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Lake States (LS) Variant Overview of the Forest Vegetation Simulator

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Chequamegon-Nicolet NF
(Barbara Billings-Mattarn, FS-R9)

Lake States (LS) Variant Overview of the Forest Vegetation Simulator

Authors and Contributors:

The FVS staff has maintained model documentation for this variant in the form of a variant overview since its release in 1993. The original authors were Renate Bush and Gary Brand. In 2006, Gary Dixon reformulated many of the model components, created a test version of the variant and wrote this new variant overview. 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. Gary Dixon cross-checked information contained in this variant overview with the FVS source code.

FVS Staff. 2008 (revised January 22, 2025). Lake States (LS) Variant Overview – Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Forest Management Service Center. 58p.

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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)	907 – Ottawa	
NPV Code	FDn12 (Northern Dry-Sand Pine Woodland)	
Slope	5 percent	
Aspect	0 (no meaningful aspect)	
Elevation (default location)	14 (1400 feet)	
Latitude (default location)	46.45	
Longitude (default location)	90.17	
Site Species	RN	
Site Index	60 feet (total age; 50 years)	
Maximum Stand Density Index	Species specific	
Maximum Basal Area	Species specific	
Volume Equations	National Volume Estimator Library	
Pulpwood Volume Specifications:		
Minimum DBH / Top Diameter	Hardwoods	Softwoods
903 – Chippewa (aspen, balsam poplar)	6.0 / 4.0 inches	5.0 / 4.0 inches
903 – Chippewa (all other species)	5.0 / 4.0 inches	5.0 / 4.0 inches
909 – Superior	6.0 / 4.0 inches	5.0 / 4.0 inches
All other locations	5.0 / 4.0 inches	5.0 / 4.0 inches
Stump Height	0.5 feet	0.5 feet
Sawtimber Volume Specifications:		
Minimum DBH / Top Diameter	Hardwoods	Softwoods
903 – Chippewa (aspen, balsam poplar)	11.0 / 9.6 inches	9.0 / 7.6 inches
903 – Chippewa (all other species)	9.0 / 7.6 inches	9.0 / 7.6 inches
907 – Ottawa (aspen, balsam poplar)	9.0 / 7.6 inches	9.0 / 7.6 inches
907 – Ottawa (all other species)	11.0 / 7.6 inches	9.0 / 7.6 inches
All other locations	11.0 / 9.6 inches	9.0 / 7.6 inches
Stump Height	1.0 foot	1.0 foot
Sampling Design:		
Large Trees (variable radius plot)	40 BAF	
Small Trees (fixed radius plot)	1/300th acre	
Breakpoint DBH	5.0 inches	

1.0 Introduction

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

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

The original Lake States (LS) variant was developed in 1993 using relationships from the LS-TWIGS model (Miner and others 1988), and equations from other variants for FVS relationships not present in LS-TWIGS. The model was reformulated in 2006 to improve model estimates; the only remnant of the original LS-TWIGS formulation was in the large tree diameter growth equations. In 2017, the large tree diameter growth equations from LS-TWIGS were replaced with equations from Deo and Froese (2013).

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 LS variant covers forest areas in the Great Lake states of Michigan, Minnesota, and Wisconsin. This includes Chippewa and Superior National Forests in Minnesota. Chequamegon and Nicolet National Forests in Wisconsin are also included as well as the Hiawatha, Ottawa, Huron and Manistee National Forests in Michigan. The suggested geographic range of use for the LS variant is shown in figure 2.0.1.

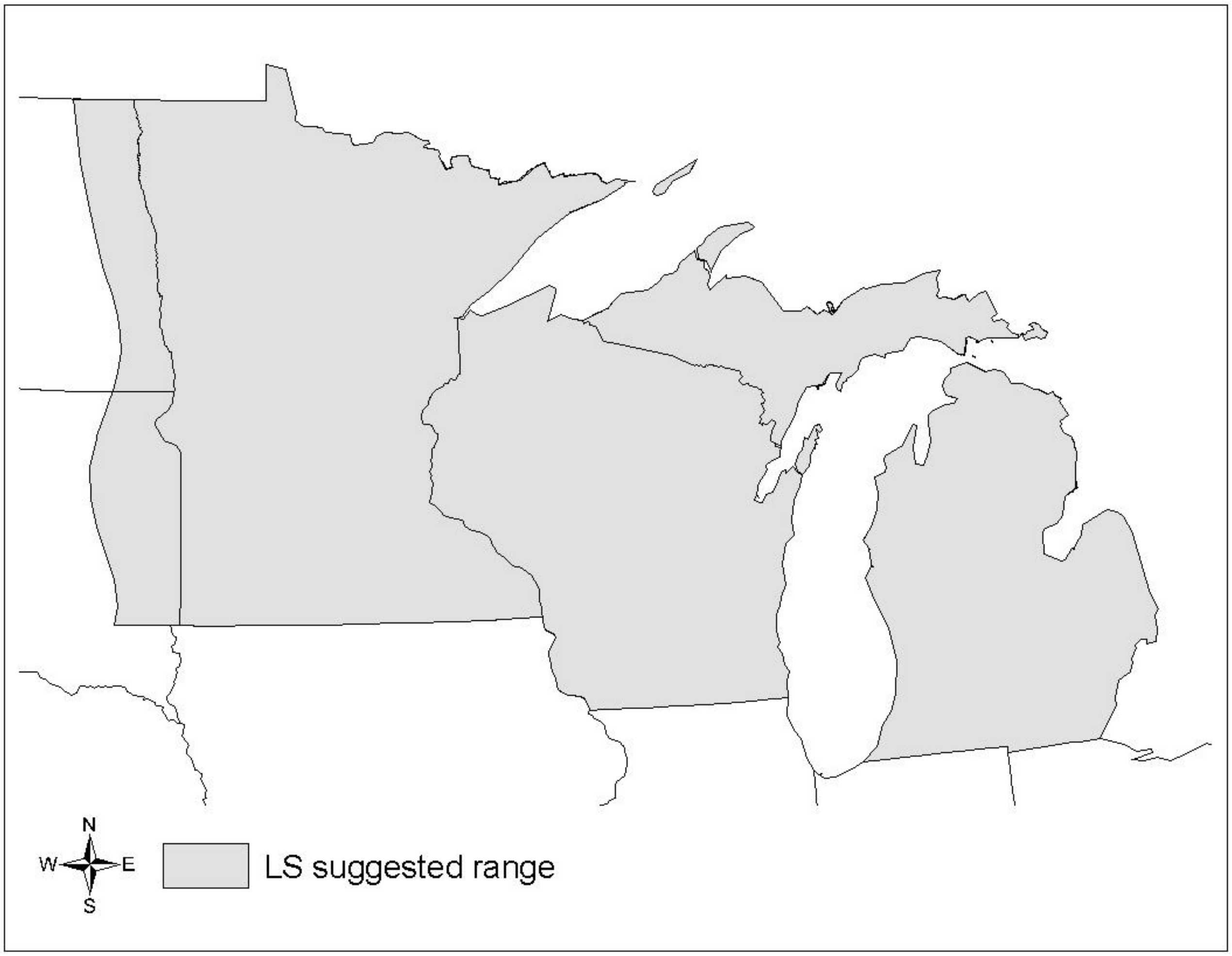

Figure 2.0.1 Suggested geographic range of use for the LS variant.

3.0 Control Variables

FVS users need to specify certain variables used by the LS 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 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 LS variant, a default forest code of 907 (Ottawa National Forest) will be used. Location codes recognized in the LS variant – and their associated default latitude, longitude, and elevation values – are shown in tables 3.1.1 and 3.1.2.

Table 3.1.1 Location codes used in the LS variant.

Location Code	Location	Latitude	Longitude	Elevation
902	Chequamegon National Forest	45.93	90.44	15 (1500 feet)
903	Chippewa National Forest	47.38	94.60	13 (1300 feet)
904	Huron-Manistee National Forest	44.25	85.40	9 (900 feet)
906	Nicolet National Forest	45.93	90.44	15 (1500 feet)
907	Ottawa National Forest	46.45	90.17	14 (1400 feet)
909	Superior National Forest	46.78	92.11	16 (1600 feet)
910	Hiawatha National Forest	45.75	87.06	8 (800 feet)
913	Chequamegon-Nicolet National Forest	45.93	90.44	15 (1500 feet)
924	Manistee (mapped to 904)	44.25	85.40	9 (900 feet)

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

Location Code	Location
7107	Lake Traverse Reservation (mapped to 903)
7109	Turtle Mountain Off-Reservation Trust Land (mapped to 903)
7501	Upper Sioux Community (mapped to 903)
7502	Lower Sioux Indian Community (mapped to 903)
7506	Prairie Island Off-Reservation Tl (mapped to 902)
7507	Shakopee Mdewakanton Sioux (mapped to 903)
7508	Menominee Reservation (mapped to 906)
7510	Red Lake Reservation (mapped to 903)
7511	Bois Forte Reservation (mapped to 909)
7512	Fond Du Lac Reservation (mapped to 909)
7513	Grand Portage Reservation (mapped to 909)

Location Code	Location
7514	Leech Lake Reservation (mapped to 903)
7515	White Earth Reservation (mapped to 903)
7516	Mille Lacs Reservation (mapped to 903)
7517	Bad River Reservation (mapped to 902)
7518	Lac Courte Oreilles Reservation (mapped to 902)
7519	Lac Du Flambeau Reservation (mapped to 902)
7520	Oneida, (Wi Reservation (mapped to 906)
7521	Forest County Potawatomi Comm. (mapped to 906)
7523	Red Cliff Reservation (mapped to 902)
7524	St. Croix Reservation (mapped to 902)
7525	Sokaogon Chippewa, (Mole Lake (mapped to 906)
7526	Stockbridge Munsee Community (mapped to 906)
7527	Grand Traverse Off-Reservation Tl (mapped to 924)
7528	Sault Ste. Marie Off-Reservation Tl (mapped to 910)
7529	Bay Mills Reservation (mapped to 910)
7530	Hannahville Indian Community (mapped to 910)
7531	Isabella Reservation (mapped to 924)
7532	L'Anse Reservation (mapped to 907)
7533	Ontonagon Reservation (mapped to 907)
7534	Lac Vieux Desert Reservation (mapped to 907)
7535	Huron Potawatomi (mapped to 924)
7536	Little River Off-Reservation Tl (mapped to 924)
7537	Little Traverse Bay Reservation (mapped to 910)
7522	Potawatomi (Pokagon Band) (mapped to 906)

3.2 Species Codes

The LS variant recognizes 65 species, plus two other composite species categories. You may use FVS species codes, Forest Inventory and Analysis (FIA) species codes, or USDA Natural Resources Conservation Service PLANTS symbols to represent these species in FVS input data. Any valid eastern species code identifying species not recognized by the variant will be mapped to a similar species in the variant. The species mapping crosswalk is available on the FVS website variant documentation webpage. Any non-valid species code will default to the “other hardwood” category.

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

Table 3.2.1 Species codes used in the LS variant.

