Revised Volume and Taper Equations for Six Major Conifer Species in Southwest Oregon

by

David W. Hann

Department of Forest Engineering, Resources, and Management
Oregon State University
Corvallis, Oregon

Forest Biometrics Research Paper 2

February 2011

Revised Volume and Taper Equations for Six Major Conifer Species in Southwest Oregon

The equations used in ORGANON for predicting the various elements of tree volume and taper were published in the 1980s: bark thickness equations (Larsen and Hann 1985), stump diameter at 1.0-feet above the ground equations (Walters et al. 1985), total stem cubic foot volume above breast height equations (Walters et al. 1985, Hann et al. 1987), merchantable cubic foot volume above breast height equations (Walters and Hann 1986a), and stem taper above breast height equations (Walters and Hann 1986b). Details about the modeling data sets and model forms used in these equations can be found in their respective publications. The southwest Oregon taper equations for Douglas-fir were subsequently tested for application in northwest Oregon using a stem analysis data set collected on the Blodgett Tract of the College of Forestry Research Properties. This analysis found that the southwest Oregon equations were superior to all other publically available taper equations in the region. As a result, the southwest Oregon volume and taper equations are the default equations for conifer species in the four versions of ORGANON.

A new ORGANON study in the 1990s resulted in the collection of additional stem analysis data for Douglas-fir and white/grand firs in either old growth stands or hardwood dominated stands in southwest Oregon. The Douglas-fir data were collected for both understory trees and dominant trees and the white/grand firs data were collected for just understory trees. A description of the data collection procedures using in this study can be found in Hann and Weiskittel (2010).

Preliminary analysis of the new Douglas-fir data indicated that the volume and taper equations were biased for trees with diameters at breast height (D) over 30-inches (Hann and Weiskittel 2010). Furthermore, there have been great improvements made in the statistical tools available for nonlinear regression analysis since the 1980s. Therefore, the objective of this analysis was to refit the equations used in ORGANON for predicting the various elements of tree volume and taper.

Total Stem Cubic Foot Volume Above Breast Height

The expanded data set available for modeling total stem cubic foot volume above breast height is (V_{abh}) described in Table 1. Hann et al. (1987) used the following model form to characterize V_{abh}:

$$V_{abh} = b_1 X_1 X_2 D^2 H_{abh} \qquad (1)$$

Where,

$X_1 = (H_{abh}/D)^{b2}$

$X_2 = \exp(b_3 CR_{abh})$

H_{abh} = Total height above breast height, in feet

CR_{abh} = Crown ratio above breast height

$= HCB_{abh}/H_{abh}$

HCB_{abh} = Height above breast height to crown base, in feet

Fitting this model form was restricted by the limited capabilities of the nonlinear regression program used at that time. The following revised total stem cubic foot volume equation model form with multiplicative correction was developed by Hann and Weiskittel (2010) to correct for the over prediction bias in Equation (1):

$$V_{abh} = b_1 X_1 X_3 D^2 H_{abh} \quad (2)$$

Where,

$X_1 = (H_{abh}/D)^{X2}$

$X_2 = b_2[1.0 - \exp(b_3 D^{b4})]^K$

$X_3 = 1.0 – b_7\exp(-30.0[(120.0 – D)/100.0]^{30})$

The use of a power of 30 in X_3, however, makes the equation susceptible to large biases in prediction due to any possible measurement error in D. In addition, Equation (2) does not include the impact of CR_{abh} upon V_{abh}.Therefore, the following V_{abh} model form was developed to minimize the potential impact of measurement error and incorporate CR_{abh}:

$$V_{abh} = b_1 X_1 X_4 X_5 D^2 H_{abh} \quad (3)$$

Where,

$X_4 = \exp[b_5(CR_{abh})^{b6}]$

$X_5 = D^{b7}$

Equation (3) was fit using weighted nonlinear regression with a weight of $(D^2H_{abh})^{-2}$. The resulting parameter estimates and their standard errors are found in Table 2.

Table 1. Descriptive statistics of the data used to model total stem cubic foot volume above breast height in southwest Oregon.

