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Asymptotic Height-Diameter Equations for Twenty-Four Tree Species in Western Oregon

by

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ASYMPTOTIC HEIGHT-DIAMETER EQUATIONS FOR TWENTY-FOUR TREE SPECIES IN WESTERN OREGON

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Introduction

Use of equations predicting tree height from diameter outside bark at breast height (DBH) makes tedious height measurements unnecessary in estimating tree volume in timber cruises (Larsen and Hann 1987) and in ecological field studies. They also are vital as a means to predict tree height growth and volume in growth-and-yield models (e.g., Hester *et al.* 1989) and in ecological, process-based simulations of tree dynamics (e.g., Garman *et al.* 1992; Urban *et al.* 1993; Hansen *et al.*, 1995). Such equations are especially important for the ecologically based ZELIG.PNW gap model (Urban 1993), which simulates tree growth over very long periods (500 years or more) and is being used increasingly to evaluate ecological properties and dynamics of managed and natural stands in the Pacific Northwest (Garman *et al.* 1992; Hansen *et al.* 1993a, 1995; Urban *et al.* 1993).

Equations vary in underlying mathematical function, but generally are species-specific and are generated from regression analysis of empirical observations. Height-diameter equations based on non-asymptotic functions (e.g., USDA Forest Service 1985a; Larsen and Hann 1987; Wang and Hann 1988 and references therein) and even second-order polynomial equations (e.g., McDonald 1983; Dale and Hemstrom 1984) provide reasonable predictions in modeling and field applications where tree sizes fall within the diameter range of the data used to generate equation coefficients. Because of their mathematical form, however, these equations are deficient for extrapolations beyond the empirical data set—predicting, for example, an unreasonable increase, or even decrease, in height for diameters greater than observed values (Figure 1).

Because data spanning the range of possible diameters are not readily obtainable, non-asymptotic height-diameter equations currently available are inadequate when dealing with trees approaching their maximum diameter, and thus are inappropriate for use in the ZELIG.PNW and related models and in field studies involving old-growth individuals. Height-diameter equations based on asymptotic functions adequately fit height-diameter relationships over the range of observed data, but constrain height increase above maximum observed values (Figure 1). The asymptotic equations that have been developed for species in the Pacific Northwest (e.g., USDA Forest Service 1985a and references therein; Krumland and Wensel 1988; Huang *et al.* 1992) have two drawbacks: they either are available for a limited number of species; or they

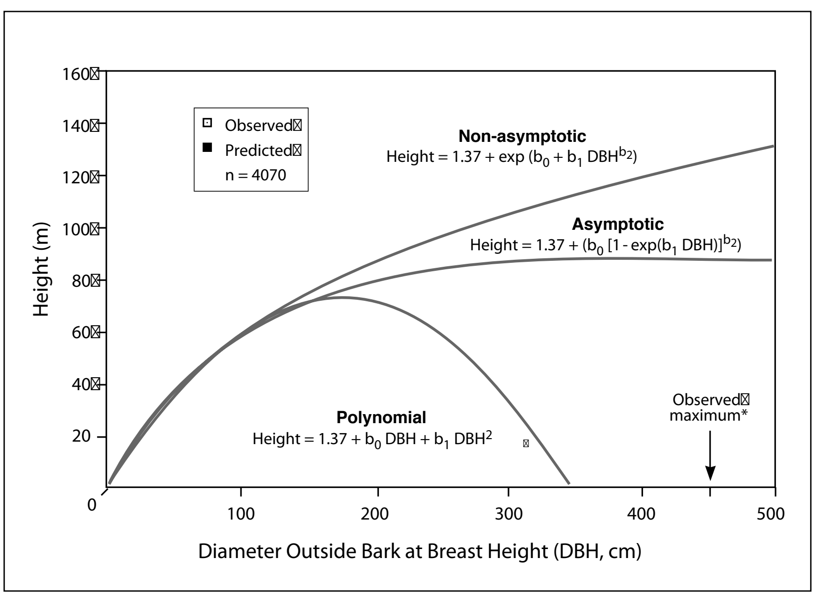

Figure 1. Comparison of three height-diameter equation forms for Douglas-fir in the Northern Oregon Cascades region.

**Waring and Franklin (1979).*

require measures of age at DBH or stand age that are not always available in simulation applications or are of limited used in field applications, where determining age of large individuals may be impossible.

Access to a collection of regional data bases provided us with the opportunity to develop height-diameter equations for common tree species from a similar asymptotic function. Asymptotic equations for predicting total tree height from DBH as a function of site class for seven ecoregions in western Oregon are presented in this paper. Twenty-four species are included:

Conifers	
Pacific silver fir	*Abies amabilis* (Dougl.) ex Forbes
White fir	*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.
Grand fir	*Abies grandis* (Dougl. ex D. Don) Lindl.
Red fir	*Abies magnifica* A. Murr.
Noble fir	*Abies procera* Rehd.
Incense-cedar	*Calocedrus decurrens* (Torr.) Florin
Port-Orford-cedar	*Chamaecyparis lawsoniana* (A. Murr.) Parl.
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
Jeffrey pine	*Pinus jeffreyi* Grev. & Balf.
Sugar pine	*Pinus lambertiana* Dougl.
Western white pine	*Pinus monticola* Dougl. ex D. Don
Ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Pacific yew	*Taxus brevifolia* Nutt.
Western redcedar	*Thuja plicata* Donn ex D. Don
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.