Species Group	Species Number[1]	Species Code	FIA Code	PLANTS Symbol	Scientific Name[2]	Common Name[2]
1	1	JP	105	PIBA2	*Pinus banksiana*	jack pine
1	2	SC	130	PISY	*Pinus sylvestris*	Scots pine
2	3	RN	125	PIRE	*Pinus resinosa*	red pine (natural)
2	4	RP	125	PIRE	*Pinus resinosa*	red pine (plantation)
3	5	WP	129	PIST	*Pinus strobus*	eastern white pine
4	6	WS	094	PIGL	*Picea glauca*	white spruce
4	7	NS	091	PIAB	*Picea abies*	Norway spruce
5	8	BF	012	ABBA	*Abies balsamea*	balsam fir
6	9	BS	095	PIMA	*Picea mariana*	black spruce
7	10	TA	071	LALA	*Larix laricina*	tamarack
8	11	WC	241	THOC2	*Thuja occidentalis*	arborvitae
9	12	EH	261	TSCA	*Tsuga canadensis*	eastern hemlock
10	13	OS	299	2TN		other softwood[3]
10	14	RC	068	JUVI	*Juniperus virginiana*	eastern redcedar
11	15	BA	543	FRNI	*Fraxinus nigra*	black ash
11	16	GA	544	FRPE	*Fraxinus pennsylvanica*	green ash
12	17	EC	742	PODE3	*Populus deltoides*	eastern cottonwood
13	18	SV	317	ACSA2	*Acer saccharinum*	silver maple
14	19	RM	316	ACRU	*Acer rubrum*	red maple
14	20	BC	762	PRSE2	*Prunus serotina*	black cherry
15	21	AE	972	ULAM	*Ulmus americana*	American elm
15	22	RL	975	ULRU	*Ulmus rubra*	slippery elm
15	23	RE	977	ULTH	*Ulmus thomasii*	rock elm
16	24	YB	371	BEAL2	*Betula alleghaniensis*	yellow birch
17	25	BW	951	TIAM	*Tilia americana*	American basswood
18	26	SM	318	ACSA3	*Acer saccharum*	sugar maple
18	27	BM	314	ACNI5	*Acer nigrum*	black maple
18	28	AB	531	FAGR	*Fagus grandifolia*	American beech
19	29	WA	541	FRAM2	*Fraxinus americana*	white ash
20	30	WO	802	QUAL	*Quercus alba*	white oak
20	31	SW	804	QUBI	*Quercus bicolor*	swamp white oak
20	32	BR	823	QUMA2	*Quercus macrocarpa*	bur oak
20	33	CK	826	QUMU	*Quercus muehlenbergii*	chinkapin oak
21	34	RO	833	QURU	*Quercus rubra*	northern red oak
22	35	BO	837	QUVE	*Quercus velutina*	black oak

Species Group	Species Number[1]	Species Code	FIA Code	PLANTS Symbol	Scientific Name[2]	Common Name[2]
22	36	NP	809	QUEL	*Quercus ellipsoidalis*	northern pin oak
23	37	BH	402	CACO15	*Carya cordiformis*	bitternut hickory
23	38	PH	403	CAGL8	*Carya glabra*	pignut hickory
23	39	SH	407	CAOV2	*Carya ovata*	shagbark hickory
24	40	BT	743	POGR4	*Populus grandidentata*	bigtooth aspen
25	41	QA	746	POTR5	*Populus tremuloides*	quaking aspen
25	42	BP	741	POBA2	*Populus balsamifera*	balsam poplar
26	43	PB	375	BEPA	*Betula papyrifera*	paper birch
27	45	BN	601	JUCI	*Juglans cinerea*	butternut
27	46	WN	602	JUNI	*Juglans nigra*	black walnut
27	47	HH	701	OSVI	*Ostrya virginiana*	hophornbeam
27	48	BK	901	ROPS	*Robinia pseudoacacia*	black locust
28	49	OH	998	2TB		other hardwood[3]
28	50	BE	313	ACNE2	*Acer negundo*	boxelder
28	51	ST	315	ACPE	*Acer pensylvanicum*	striped maple
28	52	MM	319	ACSP2	*Acer spicatum*	mountain maple
28	53	AH	391	CACA18	*Carpinus caroliniana*	American hornbeam
28	54	AC	421	CADE12	*Castanea dentata*	American chestnut
28	55	HK	462	CEOC	*Celtis occidentalis*	common hackberry
28	56	DW	491	COFL2	*Cornus florida*	flowering dogwood
28	57	HT	500	CRATA	*Crataegus*	hawthorn
28	58	AP	660	MALUS	*Malus*	apple
28	59	BG	693	NYSY	*Nyssa sylvatica*	blackgum
28	60	SY	731	PLOC	*Platanus occidentalis*	American sycamore
28	61	PR	761	PRPE2	*Prunus pensylvanica*	pin cherry
28	62	CC	763	PRVI	*Prunus virginiana*	chokecherry
28	63	PL	760	PRUNU	*Prunus*	plum
28	64	WI	920	SALIX	*Salix*	willow
28	65	BL	922	SANI	*Salix nigra*	black willow
28	66	DM	923[4]	SAER	*Salix eriocephala*	Missouri River willow
28	67	SS	931	SAAL5	*Sassafras albidum*	sassafras

Species Group	Species Number[1]	Species Code	FIA Code	PLANTS Symbol	Scientific Name[2]	Common Name[2]
28	68	MA	935	SOAM3	*Sorbus americana*	American mountain ash

[1]Species number 44 represent a removed species group.
[2]Set based on the USDA Forest Service NRM TAXA lists and the USDA Plants database.
[3]Other categories use FIA codes and NRM TAXA codes that best match the other category.
[4]923 is no longer an active FIA code but is used here to represent the species.

3.3 Habitat Type, Plant Association, and Ecological Unit Codes

The native plant communities (NPV) of Minnesota (Minnesota Department of Natural Resources 2003) are used in the fuel model selection logic in the Fire and Fuels extension of the LS variant. A complete list of acceptable NPV codes is shown in Appendix A. If no NPV code or an incorrect NPV code is entered in the input data, then the default code of FDn12 (Northern Dry-Sand Pine Woodland) is used. 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 the growth equations for the LS variant. Users should always use that site index curves from Carmean and others (1989) to estimate site index. In assigning site index, users should use site curves based on total age at an index age of 50. 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. If site index is missing or incorrect, the site species is set to red pine with a default site index set to 60.

Site indices for species not assigned a site index are converted from the site species site index in one of three ways developed by Carmean and Vasilevsky (1971) and Carmean (1979). If a species is associated with the given stand site index, then equation {3.4.1} is used to compute the site index. If a species is not associated with the given site species, then a conversion through aspen is attempted utilizing equation {3.4.2}. If the aspen conversion is not available, then the site index for the site species is assigned to the remaining species for which site index was not specified. Coefficients for equations {3.4.1} and {3.4.2} are located in Appendix B.

{3.4.1} $SI_{unknown} = a_1 + a_2 * SI_{site\ species}$

{3.4.2} $SI_{unknown} = a_1 + a_2 * SI_{aspen}$

where:

$SI_{unknown}$	is site index of the species with unknown site index
$SI_{site\ species}$	is site index of site species
SI_{aspen}	is site index of aspen

a_1, a_2 are species group specific coefficients shown in Appendix B

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 by species 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, species SDI maximums are assigned from the SDI maximums shown in table 3.5.1 or from user input. Maximum stand density index at the stand level is a weighted average, by basal area, of the individual species SDI maximums.

Stand SDI is calculated using the Zeide calculation method (Dixon 2002).

{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)

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

Species Code	SDI Maximum*	Mapped to
JP	356	
SC	408	
RN	505	
RP	505	
WP	529	
WS	412	
NS	412	white spruce
BF	655	
BS	500	
TA	387	
WC	771	
EH	510	
OS	354	eastern redcedar
RC	354	
BO	370	
NP	336	
BH	301	
PH	276	
SH	302	
BT	520	
QA	562	
BP	384	
PB	466	
BN	283	black walnut
WN	283	
HH	304	
BK	343	
OH	257	flowering dogwood

Species Code	SDI Maximum*	Mapped to
BA	423	
GA	414	
EC	648	
SV	590	
RM	421	
BC	384	
AE	282	
RL	227	
RE	282	American elm
YB	369	
BW	526	
SM	371	
BM	371	sugar maple
AB	364	
WA	408	
WO	361	
SW	361	white oak
BR	423	
CK	336	
RO	414	

Species Code	SDI Maximum*	Mapped to
BE	344	
ST	243	
MM	243	striped maple
AH	375	
AC	243	striped maple
HK	420	
DW	257	
HT	463	
AP	422	eastern redbud
BG	430	
SY	499	
PR	463	hawthorn
CC	463	hawthorn
PL	463	hawthorn
WI	447	black willow
BL	447	
DM	447	black willow
SS	492	
MA	338	honeylocust

*Source of SDI maximums is an unpublished analysis of FIA data by John Shaw.

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 are used to estimate tree heights missing in the input data and periodic small-tree diameter growth. In the LS variant, height is estimated using either the Curtis-Arney equation (Curtis 1967, Arney 1985) or the Wykoff equation (Wykoff and others 1982). The equation used by default is indicated by a C or W, in the third column of table 4.1.1. By default, the LS variant does not calibrate the height-diameter relationship for estimating missing tree heights based on measured heights in the input data. To override this, the user must use the NOHTDREG keyword and "turn on" calibration. When calibration is turned on, FVS will use the Wykoff equation form with a calibrated B_1 value, if there are at least 3 measured heights for that species over 3 inches DBH in the stand.

The functional form of the Curtis-Arney equation for trees three inches DBH and larger is shown in equation {4.1.1}. For trees less than three inches DBH using the Curtis-Arney equation, a modified Curtis-Arney equation combined with a simple linear equation is used. The functional form of the Wykoff equation is shown in equation {4.1.2}. Equation coefficients and which equation is used for which species are shown in table 4.1.1.

{4.1.1} Curtis-Arney equation

$DBH \geq 3.0'': HT = 4.5 + P_2 * \exp(-P_3 * DBH \wedge P_4)$
$DBH < 3.0'': HT = ((4.5 + P_2 * \exp(-P_3 * 3.0 \wedge P_4) - 4.51) * (DBH - D_{bw}) / (3 - D_{bw})) + 4.51$

{4.1.2}Wykoff functional form

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

where:

HT	is tree height
DBH	is tree diameter at breast height
D_{bw}	is bud width diameter at 4.51 feet shown in table 4.1.1
B_1 - B_2	are species-specific coefficients shown in table 4.1.1
P_2 - P_4	are species-specific coefficients shown in table 4.1.2

Coefficients for the height-diameter relationships in the LS variant are from equations fit to data for the Southern variant of FVS. Wykoff and Curtis-Arney coefficients for all species, are shown in table 4.1.1. Species for which there was not enough data to fit these relationships use coefficients from a similar species.

Table 4.1.1 Coefficients, default equation used, and surrogate species for height-diameter relationships for the LS variant.

