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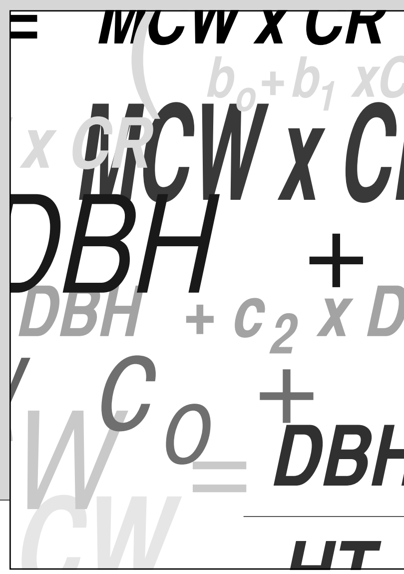
Equations for Predicting the Largest Crown Width of Stand-Grown Trees in Western Oregon

by

David W. Hann



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Abbreviations

CL	Crown length
CR	Crown ratio
DBH	Diameter at breast height
HT	Total height
LCW	Largest crown width of a stand-grown tree of a given species.
MCW	Maximum crown width of an open-grown tree of a given species.

Introduction

Estimates of crown width of stand-grown trees at various heights from crown base to tip are crucial for operating the growth-and-yield model ORGANON (Hann *et al*. 1995) and the stand-visualization model VIZ4ST (Hanus and Hann 1997). In ORGANON, the estimates are used to compute crown closure of the stand at the tip of each tree. That variable is then used to predict the rate of height growth (Hann and Ritchie 1988; Ritchie and Hann 1990) and the probability of death (Hann and Wang 1990) of the tree. In VIZ4ST, crown-width equations are used for arranging trees on the ground (Hanus *et al*. 1998) and for characterizing the size and shape of each tree crown drawn to the personal-computer screen (Hanus and Hann, Visualization of Forest Stand Structures, in review).

Much of the modeling of crown width in the western United States and western Canada has focused on equations for predicting the greatest horizontal extension of the crown of both open- and stand-grown trees. For open-grown trees, this measurement has been called "maximum crown width" (MCW), and it is commonly used to compute the crown competition factor (Krajicek *et al*. 1961) for a stand. To date, MCW equations have been developed for many Northwest species: Douglas-fir and lodgepole pine in British Columbia (Smith and Bailey 1964), 22 conifer and hardwood species in British Columbia (Smith 1966), Douglas-fir in northwest Oregon and British Columbia (Arney 1973), 15 conifer and hardwood species in southwest Oregon (Paine and Hann 1982), and western hemlock and Sitka spruce in southeast Alaska and British Columbia (Farr *et al*. 1989). Usually, MCW is predicted as a function of diameter at breast height (DBH) alone, although Smith and Bailey (1964) explored the utility of adding total height as an independent variable.

The greatest horizontal extension of the crown of stand-grown trees is often less than the maximum extension of open-grown trees. The crown width of interest here is the largest crown width of a given tree within a stand; therefore, that measurement will be called "largest crown width" (LCW) in order to differentiate it from MCW. Largest-crown-width equations have been developed for Douglas-fir and lodgepole pine in British Columbia (Smith and Bailey 1964) and for many other conifer and hardwood species in the Northwest: 19 in British Columbia (Smith 1966), 11 in northern Idaho and western Montana (Moeur 1981, Ritchie and Hann 1985), 15 in northern California (Warbington and Levitan 1993), and 5 species or species groups in southwest Oregon (Dubrasich *et al*. 1997). Smith (1966) and Warbington and Levitan (1993) predicted LCW as a function of DBH alone; Smith and Bailey (1964) found that adding total height to the equation explained significantly more variation. Moeur (1981) found that LCW was a function not only of DBH and total height but also of crown length and stand basal area; therefore, an estimator of MCW can be formed with the Moeur (1981) equations when crown length equals total height, although it is unknown if the resulting estimators are reasonable.