Hardwoods	
Bigleaf maple	*Acer macrophyllum* Pursh
Red alder	*Alnus rubra* Bong.
Pacific madrone	*Arbutus menziesii* Pursh
Chinkapin	*Castanopsis chrysophylla* (Dougl.) A. DC.
Tanoak	*Lithocarpus densiflorus* (Hook & Arn.) Rehd.
Oregon white oak	*Quercus garryana* Dougl. ex Hook.
California black oak	*Quercus kelloggii* Newb.

Methods

Tree heights and diameters used in this study were obtained from six sources:

1. USDA Forest Service, Inventory and Economics (IE) Research, Development, and Application (RD&A) Program, 1984-1986 remeasurement period, western Oregon (USDA Forest Service 1985a,b);
2. USDI BLM Inventory Program, 1988 remeasurement period, Salem, Eugene, Coos Bay, Roseburg, and Medford Districts (USDI Bureau of Land Management 1987);
3. Ecology-plot data sets from Siuslaw, Willamette, Umpqua, Siskiyou, and Rogue National Forest, USDA Forest Service, National Forest Ecology Program (e.g., Hemstrom *et al.* 1987);
4. Permanent Plot Reference Stands in western Oregon, data maintained in the Forest Science Data Bank by Oregon State University, Forest Science Department (Hawk *et al.* 1978; Michener *et al.* 1990). Four data sets were included: H. J. Andrews Experimental Forest (OHJA), ponderosa pine growth and yield (PPGY), hemlock-spruce growth and yield (HSGY), and noble fir growth and yield (NFGY);
5. Old-Growth Douglas-fir Chronosequence Study, western Oregon (Spies and Franklin 1991);
6. Douglas-fir Plantation Study, COPE, Oregon State University (Hansen *et al.* 1993b).

Data were collected from 8727 fixed- and variable-radius plots representing managed and natural stands about 15 to 475 years old. Dead trees, stems with broken tops, and trees with estimated diameter or height were eliminated from further consideration. For data sets with repeated measures, only the most recent height-diameter measurement for an individual was used.

Tree height was derived by the tangent method (Larsen *et al.* 1987) in data sources 1 through 5 and with a telescoping fiberglass pole in data source 6. Diameter at breast height was measured to the nearest centimeter in source 5 and to the nearest 0.1 cm in all other sources. Elevation of each plot was either provided in the data source or estimated by locating the plot on a topographic map. Because of the wide geographic range of data and the potential for physiographic effects on height-diameter relationships, data were segregated into distinct ecoregions. This was accomplished by overlaying geographic coordinates of each plot on a modified map of the eight western Oregon ecoregions (Figure 2) with the ARC/INFO geographic information system. Because data were limited, the Willamette Valley region was not used in this analysis.

Although variability in height-to-diameter relationships has been related to a variety of stand-level attributes, such as site productivity and basal area (Larsen and Hann 1987), incomplete data precluded our considering factors other than site productivity in building equations. We aggregated data by site class primarily because models such as the current version

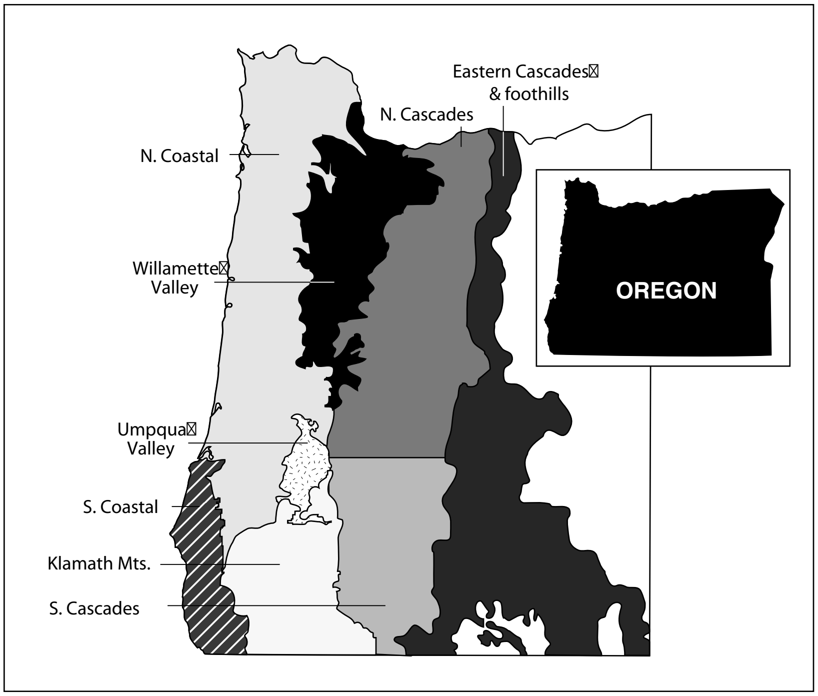

Figure 2. Western Oregon ecoregions. Modified from USEPA ERL-C, 1/15/93.

of ZELIG.PNW are more sensitive to gross differences in site productivity than to specific measures of site index. Thus, the equations presented are more generalized than those that distinguish among site indices.