Attribute	Mean	Minimum	Maximum	Standard Deviation
Douglas-fir (n = 851)				
V_{abh}	79.60	0.01	1502.98	164.33
D	14.85	0.9	72.0	10.67
H_{abh}	81.14	4.5	237.2	43.98
HCB_{abh}	39.53	0.0	162.0	29.43
Incense Cedar (n = 154)				
V_{abh}	11.72	0.0042	153.12	20.96
D	9.64	0.9	33.4	6.69
H_{abh}	37.56	4.2	114.9	24.08
HCB_{abh}	13.66	0.0	63.7	14.54
Ponderosa Pine (n = 141)				
V_{abh}	49.26	0.0259	480.03	68.37
D	14.41	1.4	35.6	7.61
H_{abh}	76.30	10.8	188.3	35.03
HCB_{abh}	40.82	2.5	124.0	23.80
Sugar Pine (n = 91)				
V_{abh}	62.68	0.0525	364.53	69.74
D	17.66	2.0	42.2	8.65
H_{abh}	83.31	10.0	170.9	33.87
HCB_{abh}	42.27	0.0	103.7	23.57
White and Grand Firs (n = 255)				
V_{abh}	43.37	0.0158	509.86	68.25
D	12.35	1.4	42.9	7.04
H_{abh}	71.53	6.6	157.4	34.10
HCB_{abh}	29.88	0.0	99.7	24.08

Table 2. Parameter estimates and their weighted standard errors for the southwest Oregon total stem cubic foot volume above breast height Equation (3).

Species	Parameter Estimates and Weighted Standard Errors (in Parentheses)							k
	b_1	b_2	b_3	b_4	b_5	b_6	b_7	
Douglas-fir	0.00124485628 (7.897305E-05)	0.346490193 (0.02988941)	-0.56574969 (0.106573)	0.632239239 (0.07548751)	-0.152406551 (0.02079595)	4.55802463 (1.033951)	-0.0511867106 (0.01874057)	1.0
Incense Cedar	0.000907632813 (5.149066E-05)	0.342846727 (0.03976896)	-0.638653879 (0.3054320)	1.58572040 (0.7530532)	0.0 (NA)	0.0 (NA)	0.0 (NA)	1.0
Ponderosa Pine	0.00127677676 (9.898660E-05)	0.162198194 (0.04451275)	1.0 (NA)	0.0 (NA)	0.0 (NA)	0.0 (NA)	0.0 (NA)	0.0
Sugar Pine	0.000855844369 (6.864747E-05)	0.388366991 (0.04933178)	1.0 (NA)	0.0 (NA)	0.0 (NA)	0.0 (NA)	0.0 (NA)	0.0
White/Grand Firs	0.00133397259 (0.0001086505)	0.357808283 (0.04253698)	-0.755355039 (0.08450604)	0.5 (NA)	-0.261766125 (0.03518579)	1.0 (NA)	0.0 (NA)	1.0

Merchantable Cubic Foot Volume Above Breast Height

The expanded data set available for modeling merchantable cubic foot volume above breast height is (MV_{abh}) described in Table 3. Walters and Hann (1986a) used the following model form to characterize MV_{abh}:

$$MV_{abh} = V_{abh} [1.0 - b_1(TD_{ib}/PD_{ib})^{b2}] \quad (4)$$

Where,

MV_{abh} = Merchantable cubic foot volume above breast height

TD_{ib} = Top diameter inside bark, in inches

PD_{ib} = Predicted diameter at breast height inside bark, in inches

Theoretically, Equation (4) should go to zero if $TD_{ib} = PD_{ib}$ and this will only occur if $b_1 = 1.0$. Unfortunately, Walters and Hann (1986a) found b_1 to be less than 1.0 in most cases. Equation (4) also does not include an impact of crown ratio (CR) upon predicted V_{abh}. The following model form was created to address these limitations:

$$MV_{abh} = V_{abh}\left[1.0 - e^{b_1(1.0 - TD_{ib}/PD_{ib})^{b_2}} (TD_{ib}/PD_{ib})^{(b_3 + b_4 CR^{b_5})}\right] \quad (5)$$

Where,

CR = 1.0 – HCB/H

HCB = Height to crown base, in feet

H = Total height, in feet

Equation (5) was fit using weighted nonlinear regression with a weight of $(V_{abh})^{-2}$. The resulting parameter estimates and their standard errors are found in Table 4.

Table 3. Descriptive statistics of the data used to model merchantable cubic foot volume above breast height in southwest Oregon.

