weighted combination of two predictive relationships. The first of these equations use tree- and site-specific information to estimate R_a. The response of the second equation depends on the stand's proximity to the maximum basal area for the habitat, and is discussed in detail below. Both DBH and the growth increment g are constrained small non-zero values in the calculation. DBH is set to a minimum of 0.5 in., and when DBH is less than 1 inch, DBH increment is set to a minimum of 0.05 in.

$$R_a = \frac{1}{1+e^{SPP+0.2233\sqrt{DBH}-0.046\sqrt{BA}+11.2007g+0.2463\,RDBH+\frac{6.0713g-0.5544}{DBH}}} \qquad \textbf{Equation 4.12}$$

where:

R_a = estimated annual mortality rate
SPP = species-dependent constant (see Table 4.21)
DBH = diameter (in) at breast height (4.5 ft)
BA = stand basal area (ft^2 ac^{-1})
g = periodic annual DBH increment for previous growth period, adjusted for differences in potential annual DBH increment indexed by Habitat Type and National Forest
RDBH = the ratio of tree DBH to the arithmetic mean stand DBH

Table 4.21 Species-dependent constants for the mortality model (see Equation 4.12).

Species	Species
western white pine	2.7625
western larch	2.5865
Douglas-fir	3.0804
grand fir	3.0804
western hemlock	3.3703
western redcedar	4.3423
lodgepole pine	2.6420
Engelmann spruce	3.7027
subalpine fir	2.9743
ponderosa pine	2.9743
mountain hemlock	2.7625

The second part of the annual mortality calculation is expressed by Equations 4.13 and 4.14:

$$TPA_{10} = \frac{BA + \left(1 - \frac{BA}{BAMAX}\right) BAI}{0.005454\, QMD_{10}^2}$$

Equation 4.13

$$R_b = 1 - \left(1 - \frac{TPA_0 - TPA_{10}}{TPA_0}\right)^{0.1}$$

Equation 4.14

where:

TPA_{10} = estimated stem density ten years hence (ac^{-1})
R_b = estimated annual mortality rate from approach to maximum basal area
BA = stand basal area (ft^2 ac^{-1})
BAMAX = habitat-type dependent maximum basal area (ft^2 ac^{-1}) (see Tables 4.22, 4.23)
BAI = estimated basal area increment (ft^2 ac^{-1})
QMD_{10} = stand quadratic mean diameter (in) ten years hence (in)
R_b = estimated annual mortality rate from approach to maximum basal area
TPA_0 = current stem density (ac^{-1})

The independent estimates of R_a and R_b are combined into R_t (Equation 4.15), the estimated annual mortality. The estimates are weighted such that the R_b term dominates as the stand approaches the carrying capacity of its habitat type (BAMAX), and R_a dominates when the stand is well below its carrying capacity:

$$R_t = e^{SEIADJ} \times R_b\left(\frac{BA}{BAMAX}\right) + R_a\left(1 - \frac{BA}{BAMAX}\right)$$ **Equation 4.15**

where:

SEIADJ = adjustment based on SEI calibration of large-tree diameter growth (see Equation 4.7)

The SEIADJ term incorporates site information derived from an adjustment made for the large-tree diameter growth model. In Equation 4.7 that adjustment is based on a logarithmic measurement scale, and is converted in Equation 4.15 to a linear basis. Maximum carrying capacity is indexed by BEC subzone (Table 4.22) in most cases. If model users use the SEI variant without the graphical interface, they may choose to not use the BECINFO keyword. When this keyword is absent, BEC subzone indexing is replaced by the NI variant Habitat Code-based values shown in Table 4.23.

Table 4.22: Maximum basal area (m^2 ac^{-1}) (BAMAX) of each BEC variant (see Equations 4.12 and 4.14).

BEC variant		Site Series							BAMAX
		2	3	4	1	5	6	7	(m^2 ha^{-1})
ESSF	dk	■							60
			■						61
				■		■	■	■	62
					■				64
	wc4			■	■	■	■	■	64
	wm			■	■	■	■	■	62
ICH	dw			■	■	■	■	■	50
	mk1	■							50
			■						46
				■					42
					■				59
						■	■	■	50
	mw2		■						99
				■					91
					■				76
						■	■	■	90
	mw3	■	■				■	■	76
				■		■			69
					■				81
	wk1		■	■	■	■	■	■	67
IDF	dk1	■	■			■	■		46
				■					40
					■				52
	dk2	■		■		■	■	■	58
			■						55
					■				60
	dk3	■	■	■	■	■	■	■	42
	dm1		■	■	■	■	■	■	43
	dm2		■		■	■	■	■	53
				■					52
	mw1	■	■	■	■	■	■	■	47
	xh1	■	■	■	■	■	■	■	48
	xh2	■	■	■	■	■	■	■	48
MS	dk	■	■						55
				■					46
					■	■	■	■	57
	dm1	■	■						62
				■	■				63
						■			57
							■		64
								■	62
PP	dh2		■	■	■	■	■	■	32
	xh2	■	■	■	■				32
							■	■	21