The equations of Ritchie and Hann (1985) and Dubrasich *et al*. (1997) guarantee a reasonable estimator of MCW when crown length equals total height, or when crown ratio (CR) is one, by incorporating the MCW predicted from previously developed equations in the LCW equation. Ritchie and Hann (1985) used the following simple model form:

$$LCW = MCW \times CR^{b_1} \quad [1]$$

Dubrasich *et al*. (1997) found that the exponent of CR was a function of DBH, total height (HT), and crown length (CL). Their model form was:

$$LCW = MCW \times CR^{\left(b_o + b_1 x CL + b_2 x \frac{DBH}{HT}\right)} \quad [2]$$

The equations of Dubrasich *et al*. (1997) were developed with data from five older stands in southwest Oregon only. The objective of this study, therefore, was to develop LCW equations for 15 major species of western Oregon (Table 1) from existing MCW equations and a more extensive data set. The resulting LCW equations can then be combined with crown profile equations, such as those of Ritchie and Hann (1985) or Mortzheim (1996), to predict width at any point in the crown (Dubrasich *et al*. 1997).

Table 1. Common and scientific names of species covered by the data sets used for determining largest crown width.

Common name	Scientific name
Softwoods	
Douglas-fir	Pseudotsuga menziesii (Mirb.) Franco
Grand fir	Abies grandis (Dougl. ex D. Don) Lindl.
Incense-cedar	Calocedrus decurrens (Torr.) Florin.
Ponderosa pine	Pinus ponderosa Laws.
Sugar pine	Pinus lambertiana Dougl.
Western hemlock	Tsuga heterophylla (Raf.) Sarg.
White fir	Abies concolor (Gord. & Glend.) Lindl. ex Hildebr.
Hardwoods	
Bigleaf maple	Acer macrophyllum Pursh
California black oak	Quercus kelloggii Newb.
Canyon live oak	Quercus chrysolepis Liebm.
Golden chinkapin	Castanopsis chrysophylla (Dougl.) A. DC.
Oregon white oak	Quercus garryana Dougl. ex Hook.
Pacific madrone	Arbutus menziesii Pursh
Red alder	Alnus rubra Bong.
Tanoak	Lithocarpus densiflorus (Hook. & Arn.) Rehd.

Data Collection

The southwest-Oregon data for this study were collected in 1983 as part of the Forestry Intensified Research (FIR) Growth and Yield project, and in 1992 through 1996 as part of the Northern Spotted Owl Habitat project. The northwest-Oregon data were collected in 1994 and 1995 as part of the ongoing inventory of the 11,648-acre McDonald-Dunn Research Forest of the College of Forestry, Oregon State University.

Study Sites

The southwest-Oregon area extends from near the California border on the south to Cow Creek drainage on the north, and from the crest of the Cascade Mountains on the east to approximately 15 miles west of Glendale (Figure 1). Elevation ranges from 900 to 5,100 feet, January mean minimum temperature from 23° to 32°F, and July mean maximum temperature from 79° to 90°F. Annual precipitation in the area varies from 29 to 83 inches, with less than 10% of the total falling during June, July, and August. Temporary plots were established within 319 stands selected from the area according to the following standard criteria:

- uniform structure such that species mix, competitive structure, and resulting management practices were essentially unchanged throughout;
- common bedrock, landform, and soil series; and similar aspect, slope, and elevation;
- no silvicultural treatment within the preceding 5 years;
- preponderance of stand Douglas-fir, white fir, grand fir, ponderosa pine, sugar pine, incense-cedar, or a mixture of these.