Because we wanted to aggregate height-diameter data for each species across plots of similar productivity, we estimated site class by species on a plot instead of using only the dominant species. Site class was calculated from estimated mean annual increment at culmination by using species-specific equations based on site index and a weighted plant-discount factor (USDA Forest Service 1985a). Site-index values used in calculating site class were either provided in the original data bases or were estimated. The site-index species and corresponding site index were provided in data sources 1 and 2 and in most of data source 3. Where site index was not reported in data source 3, plant association guides (Hemstrom and Logan 1986; Logan *et al*. 1987) were used to derive site index for Douglas-fir. For other species in data source 3 and for all species in other data sources except old-growth Douglas-fir, site index was estimated with the species-specific site-index equations used by the USDA Forest Service IE program (USDA Forest Service 1985a,b) and the USDI Bureau of Land Management Inventory program (USDI BLM 1987). In deriving site index for a species, only the largest individuals were used. Because using the site-index equations for red alder led to unrealistic estimates, site index for this species was estimated from site-index relationships between red alder and Douglas-fir (Hoyer *et al*. 1978) when Douglas-fir was the site-index species. Site class was estimated for old-growth Douglas-fir from the site-class maps of Isaac (1949).

Data Analysis

Height-from-diameter equations were generated by using the Chapman-Richards function (Richards 1959). Equation parameters were estimated by using the NonLinear Regression module (NLR) of SPSSX (SPSS 1988). Regression equations were generated for each species by ecoregion:

$$Ht = 1.37 + (b_0 [1-\exp(b_1 DBH)]^{b_2}) \quad (1)$$

where Ht = total tree height, m; DBH = diameter outside bark at breast height, cm; b_0 = asymptote or maximum height; b_1 = steepness parameter; and b_2 = curvature parameter. Although several nonlinear equations are well suited for estimating height-diameter curves (Huang *et al*. 1992), we were most familiar with the Chapman-Richards function. Preliminary equation fits for several species having large sample sizes (>1000) indicated heterogeneity in error variances, which leads to incorrect estimates of the variance of regression coefficients (Neter and Wasserman 1974). A weighted regression approach with 1/DBH as the weight provided minimum variance of parameters and was used in deriving all equations.

Species data were combined among site classes when sample sizes were insufficient to produce a statistically significant ($P < 0.05$) asymptote or when the predicted asymptote was unrealistically large. The latter case occurred when observed data spanned only a limited range of diameters and heights or when heights did not exhibit an asymptotic trend at large diameters. A *t*-test was used to determine if coefficients were significantly different ($P < 0.05$) between site-class regression equations for a species. Site-class data were grouped if regression coefficients were not significantly different.

Results and Discussion

Equation coefficients and statistics and descriptive statistics for the empirical data sets for each species by ecoregion are presented in Table 1 (Appendix). For all but nine species, only one equation was derived for an ecoregion because of limited sample sizes or similarity in regression coefficients among site classes. Because of the small sample size for Pacific yew, data from all ecoregions and site classes were combined to generate a significant height-diameter equation. Sample sizes of Douglas-fir and western hemlock were adequate for generating equations for two elevational zones ($\leq$1000 m, and >1000 m).

Overall, the high values of the adjusted coefficient of determination indicate the adequacy of the Chapman-Richards function to predict height from DBH. In addition, predicted asymptotes of coniferous species compared well with values reported by Waring and Franklin (1979) and Franklin and Dyrness (1973) for “typical” maximum heights on good growing sites. Some general species differences in goodness of equation fit were evident.

The coefficient of determination was generally higher for coniferous species (0.70-0.96) than for hardwood species (0.59-0.86) because of differences in apical dominance between hardwoods and conifers and greater variability in estimation of hardwood tree heights. For species having separate equations for site-class groups, the estimated asymptote (=maximum height) tended to decrease with lower site productivity. Exceptions to this trend were evident for Douglas-fir >1000 m in the southern Oregon Cascades region and for western hemlock $\leq$1000 m in the northern Oregon Coastal region and >1000 m in the northern Oregon Cascades region. In these cases, the asymptote increased with decreasing site productivity, although asymptotes were not significantly different ($P > 0.05$). The steepness parameters (b_1) of these equations, however, were significantly different ($P < 0.05$) and decreased with decreasing site productivity, predicting that stems reach their estimated maximum height more slowly on less productive sites.