Species Code	W or C	SN Variant Surrogate / source	Curtis-Arney Coefficients				Wykoff Coefficients	
			P_2	P_3	P_4	D_{bw}	Default B_1	B_2
JP	W	hemlock	266.4562	3.9931	-0.3860	0.1	4.5084	-6.0116
SC	W	pond pine	142.7468	3.9726	-0.5871	0.5	4.5457	-6.8000
RN	C	hemlock	266.4562	3.9931	-0.3860	0.1	4.5084	-6.0116
RP	C	hemlock	266.4562	3.9931	-0.3860	0.1	4.5084	-6.0116
WP	C	eastern white pine	2108.8442	5.6595	-0.1856	0.4	4.6090	-6.1896
WS	C	spruce/fir	2163.9468	6.2688	-0.2161	0.2	4.5084	-6.0116
NS	C	spruce/fir	2163.9468	6.2688	-0.2161	0.2	4.5084	-6.0116
BF	C	spruce/fir	2163.9468	6.2688	-0.2161	0.1	4.5084	-6.0116
BS	C	spruce/fir	2163.9468	6.2688	-0.2161	0.2	4.5084	-6.0116
TA	C	spruce/fir	2163.9468	6.2688	-0.2161	0.1	4.5084	-6.0116
WC	W	spruce/fir	2163.9468	6.2688	-0.2161	0.1	4.5084	-6.0116
EH	C	hemlock	266.4562	3.9931	-0.3860	0.1	4.5084	-6.0116
OS	W	misc. softwoods	212.7933	3.4715	-0.3259	0.3	4.0374	-4.2964
RC	W	Virginia pine	926.1803	4.4621	-0.2005	0.5	4.4718	-5.0078
BA	W	black ash	178.9308	4.9286	-0.6378	0.2	4.6155	-6.2945
GA	W	green ash	404.9692	3.3902	-0.2551	0.2	4.6155	-6.2945
EC	W	cottonwood spp.	190.9797	3.6928	-0.5273	0.1	4.9396	-8.1838
SV	C	silver maple	80.5118	26.9833	-2.0220	0.2	4.5991	-6.6706
RM	W	red maple	268.5564	3.1143	-0.2941	0.2	4.3379	-3.8214
BC	W	black cherry	364.0248	3.5599	-0.2726	0.1	4.3286	-4.0922
AE	W	American elm	418.5942	3.1704	-0.1896	0.1	4.6008	-7.2732
RL	W	slippery elm	1337.5472	4.4895	-0.1475	0.1	4.6238	-7.4847
RE	W	elm species	1005.8067	4.6474	-0.2034	0.1	4.3744	-4.5257
YB	W	birch species	170.5253	2.6883	-0.4008	0.1	4.4388	-4.0872
BW	W	basswood	293.5715	3.5226	-0.3512	0.1	4.5820	-5.0903
SM	W	sugar maple	209.8555	2.9528	-0.3679	0.2	4.4834	-4.5431
BM	C	sugar maple	209.8555	2.9528	-0.3679	0.2	4.4834	-4.5431
AB	W	American beech	526.1393	3.8923	-0.2259	0.1	4.4772	-4.7206
WA	W	white ash	91.3528	6.9961	-1.2294	0.2	4.5959	-6.4497
WO	W	white oak	170.1331	3.2782	-0.4874	0.2	4.5463	-5.2287
SW	W	cherrybark oak	182.6306	3.1290	-0.4639	0.1	4.7342	-6.2674
BR	W	scarlet oak	196.0565	3.0067	-0.3850	0.2	4.5225	-4.9401
CK	W	chinkapin oak	72.7907	3.6707	-1.0988	0.1	4.3420	-5.1193
RO	W	northern red oak	700.0636	4.1061	-0.2139	0.2	4.5202	-4.8896
BO	W	black oak	224.7163	3.1165	-0.3598	0.2	4.4747	-4.8698

Species Code	W or C	SN Variant Surrogate / source	Curtis-Arney Coefficients				Wykoff Coefficients	
			P_2	P_3	P_4	D_{bw}	Default B_1	B_2
NP	W	scarlet oak	196.0565	3.0067	-0.3850	0.2	4.5225	-4.9401
BH	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918
PH	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918
SH	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918
BT	W	bigtooth aspen	66.6489	135.4826	-2.8862	0.2	4.9396	-8.1838
QA	W	hickory species	337.6685	3.6273	-0.3208	0.3	4.5128	-4.9918
BP	W	white ash	91.3528	6.9961	-1.2294	0.2	4.5959	-6.4497
PB	W	birch species	170.5253	2.6883	-0.4008	0.1	4.4388	-4.0872
BN	W	butternut	285.8798	3.5214	-0.3194	0.3	4.5018	-5.6123
WN	W	black walnut	93.7104	3.6575	-0.8825	0.4	4.5018	-5.6123
HH	W	eastern hophornbeam	109.7324	2.2503	-0.4130	0.2	4.0322	-3.0833
BK	C	black locust	880.2845	4.5964	-0.2182	0.1	4.4299	-4.9920
OH	W	hackberry species	484.7530	3.9393	-0.2600	0.1	4.4207	-5.1435
BE	W	butternut	285.8798	3.5214	-0.3194	0.3	4.5018	-5.6123
ST	W	hackberry species	484.7530	3.9393	-0.2600	0.1	4.4207	-5.1435
MM	W	hackberry species	484.7530	3.9393	-0.2600	0.1	4.4207	-5.1435
AH	C	eastern hophornbeam	109.7324	2.2503	-0.4130	0.2	4.0322	-3.0833
AC	W	cottonwood species	190.9797	3.6928	-0.5273	0.1	4.9396	-8.1838
HK	C	hackberry species	484.7530	3.9393	-0.2600	0.1	4.4207	-5.1435
DW	W	flowering dogwood	863.0501	4.3856	-0.1481	0.1	3.7301	-2.7758
HT	W	hackberry species	484.7530	3.9393	-0.2600	0.1	4.4207	-5.1435
AP	W	apple species	574.0201	3.8637	-0.1632	0.2	3.9678	-3.2510
BG	C	blackgum	319.9788	3.6731	-0.3065	0.2	4.3802	-4.7903
SY	W	sycamore	644.3568	3.9205	-0.2144	0.1	4.6355	-5.2776
PR	C	hackberry species	484.7530	3.9393	-0.2600	0.1	4.4207	-5.1435
CC	W	hackberry species	484.7530	3.9393	-0.2600	0.1	4.4207	-5.1435
PL	W	apple species	574.0201	3.8637	-0.1632	0.2	3.9678	-3.2510
WI	W	willow species	408.2772	3.8181	-0.2721	0.1	4.4911	-5.7928
BL	W	willow species	408.2772	3.8181	-0.2721	0.1	4.4911	-5.7928
DM	W	hackberry species	484.7530	3.9393	-0.2600	0.1	4.4207	-5.1435
SS	C	sassafras	755.1038	4.3950	-0.2178	0.1	4.3383	-4.5018
MA	W	hackberry species	484.7530	3.9393	-0.2600	0.1	4.4207	-5.1435

4.2 Bark Ratio Relationships

Bark ratio estimates are used to convert between diameter outside bark and diameter inside bark in various parts of the model. The equation is shown in equation {4.2.1} and the appropriate bark ratios by species group are given in table 4.2.1.

{4.2.1} $DIB = BRATIO * DOB$

where:

BRATIO is species-specific bark ratio
DIB is tree diameter inside bark at breast height
DOB is tree diameter outside bark at breast height

Table 4.2.1 Bark ratios by species groups for the LS variant.

Species Group	Bark Ratio
1, 2, 3, 9, 10	.91
4, 8	.95
5, 6, 7, 11, 13, 14, 16, 18, 23, 26, 27	.94
12, 15	.93
17, 19, 21, 22, 24, 25, 28	.92

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 LS variant, crown ratios missing in the input data, for both live and dead trees, are predicted using equation {4.3.1.1} by Holdaway (1986) with coefficients for this equation shown in table 4.3.1.1.

{4.3.1.1} $CR = 10 * (b_1 / (1 + b_2 * BA) + (b_3 * (1 – \exp(b_4 * DBH))))$

where:

CR is crown ratio expressed as a percent
BA is total stand basal area
DBH is tree diameter at breast height
$b_1 – b_4$ are species-specific coefficients shown in table 4.3.1.1

Table 4.3.1.1 Coefficients of the crown ratio equation {4.3.1.1} in the LS variant.

Species Group	b_1	b_2	b_3	b_4
1	6.640	0.0135	3.200	-0.0518

Species Group	b_1	b_2	b_3	b_4
2	5.350	0.0053	1.528	-0.0330
3	6.790	0.0058	7.590	-0.0103
4	7.840	0.0057	1.272	-0.1420
5	5.630	0.0047	3.523	-0.0689
6	5.540	0.0072	4.200	-0.0530
7	6.000	0.0053	0.431	-0.0012
8, 9, 10	5.710	0.0077	2.290	-0.2530
11	4.500	0.0032	0.0795	-0.1050
12, 14	4.350	0.0046	1.820	-0.2740
13	4.850	0.0050	9.810	-0.0099
15	4.400	0.0025	1.000	-0.0940
16	4.180	0.0025	1.410	-0.5120
17	4.440	0.0037	2.090	-0.0650
18	3.400	0.0066	2.870	-0.4340
19	4.490	0.0029	1.210	-0.0650
20	5.840	0.0082	3.260	-0.0490
21	4.200	0.0016	2.760	-0.0250
22	5.060	0.0033	1.730	-0.0610
23	6.210	0.0073	9.990	-0.0100
24	4.110	0.0054	1.650	-0.1100
25, 27, 28	4.000	0.0024	-2.830	0.0210
26	5.000	0.0066	4.920	-0.0263

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 equation {4.3.1.1} by Holdaway (1986) and the coefficients shown in Table 4.3.1.1. 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.

4.3.3 Crown Ratio for Newly Established Trees

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

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

where:

CR is crown ratio expressed as a proportion (bounded to $0.2 \leq CR \leq 0.9$)

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 LS 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 to calculate percent canopy cover (*PCC*) and crown competition factor (CCF) within the model. When available, forest-grown maximum crown width equations are used to compute *PCC* and open-grown maximum crown width equations are used to compute *CCF*.

The LS variant computes tree crown width using equations {4.4.1} through {4.4.5}. Species equation assignment and coefficients are shown in tables 4.4.1 and 4.4.2 for forest- and open-grown equations, respectively. Equations are numbered via the FIA species code and equation number, i.e. the forest grown equation from Bechtold (2003) assigned to Eastern white pine has the number: 12901.

{4.4.1} Bechtold (2003); Equation 01

$DBH \geq 5.0$: $FCW = a_1 + (a_2 * DBH) + (a_3 * DBH^2) + (a_4 * CR) + (a_5 * HI)$
$DBH < 5.0$: $FCW = [a_1 + (a_2 * 5.0) + (a_3 * 5.0^2) + (a_4 * CR) + (a_5 * HI)] * (DBH / 5.0)$

{4.4.2} Bragg (2001); Equation 02

$DBH \geq 5.0$: $FCW = a_1 + (a_2 * DBH^{a_3})$
$DBH < 5.0$: $FCW = [a_1 + (a_2 * 5.0^{a_3})] * (DBH / 5.0)$

{4.4.3} Ek (1974); Equation 03

$DBH \geq 3.0$: $OCW = a_1 + (a_2 * DBH^{a_3})$
$DBH < 3.0$: $OCW = [a_1 + (a_2 * 3.0^{a_3})] * (DBH / 3.0)$

{4.4.4} Krajicek and others (1961); Equation 04

$DBH \geq 3.0$: $OCW = a_1 + (a_2 * DBH)$
$DBH < 3.0$: $OCW = [a_1 + (a_2 * 3.0)] * (DBH / 3.0)$

{4.4.5} Smith and others (1992); Equation 05

$DBH \geq 3.0$: $OCW = a_1 + (a_2 * DBH * 2.54) + (a_3 * (DBH * 2.54)^2) * 3.28084$
$DBH < 3.0$: $OCW = [a_1 + (a_2 * 3.0 * 2.54) + (a_3 * (3.0 * 2.54)^2) * 3.28084] * (DBH / 3.0)$

where:

FCW	is crown width of forest grown trees (used in *PCC* calculations)
OCW	is crown width of open-grown trees (used in *CCF* calculations))
DBH	is tree diameter at breast height, if bounded
CR	is crown ratio expressed as a percent
HI	is the Hopkins Index $HI = (ELEVATION - 887) / 100) * 1.0 + (LATITUDE – 39.54) * 4.0 + (-82.52 - LONGITUDE) * 1.25$
$a_1 - a_5$	are the coefficients shown in tables 4.4.1 and 4.4.2

Table 4.4.1. Crown width equation assignment and coefficients for forest-grown trees in the LS variant.