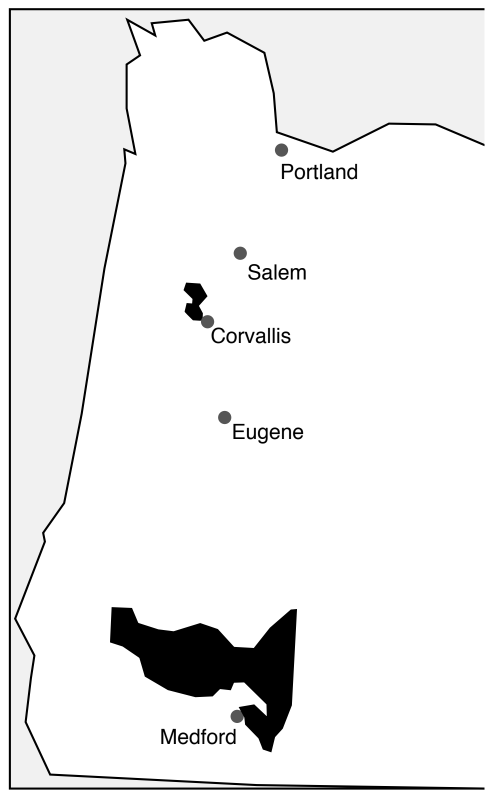

Figure 1. Location of the study areas in southwest and northwest Oregon.

Within each selected stand, a randomly placed cluster of from 4 to 10 nested variable-radius and fixed-area subplots was installed for measuring attributes of all trees taller than 6 inches. Variable-radius subplots were established with basal-area factors of 60 for trees with 36.1-inch or greater DBH and 20 for trees with 8.1- to 36-inch DBH. Circular fixed-area subplots were established with a radius of 15.56 feet for trees with 4.1- to 8-inch DBH and a radius of 7.78 feet for trees with 4-inch DBH or less.

The northwest-Oregon site is north of the city of Corvallis in the western Willamette Valley (Figure 1, p.5). Elevation of the Research Forest ranges from 30 to 2,000 feet. In nearby Corvallis (elevation 245 feet), January mean minimum temperature averages 33°F, July mean maximum temperature averages 80°F, and annual precipitation averages 43 inches. Crown-width measurements were collected on 32 stands as part of a re-measurement of inventory data.

A grid of nested variable-radius and fixed-area subplots had been previously installed across each stand for measuring attributes of all trees taller than 6 inches. Average sampling intensity was one nested plot per 2 acres. A variable-radius subplot with a basal-area factor of 20 was used for trees with 8.1-inch or greater DBH. Circular fixed-area subplots were established with a radius of 15.56 feet for trees with 4.1- to 8-inch DBH and a radius of 7.78 feet for trees with 4-inch DBH or less.

Measurement Procedures

Tree measurements taken on each sample tree on both sites were DBH (in.), total height (ft), and height to live-crown base (ft). Four crown radii in feet were also measured on a subsample of undamaged trees. For these, one azimuth was randomly selected through the center of the tree and a second was computed at 90° to the first. Two horizontal crown radii were then measured along each azimuth, each radius beginning at the center of the tree bole and ending at the greatest horizontal extension of the crown from the bole. The radius was measured directly on those branches that were within 10 feet of the ground, and otherwise by vertical sighting with a clinometer in order to locate the point of branch-tip projection.

The measurements were edited in the field, transported to the research or inventory office, and further edited before being loaded onto appropriate computer data bases. When the data were extracted for this study, the two opposite radii were added to form two measures of largest crown diameter. The quadratic average of these two measurements was then computed by using the square root of their product for estimating tree LCW. Finally, crown length was computed by subtracting height to crown base from total height, and crown ratio was computed by dividing crown length by total height. Table 2 summarizes the resulting data sets.

Data Analysis

The first step of the analysis was selection of an appropriate MCW equation for each species. Equations of Paine and Hann (1982) were used without geographic position for southwest-Oregon Douglas-fir and other southwest-Oregon species that those equations covered. Application of an equation for northwest-Oregon Douglas-fir (Arney 1973) could not be used for this analysis because it predicts a declining MCW when DBH exceeds 54.2. The LCW data set contains trees with DBH up to 81.0 inches. The Paine and Hann (1982) MCW equation incorporating geographic position as an independent variable was therefore used for northwest Oregon

Table 2. Data sets for largest crown width (LCW).