The equations presented in this report provide predictive regional estimates of height-diameter trends for tree species over a wide range of diameters and were designed to address the specific needs of the ZELIG. PNW simulation model. These equations can also be used in other models and in field applications when more site-specific estimators are not available or when generalized relationships between height and diameter are more desirable. The equations presented especially provide better estimates of height of large-diameter stems than do non-asymptotic equations. Nevertheless, despite the generally good fit between these equations and both observed data and literature reports of maximum height, equations should be tested before using them for a specific locale or different stand treatments. This is especially important because our equations were based on a range of natural and managed stand conditions, without regard to stand age or canopy status of individual stems. A small sample (e.g., 30-40) covering a wide range of tree diameters may adequately test the appropriateness of an equation. Significant discrepancies between predicted and observed values would require deriving new equation coefficients from the data sets used in this report and additional field measures.

Although height-diameter relationships typically are held constant in most simulation models, the natural variation in these relationships may be of value in some ecological applications. In such instances, the asymptotic variance-covariance matrix of regression coefficients could be generated and used to develop distributions centered on the reported coefficients. Values of coefficients used to derive height from DBH could then be randomly selected from this distribution to emulate at least the natural variability implicit in the empirical data sets. Data used in this study have been archived in the OSU Forest Science Data Bank under StudyId TV00911 and are available for generating the variance-covariance matrices or for further assessment of height-diameter relationships.

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Appendix: Height-Diameter Regression Coefficients and Descriptive Statistics for the Modeling Data Sets

Table 1. Height-diameter regression coefficients and descriptive statistics for the modeling data sets.

Species/ecoregion	Site class	N	Regression coefficients (SE)[1] b_0	b_1	b_2	Mean square error	Adj. COD[2]	Mean (range) of DBH (cm)	Height (m)	Elevation (m)
Conifers										
Pacific silver fir										
N. Oregon Cascades	3-5	328	60.02491 (6.63537)	-0.020250 (0.003970)	1.320270 (0.090940)	20.650	0.911	34.3 (2.5-95.0)	22.3 (1.8-53.6)	1309 (792-1874)
White fir										
S. Oregon Cascades	All	1748	63.50341 (2.21041)	-0.015460 (0.001080)	1.129460 (0.026780)	32.750	0.860	50.7 (2.5-132.1)	29.3 (2.1-63.4)	1389 (420-1874)
Klamath Mts.	1-3	733	54.41967 (1.65845)	-0.019540 (0.001760)	1.103260 (0.060320)	28.353	0.720	69.5 (2.5-136.4)	37.4 (2.1-61.9)	1454 (329-1956)
	4-5	311	39.24277 (2.04794)	-0.029820 (0.003620)	1.225030 (0.066330)	17.374	0.850	37.7 (2.5-123.4)	21.7 (1.8-50.3)	1336 (487-1996)
Grand fir										
Oregon Cascades	All	249	59.13930 (6.35227)	-0.016900 (0.003580)	1.047300 (0.061130)	26.738	0.870	33.3 (2.8-103.1)	21.7 (2.1-58.5)	863 (91-1737)
N. Oregon Coastal	All	287	57.11220 (7.43085)	-0.013600 (0.003350)	0.885000 (0.036250)	15.602	0.910	24.0 (2.5-125.5)	15.6 (2.1-48.5)	371 (30-1067)
Klamath Mts.	All	277	61.40060 (11.09590)	-0.014300 (6.000000)	0.996200 (0.004310)	14.360	0.890	21.8 (2.5-98.8)	15.1 (2.1-49.7)	748 (243-1554)

Table 1. continued.

Species/ecoregion	Site class	N	Regression coefficients (SE)[1] b_0	b_1	b_2	Mean square error	Adj. COD[2]	Mean (range) of DBH (cm)	Height (m)	Elevation (m)
Conifers										
Red fir										
S. Oregon Cascades	All	660	59.05185 (1.84653)	-0.016177 (0.001283)	1.152987 (0.044400)	29.126	0.852	73.6 (2.5-180.6)	35.8 (1.8-71.6)	1658 (1200-1950)
Klamath Mts.	All	425	60.97739 (3.15431)	-0.012986 (0.001462)	1.011279 (0.031016)	23.587	0.918	62.4 (2.5-149.6)	29.7 (1.8-61.9)	1650 (1252-1996)
Noble fir										
N. Oregon Cascades	1-3	331	78.60353 (4.62300)	-0.013330 (0.001660)	1.185140 (0.058450)	16.871	0.960	35.0 (2.5-162.6)	21.2 (1.8-82.3)	1188 (732-1707)
	4-5	281	60.13650 (3.19928)	-0.015899 (0.001819)	1.131569 (0.046828)	25.364	0.906	57.8 (2.5-152.4)	30.2 (1.8-65.7)	1270 (641-1737)
N. Oregon Coastal	All	68	75.47281 (15.63323)	-0.008612 (0.003209)	0.970622 (0.073579)	15.464	0.936	43.5 (3.6-138.9)	21.9 (2.7-56.3)	992 (549-1300)
Incense-cedar										
N. Oregon Cascades	All	117	39.82180 (1.959605)	-0.027393 (0.004784)	1.403222 (0.205042)	14.100	0.922	54.0 (2.5-142.0)	23.6 (2.1-39.9)	709 (304-1213)
S. Oregon Cascades	All	472	43.447950 (3.197665)	-0.013141 (0.002080)	0.952702 (0.043032)	7.140	0.924	27.5 (2.5-126.5)	12.1 (1.8-33.8)	1124 (427-1767)
Klamath Mts.	All	959	45.132900 (1.449394)	-0.015037 (0.001174)	1.000513 (0.029251)	8.613	0.936	29.8 (2.5-150.4)	13.6 (1.8-39.9)	706 (243-1341)
Port-Orford-cedar										
S. Oregon Coastal	All	130	57.68749	-0.017268	1.269867	25.125	0.893	64.7	31.8	994