Species Code	Equation Number[1]	a_1	a_2	a_3	a_4	a_5	Limits and Bounds
JP	10501	0.7478	0.8712		0.0913		FCW ≤ 25
SC	13001	3.5522	0.6742		0.0985		FCW ≤ 27
RN	12501	-3.6548	1.9565	-0.0409	0.0577		DBH ≤ 24
RP	12501	-3.6548	1.9565	-0.0409	0.0577		DBH ≤ 24
WP	12901	0.3914	0.9923		0.1080		FCW ≤ 45
WS	09401	0.3789	0.8658		0.0878		FCW ≤ 30
NS	09101	1.8336	0.9932		0.0431	0.1012	FCW ≤ 27
BF	01201	0.6564	0.8403		0.0792		FCW ≤ 34
BS	09501	-0.8566	0.9693		0.0573		FCW ≤ 27
TA	07101	-0.3276	1.3865		0.0517		FCW ≤ 29
WC	24101	-0.0634	0.7057		0.0837		FCW ≤ 27
EH	26101	6.1924	1.4491	-0.0178		-0.0341	DBH ≤ 40
OS	06801	1.2359	1.2962		0.0545		FCW ≤ 33
RC	06801	1.2359	1.2962		0.0545		FCW ≤ 33
BA	54301	5.2824	1.1184				FCW ≤ 34
GA	54401	2.9672	1.3066		0.0585		FCW ≤ 61
EC	74201	3.4375	1.4092				FCW ≤ 80
SV	31701	3.3576	1.1312		0.1011	-0.1730	FCW ≤ 45
RM	31601	2.7563	1.4212	-0.0143	0.0993	-0.0276	DBH ≤ 50
BC	76201	3.0237	1.1119		0.1112	-0.0493	FCW ≤ 52
AE	97201	1.7296	2.0732		0.0590	-0.0869	FCW ≤ 50
RL	97501	9.0023	1.3933			-0.0785	FCW ≤ 49
RE	97201	1.7296	2.0732		0.0590	-0.0869	FCW ≤ 50
YB	37101	-1.1151	2.2888	-0.0493	0.0985	-0.0396	DBH ≤ 24
BW	95101	1.6871	1.2110		0.1194	-0.0264	FCW ≤ 61
SM	31801	4.9399	1.0727		0.1096	-0.0493	FCW ≤ 54
BM	31801	4.9399	1.0727		0.1096	-0.0493	FCW ≤ 54
AB	53101	3.9361	1.1500		0.1237	-0.0691	FCW ≤ 80
WA	54101	1.7625	1.3413		0.0957		FCW ≤ 62
WO	80201	3.2375	1.5234		0.0455	-0.0324	FCW ≤ 69
SW	80201	3.2375	1.5234		0.0455	-0.0324	FCW ≤ 69
BR	82301	1.7827	1.6549		0.0343		FCW ≤ 61
CK	82601	0.5189	1.4134		0.1365	-0.0806	FCW ≤ 45
RO	83301	2.8908	1.4077		0.0643		FCW ≤ 82
BO	83701	2.8974	1.3697		0.0671		FCW ≤ 52
NP	80901	4.8935	1.6069				FCW ≤ 44
BH	40201	8.0118	1.4212				FCW ≤ 41
PH	40301	3.9234	1.5220		0.0405		FCW ≤ 53

Species Code	Equation Number[1]	a_1	a_2	a_3	a_4	a_5	Limits and Bounds
SH	40701	4.5453	1.3721		0.0430		FCW ≤ 54
BT	74301	0.6847	1.1050		0.1420	-0.0265	FCW ≤ 43
QA	74601	0.7315	1.3180		0.0966		FCW ≤ 39
BP	74101	6.2498	0.8655				FCW ≤ 25
PB	37501	2.8399	1.2398		0.0855	-0.0282	FCW ≤ 42
BN	60201	3.6031	1.1472		0.1224		FCW ≤ 37
WN	60201	3.6031	1.1472		0.1224		FCW ≤ 37
HH	70101	7.8084	0.8129		0.0941	-0.0817	FCW ≤ 39
BK	90101	3.0012	0.8165		0.1395		FCW ≤ 48
OH	49101	2.9646	1.9917		0.0707		FCW ≤ 36
BE	31301	6.4741	1.0778		0.0719	-0.0637	FCW ≤ 57
ST	31301	6.4741	1.0778		0.0719	-0.0637	FCW ≤ 57
MM	31301	6.4741	1.0778		0.0719	-0.0637	FCW ≤ 57
AH	39101	0.9219	1.6303		0.1150	-0.1113	FCW ≤ 42
AC	40701	4.5453	1.3721		0.0430		FCW ≤ 54
HK	46201	7.1043	1.3041		0.0456		FCW ≤ 51
DW	49101	2.9646	1.9917		0.0707		FCW ≤ 36
HT	49101	2.9646	1.9917		0.0707		FCW ≤ 36
AP	76102	4.1027	1.3960	1.0775			FCW ≤ 52
BG	69301	5.5037	1.0567		0.0880	0.0610	FCW ≤ 50
SY	73101	-1.3973	1.3756		0.1835		FCW ≤ 66
PR	76102	4.1027	1.3960	1.0775			FCW ≤ 52
CC	76102	4.1027	1.3960	1.0775			FCW ≤ 52
PL	76102	4.1027	1.3960	1.0775			FCW ≤ 52
WI	97201	1.7296	2.0732		0.0590	-0.0869	FCW ≤ 50
BL	97201	1.7296	2.0732		0.0590	-0.0869	FCW ≤ 50
DM	97201	1.7296	2.0732		0.0590	-0.0869	FCW ≤ 50
SS	93101	4.6311	1.0108		0.0564		FCW ≤ 29
MA	55201	4.1971	1.5567		0.0880		FCW ≤ 46

[1] Equation number is a combination of the species FIA code (###) and source (##), see equations on previous page. Maximum crown widths and DBH have been assigned to prevent poor behavior beyond the source data.

Table 4.4.2. Crown width equation assignment and coefficients for open-grown trees for the LS variant.

Species Code	Equation Number[1]	a_1	a_2	a_3	a_4	a_5	Limits and Bounds
JP	10503	0.2990	5.6440	0.6036			FCW ≤ 30
SC	13001	3.5522	0.6742		0.0985		FCW ≤ 27
RN	12503	4.2330	1.4620	1.0000			FCW ≤ 39

Species Code	Equation Number[1]	a_1	a_2	a_3	a_4	a_5	Limits and Bounds
RP	12503	4.2330	1.4620	1.0000			FCW ≤ 39
WP	12903	1.6200	3.1970	0.7981			FCW ≤ 58
WS	09403	3.5940	1.9630	0.8820			FCW ≤ 37
NS	09104	5.0570	1.1313				FCW ≤ 47
BF	01203	0.3270	5.1160	0.5035			FCW ≤ 34
BS	09503	3.6550	1.3980	1.0000			FCW ≤ 27
TA	07103	2.2050	3.4750	0.7506			FCW ≤ 29
WC	24101	-0.0634	0.7057		0.0837		FCW ≤ 27
EH	26101	6.1924	1.4491	-0.0178		-0.0341	DBH ≤ 40
OS	06801	1.2359	1.2962		0.0545		FCW ≤ 33
RC	06801	1.2359	1.2962		0.0545		FCW ≤ 33
BA	54301	5.2824	1.1184				FCW ≤ 34
GA	54403		4.7550	0.7381			FCW ≤ 61
EC	74203	2.9340	2.5380	0.8617			FCW ≤ 80
SV	31701	3.3576	1.1312		0.1011	-0.1730	FCW ≤ 45
RM	31603		4.7760	0.7656			FCW ≤ 55
BC	76203	0.6210	7.0590	0.5441			FCW ≤ 52
AE	97203	2.8290	3.4560	0.8575			FCW ≤ 72
RL	97501	9.0023	1.3933			-0.0785	FCW ≤ 49
RE	97203	2.8290	3.4560	0.8575			FCW ≤ 72
YB	37101	-1.1151	2.2888	-0.0493	0.0985	-0.0396	DBH ≤ 24
BW	95101	1.6871	1.2110		0.1194	-0.0264	FCW ≤ 61
SM	31803	0.8680	4.1500	0.7514			FCW ≤ 54
BM	31803	0.8680	4.1500	0.7514			FCW ≤ 54
AB	53101	3.9361	1.1500		0.1237	-0.0691	FCW ≤ 80
WA	54101	1.7625	1.3413		0.0957		FCW ≤ 62
WO	80204	1.8000	1.8830				FCW ≤ 69
SW	80204	1.8000	1.8830				FCW ≤ 69
BR	82303	0.9420	3.5390	0.7952			FCW ≤ 78
CK	82601	0.5189	1.4134		0.1365	-0.0806	FCW ≤ 45
RO	83303	2.8500	3.7820	0.7968			FCW ≤ 82
BO	83704	4.5100	1.6700				FCW ≤ 52
NP	80901	4.8935	1.6069				FCW ≤ 44
BH	40201	8.0118	1.4212				FCW ≤ 41
PH	40301	3.9234	1.5220		0.0405		FCW ≤ 53
SH	40703	2.3600	3.5480	0.7986			FCW ≤ 54
BT	74301	0.6847	1.1050		0.1420	-0.0265	FCW ≤ 43
QA	74603	4.2030	2.1290	1.0000			FCW ≤ 43
BP	74101	6.2498	0.8655				FCW ≤ 25
PB	37503	3.6390	1.9530	1.0000			FCW ≤ 42

Species Code	Equation Number[1]	a_1	a_2	a_3	a_4	a_5	Limits and Bounds
BN	60201	3.6031	1.1472		0.1224		FCW ≤ 37
WN	60201	3.6031	1.1472		0.1224		FCW ≤ 37
HH	70101	7.8084	0.8129		0.0941	-0.0817	FCW ≤ 39
BK	90101	3.0012	0.8165		0.1395		FCW ≤ 48
OH	49101	2.9646	1.9917		0.0707		FCW ≤ 36
BE	31301	6.4741	1.0778		0.0719	-0.0637	FCW ≤ 57
ST	31301	6.4741	1.0778		0.0719	-0.0637	FCW ≤ 57
MM	31301	6.4741	1.0778		0.0719	-0.0637	FCW ≤ 57
AH	39101	0.9219	1.6303		0.1150	-0.1113	FCW ≤ 42
AC	40703	2.3600	3.5480	0.7986			FCW ≤ 54
HK	46201	7.1043	1.3041		0.0456		FCW ≤ 51
DW	49101	2.9646	1.9917		0.0707		FCW ≤ 36
HT	49101	2.9646	1.9917		0.0707		FCW ≤ 36
AP	76102	4.1027	1.3960	1.0775			FCW ≤ 52
BG	69301	5.5037	1.0567		0.0880	0.0610	FCW ≤ 50
SY	73101	-1.3973	1.3756		0.1835		FCW ≤ 66
PR	76102	4.1027	1.3960	1.0775			FCW ≤ 52
CC	76102	4.1027	1.3960	1.0775			FCW ≤ 52
PL	76102	4.1027	1.3960	1.0775			FCW ≤ 52
WI	97203	2.8290	3.4560	0.8575			FCW ≤ 72
BL	97203	2.8290	3.4560	0.8575			FCW ≤ 72
DM	97203	2.8290	3.4560	0.8575			FCW ≤ 72
SS	93101	4.6311	1.0108		0.0564		FCW ≤ 29
MA	55201	4.1971	1.5567		0.0880		FCW ≤ 46

[1] Equation number is a combination of the species FIA code (###) and source (##), see equations on previous page. Maximum crown widths and DBH have been assigned to prevent poor behavior beyond the source data.