Species	Number	LCW (ft)		Crown ratio		Diameter at breast height (in.)		Total height (ft)		Crown length (ft)		DBH:total height	
	of trees	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Softwoods													
Douglas-fir													
Northwest Oregon	925	32.4	5.9-66.0	0.449	0.050-0.926	26.4	2.8-81.0	127.4	19.5-210.7	56.4	1.8-182.3	0.200	0.068-0.421
Southwest Oregon	2045	24.3	3.2-63.3	0.442	0.102-0.933	22.1	0.4-81.3	107.4	6.9-244.2	46.2	1.7-163.0	0.187	0.056-0.455
Incense-cedar	263	17.7	3.5-39.2	0.463	0.104-0.870	19.1	0.7-68.8	71.5	7.0-183.7	33.6	1.1-96.9	0.239	0.083-0.459
Ponderosa pine	130	17.4	2.6-39.2	0.409	0.150-0.789	18.1	0.9-48.2	94.2	11.1-203.1	38.2	3.9-102.1	0.179	0.080-0.346
Sugar pine	101	23.5	7.0-57.4	0.479	0.241-0.796	23.5	1.9-69.7	97.9	15.6-167.6	45.7	8.5-87.2	0.227	0.113-0.426
True firs	464	19.3	2.1-36.2	0.495	0.101-0.917	15.1	0.3-50.2	82.8	6.5-220.7	41.8	1.1-149.6	0.175	0.045-0.326
Western hemlock	32	25.6	4.9-55.8	0.706	0.343-0.870	13.7	0.8-30.8	75.5	11.0-155.8	55.0	5.8-129.1	0.176	0.073-0.298
Hardwoods													
Bigleaf maple	71	24.0	3.0-67.0	0.485	0.165-0.804	11.6	0.7-31.3	67.2	9.0-143.8	32.4	4.4-98.4	0.163	0.040-0.358
California black oak	53	18.5	2.1-41.3	0.323	0.135-0.606	13.3	0.6-34.6	50.7	9.5 -87.9	16.5	4.5-48.7	0.239	0.063-0.655
Canyon live oak	35	12.2	2.7-35.9	0.404	0.090-0.740	6.3	1.3-22.6	31.0	10.8 -56.2	12.2	3.5-35.3	0.197	0.100-0.402
Golden chinkapin	77	11.9	2.7-24.2	0.433	0.178-0.813	8.3	0.5-21.1	43.4	8.0 -86.5	17.6	2.8-63.3	0.189	0.057-0.376
Oregon white oak	11	12.3	4.4-24.1	0.296	0.124-0.456	9.3	1.2-16.5	51.0	11.5 -94.7	16.3	3.2-38.5	0.178	0.104-0.251
Pacific madrone	262	14.4	3.1-52.3	0.331	0.092-0.748	10.6	1.5-32.5	51.9	13.2-103.1	17.1	3.4-52.1	0.201	0.086-0.465
Red alder	16	18.3	2.6-38.5	0.458	0.214-0.741	9.6	0.7-17.4	63.4	12.6 -95.3	28.6	2.7-49.1	0.139	0.056-0.220
Tanoak	60	15.5	3.9-38.5	0.495	0.153-0.855	8.4	0.8-29.9	42.7	9.7-100.7	20.5	4.2- 50.6	0.184	0.082-0.351

Douglas-fir. Position variables were set to values characterizing the northern edge of the 1982 study area. The resulting MCW predictions were close to predictions by Arney (1973), ±5.5% for trees with 0- to 35-inch DBH; however, the equation peaked at 81.5 inches instead of 54.2 inches.