Table 1. continued.

Species/ecoregion (m)	Site class	N	Regression coefficients (SE)[1] b$_0$	b$_1$	b$_2$	Mean square error	Adj. COD[2]	Mean (range) of DBH (cm)	Height (m)	Elevation
Conifers			(4.37876)	(0.003857)	(0.199905)			(2.5-168.4)	(3.0-55.2)	(509-1441)
Sitka spruce										
N. Oregon Coastal	1-2	423	65.27757 (4.96537)	-0.012361 (0.002848)	0.967921 (0.117832)	71.248	0.711	101.7 (2.7-260.5)	44.9 (2.0-70.1)	190 (30-640)
	3-5	253	56.68058 (1.10925)	-0.036481 (0.002573)	1.952726 (0.159429)	38.645	0.599	62.0 (2.7-231.1)	42.9 (2.0-64.5)	121 (30-853)
Jeffrey pine										
Klamath Mts.	All	149	43.23946 (6.67237)	-0.016477 (0.005140)	1.135781 (0.127676)	16.110	0.788	52.3 (2.8-108.2)	22.1 (2.1-39.6)	1007 (365-1965)
Sugar pine										
N. Oregon Cascades	All	127	59.77862 (6.23717)	-0.014655 (0.005745)	1.003985 (0.274944)	34.527	0.723	91.1 (3.6-155.5)	42.3 (2.4-59.7)	944 (304-1508
)										
S. Oregon Cascades	All	209	56.30029 (5.52069)	-0.012054 (0.002896)	1.027054 (0.130860)	29.879	0.863	76.4 (2.8-188.5)	36.6 (2.1-59.7)	1155 (499-1737)
Klamath Mts.	All	778	58.41553 (1.59306)	-0.013899 (0.001208)	1.024711 (0.051583)	20.034	0.910	75.0 (2.5-172.2)	33.8 (2.1-58.2)	912 (213-1703
)										
Western white pine										
Oregon Cascades (N. and S.)	All	236	57.76184 (3.65712)	-0.021470 (0.003990)	1.193010 (0.139340)	35.174	0.730	64.3 (3.3-142.2)	38.8 (2.4-61.0)	1417 (427-1447)
Ponderosa pine										
S. Oregon Cascades	All	1198	57.44885 (3.43104)	-0.012595 (0.001450)	1.109767 (0.040767)	13.193	0.877	29.1 (2.5-134.9)	14.5 (1.8-44.8)	1302 (274-1920)
Eastern foothills	All	1018	44.60542 (1.49539)	-0.024401 (0.002145)	1.219469 (0.059603)	12.333	0.849	43.3 (3.8-117.7)	24.7 (1.7-50.0)	813 (500-1493)

Table 1. continued.