4.5 Crown Competition Factor

The LS 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. In the LS variant, crown competition factor for an individual tree is calculated using equation {4.5.1}, and is based on crown width of open-grown trees.

{4.5.1} All species

DBH > 0.1": $CCF_t = 0.001803 * OCW_t$^2

$DBH \leq 0.1$”: $CCF_t = 0.001$

where:

CCF_t	is crown competition factor for an individual tree
OCW_t	is open-grown crown width for an individual tree
DBH	is tree diameter at breast height

4.6 Small Tree Growth Relationships

Trees are considered “small trees” for FVS modeling purposes when they are smaller than some threshold diameter. This threshold diameter is set to 5.0” for all species in the LS variant.

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

FVS blends small tree growth estimates with large tree growth estimates to assure a smooth transition between the two models. In the LS variant both height growth and diameter growth estimates use this blending technique. Small and large tree estimates are weighted over the diameter range 1.5”-5.0” *DBH* for all species. The weight is calculated using equation {4.6.1} and applied as shown in equation {4.6.2}.

{4.6.1}

$DBH \leq 1.5$”: $XWT = 0$
1.5” < DBH < 5.0”: $XWT = (DBH - 1.5) / (5.0 - 1.5)$
$DBH \geq 5.0$”: $XWT = 1$

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

where:

XWT	is the weight applied to the growth estimates
DBH	is tree diameter at breast height
STGE	is the growth estimate obtained using the small-tree growth model
LTGE	is the growth estimate obtained using the large-tree growth model

For example, the closer a tree’s *DBH* value is to the minimum diameter of 1.5”, the more the growth estimate will be weighted towards the small-tree growth model estimate. The closer a tree’s *DBH* value is to the maximum diameter of 5.0”, the more the growth estimate will be weighted towards the large-tree growth model estimate. If a tree’s *DBH* value falls outside of the range 1.5” – 5.0”, then only the small-tree or large-tree growth model estimate is used.

4.6.1 Small Tree Height Growth

Small tree height growth is estimated by calculating a potential height growth and modifying the estimate based on intra-stand competition. The estimate is then adjusted by cycle length, scaling factors computed by FVS based on the input small-tree height increment data, and any growth multipliers entered by the user. Potential height growth and the modifier value are estimated using the same equations described in section 4.7.2 to calculate large tree height growth. However, the scaling factor, 0.8, shown in equation {4.7.2.3} is not applied when estimating small tree height growth. Small tree height growth estimates are weighted with large tree height growth estimates as described above.

4.6.2 Small Tree Diameter Growth

Small tree diameter increment is estimated using the height-diameter relationships discussed in section 4.1. The functions are algebraically solved to estimate diameter as a function of height. Height at the start of the projection cycle is known. Height at the end of the projection cycle is obtained by adding the height growth (section 4.6.1) to the starting height. Diameter is predicted at the start of the projection cycle based on the height at the start of the projection cycle; diameter at the end of the projection cycle is estimated from the height at the end of the projection cycle. Small tree diameter growth is calculated as the difference between the predicted diameter at the start of the projection cycle and predicted diameter at the end of the projection cycle, and adjusted for bark ratio. Small tree diameter growth estimates are weighted with large tree diameter growth estimates as described above.

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 5.0" for all species in the LS 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 LS variant uses a large-tree diameter increment model based on Deo and Froese (2013) identified in equation {4.7.1.1}.

{4.7.1.1} $\ln(DDS) = b_1 + (b_2 * (1/DBH)) + (b_3 * DBH) + (b_4 * DBH\text{^}2)\ (b_5 * (DBH/QMD5)) + (b_6 * DBH\text{^}2/QMD5) + (b_7 * BA5) + (b_8 * BAL5) + (b_9 * CR) + (b_{10} * CR\text{^}2) + (b_{11} * SI)$

where:

DDS is the predicted 10-year periodic change in squared **outside**-bark diameter. *DDS* is converted to a squared **inside**-bark diameter before predicting diameter growth.
DBH is tree diameter at breast height
QMD5 is quadratic mean diameter of trees 5 in. or greater in DBH

CR	is crown ratio expressed as a percent
SI	is site index of the species
BA5	is the basal area per acre in trees over 5 in. DBH
BAL5	is the basal area in trees larger than subject tree that are 5 in. or greater in DBH
b_1- b_{11}	are species-specific coefficients shown in tables 4.7.1.1 and 4.7.1.2

Some stand and tree values are bound based on the species:

for SC, JP, TA, BH, PH, SH, BG:	if QMD5>13, then QMD5=13
for WC:	if QMD5>15, then QMD5=15
for EC, WO, SW, BR, CK:	if QMD5>25, then QMD5=25
for EC:	if CR>60, then CR=60
for SY, BL:	if CR>85, then CR=85

Table 4.7.1.1 Coefficients (b_1 – b_6) for the 10-year diameter growth equation in the LS variant.

Species Code	b_1	b_2	b_3	b_4	b_5	b_6
JP	1.39500	-3.93980		0.01213	1.37270	-0.17735
SC	1.39500	-3.93980		0.01213	1.37270	-0.17735
RN	0.21748		0.30253	-0.00885		
RP	0.21748		0.30253	-0.00885		
WP	4.18210	-13.91100			-0.33396	
WS	3.93030	-9.39950			-0.58596	
NS	3.93030	-9.39950			-0.58596	
BF	3.45800	-10.10300			-0.63924	
BS	3.42060	-9.49270			-1.43830	
TA	-0.46100		0.42230			-0.11080
WC	-0.74827		0.33025			-0.08958
EH	3.23090	-11.81600				
OS	0.21748		0.30253	-0.00885		
RC	3.09820	-8.58440				
BA	2.53130	-10.14600				
GA	2.53130	-10.14600				
EC	1.81510		0.09153		1.02090	-0.03235
SV	2.23020	-6.99620	0.11324	-0.00186		
RM	-0.32580		0.33549	-0.00703	-0.53201	
BC	-0.32580		0.33549	-0.00703	-0.53201	
AE	3.24350	-10.73700				
RL	3.24350	-10.73700				

Species Code	b_1	b_2	b_3	b_4	b_5	b_6
RE	3.24350	-10.73700				
YB	2.54000	-7.30400				
BW	3.69120	-11.03500			-0.34599	
SM	3.29460	-12.69100				
BM	3.29460	-12.69100				
AB	2.72840	-12.05900				
WA	2.47033	-9.94277				
WO	1.90185	-5.69505	0.09625			-0.01611
SW	1.90185	-5.69505	0.09625			-0.01611
BR	1.90185	-5.69505	0.09625			-0.01611
CK	1.90185	-5.69505	0.09625			-0.01611
RO	0.44520		0.22472	-0.00397		
BO	0.49086		0.23430	-0.00371		
NP	0.49086		0.23430	-0.00371		
BH	0.05897			0.01986	4.09180	-0.33415
PH	0.05897			0.01986	4.09180	-0.33415
SH	0.05897			0.01986	4.09180	-0.33415
BT	3.44830	-8.18780				
QA	3.39040	-7.18150			-0.16910	
BP	3.39040	-7.18150			-0.16910	
PB	2.68840	-7.31810				
BN	2.95910	-9.51990				
WN	2.95910	-9.51990				
HH	5.38792	-13.25910			-2.44892	
BK	3.02200	-13.62700				
OH	3.18760	-10.28700				
BE	3.18760	-10.28700				
ST	3.18760	-10.28700				
MM	3.18760	-10.28700				
AH	3.03080	-8.10590				
AC	3.03080	-8.10590				
HK	1.23520	-5.21440	0.18300	-0.00314		
DW	3.03080	-8.10590				
HT	3.03080	-8.10590				

Species Code	b_1	b_2	b_3	b_4	b_5	b_6
AP	3.03080	-8.10590				
BG	-0.28233			0.01581	3.37463	-0.26631
SY	3.86690	-8.87037				
PR	3.03080	-8.10590				
CC	3.03080	-8.10590				
PL	3.03080	-8.10590				
WI	3.86690	-8.87037				
BL	3.86690	-8.87037				
DM	3.86690	-8.87037				
SS	3.38410	-10.28200				
MA	3.03080	-8.10590				

Table 4.7.1.2 Coefficients (b_7 – b_{11}) for the 10-year diameter growth equation in the LS variant.

Species Code	b_7	b_8	b_9	b_{10}	b_{11}
JP		-0.00428	0.02997	-0.00015	0.00385
SC		-0.00428	0.02997	-0.00015	0.00385
RN	-0.00114	-0.00306	0.01947		0.00581
RP	-0.00114	-0.00306	0.01947		0.00581
WP		-0.00412	0.03382	-0.00012	
WS		-0.00375	0.01635		
NS		-0.00375	0.01635		
BF	-0.00192		0.02677	-0.00009	0.00317
BS	0.00495	-0.00680	0.01839		0.00742
TA				0.00012	
WC	-0.00118		0.02758	-0.00015	0.00537
EH	-0.00166		0.01535		0.00676
OS	-0.00114	-0.00306	0.01947		0.00581
RC	-0.00386		0.01628		
BA	-0.00095		0.01677		0.01285
GA	-0.00095		0.01677		0.01285
EC		-0.00428		0.00031	

Species Code	b_7	b_8	b_9	b_{10}	b_{11}
SV		-0.00171	0.03114	-0.00014	
RM	-0.00203		0.03314	-0.00016	0.00520
BC	-0.00203		0.03314	-0.00016	0.00520
AE			0.05258	-0.00038	
RL			0.05258	-0.00038	
RE			0.05258	-0.00038	
YB		-0.00223	0.01369		0.00647
BW		-0.00259	0.01932		
SM	-0.00210		0.01787		0.00496
BM	-0.00210		0.01787		0.00496
AB			0.01843		0.00856
WA	-0.00228		0.04226	-0.00029	0.01152
WO		-0.00367	0.03021	-0.00022	
SW		-0.00367	0.03021	-0.00022	
BR		-0.00367	0.03021	-0.00022	
CK		-0.00367	0.03021	-0.00022	
RO		-0.00148		0.00009	0.01305
BO	-0.00186		0.00770		0.00724
NP	-0.00186		0.00770		0.00724
BH		0.00184		0.00008	
PH		0.00184		0.00008	
SH		0.00184		0.00008	
BT		-0.00134	0.02367		
QA		-0.00311	0.01543		0.00619
BP		-0.00311	0.01543		0.00619
PB				0.00020	0.00350
BN		-0.00169	0.03012		0.00356
WN		-0.00169	0.03012		0.00356
HH		-0.00353			
BK	-0.00288		0.04569	-0.00037	0.00766
OH			0.04919	-0.00045	
BE			0.04919	-0.00045	
ST			0.04919	-0.00045	
MM			0.04919	-0.00045	

Species Code	b_7	b_8	b_9	b_{10}	b_{11}
AH	-0.00179		0.00489		
AC	-0.00179		0.00489		
HK	-0.00439	0.00331	0.02814	-0.00011	0.00447
DW	-0.00179		0.00489		
HT	-0.00179		0.00489		
AP	-0.00179		0.00489		
BG			0.01650		
SY		-0.00535	0.02034		
PR	-0.00179		0.00489		
CC	-0.00179		0.00489		
PL	-0.00179		0.00489		
WI		-0.00535	0.02034		
BL		-0.00535	0.02034		
DM		-0.00535	0.02034		
SS		-0.00170	0.03201	-0.00026	
MA	-0.00179		0.00489		

4.7.2 Large Tree Height Growth

The large-tree height growth model also uses the modeling technique of estimating a potential height growth and modifying this potential growth based on tree competition. Potential height growth is estimated using site index curves from Carmean et al (1989). Surrogate curves, based on general growth form for the species, were chosen for species for which curves were not given in Carmean et al. The general form of the equation to estimate height given tree age and site index is shown in equation {4.7.2.1}. Algebraic manipulation to estimate tree age from height and site index yields the equation shown in {4.7.2.2}. Coefficients by species and which of the Carmean et al equations are used for which species are shown in table 4.7.2.1.