Because no MCW equations are provided in Paine and Hann (1982) for red alder, bigleaf maple, or canyon live oak, other published MCW equations were examined for applicability to those species. The equation of Smith (1966) was selected for red alder. No equations were found for the other two species; therefore, predictions from other MCW equations for evergreen hardwoods in Paine and Hann (1982) were compared to LCW values for long-crowned canyon live oaks, and the tanoak MCW equation was chosen to characterize that species. Similarly, predictions from MCW equations for sugar and red maple (Ek 1974) were compared to LCW values for long-crowned bigleaf maple, and the red maple equation was chosen as a plausible estimator for bigleaf maple.

The general model form for all of the MCW equations used in this study was:

$$MCW = c_o + c_1 \ x \ DBH + c_2 \ x \ DBH^2 \qquad \textbf{[3]}$$

The species-specific parameters used for Equation [3] in this analysis are given in Table 3.

Equation [2] (p.4) was then fit to the data by means of weighted, nonlinear regression (weight 1.0/MCW²). Regression coefficients for the equation were examined with a t-test for significant difference (p =

Table 3. Previously published parameter estimates for Equation [3] and their sources.[1]

Species	c_0	c_1	c_2	Source
Softwoods				
Douglas-fir				
Northwest Oregon	4.6198	1.8426	-0.011311	Paine and Hann (1982)
Southwest Oregon	4.6366	1.6078	-0.0096250	Paine and Hann (1982)
Incense-cedar	3.2837	1.2031	-0.0071858	Paine and Hann (1982)
Ponderosa pine	3.4835	1.3430	-0.0082544	Paine and Hann (1982)
Sugar pine	4.6601	1.0702	0.0	Paine and Hann (1982)
True firs	6.1880	1.0069	0.0	Paine and Hann (1982)
Western hemlock	4.5652	1.4147	0.0	Paine and Hann (1982)
Hardwoods				
Bigleaf maple	4.0953	2.3849	-0.011630	Ek (1974)
California black oak	3.3625	2.0303	-0.0073307	Paine and Hann (1982)
Canyon live oak	4.4443	1.7040	0.0	Paine and Hann (1982)
Golden chinkapin	2.9794	1.5512	-0.014161	Paine and Hann (1982)
Oregon white oak	3.0786	1.9242	0.0	Paine and Hann (1982)
Pacific madrone	3.4299	1.3532	0.0	Paine and Hann (1982)
Red alder	8.0	1.53	0.0	Smith (1966)
Tanoak	4.4443	1.7040	0.0	Paine and Hann (1982)

[1]Fit with diameter at breast height in inches and height in feet.

0.05) from zero. Weighted residuals were plotted across the predicted, weighted LCW to check effectiveness of the weighting scheme, and across crown ratio, crown length, and DBH:total height for adequacy of fit to the data.

Results and Discussion

Table 4 (p.10) presents the regression coefficients, the standard error of each, the weighted mean square error, and the unweighted adjusted coefficient of determination for Equation [2] (p.4). Graphs of the weighted residuals across the predicted, weighted LCW and across crown ratio, crown length, and DBH:total height indicated that the weighting scheme was successful at homogenizing variance (Figure 2, p.11), and the model form adequately characterized the relationship between LCW and the predictor variables (Figure 3, p.12).

The value of the exponent of crown ratio in Equation [2] can have a strong effect upon the predicted LCW. An exponent of one indicates a conic relationship in which LCW decreases linearly from MCW to zero as crown ratio decreases from one to zero; an exponent of zero indicates a cylindrical relationship in which LCW is equal to MCW regardless of the position of the crown base; an exponent of one-half indicates a parabolic relationship in which LCW remains close to MCW for long-crowned trees but quickly moves to zero for short-crowned trees; and a negative exponent will cause LCW to exceed MCW.