Species/ecoregion (m)	Site class	N	Regression coefficients (SE)[1] b$_0$	b$_1$	b$_2$	Mean square error	Adj. COD[2]	Mean (range) of DBH (cm)	Height (m)	Elevation
Klamath Mts.	All	823	56.64259 (1.82775)	-0.016824 (0.001416)	1.155625 (0.049505)	17.632	0.923	47.5 (2.5-147.6)	25.1 (2.1-52.4)	884 (91-1831)
Douglas-fir ≤1000 m										
N. Oregon Cascades	1-2	4070	84.92352 (1.76900)	-0.010853 (0.000450)	0.936797 (0.009731)	31.847	0.908	46.6 (2.5-231.1)	31.8 (2.4-93.0)	513 (122-999)
	3	4500	76.85529 (1.17403)	-0.011561 (0.000402)	0.928818 (0.008958)	36.944	0.916	64.9 (2.5-228.6)	36.8 (2.1-94.8)	659 (1 3 0-1000)
	4-5	1782	61.63578 (1.19259)	-0.014693 (0.000723)	0.927064 (0.015308)	34.635	0.878	64.9 (2.5-246.4)	34.4 (2.1-84.9)	741 (1 3 0-1000)
S. Oregon Cascades	1-2	80	87.97810 (5.56708)	-0.009452 (0.002881)	0.880569 (0.073318)	29.462	0.916	73.4 (3.6-163.3)	44.1 (4.0-77.7)	851 (499-993)
	3-5	1298	71.84386 (2.36891)	-0.010576 (0.001087)	0.894860 (0.036989)	25.936	0.913	55.6 (2.5-192.0)	30.9 (2.1-70.1)	822 (146-996)
N. Oregon Coastal	1-2	8332	85.60765 (1.16569)	-0.010226 (0.000288)	0.934949 (0.006692)	32.648	0.921	48.6 (2.5-231.1)	30.7 (1.8-91.1)	384 (50-853)
	3	6071	76.47562 (1.21720)	-0.010872 (0.000371)	0.915672 (0.007804)	28.823	0.923	50.5 (2.5-246.0)	29.7 (1.3-90.2)	406 (40-987)
	4-5	1238	70.32194 (2.30980)	-0.009887 (0.000847)	0.853661 (0.024403)	24.514	0.904	41.4 (2.5-244.5)	23.8 (2.1-73.1)	505 (40-975)
S. Oregon Coastal	1-2	222	72.49809 (3.25700)	-0.014119 (0.001823)	1.085139 (0.075401)	40.308	0.821	98.8 (2.5-204.5)	50.1 (3.0-82.0)	434 (39-868)
	3	572	74.38152 (3.44987)	-0.009502 (0.001082)	0.901194 (0.030050)	30.483	0.910	78.6 (2.5-231.1)	37.2 (3.0-72.5)	530 (61-999)
	4-5	306	64.47390 (6.24304)	-0.008325 (0.002108)	0.771734 (0.056540)	23.677	0.907	64.2 (2.5-179.2)	28.8 (2.7-63.4)	632 (115-981)

Table 1. continued.

Species/ecoregion (m)	Site class	N	Regression coefficients (SE)[1] b$_0$	b$_1$	b$_2$	Mean square error	Adj. COD[2]	Mean (range) of DBH (cm)	Height (m)	Elevation
Klamath Mts.	1-2	1016	73.32803 (5.36939)	-0.012062 (0.000787)	0.951032 (0.013858)	26.086	0.931	43.7 (2.5-186.7)	26.5 (1.3-83.2)	688 (329-993)
	3	2570	67.31327 (1.07682)	-0.013093 (0.000498)	0.914498 (0.009457)	21.697	0.942	56.8 (2.5-216.7)	31.4 (2.1-75.6)	680 (213-999)
	4-5	5915	62.49299 (1.29826)	-0.010851 (0.000472)	0.824333 (0.006228)	14.772	0.936	34.9 (2.5-197.1)	20.1 (1.9-72.5)	658 (91-993)
Umpqua Valley	1-3	600	69.86649 (2.66466)	-0.011969 (0.001212)	0.911253 (0.032009)	16.187	0.942	36.7 (2.5-162.6)	23.0 (2.7-68.3)	365 (121-792)
	4-5	437	57.03480 (2.38718)	-0.015450 (0.001448)	0.943379 (0.022727)	13.252	0.949	38.8 (2.5-147.6)	22.1 (2.4-61.0)	445 (91-792)
Douglas-fir >1000 m										
N. Oregon Cascades	1-2	148	80.91850 (5.62301)	-0.012198 (0.002039)	1.085999 (0.075340)	16.506	0.963	91.6 (3.6-189.2)	48.9 (2.4-78.3)	1144 (1006-1874)
	3	1143	67.51043 (1.27398)	-0.015671 (0.000812)	1.128344 (0.028796)	41.700	0.859	88.7 (2.5-218.4)	44.5 (2.4-81.1)	1169 (1002-1707)
	4-5	1049	56.87761 (1.42565)	-0.016381 (0.001168)	1.068793 (0.035926)	47.481	0.787	83.1 (2.8-226.1)	37.6 (2.7-71.0)	1225 (1005-1865)
S. Oregon Cascades	1-2	405	76.57003 (5.17436)	-0.012764 (0.000475)	1.137673 (0.045628)	33.354	0.913	60.2 (2.5-192.3)	33.6 (2.7-81.1)	1199 (1005-1767)
	3	940	62.13790 (1.27499)	-0.016999 (0.000976)	1.073994 (0.031458)	31.498	0.862	75.2 (3.3-210.8)	39.5 (1.8-70.1)	1263 (1002-1737)

Table 1. continued.