Attribute	Mean	Minimum	Maximum	Standard Deviation
Douglas-fir (n = 3039)				
MV_{abh}	71.49	0.0004	1502.93	140.94
D_{ib}	13.46	0.8	61.9	8.08
TD_{ib}	4.76	0.1	12.0	3.33
H_{abh}	90.22	9.3	252.3	37.96
HCB_{abh}	47.45	1.2	168.5	26.68
Incense Cedar (n = 387)				
MV_{abh}	16.13	0.0033	153.12	23.19
D_{ib}	10.14	0.7	27.8	5.74
TD_{ib}	3.55	0.1	3.6	3.14
H_{abh}	48.41	4.2	114.9	24.34
HCB_{abh}	18.85	0.0	61.5	15.48
Ponderosa Pine (n = 527)				
MV_{abh}	47.48	0.0251	480.08	63.62
D_{ib}	12.90	1.1	32.7	5.99
TD_{ib}	5.18	0.3	11.9	3.21
H_{abh}	82.38	10.8	188.3	31.10
HCB_{abh}	44.77	2.3	110.5	21.55
Sugar Pine (n = 349)				
MV_{abh}	59.35	0.0457	364.50	64.91
D_{ib}	15.56	1.7	37.1	6.61
TD_{ib}	5.31	0.3	11.9	3.33
H_{abh}	88.14	10.0	170.9	28.58
HCB_{abh}	45.45	0.0	101.9	21.33
White and Grand Firs (n = 885)				
MV_{abh}	45.24	0.0105	509.85	66.33
D_{ib}	12.04	1.1	39.4	6.05
TD_{ib}	4.87	0.2	12.0	3.22
H_{abh}	78.52	6.6	157.4	31.82
HCB_{abh}	33.97	0.0	101.8	23.98

Table 4 Parameter estimates and their weighted standard errors for the southwest Oregon merchantable cubic foot volume Equation (5).

Species	b_1	b_2	b_3	b_4	b_5
Douglas-fir	-3.39101798 (0.1314467)	0.918583494 (0.01091785)	1.3330217 (0.08568327)	-0.935974246 (0.07510535)	3.0 (NA)
Incense Cedar	-3.75729892 (0.3349179)	1.23328561 (0.0386284)	1.17859869 (0.1891546)	-0.451357433 (0.1584315)	2.0 (NA)
Ponderosa Pine	-4.87435933 (0.218616)	1.19484691 (0.01761545)	0.634341265 (0.120726)	0.0 (NA)	0.0 (NA)
Sugar Pine	-4.87435933 (0.218616)	1.27588884 (0.02006759)	0.634341265 (0.120726)	0.0 (NA)	0.0 (NA)
White/Grand Firs	-0.765199041 (0.0220436)	0.25 (NA)	3.80136398 (0.1148534)	-1.7902001 (0.1424394)	1.0 (NA)

Diameter Inside Bark at Breast Height

The expanded data set available for modeling diameter inside bark at breast height (D_{ib}), in inches, is described in Table 5. Larsen and Hann (1985) used the following model form to characterize D_{ib}:

$$D_{ib} = b_1 D^{b2} \quad (6)$$

The following model form was created to incorporate the effect of CR upon D_{ib}:

$$D_{ib} = (b_1 D^{b2})EXP[b_3(1.0 - CR)^{0.5}] \quad (7)$$

Where,

D_{ib} = Diameter at breast height inside bark, in inches

Equation (7) was fit using weighted nonlinear regression with a weight of $(D)^{-2}$. The resulting parameter estimates and their standard errors are found in Table 6.

Table 5. Descriptive statistics of the data used to model diameter inside bark at breast height in southwest Oregon.

Attribute	Mean	Minimum	Maximum	Standard Deviation
Douglas-fir (n = 1397)				
D_{ib}	12.88	0.8	61.9	8.52
D	14.74	0.9	72.0	9.87
H	86.88	9.0	241.7	41.33
HCB	45.04	1.2	168.5	27.27
Incense Cedar (n = 185)				
D_{ib}	8.31	0.7	30.9	5.63
D	9.96	0.8	36.4	6.71
H	44.09	8.7	123.2	24.21
HCB	19.28	1.0	66.0	14.83
Ponderosa Pine (n = 171)				
D_{ib}	12.90	1.1	32.7	6.95
D	15.16	1.3	35.6	7.90
H	84.61	15.3	192.8	36.06
HCB	47.77	6.8	115.0	23.64
Sugar Pine (n = 103)				
D_{ib}	15.52	1.7	37.1	7.41
D	18.07	1.9	42.2	8.56
H	89.90	14.5	175.4	33.62
HCB	46.56	2.5	106.4	23.69
White and Grand Firs (n = 342)				
D_{ib}	11.08	1.1	39.4	6.09
D	12.29	1.3	42.9	6.71
H	77.47	11.1	161.9	33.50
HCB	37.09	2.1	106.3	24.03

Table 6. Parameter estimates and their weighted standard errors, by species, for the southwest Oregon diameter inside bark at breast height Equation (7).