Table 4.23: Maximum basal area ($m^2\ ac^{-1}$) (variable BAMAX) of each habitat type (see Equations 4.13 and 4.15). These Habitat Code-based values will be used only when the model is used outside the Prognosis^{BC} graphical interface and the BECINFO keyword is absent.

Habitat Code	BAMAX	Habitat Code	BAMAX	Habitat Code	BAMAX
130	32	470	67	660	67
170	51	510	76	670	92
250	57	520	87	680	80
260	71	530	101	690	90
280	55	540	115	710	60
290	62	550	115	720	69
310	71	570	90	730	51
320	71	610	90	830	51
330	46	620	101	850	37
420	71	640	41	999	69

4.14 Volume Estimation

The estimation procedure for total and merchantable log volumes makes use of BC Ministry of Forests Inventory Branch subroutines (version 4.1, February 1994) developed by Prof. A. Kozak, replacing the estimation methods used by the US variants. Default values for the estimation procedure are:

minimum DBH	17.5 cm
top diameter	10.0 cm
stump height	30.0 cm

$$\begin{aligned}\ln(d_i) &= \ln(a_0) + a_1 \ln(DBH) + \ln(a_2)\,DBH + b_1 \ln(X)\,Z^2 \\ &\quad + b_2 \ln(X)\ln(Z+0.001) + b_3 \ln(X)\sqrt{Z} \\ &\quad + b_4 \ln(X)e^Z + b_5 \ln(X)\frac{DBH}{H}\end{aligned}$$

Equation 4.16

and:

$$Z = \frac{h_i}{H}$$
$$X = \frac{1-\sqrt{Z}}{1-\sqrt{p}}$$

Equation 4.17

These default values apply initially to all species, and may be changed by the user. Volume estimates are based on a variable exponent taper equation (Kozak 1988), which upon transformation can be expressed

d_i = diameter (cm) at height *I* (m)
a_0-a_3 = coefficients of DBH terms
DBH = diameter (cm) at breast height (1.30 m)
b_1-b_5 = coefficients of *X* terms
H = total height (m)
h_i = height (m) from ground
p = taper inflection point height / total height

Kozak's taper function cannot be expressed as a closed-form integral to compute either top diameter or volume. Instead, an iterative search procedure is used to converge to the chosen top diameter. Volume predictions are then based on a calculation that divides the merchantable portion of the stem into 3 metre sections and uses a 5-point Newton approximation to estimate the volume of each section. Separate calculations are used for the calculation of the stump volume.

Table 4.24: Coefficients for the taper function (see Equations 4.16 and 4.17).

Variable	Species										
	PW	**LW**	**FD**	**BG**	**HW**	**CW**	**PL**	**SE**	**BL**	**PY**	**HM**
a_0	0.98402	0.74683	0.92084	1.00874	0.75203	1.03358	0.77460	0.89731	1.00874	0.85659	0.75203
a_1	0.94132	1.00390	0.92387	0.91636	1.02897	0.89697	1.04032	0.95709	0.91636	0.93640	1.02897
a_2	0.99970	0.99723	1.00057	1.00116	0.99866	0.99908	0.99698	0.99937	1.00116	1.00210	0.99866
b_1	1.57103	0.74705	1.09556	1.41599	1.17480	1.59826	0.74575	1.53227	1.41599	0.74705	1.17480
b_2	–0.36934	–0.13373	–0.20219	–0.32567	–0.26358	–0.41154	–0.13018	–0.36468	–0.32567	–0.08714	–0.26358
b_3	2.70320	0.39711	0.96733	2.79327	2.23333	2.40242	0.55882	2.74121	2.79327	–0.06345	2.23333
b_4	–1.33470	–0.18354	–0.51460	–1.32679	–1.00202	–1.25217	–0.32418	–1.36276	–1.32679	0.05142	–1.00202
b_5	0.04963	0.07834	0.08170	0.10843	0.04518	0.09428	0.19869	0.11776	0.10843	0.07172	0.04518
p	0.25	0.30	0.25	0.30	0.25	0.30	0.25	0.30	0.30	0.25	0.25

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