Species/ecoregion (m)	Site class	N	Regression coefficients (SE)[1] b_0	b_1	b_2	Mean square error	Adj. COD[2]	Mean (range) of DBH (cm)	Height (m)	Elevation
S. Oregon Cascades	4-5	1021	64.85344	-0.010336	0.876014	20.881	0.902	47.4	25.0	1280
			(3.00066)	(0.000991)	(0.018673)			(2.5-173.0)	(1.8-61.2)	(1005-1920)
S. Oregon Coastal	3	92	64.46814	-0.012289	0.913189	26.957	0.660	85.5	42.3	1164
			(13.12033)	(0.008631)	(0.356824)			(39.4-147.3)	(23.8-60.7)	(1002-1627)
	4-5	71	55.15976	-0.013232	1.021243	52.630	0.533	83.7	35.0	1229
			(11.59724)	(0.008504)	(0.374013)			(24.1-170.7)	(13.7-58.5)	(1005-1584)
Klamath Mts.	1-2	321	70.27658	-0.012498	0.966682	27.655	0.912	64.4	34.8	1187
			(8.13985)	(0.002752)	(0.019092)			(3.1-206.3)	(3.4-78.3)	(1008-1658)
Klamath Mts.	3	748	64.82814	-0.012868	0.926170	20.387	0.898	80.7	39.9	1296
			(1.49842)	(0.000756)	(0.020175)			(2.5-214.6)	(2.4-66.8)	(1014-1831)
	4-5	1584	57.21674	-0.012738	0.916518	15.320	0.935	44.1	22.3	1186
			(1.60036)	(0.000761)	(0.012748)			(2.5-194.3)	(1.6-59.1)	(1005-1975)
Pacific yew										
All	All	79	18.93883	-0.029985	0.873014	2.987	0.876	19.2	8.0	714
			(3.65131)	(0.013795)	(0.104395)			(2.5-62.0)	(1.8-18.6)	(91-1158)
Western redcedar										
N. Oregon Cascades	1-3	544	56.91574	-0.012625	0.935899	28.097	0.877	47.7	23.5	576
			(3.20063)	(0.001910)	(0.057524)			(2.5-165.1)	(1.2-56.7)	(61-1201)
	4-5	180	53.00410	-0.014652	0.998083	18.061	0.905	44.4	22.5	706
			(4.86965)	(0.003376)	(0.096895)			(2.5-140.2)	(2.7-47.5)	(91-1252)
N. Oregon Coastal	All	582	55.19896	-0.012114	0.910763	20.512	0.907	48.0	22.2	316

Table 1. continued.

Species/ecoregion (m)	Site class	N	Regression coefficients (SE)[1] b_0	b_1	b_2	Mean square error	Adj. COD[2]	Mean (range) of DBH (cm)	Height (m)	Elevation
			(2.28690)	(0.001400)	(0.043191)			(2.5-192.8)	(2.4-54.9)	(24-883)
Western hemlock ≤1000 m										
N. Oregon Cascades	1-2	975	66.62968 (5.30705)	-0.011297 (0.001892)	0.852724 (0.033109)	19.183	0.879	27.8 (2.5-114.3)	19.8 (1.8-64.3)	618 (121-996)
	3	1006	63.13141 (2.04526)	-0.016323 (0.001270)	1.078909 (0.036233)	22.588	0.909	31.3 (2.5-131.8)	21.3 (1.8-70.2)	676 (91-999)
	4-5	522	57.47559 (2.03989)	-0.016773 (0.001507)	1.028543 (0.039017)	20.492	0.912	31.7 (2.5-125.7)	20.0 (1.4-56.7)	796 (91-975)
S. Oregon Cascades	All	82	63.83492 (5.49703)	-0.017851 (0.003523)	1.143131 (0.100353)	24.300	0.837	40.7 (3.1-89.7)	27.5 (2.7-55.5)	745 (427-987)
N. Oregon Coastal	1-2	3152	60.87614 (1.38821)	-0.021948 (0.001062)	1.078265 (0.017865)	30.378	0.863	37.8 (2.5-171.5)	29.8 (2.1-78.4)	249 (30-950)
	3	935	61.56806 (1.78611)	-0.017278 (0.001359)	1.072261 (0.040181)	21.260	0.929	41.8 (2.5-169.1)	25.8 (1.8-59.7)	415 (9-885)
S. Oregon Coastal	All	76	65.81506 (10.60141)	-0.013714 (0.004299)	1.027756 (0.092823)	21.364	0.894	48.4 (2.5-132.6)	29.1 (3.4-58.8)	405 (91-768)
Klamath Mts.	All	117	61.42714 (6.35618)	-0.016013 (0.003738)	1.063541 (0.095756)	16.498	0.911	24.7 (2.8-95.5)	16.5 (1.8-51.2)	655 (243-993)
Western hemlock >1000 m										

Table 1. continued.