Species	Parameter Estimates and Weighted Standard Errors (in Parentheses)		
	b_1	b_2	b_3
Douglas-fir	0.92443655 (.004617388)	0.988866545 (.001116638)	-0.0341455033 (.005969868)
Incense Cedar	0.878755351 0.01110895	1.0 (NA)	-0.0769605545 0.01965432
Ponderosa Pine	0.808600262 (0.01023226)	1.0174258954 (0.004792178)	0.0 (NA)
Sugar Pine	0.858979036 (0.002263008)	1.0 (NA)	0.0 (NA)
White/Grand Firs	0.921624941 (0.006400245)	1.0 (NA)	-0.0341539565 (0.01023344)

Diameter Inside Bark at a 1.0-Foot Stump

The expanded data set available for modeling diameter inside bark at a 1.0-foot stump (SD_{ib}), in inches, is described in Table 7. Walters et al. (1985) used the following model form to characterize SD_{ib}:

$$SD_{ib} = b_1 + b_2 D^{b3} EXP(b_4 CR) \quad (8)$$

The following generalization of Equation (8) was used in this study:

$$SD_{ib} = b_1 + b_2 D^{b3} EXP(b_4 CR^{b5}) \quad (9)$$

Equation (9) was fit using weighted nonlinear regression with a weight of $(D)^{-2}$. The resulting parameter estimates and their standard errors are found in Table 8.

Table 7. Descriptive statistics of the data used to model diameter inside bark for a one foot stump of Douglas-fir in southwest Oregon (n = 1392; five trees had stump heights ≠ 1.0).

Attribute	Mean	Minimum	Maximum	Standard Deviation
Douglas-fir (n = 1392, five trees had stump heights ≠ 1.0)				
SD_{ib}	14.47	0.9	68.5	9.71
D	14.74	0.9	72.0	9.84
H	86.88	9.0	241.7	41.33
HCB	45.04	1.2	168.5	27.27
Incense Cedar (n = 185)				
SD_{ib}	10.12	1.2	36.4	6.77
D	9.96	0.8	36.4	6.71
H	44.09	8.7	123.2	24.21
HCB	19.28	1.0	66.0	14.83
Ponderosa Pine (n = 170, one tree had a stump height ≠ 1.0)				
SD_{ib}	15.22	1.4	38.7	7.88
D	15.21	1.3	35.6	7.89
H	84.86	15.3	192.8	36.01
HCB	47.85	6.8	115.0	23.68
Sugar Pine (n = 103)				
SD_{ib}	18.79	1.9	44.9	8.87
D	18.07	1.9	42.2	8.56
H	89.90	14.5	175.4	33.62
HCB	46.56	2.5	106.4	23.69
White and Grand Firs (n = 340, two trees had stump heights ≠ 1.0)				
SD_{ib}	12.80	1.4	45.8	7.50
D	12.28	1.3	42.9	6.72
H	77.45	11.1	161.9	33.60
HCB	37.09	2.1	106.3	24.10

Table 8. Parameter estimates and their weighted standard errors for the southwest Oregon diameter inside bark at a one foot stump Equation (9).

Species	Parameter Estimates and Weighted Standard Errors (in Parentheses)				
	b_1	b_2	b_3	b_4	b_5
Douglas-fir	0.149809111 (0.0272635)	0.900790279 (0.01238386)	1.0213663112 (0.004316831)	0.133648456 (0.01449769)	3.67532829 (0.565661)
Incense Cedar	0.451569966 (0.06877539)	0.831752493 (0.03942509)	10560026859 (0.01665373)	0.216216295 (0.08817787)	7.00446878 (2.814423)
Ponderosa Pine	0.0 (NA)	1.00221381 (0.00396542)	0.0 (NA)	0.0 (NA)	0.0 (NA)
Sugar Pine	0.0 (NA)	1.04030514 (0.006143851)	0.0 (NA)	0.0 (NA)	0.0 (NA)
White/Grand Firs	0.393048214 (0.08628714)	0.729932627 (0.03090854)	1.0978510098 (0.01293763)	0.120814754 (0.01713955)	1.0 (NA)