In the equations for Douglas-fir, white and grand firs, sugar pine, incense-cedar, Pacific madrone, tanoak, and canyon live oak, crown length was significant. The ratio DBH:total height was significant for Douglas-fir, sugar pine, incense-cedar, golden chinkapin, California black oak, and bigleaf maple. Crown ratio with a constant exponent adequately characterized LCW for ponderosa pine, red alder, and Oregon white oak. No regression coefficients were significant for western hemlock, indicating a cylindrical relationship between LCW and MCW.

With a given crown ratio, an increase in crown length in Equation [2] causes a decrease in the predicted LCW. The greater the crown length, the taller the tree, and therefore the greater the chance of crown damage due to abrasion from wind whipping (Oliver and Larson 1996). Also, with a given crown ratio, an increase in DBH:total height causes a decrease in LCW. Oliver and Larson (1966) found that trees under competition stress allocate more photosynthate production to height growth than to diameter growth; therefore, a large value for DBH:total height will indicate a dominant tree in the overstory and a small value will indicate a suppressed tree in the understory. They also report that tree species such as Douglas-fir show high epinastic control in the overstory and weak epinastic control in the understory, the latter trees having a wide umbrella-like appearance.

Incense-cedar was the only species for which a significant, negative parameter (DBH:total height <0.2) caused LCW to exceed MCW. Exami-

Table 4. Parameter estimates, standard errors of the parameters (in parentheses), weighted mean square errors (MSE), and the unweighted, adjusted coefficients of determination (R^2) derived in this study for Equation [2].[1]

Species	b_0	b_1	b_2	Weighted MSE	Unweighted adjusted R^2
Softwoods					
Douglas-fir					
Northwest Oregon	0.0	0.004363240 (0.000368411)	0.6020020 (0.0947812)	0.0154799	0.7361
Southwest Oregon	0.0	0.003718340 (0.000268786)	0.8081210 (0.0625169)	0.0195135	0.8303
Incense-cedar	-0.2513890 (0.0395174)	0.006925120 (0.000886226)	0.985922 (0.230431)	0.0251997	0.8655
Ponderosa pine	0.3555320 (0.0188240)	0.0	0.0	0.0204343	0.8841
Sugar pine	0.0	0.00339675 (0.00131841)	0.532418 (0.250421)	0.0180967	0.8583
True firs	0.0	0.003084020 (0.000361507)	0.0	0.0451919	0.6131
Western hemlock	0.0	0.0	0.0		0.8669
Hardwoods					
Bigleaf maple	0.0	0.0	1.470180 (0.212516)	0.0372958	0.7011
California black oak	0.0	0.0	1.271960 (0.132828)	0.0342454	0.6874
Canyon live oak	0.0	0.02076760 (0.00492855)	0.0	0.0579886	0.6326
Golden chinkapin	0.0	0.0	1.161440 (0.174596)	0.0446103	0.6946
Oregon white oak	0.3648110 (0.0892288)	0.0	0.0	0.0543478	0.4946
Pacific madrone	0.1186210 (0.0279632)	0.00384872 (0.00189222)	0.0	0.0439045	0.6775
Red alder	0.3227140 (0.0815486)	0.0	0.0	0.0448033	0.7332
Tanoak	0.0	0.01119720 (0.00219128)	0.0	0.0450964	0.7612

[1]Fit with diameter at breast height in inches and height in feet.

nation of alternative formulations of Equation [2] (p.4) that forced LCW to be less than or equal to MCW showed substantial loss of predictive capability.

