United States
Department of
Agriculture

Forest Service

Pacific Northwest
Forest and Range
Experiment Station

Research Paper
PNW- 281

March 1981

Predicting Crown Weight of Coast Douglas-fir and Western Hemlock

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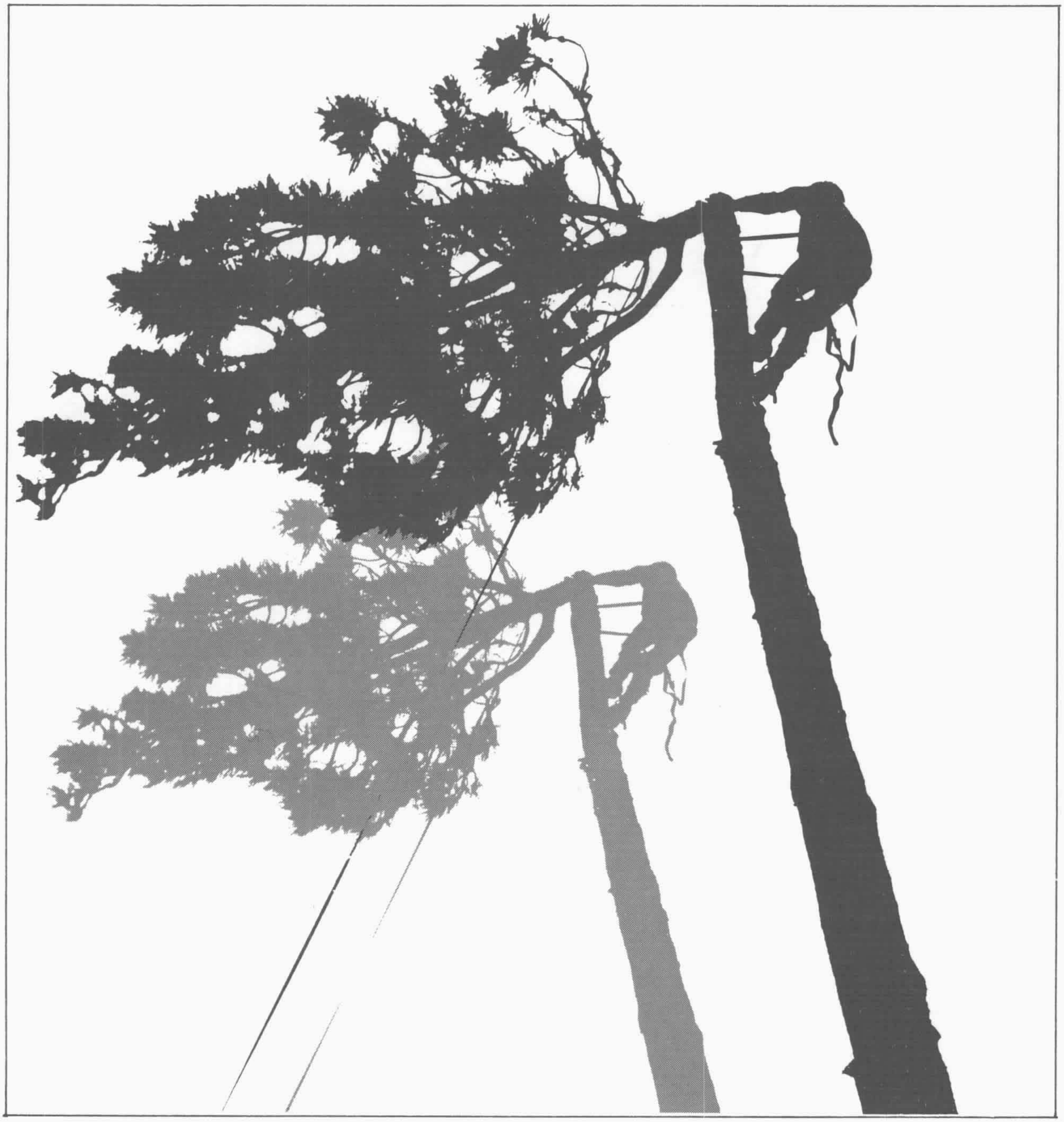

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Abstract

Snell, J. A. Kendall, and Brian F. Anholt.
1981. Predicting crown weight of coast Douglas-fir and western hemlock. USDA For. Serv. Res. Pap. PNW-281, 13 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Equations are presented for estimating weights of total crowns and crown components for Douglas-fir and western hemlock.

Keywords: Crown weights, biomass, residue weights, Douglas-fir, Pseudotsuga menziesii, western hemlock, Tsuga heterophylla.

Summary

Five large coast Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco var. menziesii) and three large western hemlock (Tsuga heterophylla (Raf.) Sarg.) were sampled to supplement existing data on crown weight and accumulative proportion equations for these species west of the summit of the Cascade Range in Oregon and Washington.

Existing data for the same species were categorized as coming from either east or west of the summit of the Cascade Range. Analysis of covariance was used to determine whether the crown weight slope coefficients developed from the east side data were significantly different from those developed from the west side data. No difference was found, and the sets of data were pooled and refitted to the same regression model used in the covariance analysis.