Taper Above Breast Height

The expanded data set available for modeling diameter inside bark at any point on the stem above breast height (d_{ib}), in inches, is described in Table 9. Walters et al. (1985) used the following taper equation model form to characterize d_{ib}:

$$d_{ib} = PD_{ib}[Z_0 + (b_{1,1} + b_{1,2}HD + b_{1,3}HD^2)Z_1 + b_{2,1}Z_2] \qquad (10)$$

Where,

$HD = H_{abh}/D$

$Z_0 = 1.0 - RH + I_2(RH + I_1(JP_1(1.0 + JP_2) - 1.0)) - (RH - 1.0)(RH - I_2RH)$

$Z_1 = (I_2(RH + I_1(JP_1(RH + (WLT)(JP_2)) - RH)) - (RH - 1.0)(RH - I_2RH))$

$Z_2 = I_2((RH^2) + I_1((JP_1)(WLT)(2.0RH - WLT + (WLT)(JP_2)) - RH^2))$

$RH = h_{abh}/H_{abh}$

h_{abh} = Height above breast height to the d_{ib} value of interest, in feet

$WLT = (\alpha HCB - 4.5)/H_{abh}$

I_1 = 0.0 when $0.0 \leq RH \leq WLT$, = 1.0 when $WLT < RH \leq 1.0$

I_2 = 0.0 when $WLT \leq 0.0$, = 1.0 when $0.0 < WLT$

$JP_1 = (RH - 1.0)/(WLT - 1.0)$

$JP_2 = (WLT-RH)/(WLT-1.0)$

Table 9. Descriptive statistics of the data used to model diameter inside bark stem taper above breast height of Douglas-fir in southwest Oregon (n = 1397).

Attribute	Mean	Minimum	Maximum	Standard Deviation
Section-level Attributes				
Douglas-fir (n=9638)				
D_{ib}	9.96	0.1	61.9	8.18
h_{abh}	48.86	0.0	236.5	42.80
Incense Cedar (n=887)				
D_{ib}	5.89	0.1	30.9	4.83
h_{abh}	23.93	0.0	114.8	22.37
Ponderosa Pine (n=1419)				
D_{ib}	9.26	0.3	32.7	6.18
h_{abh}	43.82	0.0	186.5	34.80
Sugar Pine (n=980)				
D_{ib}	10.17	0.3	37.1	6.53
h_{abh}	46.36	0.0	167.0	34.50
White/Grand Firs (n=2477)				
D_{ib}	8.46	0.1	39.4	6.22
h_{abh}	41.66	0.0	154.5	34.17
Tree-level Attributes				
Douglas-fir (n=1395)				
D	14.74	0.9	72.0	9.87
H_{abh}	82.38	4.5	237.2	41.33
HCB	45.04	1.2	168.5	27.27
Incense Cedar (n=185)				
D	9.96	0.8	36.4	6.71
H_{abh}	39.59	4.2	118.7	24.21
HCB	19.28	1.0	66.0	14.83
Ponderosa Pine (n=171)				
D	15.16	1.3	35.63	7.90
H_{abh}	80.11	10.8	188.3	36.06
HCB	47.77	6.8	115.0	23.64
Sugar Pine (n=103)				
D	18.07	1.9	42.2	8.56
H_{abh}	85.40	10.0	170.9	33.62
HCB	46.56	2.5	106.4	23.69
White/Grand Firs (n=342)				
D	12.29	1.3	42.9	6.71
H_{abh}	72.97	6.6	157.4	33.50
HCB	37.09	2.1	106.3	24.03

However, Equation (10) produced biased and imprecise predictions for D greater than 30-inches. After testing dozens of alternatives, the following model form was judged to be the best:

$$d_{ib} = PD_{ib}(Z_0 + X_1Z_1 + X_2Z_2) \quad (11)$$

Where,

$$X_1 = b_{1,1} + b_{1,2}EXP(b_{1,3}HD^2)$$

$$X_2 = b_{2,1}$$

Equation (11) was fit using weighted nonlinear regression with a weight of $(PD_{ib})^{-2}$. The resulting parameter estimates and their standard errors are found in Table 10. Comprehensive testing of Equation (11) using all of the undamaged and damaged conifer trees measured in southwest Oregon indicated that the following restrictions should be placed on the application of the equations to minimize prediction problems that were associated with damaged trees:

If $HD < 3.0$, $HD = 3.0$

If $BR > 0.85$, $BR = 0.85$

Table 10. Parameter estimates and their weighted standard errors for the southwest Oregon above breast height diameter inside bark stem taper Equation (11).