That the LCW of western hemlock and incense cedar may equal or exceed MCW may be due to a problem in either the MCW equation or the LCW sample—or it may represent real behavior. Results of an examination of the first two possibilities appear to rule them out and support the latter. First, the MCW equation for western hemlock (Paine and Hann

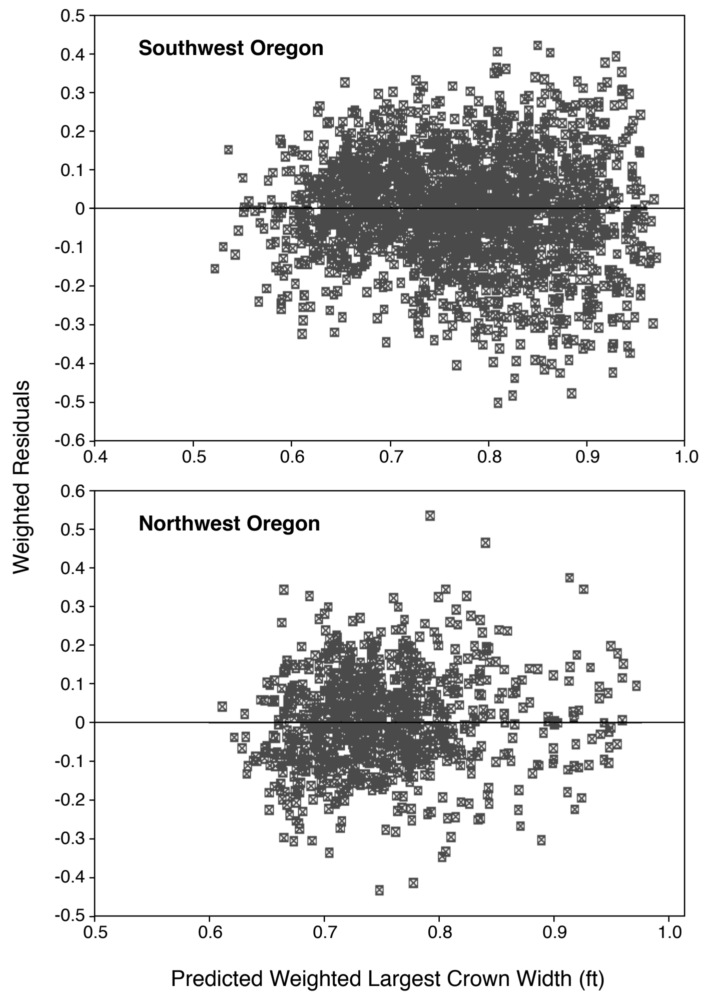

Figure 2. Weighted residuals for data-sets for Douglas-fir in southwest and northwest Oregon plotted across the predicted, weighted, largest crown width.

1982) was based on 62 trees in southwest Oregon with a DBH ranging from 0.6 to 23.8 inches. Because of the narrow geographic range, that equation was compared to ones for western hemlock in British Columbia (Smith 1966) and southeast Alaska (Farr *et al*. 1989). The very close predictions that were found do not suggest an equation problem. The MCW equation for incense-cedar (Paine and Hann 1982) was based on 111 trees with a DBH range from 0.5 to 44.8 inches. Given the size and range of that sample and the simplicity of the broadly used MCW model form to which the data were fitted, it is again unlikely that the behavior is due to a problem with the equation.