{4.7.2.1} $HT = b_6 + b_1 * SI\text{^}b_2 * (1 – \exp(b_3 * A))\text{ ^ }(b_4 * SI\text{^}b_5)$

{4.7.2.2} $A = 1./b_3*(\ln(1-((HT-b_6)/b_1/SI\text{^}b_2)\text{^}(1./b_4/SI\text{^}b_5)))$

where:

HT	is tree height
SI	is species site index
A	is tree age
$b_1 – b_6$	are coefficients shown in table 4.7.2.1

$b_6 = 0$ for total age curves; $b_6 = 4.5$ for breast-height age curves

First, tree age is estimated using site index and the height of the tree at the beginning of the cycle. Next, age is incremented by 10 years and a new height is estimated using the updated age and site index. The difference between the new estimated height and the tree height at the beginning of the cycle is potential height growth. A small random component is applied to insure some distribution in estimated heights.

Potential height growth gets modified by a combination of two factors. One factor is the same modifier, CM, calculated using equation {4.7.1.2} and applied to large-tree diameter growth. The other is a function of individual tree height relative to the average height of the 40-largest diameter trees in the stand. The potential height growth modifier is shown in equation {4.7.2.3}, and the resulting height growth estimate is shown in equation {4.7.2.4}. Estimated height growth is then adjusted for cycle length and user-supplied growth multipliers.

{4.7.2.3} $PHMOD = [1 - ((1 - CM) * (1 - RELHT))] * 0.8$

{4.7.2.4} $HTG_i = PHTG * PHMOD$

where:

HTG_i	is estimated height growth of an individual tree
PHTG	is potential height growth estimated as described above
PHMOD	is potential height growth modifier
CM	is growth modifier as described in section 4.7.1
RELHT	is tree height divided by average height of the 40 largest diameter trees in the stand

Table 4.7.2.1. Coefficients for site index curves used in the LS variant.

Species Code	Carmean et al Figure	Model Coefficients					
		b_1	b_2	b_3	b_4	b_5	b_6
JP	74	1.633	1	-0.0223	1.2419	0	0
SC	108	1.2096	1.0027	-0.0671	1.2282	0.0335	0
RN	95	1.89	1	-0.0198	1.3892	0	0
RP	95	1.89	1	-0.0198	1.3892	0	0
WP	104	3.2425	0.798	-0.0435	52.0549	-0.7064	0
WS	68	1.3342	1.0008	-0.0401	1.8068	0.0248	0
NS	63	6.7791	0.6876	-0.0280	12.1447	-0.4142	0
BF	55	2.077	0.9303	-0.0285	2.8937	-0.1414	0
BS	70	1.762	1	-0.0201	1.2307	0	0
TA	59	1.1151	1	-0.0504	1.3076	0.0009	0
WC	126	1.973	1	-0.0154	1.0895	0	0
EH	127	2.1493	0.9979	-0.0175	1.4086	-0.0008	0
OS	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0
RC	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0
BA	14	4.2286	0.7857	-0.0178	4.6219	-0.3591	0
GA	15	1.6505	0.9096	-0.0644	125.7045	-0.8908	0
EC	28	1.3615	0.9813	-0.0675	1.5494	-0.0767	0

Species Code	Carmean et al Figure	Model Coefficients					
		b_1	b_2	b_3	b_4	b_5	b_6
SV	4	1.0645	0.9918	-0.0812	1.5754	-0.0272	0
RM	1	2.9435	0.9132	-0.0141	1.658	-0.1095	0
BC	35	7.1846	0.6781	-0.0222	13.9186	-0.5268	0
AE	53	6.4362	0.6827	-0.0194	10.9767	-0.5477	0
RL	53	6.4362	0.6827	-0.0194	10.9767	-0.5477	0
RE	53	6.4362	0.6827	-0.0194	10.9767	-0.5477	0
YB	5	2.2835	0.9794	-0.0054	0.5819	-0.0281	0
BW	51	4.7633	0.7576	-0.0194	6.511	-0.4156	0
SM	2	3.3721	0.8407	-0.015	2.6208	-0.2661	0
BM	2	3.3721	0.8407	-0.015	2.6208	-0.2661	0
AB	11	29.73	0.3631	-0.0127	16.7616	-0.6804	0
WA	12	1.5768	0.9978	-0.0156	0.6705	0.0182	0
WO	41	4.5598	0.8136	-0.0132	2.241	-0.188	0
SW	44	1.3466	0.959	-0.0574	8.9538	-0.3454	0
BR	36	2.1037	0.914	-0.0275	3.7962	-0.253	0
CK	36	2.1037	0.914	-0.0275	3.7962	-0.253	0
RO	38	0.4737	1.2905	-0.0236	0.0979	0.6121	0
BO	49	2.9989	0.8435	-0.02	3.4635	-0.302	0
NP	36	2.1037	0.914	-0.0275	3.7962	-0.253	0
BH	10	1.8326	1.0015	-0.0207	1.408	-0.0005	0
PH	10	1.8326	1.0015	-0.0207	1.408	-0.0005	0
SH	10	1.8326	1.0015	-0.0207	1.408	-0.0005	0
BT	32	5.2188	0.6855	-0.0301	50.0071	-0.8695	0
QA	32	5.2188	0.6855	-0.0301	50.0071	-0.8695	0
BP	25	1.2941	0.9892	-0.0315	1.0481	-0.0368	0
PB	8	1.7902	0.9522	-0.0173	1.1668	-0.1206	0
BN	16	1.2898	0.9982	-0.0289	0.8546	0.0171	0
WN	16	1.2898	0.9982	-0.0289	0.8546	0.0171	0
HH	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0
BK	50	0.968	1.0301	-0.0468	0.1639	0.4127	0
OH	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0
BE	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0
ST	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0
MM	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0
AH	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0
AC	53	6.4362	0.6827	-0.0194	10.9767	-0.5477	0
HK	19	1.5932	1.0124	-0.0122	0.6245	0.013	0
DW	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0
HT	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0
AP	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0

Species Code	Carmean et al Figure	Model Coefficients					
		b_1	**b_2**	**b_3**	**b_4**	**b_5**	**b_6**
BG	27	1.3213	0.9995	-0.0254	0.8549	-0.0016	0
SY	25	1.2941	0.9892	-0.0315	1.0481	-0.0368	0
PR	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0
CC	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0
PL	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0
WI	50	0.968	1.0301	-0.0468	0.1639	0.4127	0
BL	50	0.968	1.0301	-0.0468	0.1639	0.4127	0
DM	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0
SS	50	0.968	1.0301	-0.0468	0.1639	0.4127	0
MA	58	0.9276	1.0591	-0.0424	0.3529	0.3114	0

5.0 Mortality Model

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

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

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

{5.0.2} $RIP = 1 – (1 – RI)^Y$

where:

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

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

Species Code	p_0	p_1
JP	5.1676998	-0.0077681
SC	5.5876999	-0.0053480
RN	5.1676998	-0.0077681
RP	5.1676998	-0.0077681
WP	5.5876999	-0.0053480
WS	5.1676998	-0.0077681
NS	5.1676998	-0.0077681
BF	5.1676998	-0.0077681
BS	5.1676998	-0.0077681
TA	5.1676998	-0.0077681
WC	5.1676998	-0.0077681
EH	5.1676998	-0.0077681
OS	5.5876999	-0.0053480

Species Code	p_0	p_1
RC	5.5876999	-0.0053480
BA	5.9617000	-0.0340128
GA	5.1676998	-0.0077681
EC	5.9617000	-0.0340128
SV	5.1676998	-0.0077681
RM	5.1676998	-0.0077681
BC	5.9617000	-0.0340128
AE	5.1676998	-0.0077681
RL	5.1676998	-0.0077681
RE	5.1676998	-0.0077681
YB	5.9617000	-0.0340128
BW	5.1676998	-0.0077681
SM	5.1676998	-0.0077681
BM	5.1676998	-0.0077681
AB	5.1676998	-0.0077681
WA	5.9617000	-0.0340128
WO	5.9617000	-0.0340128
SW	5.9617000	-0.0340128
BR	5.9617000	-0.0340128
CK	5.9617000	-0.0340128
RO	5.9617000	-0.0340128
BO	5.9617000	-0.0340128
NP	5.9617000	-0.0340128
BH	5.9617000	-0.0340128
PH	5.9617000	-0.0340128
SH	5.9617000	-0.0340128
BT	5.9617000	-0.0340128
QA	5.9617000	-0.0340128
BP	5.9617000	-0.0340128
PB	5.9617000	-0.0340128
BN	5.9617000	-0.0340128
WN	5.9617000	-0.0340128
HH	5.1676998	-0.0077681
BK	5.1676998	-0.0077681
OH	5.9617000	-0.0340128
BE	5.9617000	-0.0340128
ST	5.9617000	-0.0340128
MM	5.9617000	-0.0340128
AH	5.1676998	-0.0077681

Species Code	p_0	p_1
AC	5.9617000	-0.0340128
HK	5.9617000	-0.0340128
DW	5.1676998	-0.0077681
HT	5.9617000	-0.0340128
AP	5.9617000	-0.0340128
BG	5.1676998	-0.0077681
SY	5.9617000	-0.0340128
PR	5.9617000	-0.0340128
CC	5.9617000	-0.0340128
PL	5.9617000	-0.0340128
WI	5.1676998	-0.0077681
BL	5.1676998	-0.0077681
DM	5.9617000	-0.0340128
SS	5.1676998	-0.0077681
MA	5.9617000	-0.0340128

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

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

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

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

{5.0.4} $MORT = MR * (1 – MWT) * 0.1$

where:

MR	is the proportion of the tree record attributed to mortality (bounded: $0.01 \leq MR \leq 1$)
RELHT	is tree height divided by average height of the 40 largest diameter trees in the stand
MORT	is the final mortality rate of the tree record
MWT	is a mortality weight value shown in Table 5.0.2

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

Species Code	MWT
JP	0.30
SC	0.30
RN	0.30
RP	0.30
WP	0.50
WS	0.50
NS	0.50
BF	0.90
BS	0.70
TA	0.10
WC	0.70
EH	0.70
OS	0.30
RC	0.20
BA	0.30
GA	0.70
EC	0.10
SV	0.70
RM	0.85
BC	0.40
AE	0.50
RL	0.70
RE	0.50
YB	0.50
BW	0.70
SM	0.90
BM	0.10
AB	0.70
WA	0.30
WO	0.50
SW	0.50
BR	0.50
CK	0.30
RO	0.50

Species Code	MWT
BO	0.50
NP	0.90
BH	0.50
PH	0.50
SH	0.50
BT	0.10
QA	0.10
BP	0.10
PB	0.30
BN	0.30
WN	0.30
HH	0.70
BK	0.10
OH	0.30
BE	0.70
ST	0.90
MM	0.50
AH	0.90
AC	0.90
HK	0.50
DW	0.90
HT	0.30
AP	0.40
BG	0.30
SY	0.50
PR	0.10
CC	0.50
PL	0.30
WI	0.90
BL	0.10
DM	0.50
SS	0.30
MA	0.50

6.0 Regeneration

The LS 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 LS variant.