Species/ecoregion (m	Site class	N	Regression coefficients (SE)[1] b_0	b_1	b_2	Mean square error	Adj. COD^2	Mean (range) of DBH (cm)	Height (m)	Elevation
N. Oregon Cascades	3	284	57.15919 (1.98512)	-0.023814 (0.002424)	1.562296 (0.127342)	21.960	0.923	48.1 (2.5-155.5)	27.4 (2.0-60.4)	1166 (1002-1557)
	4-5	335	60.53637 (3.41548)	-0.015993 (0.002236)	1.087962 (0.067720)	17.930	0.930	39.2 (2.5-130.0)	23.0 (1.8-68.2)	1146 (1005-1517)
S. Oregon Cascades	All	134	63.62065 (9.09872)	-0.016411 (0.005381)	1.182677 (0.183732)	21.231	0.863	46.1 (3.3-120.1)	28.5 (3.7-57.3)	1167 (1002-1517)
Mountain hemlock										
N. Oregon Cascades	3-5	647	38.37431 (0.99208)	-0.031533 (0.002237)	1.509506 (0.074758)	11.039	0.861	49.0 (4.9-111.8)	24.7 (2.3-40.0)	1270 (1000-1871)
S. Oregon Cascades	All	153	37.90131 (3.27879)	-0.029794 (0.008297)	1.372206 (0.288093)	20.795	0.704	51.3 (13.5-115.3)	25.2 (5.8-39.6)	1664 (987-1999)
					Hardwoods					
Bigleaf maple										
N. Oregon Cascades	All	571	30.41311 (1.61544)	-0.034245 (0.006400)	0.682100 (0.046909)	21.397	0.610	29.6 (2.5-189.5)	20.3 (1.5-52.4)	417 (61-1158)
N. Oregon Coastal	All	627	30.17141 (1.30188)	-0.037380 (0.005200)	0.812910 (0.047520)	18.313	0.690	28.7 (2.5-109.0)	19.1 (3.0-38.4)	305 (30-914)
Klamath Mts.	All	138	25.01949 (3.49016)	-0.034669 (0.015586)	0.722190 (0.110383)	20.244	0.619	24.2 (2.8-115.1)	14.2 (1.4-32.0)	497 (121-1036)
Red alder										

Table 1. continued.

Species/ecoregion (m)	Site class	N	Regression coefficients (SE)[1] b $_0$	b $_1$	b $_2$	Mean square error	Adj. COD[2]	Mean (range) of DBH (cm)	Height (m)	Elevation
					Hardwoods					
N. Oregon Cascades	All	599	35.55002	-0.028323	0.796024	15.760	0.731	25.2	19.4	456
			(2.99817)	(0.006062)	(0.045629)			(2.5-67.3)	(3.0-38.1)	(61-914)
N. Oregon Coastal	1-3	1641	37.36855	-0.023400	0.761640	19.088	0.750	23.4	17.5	334
			(2.77986)	(0.004250)	(0.031550)			(2.5-93.7)	(1.4-49.0)	(24-914)
	4-5	253	34.91167	-0.027180	0.724150	20.758	0.650	32.6	22.1	325
			(3.08113)	(0.007630)	(0.070710)			(2.8-95.8)	(4.3-48.2)	(30-701)
Klamath Mts.	All	215	37.65195	-0.017400	0.674880	10.673	0.780	18.3	14.2	530
			(9.35910)	(0.010000)	(0.059900)			(2.5-71.4)	(3.0-32.6)	(152-945)
Pacific madrone										
N. Oregon Coastal	All	278	25.08500	-0.032926	0.730353	8.453	0.780	20.7	13.0	423
			(1.96024)	(0.007412)	(0.048911)			(2.5-107.2)	(3.4-35.1)	(61-671)
S. Oregon Cascades	All	258	24.21249	-0.033914	0.891708	16.134	0.597	26.5	13.9	882
			(2.83794)	(0.010837)	(0.105960)			(2.5-77.0)	(1.8-41.5)	(1 5 2-
1341)										
Klamath Mts.	All	2200	22.56015	-0.036086	0.842882	9.839	0.718	21.1	11.6	707
			(0.74301)	(0.003168)	(0.024876)			(2.5-126.0)	(1.4-37.5)	(3 0 4-
1341)										
Umpqua Valley	All	132	24.37220	-0.031771	0.861834	9.334	0.745	26.4	13.3	391
			(2.82143)	(0.010070)	(0.102873)			(2.5-106.2)	(1.4-28.7)	(152-701)
Chinkapin										

Table 1. continued.

Species/ecoregion	Site class	N	Regression coefficients (SE)[1] b_0	b_1	b_2	Mean square error	Adj. COD[2]	Mean (range) of DBH (cm)	Height (m)	Elevation (m)
Hardwoods										
N. Oregon Coastal	All	146	40.66479 (8.96304)	-0.017775 (0.008156)	0.873626 (0.093607)	7.170	0.865	17.5 (2.5-65.5)	11.7 (2.7-33.5)	393 (152-762)
Klamath Mts.	1-3	255	38.42058 (15.36969)	-0.017750 (0.012083)	0.860279 (0.076398)	5.547	0.799	13.0 (2.5-63.0)	9.3 (1.4-23.8)	795 (335-1219)
	4-5	560	33.17171 (7.50771)	-0.018992 (0.007225)	0.887864 (0.045668)	4.142	0.817	10.3 (2.5-75.7)	6.6 (1.4-21.9)	868 (213-1493)

Garman, S.L., S.A. Acker, J.L. Ohmann, and T.A. Spies, 1995. ASYMPTOTIC HEIGHT-DIAMETER EQUATIONS FOR TWENTY-FOUR TREE SPECIES IN WESTERN OREGON. Forest Research Laboratory, Oregon State University, Corvallis. Research Contribution 10. 22 p.

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