Species	$b_{1,1}$	$b_{1,2}$	$b_{1,3}$	$b_{2,1}$	α
Douglas-fir	-0.550298007 (0.008024195)	-0.69479837 (0.03056953)	-0.0613100423 (0.003031063)	0.356974513 (0.01659491)	0.50
Incense Cedar	-0.596278066 (0.04589183)	-0.839878829 (0.06448906)	-0.0685768402 (0.01207676)	0.134178717 (0.05093567)	0.71
Ponderosa Pine	-0.595823501 (0.02169944)	-1.25803662 (0.354493)	-0.13867406 (0.02000517)	0.0998711245 (0.04726353)	0.60
Sugar Pine	-0.6 (NA)	-0.484358059 (0.02524813)	-0.033249206 (0.003815497)	0.108620349 (0.0320686)	0.74
White/Grand Firs	-0.342017552 (0.02428727)	-0.777574201 (0.05809929)	-0.0433569876 (0.005810811)	0.672963393 (0.03789176)	0.33

A comparison of the mean differences (predicted d_{ib} minus actual d_{ib}) and the associated mean square errors from the Douglas-fir taper equations of Walters and Hann (1986), Hann and Weiskittel (2010), and Equation (11) are presented in Table 11. Equation (11) exhibits lower bias and higher precision than the original equation of Walters and Hann (1986), which meets the objective of this analysis. When compared to the equation of Hann and Weiskittel (2010), Equation (11) exhibits lower bias and higher precision for trees with D values under 30-inches, very similar statistics for trees with D values between 30 and 40-inches, and higher bias and lower precision for trees with D values over 40-inches. The following two facts also influenced the decision of which equation to use in ORGANON:

1. Most management scenarios will produce trees with D values under 40-inches.
2. Only 34 of the 1395 sample trees had D values over 40.0-inches.

Based upon this information it was decided to use Equation (11) instead of the equation of Hann and Weiskittel (2010).

Table 11. Comparison of mean differences and mean square errors from the Douglas-fir taper equations of Walters and Hann (1986), Weiskittel and Hann (2010), and Equation (11).

DBH Classes in Inches	Number of Trees	Walters and Hann (1986)	Hann and Weiskittel (2010)	Equation (11)
(Predicted d_{ib}) – (Actual d_{ib}) in Inches				
0.1 to 10.0	534	0.0	0.0	0.0
10.1 to 20.0	527	0.0	0.0	0.0
20.1 to 30.0	232	-0.1	0.0	0.0
30.1 to 40.0	72	0.3	0.1	0.1
40.1 to 50.0	24	0.5	0.0	0.5
50.1 +	10	0.7	-0.3	0.3
All	1395	0.1	0.0	0.0
Mean Square Error in Inches^2				
0.1 to 10.0	534	0.07	0.12	0.06
10.1 to 20.0	527	0.26	0.31	0.21
20.1 to 30.0	232	0.67	0.79	0.61
30.1 to 40.0	72	2.23	1.69	1.71
40.1 to 50.0	24	4.87	3.28	3.57
50.1 +	10	8.27	3.91	6.48
All	1395	0.88	0.71	0.70

Literature Cited

Hann, D.W, and A.R. Weiskittel. 2010. Evaluation of alternative approaches for predicting individual tree volume growth rate. Western Journal of Applied Forestry 25: 120-126.

Hann, D.W., D.K. Walters and J.A. Scrivani. 1987. Incorporating crown ratio into prediction equations for Douglas-fir stem volume. Canadian Journal of Forest Research 17: 17-22.

Larsen, D.R. and D.W. Hann. 1985. Equations for predicting diameter and squared diameter inside bark at breast height for six major conifers of southwest Oregon. Oregon State University, Forest Research Laboratory, Corvallis, Oregon. Research Note 77. 4p.

Walters, D.K. and D.W. Hann. 1986a. Predicting merchantable volume in cubic feet to a variable top and in Scribner board feet to a 6-inch top for six major conifers of southwest Oregon. Oregon State University, Forest Research Laboratory, Corvallis, Oregon. Research Bulletin 52. 107p.

Walters, D.K. and D.W. Hann. 1986b. Taper equations for six conifer species in southwest Oregon. Oregon State University, Forest Research Laboratory, Corvallis, Oregon. Research Bulletin 56. 36p.

Walters, D.K., D.W. Hann and M.A. Clyde. 1985. Equations and tables predicting gross total stem volumes in cubic feet for six major conifers of southwest Oregon. Oregon State University, Forest Research Laboratory, Corvallis, Oregon. Research Bulletin 50. 36p.