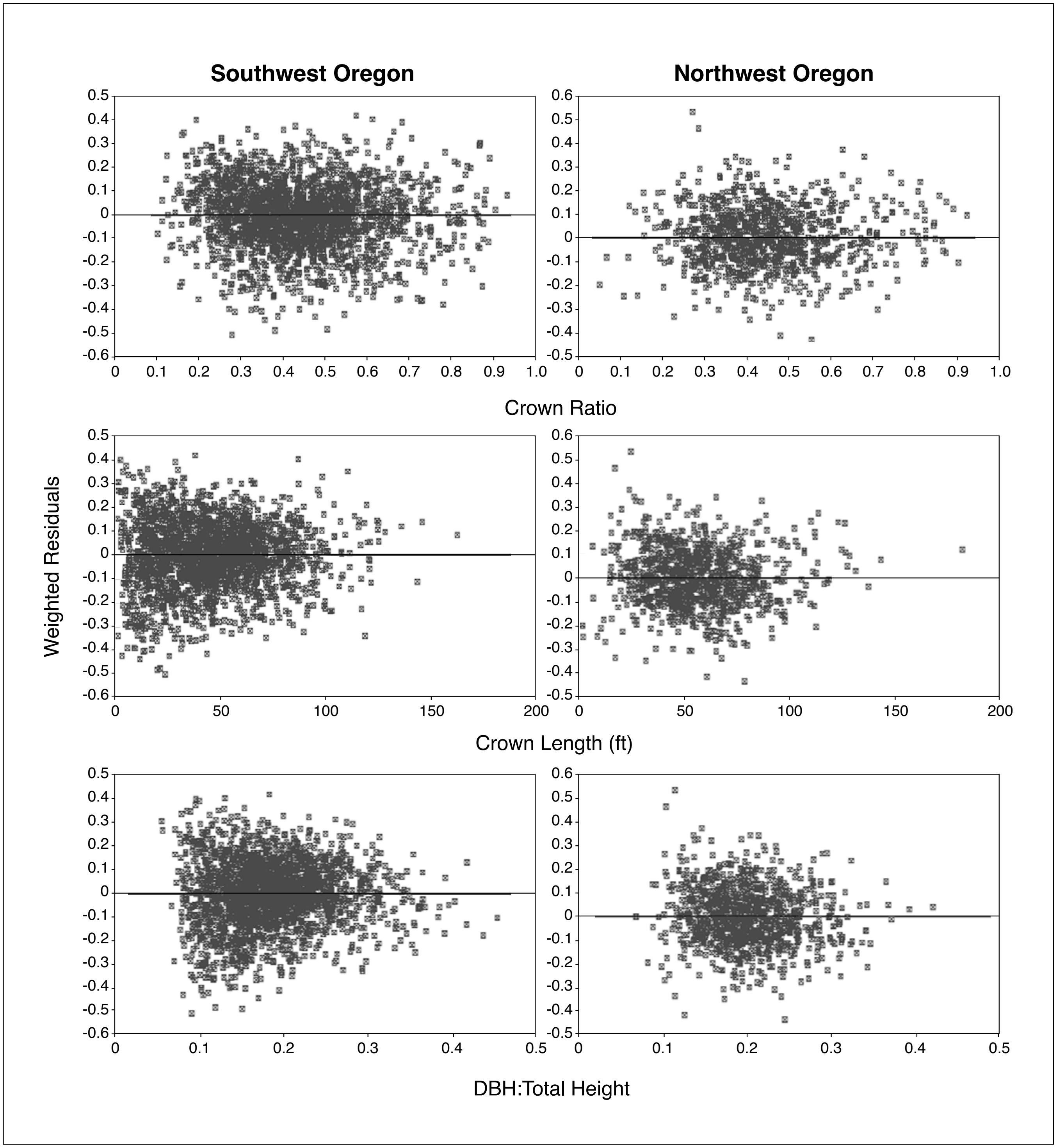

Figure 3. Weighted residuals for data-sets for Douglas-fir in southwest and northwest Oregon plotted across crown ratio, crown length, and the ratio of diameter at breast height (DBH) to total height.

Second, although the LCW data set for western hemlock consists of only 32 trees, the trees cover a wide range in attributes (Table 2, p.7). Crown-width data collected by Kershaw and Maguire (1996) for 18 unfertilized western hemlock trees at two locations in western Washington also show that LCW can equal or exceed predicted MCW. Examination of a subset of LCW data for 86 incense-cedar trees with DBH:total height <0.2 shows that DBH ranges from 0.7 to 18.3 inches, total height from 7.0 to 98.7 feet, and crown ratio from 10.4% to 82.8%. It is therefore unlikely that the representation of behavior of incense-cedar with DBH: total height >0.2 is due to a sampling fluke in the data set.

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