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
JP	No	0.1	0.33	14.0
SC	No	0.5	0.33	20.0
RN	No	0.1	0.25	18.0
RP	No	0.1	0.25	18.0
WP	No	0.4	0.33	20.0
WS	No	0.2	0.25	18.0
NS	No	0.2	0.25	18.0
BF	No	0.1	0.33	20.0
BS	No	0.2	0.25	16.0
TA	No	0.1	0.50	24.0
WC	No	0.1	0.33	16.0
EH	No	0.1	0.25	16.0
OS	No	0.3	0.25	16.0
RC	No	0.5	0.33	16.0
BA	Yes	0.2	0.33	18.0
GA	Yes	0.2	0.42	24.0
EC	Yes	0.1	0.42	24.0
SV	Yes	0.2	0.42	18.0
RM	Yes	0.2	1.00	20.0
BC	Yes	0.1	0.42	26.0
AE	Yes	0.1	0.33	16.0
RL	Yes	0.1	0.33	12.0
RE	Yes	0.1	0.50	20.0
YB	Yes	0.1	0.42	22.0
BW	Yes	0.1	0.33	16.0
SM	Yes	0.2	0.25	16.0
BM	Yes	0.2	0.25	16.0
AB	Yes	0.1	0.25	14.0
WA	Yes	0.2	0.42	24.0

Species Code	Sprouting Species	Minimum Bud Width (in)	Minimum Tree Height (ft)	Maximum Tree Height (ft)
WO	Yes	0.2	0.33	16.0
SW	Yes	0.1	0.33	16.0
BR	Yes	0.2	0.25	14.0
CK	Yes	0.1	0.33	12.0
RO	Yes	0.2	0.42	20.0
BO	Yes	0.2	0.33	16.0
NP	Yes	0.2	1.40	20.0
BH	Yes	0.3	0.50	20.0
PH	Yes	0.3	0.33	14.0
SH	Yes	0.3	0.33	14.0
BT	Yes	0.2	0.42	20.0
QA	Yes	0.3	0.42	20.0
BP	Yes	0.2	0.42	24.0
PB	Yes	0.1	0.42	18.0
BN	Yes	0.3	0.33	18.0
WN	Yes	0.4	0.33	20.0
HH	Yes	0.2	0.42	20.0
BK	Yes	0.1	0.58	24.0
OH	No	0.1	0.33	10.0
BE	Yes	0.3	0.33	16.0
ST	Yes	0.1	0.25	18.0
MM	Yes	0.1	2.10	20.0
AH	Yes	0.2	0.42	20.0
AC	Yes	0.1	0.50	20.0
HK	Yes	0.1	0.25	12.0
DW	Yes	0.1	0.25	18.0
HT	Yes	0.1	0.25	16.0
AP	Yes	0.2	0.42	20.0
BG	Yes	0.2	0.33	16.0
SY	Yes	0.1	0.58	24.0
PR	Yes	0.1	0.33	30.0
CC	Yes	0.1	2.10	20.0
PL	Yes	0.2	0.33	20.0
WI	Yes	0.1	4.70	20.0
BL	Yes	0.1	1.00	32.0
DM	Yes	0.1	2.10	20.0
SS	Yes	0.1	0.50	18.0
MA	Yes	0.1	2.10	20.0

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

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

{6.0.1} For stump sprouting hardwood species

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

{6.0.2} For root suckering hardwood species

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

{6.0.3} $TPA_s = TPA_i * PS$

{6.0.4} $PS = (1.6134 - 0.0184 * (((DSTMP_i / 0.7788 - 0.21525) * 2.54))) / (1 + \exp(1.6134 - 0.0184 * (((DSTMP_i / 0.7788) - 0.21525) * 2.54)))$

{6.0.5} $PS = (6.0065 - 0.0777*((DSTMP_i / 0.7801) * 2.54)) / (1 + \exp(6.0065 - 0.0777 * ((DSTMP_i / 0.7801) * 2.54)))$

{6.0.6} $PS = ((57.3 - 0.0032 * (DSTMP_i)^3) / 100)$

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

{6.0.8} $PS = ((89.191 - 2.611 * DSTMP_i) / 100)$

where:

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

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

Species Code	Sprouting Probability	Number of Sprout Records	Source*
BA	0.8 for DBH < 12”, 0.5 for DBH > 12”	{6.0.1}	Curtis 1959 Lees and West 1988
GA	0.8 for DBH < 12”, 0.5 for DBH > 12”	1	Ag. Handbook 654
EC	0.4 for DBH < 25", 0 for DBH > 25"	1, 0	Ag. Handbook 654
SV	0.8 for DBH < 12”, 0.5 for DBH > 12”	{6.0.1}	Ag. Handbook 654
RM	0.8 for DBH < 12”, 0.5 for DBH > 12”	{6.0.1}	Solomon and Barton 1967 Prager and Goldsmith 1977
BC	0.8 for DBH < 12”, 0.5 for DBH > 12”	1	Hough 1965 Powell and Tryon 1979
AE	0.7	1	Ag. Handbook 654
RL	0.7	1	Ag. Handbook 654
RE	0.7	1	Ag. Handbook 654
YB	0.3	1	Solomon and Barton 1967 Perala 1974
BW	0.8	{6.0.2}	Ag. Handbook 654
SM	{6.0.8}	{6.0.1}	MacDonald and Powell 1983 Ag. Handbook 654
BM	{6.0.8}	{6.0.1}	Tirmenstein 1991
AB	0.5 for DBH < 12", 0 for DBH > 12"	1, 0	Ag. Handbook 654
WA	0.8 for DBH < 12", 0.5 for DBH > 12"	1	Ag. Handbook 654
WO	{6.0.4}	1	Sands and Abrams 2009 Westfall 2010 Ag. Handbook 654
SW	90% of Eq. {6.0.4} predictions	1	Ag. Handbook 654

Species Code	Sprouting Probability	Number of Sprout Records	Source*
BR	0.8	1	Deitschmann 1965 Perala 1974
CK	0.7	1	Ag. Handbook 654
RO	{6.0.6}	{6.0.1}	Johnson 1975 Ag. Handbook 654
BO	{6.0.5}	1	Sands and Abrams 2009 Westfall 2010 Ag. Handbook 654
NP	0.8	1	Coladonato 1993
BH	0.95 for DBH < 24", 0.6 for DBH > 24"	1	Nelson 1965 Fayle 1966
PH	0.75 for DBH < 24", 0.5 for DBH > 24"	1	Ag. Handbook 654
SH	0.95 for DBH < 24", 0.6 for DBH > 24"	1	Nelson 1965
BT	0.8	{6.0.2}	Ag. Handbook 654
QA	{6.0.7}	2	Keyser 2001
BP	0.8 for DBH < 25", 0.5 for DBH > 25"	[B]	Ag. Handbook 654
PB	0.7	1	Hutnik and Cunningham 1965 Bjorkbom 1972
BN	0.3 for DBH < 8", 0 for DBH > 8"	1, 0	Ag. Handbook 654
WN	0.8 for DBH < 8", 0.5 for DBH > 8"	1	Schlesinger 1977 Schlesinger 1989 Coladonato 1991
HH	0.8	1	Ag. Handbook 654
BK	0.9	{6.0.1}	Ag. Handbook 654
BE	0.6 for DBH < 15", 0.3 for DBH > 15"	1	Maeglin and Ohman 1973 Eyre 1980
ST	0.3	1	Hibbs and Burnell 1979 Coladonato 1993
MM	0.7	1	Sullivan 1993

Species Code	Sprouting Probability	Number of Sprout Records	Source*
AH	No info available--default to 0.7	1	n/a
AC	0.8	1	Hebard et al. 1981 Carey 1992
HK	0.4 for DBH < 8", 0.2 for DBH > 8"	1	Ag. Handbook 654
DW	0.7 for DBH < 8", 0.9 for DBH > 8"	{6.0.1}	Ag. Handbook 654
HT	No info available--default to 0.7	1	n/a
AP	0.5	1	See pin cherry (PR)
BG	0.9	1	Hook and DeBell 1970 Ag. Handbook 654
SY	0.7	1	Steinbeck et al. 1972 Sullivan 1994
PR	0.7	1	Ag. Handbook 654
CC	0.8	{6.0.2}	Schier 1983 Ag. Handbook 654
PL	0.7	1	See pin cherry (PR)
WI	0.9	1	See black willow (BL)
BL	0.9	1	Ag. Handbook 654
DM	0.9	1	See black willow (BL)
SS	0.8	{6.0.2}	Ag. Handbook 654
MA	0.7	{6.0.1}	Sullivan 1992

*Many of the sources stemmed from those referenced in Agricultural Handbook 654, Silvics of North America. For the sake of being concise, only “Ag. Handbook 654” was listed when multiple publications were referenced from that handbook. When necessary, species-specific probabilities were based upon similarities with other species, either due to documented similarities or an assumed similarity. In the latter cases, assumptions were necessary due to a lack of previous research findings for these species.

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: merchantable stem cubic feet, sawlog stem cubic feet, and sawlog stem board feet (calculated using Scribner rule on the Chippewa, Superior, Chequamegon, Nicolet, Chequamegon-Nicolet, Ottawa, and Hiawatha National Forests and calculated using the International ¼-inch on other National Forests). 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 merchantability standards for the LS variant are shown in table 7.0.1.

Table 7.0.1 Volume merchantability standards for the LS variant.

Pulpwood Volume Specifications:		
Minimum DBH / Top Diameter	Hardwoods	Softwoods
903 – Chippewa (aspen, balsam poplar)	6.0 / 4.0 inches	5.0 / 4.0 inches
903 – Chippewa (all other species)	5.0 / 4.0 inches	5.0 / 4.0 inches
909 – Superior	6.0 / 4.0 inches	5.0 / 4.0 inches
All other locations	5.0 / 4.0 inches	5.0 / 4.0 inches
Stump Height	0.5 feet	0.5 feet
Sawtimber Volume Specifications:		
Minimum DBH / Top Diameter	Hardwoods	Softwoods
903 – Chippewa (aspen, balsam poplar)	11.0 / 9.6 inches	9.0 / 7.6 inches
903 – Chippewa (all other species)	9.0 / 7.6 inches	9.0 / 7.6 inches
907 – Ottawa (aspen, balsam poplar)	9.0 / 7.6 inches	9.0 / 7.6 inches
907 – Ottawa (all other species)	11.0 / 7.6 inches	9.0 / 7.6 inches
All other locations	11.0 / 9.6 inches	9.0 / 7.6 inches
Stump Height	1.0 foot	1.0 foot

For both cubic and board foot prediction, Clark's profile models (Clark et al. 1991) are used for all species and all location codes in the LS variant. Equation number is 900CLKE***, where *** signifies the three-digit FIA species code.

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 LS 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 Disease models have been developed through the participation and contribution of various organizations led by Forest Health Protection. The models are maintained by the Forest Management Service Center and regional Forest Health Protection specialists. There are no insect and disease models currently available for the LS variant. However, FVS addfiles that simulate the effects of known agents within the LS variant 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. Native Plant Community (NPV) Codes

Table 11.1.1 NPV codes recognized in the LS variant.

FVS Seq Number	NPV Code	Native Plant Community
1	FDn12	Northern Dry-Sand Pine Woodland
2	FDn22	Northern Dry-Bedrock Pine (Oak) Woodland
3	FDn32	Northern Poor Dry-Mesic Mixed Woodland
4	FDn33	Northern Dry-Mesic Mixed Woodland
5	FDn43	Northern Mesic Mixed Forest
6	FDc12	Central Poor Dry Pine Woodland
7	FDc23	Central Dry Pine Woodland
8	FDc24	Central Rich Dry Pine Woodland
9	FDc25	Central Dry Oak-Aspen (Pine) Woodland
10	FDc34	Central Dry-Mesic Pine-Hardwood Forest
11	MHn35	Northern Mesic Hardwood Forest
12	MHn44	Northern Wet-Mesic Boreal Hardwood-Conifer Forest
13	MHn45	Northern Mesic Hardwood (Cedar) Forest
14	MHn46	Northern Wet-Mesic Hardwood Forest
15	MHn47	Northern Rich Mesic Hardwood Forest
16	MHc26	Central Dry-Mesic Oak-Aspen Forest
17	MHc36	Central Mesic Hardwood Forest (Eastern)
18	MHc37	Central Mesic Hardwood Forest (Western)
19	MHc47	Central Wet-Mesic Hardwood Forest
20	FFn57	Northern Terrace Forest
21	FFn67	Northern Floodplain Forest
22	WFn53	Northern Wet Cedar Forest
23	WFn55	Northern Wet Ash Swamp
24	WFn64	Northern Very Wet Ash Swamp
25	WFs57	Southern Wet Ash Swamp
26	WFw54	Northwestern Wet Aspen Forest
27	FPn62	Northern Rich Spruce Swamp (Basin)
28	FPn63	Northern Cedar Swamp
29	FPn71	Northern Rich Spruce Swamp (Water Track)
30	FPn72	Northern Rich Tamarack Swamp (Eastern Basin)
31	FPn73	Northern Alder Swamp
32	FPn81	Northern Rich Tamarack Swamp (Water Track)
33	FPn82	Northern Rich Tamarack Swamp (Western Basin)
34	FPs63	Southern Rich Conifer Swamp
35	FPw63	Northwestern Rich Conifer Swamp

FVS Seq Number	NPV Code	Native Plant Community
36	APn80	Northern Spruce Bog
37	APn81	Northern Poor Conifer Swamp
38	APn90	Northern Open Bog
39	APn91	Northern Poor Fen
40	CTn11	Northern Dry Cliff
41	CTn12	Northern Open Talus
42	CTn24	Northern Scrub Talus
43	CTn32	Northern Mesic Cliff
44	CTn42	Northern Wet Cliff
45	CTu22	Lake Superior Cliff
46	ROn12	Northern Bedrock Outcrop
47	ROn23	Northern Bedrock Shrubland
48	LKi32	Inland Lake Sand/Gravel/Cobble Shore
49	LKi43	Inland Lake Rocky Shore
50	LKi54	Inland Lake Clay/Mud Shore
51	LKu32	Lake Superior Sand/Gravel/Cobble Shore
52	LKu43	Lake Superior Rocky Shore
53	RVx32	Sand/Gravel/Cobble River Shore
54	RVx43	Rocky River Shore
55	RVx54	Clay/Mud River Shore
56	OPn81	Northern Shrub Shore Fen
57	OPn91	Northern Rich Fen (Water Track)
58	OPn92	Northern Rich Fen (Basin)
59	OPn93	Northern Extremely Rich Fen
60	WMn82	Northern Wet Meadow/Carr
61	MRn83	Northern Mixed Cattail Marsh
62	MRn93	Northern Bulrush-Spikerush Marsh
63	MRu94	Lake Superior Coastal Marsh

11.2 Appendix B. Site Index Conversion Coefficients

Table 11.2.1 Site index a_1 coefficients for species groups for the LS variant.

Unknown Species Group	Known Species Group									
	1	2	3	4	5	6	7	8	9	10
1	0	-0.083	0	0	0	0	0	0	0	0
2	0.081	0	3.926	14.453	0	0	0	0	0	0
3	0	-4.094	0	10.9	0	0	0	0	0	0
4	0	-18.249	-13.974	0	0	0	0	-19.486	0	0
5	0	0	0	0	0	-7.212	0	-15.196	0	0
6	0	0	0	0	6.175	0	2.846	0	0	0
7	0	0	0	0	0	-3.7	0	-12.708	0	0
8	0	0	0	10.904	8.205	0	6.434	0	0	0
9,10,12	0	0	0	0	0	0	0	0	0	0
13,23,27,28	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0
14	0	-17.873	-5.606	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	-5.576	0	0	0	0	0	0	0
22	0	0	-5.576	0	0	0	0	0	0	0
24	4.385	16.194	8.276	7.893	1.605	0	0	0	0	0
25	4.385	16.194	8.276	7.893	1.605	0	0	0	0	0
26	9.002	0	0	0	-17.109	0	0	0	0	0

Unknown Species Group	Known Species Group									
	11	12	13	14	15	16	17	18	19	20
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	13.601	0	0	0	0	0	0
3	0	0	0	5.264	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9,10,12	0	0	0	0	0	0	0	0	0	0
13,23,27, 28	0	0	0	0	0	0	0	0	0	0
11	0	0	0	8.379	-0.953	-15.228	0.253	7.441	4.812	0
14	-9.376	0	0	0	6.729	-2.119	-2.628	3.4	11.937	0
15	0.946	0	0	-7.973	0	-6.136	-5.273	-1.384	3.405	0
16	11.436	0	0	2.022	5.216	0	-4.758	2.045	1.885	0
17	-0.256	0	0	2.652	4.856	4.768	0	4.931	9.642	0
18	-7.746	0	0	-3.563	1.262	-2.119	-4.97	0	1.006	0
19	-5.428	0	0	-15.895	-3.717	-2.162	-11.645	-1.143	0	0
20	0	0	0	0	0	0	0	0	0	0

Unknown Species Group	Known Species Group									
	11	12	13	14	15	16	17	18	19	20
21	23.568	0	0	10.41	7.934	6.247	12.35	10.199	22.442	1.321
22	23.568	0	0	10.41	7.934	6.247	12.35	10.199	22.442	1.321
24	4.818	0	0	16.179	0.239	9.945	-3.615	-11.564	19.238	0
25	4.818	0	0	16.179	0.239	9.945	-3.615	2.868	19.238	0
26	0	0	0	13.612	4.769	9.696	1.911	10.199	13.342	0

Unknown Species Group	Known Species Group							
	21	22	23	24	25	26	27	28
1	0	0	0	-4.661	-4.661	-11.774	0	0
2	0	0	0	-20.194	-20.194	0	0	0
3	4.678	4.678	0	-9.004	-9.004	0	0	0
4	0	0	0	-7.893	-7.893	0	0	0
5	0	0	0	-1.366	-1.366	12.096	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9,10,12	0	0	0	0	0	0	0	0
13,23,27,28	0	0	0	0	0	0	0	0
11	-37.214	-37.214	0	-4.346	-4.346	0	0	0
14	-11.597	-11.597	0	-18.897	-18.897	-16.538	0	0
15	-9.013	-9.013	0	-0.214	-0.214	-5.084	0	0
16	-6.197	-6.197	0	-9.885	-9.885	-10.258	0	0
17	-15.079	-15.079	0	3.165	3.165	-1.913	0	0
18	-11.199	-11.199	0	8.187	-2.435	-11.199	0	0
19	-34.762	-34.762	0	-23.105	-23.105	-16.344	0	0
20	-1.235	-1.235	0	0	0	0	0	0
21	0	0	0	-8.189	-16.187	-16.401	0	0
22	0	0	0	-8.189	-16.187	-16.401	0	0
24	7.992	7.992	0	0	2.223	-19.532	0	0
25	13.856	13.856	0	-2.271	0	8.5	0	0
26	13.069	13.069	0	13.926	-8.947	0	0	0

Table 11.2.2 Site index a2 coefficients for species groups for the LS variant.

Unknown Species Group	Known Species Group									
	1	2	3	4	5	6	7	8	9	10
1	0	1.028	0	0	0	0	0	0	0	0
2	0.973	0	0.959	0.792	0	0	0	0	0	0
3	0	1.043	0	0.78	0	0	0	0	0	0
4	0	1.263	1.282	0	0	0	0	1.787	0	0
5	0	0	0	0	0	1.168	0	1.852	0	0
6	0	0	0	0	0.856	0	0.769	0	0	0
7	0	0	0	0	0	1.3	0	1.975	0	0
8	0	0	0	0.56	0.54	0	0.506	0	0	0
9,10,12	0	0	0	0	0	0	0	0	0	0
13,23,27,28	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0

Unknown Species Group	Known Species Group									
	1	2	3	4	5	6	7	8	9	10
14	0	1.314	1.065	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	1.192	0	0	0	0	0	0	0
22	0	0	1.192	0	0	0	0	0	0	0
24	0.941	0.802	0.919	1	1.175	0	0	0	0	0
25	0.941	0.802	0.919	1	1.175	0	0	0	0	0
26	0.765	0	0	0	1.414	0	0	0	0	0

Unknown Species Group	Known Species Group									
	11	12	13	14	15	16	17	18	19	20
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0.761	0	0	0	0	0	0
3	0	0	0	0.939	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9,10,12	0	0	0	0	0	0	0	0	0	0
13,23,27,28	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0.894	1.007	1.332	0.99	0.961	0.887	0
14	1.119	0	0	0	0.844	1.048	0.991	0.954	0.751	0
15	0.993	0	0	1.185	0	1.176	1.086	1.096	0.916	0
16	0.751	0	0	0.954	0.85	0	0.998	0.965	0.872	0
17	1.01	0	0	1.009	0.921	1.002	0	0.992	0.828	0
18	1.041	0	0	1.048	0.912	1.036	1.008	0	0.88	0
19	1.128	0	0	1.332	1.092	1.147	1.208	1.136	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0.633	0	0	0.898	0.88	1.008	0.819	0.911	0.646	1.07
22	0.633	0	0	0.898	0.88	1.008	0.819	0.911	0.646	1.07
24	1.109	0	0	0.856	1.116	1.006	1.142	1.412	0.833	0
25	1.109	0	0	0.856	1.116	1.006	1.142	1.178	0.833	0
26	0	0	0	0.823	0.938	0.945	0.999	0.911	0.816	0

Unknown Species Group	Known Species Group							
	21	22	23	24	25	26	27	28
1	0	0	0	1.063	1.063	1.308	0	0
2	0	0	0	1.247	1.247	0	0	0
3	0.839	0.839	0	1.088	1.088	0	0	0
4	0	0	0	1	0	0	0	0
5	0	0	0	0.851	0.851	0.707	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0

Unknown Species Group	Known Species Group							
	21	22	23	24	25	26	27	28
8	0	0	0	0	0	0	0	0
9,10,12	0	0	0	0	0	0	0	0
13,23,27,28	0	0	0	0	0	0	0	0
11	1.579	1.579	0	0.902	0.902	0	0	0
14	1.114	1.114	0	1.168	1.168	1.215	0	0
15	1.136	1.136	0	0.896	0.896	1.066	0	0
16	0.992	0.992	0	0.994	0.994	1.058	0	0
17	1.221	1.221	0	0.876	0.876	1.001	0	0
18	1.098	1.098	0	0.708	0.849	1.098	0	0
19	1.549	1.549	0	1.201	1.201	1.225	0	0
20	0.935	0.935	0	0	0	0	0	0
21	0	1	0	1.025	1.168	1.255	0	0
22	1	0	0	1.025	1.168	1.255	0	0
24	0.976	0.976	0	0	0.979	1.403	0	0
25	0.856	0.856	0	1.021	0	0.95	0	0
26	0.797	0.797	0	0.713	1.053	0	0	0

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