No difference was found between the slope coefficients for live crown weights when a transformation of d.b.h. was used as the single independent variable; but when a transformation of height was also included, a difference in slope coefficients was found. Also, a significant difference was found between the slope coefficients of dead branchwood weight.

Contents

Introduction

This publication provides regression equations that can be used to estimate weights of total crowns and crown components[1/] for coast Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*, up to 87-inch diameter at breast height (d.b.h.) and western hemlock, *Tsuga heterophylla* (Raf.) Sarg., up to 47-inch d.b.h. The equations were developed from data obtained from several sources: (1) Inland data--obtained from Brown (1978) who conducted an extensive study of the crown weights of 11 commercial conifers in western Montana and northern Idaho. He included much of Fahnestock's (1960) data that had been collected in the same geographic region and was compatible. (2) Coastal data--from Grier[2/] and Woodard (1974), collected from forested areas west of the summit of the Cascade Range. (3) Shelton data--obtained from eight large trees (five Douglas-fir and three western hemlock) in the Shelton Ranger District of the Olympic National Forest and sampled in conjuction with this study.

For ease of discussion, the above sets of data will be referred to in this paper as inland, coastal, or Shelton data sets.

1/Components are defined as needles and branchwood in four diameter categories: 0.0- to 0.24-inch, 0.25- to 0.99-inch, 1.0- to 2.99-inch, and 3-inch and greater.

2/Chuck Grier, University of Washington, Seattle. These data were a consolidation of data collected and used by Grier and his colleagues--Dice (1970), Emmingham (1974), Fujimori (1971), Fujimori et al. (1976), Grier and Logan (1977), Grier and Waring (1974), Heilman (1961), and Krumlik (1974).

Description of Data

The inland data were collected from two crown-class categories--dominant/codominant[3/] and intermediate/suppressed. The coastal data were collected in direct proportion to the frequency distribution of d.b.h. and tree height of sample stands. An exception was Woodard's (1974) data; these were collected by a method similar to that described for the inland data, except that no data were collected for intermediate/suppressed trees.

Since the inland data were collected in an environment notably different from that where the coastal and Shelton data were collected, it did not seem prudent to pool data sets without first finding out whether their respective slope coefficients were significantly different. This was done by using analysis of covariance; and when no significant difference was found between slope coefficients, the data sets were pooled.

Before an analysis of covariance could be done, however, the inland data had to be adjusted to represent the typical frequency distribution of d.b.h. and tree height found in sample stands. This was accomplished by using a mix of 35-percent dominant/codominant and 65-percent intermediate/suppressed crown class (Reukema and Bruce 1977). This mix was used as weighting factors during regression and analysis of covariance.

3/For definitions of the categories, see Ford-Robertson (1971).

Woodard's (1974) data was excluded from all analyses of covariance since he sampled only dominant/codominant trees. This meant his data could not be weighted to achieve a representative d.b.h./height frequency. Since the d.b.h. range of the Shelton data did not overlap that of the inland data, it was also excluded from all analyses of covariance.

Discrepancies between sample sizes of the same data set are noted when they are used for different analyses. These discrepancies are caused by some trees being without vital information for one analysis but not for others. Missing data is common in most analyses, but it is more apparent and burdensome when data from many investigators are combined.

Limitations of the Data

The limited number of sample trees and the fact that they were not all randomly selected in the strict statistical sense are limitations of the data the reader and/or user should recognize. Nonrandom sample selection technically negates standard regression analyses, and users must be suspicious of misleading results. Standard regression analyses were used in spite of this limitation. We believe, however, that the sample trees were selected in a manner that makes them representative of Douglas-fir and western hemlock found in Pacific Northwest and Rocky Mountain areas and the nonrandom selection of trees is not a serious limitation. Users making weight estimates for use with high-cost operations, however, are advised to carefully check the validity of their estimates--it may be necessary to develop local estimators.

Field Procedures

Field procedures used to collect the Shelton data were essentially identical to those reported by Brown (1978) for the inland data. This was done to facilitate statistical combination of the two data sets.

Five Douglas-fir trees ranging from 36.1- to 86.9-inch d.b.h. and three western hemlocks ranging from 45.0- to 46.5-inch d.b.h. were selected from the Shelton Ranger District of the Olympic National Forest. The trees were dominants and codominants and were selected to represent other similar-sized trees in the area.

The live crown of each sample tree was visually divided into three horizontal sections according to branching characteristics. All dead branches within and below the live crown were considered to be a fourth section. Each tree was climbed as high as safely possible and topped. As the climber proceeded up each tree all limbs were cut flush with the bole. The limbs from each of the four crown sections (three live and one dead) were weighed separately in the field with spring scales. The three live crown sections were categorized as lower, middle, and upper. From each live crown section we selected a typical branch which we termed "a sample branch." Each sample branch was separated into component classes (see footnote 1). A moisture sample was taken in the field from each component immediately after each sample branch component was weighed. The moisture samples were later oven-dried at 103°C for 24 hours. The raw data are shown in the appendix.

Data Analysis

The Shelton data were analyzed (see below), and resulting data pooled with other data sets depending on the result of the analysis of covariance between the inland and coastal data sets. The pooled data sets were used to develop the regression equations.

Live crown analysis.--To separate the crowns of the Shelton trees into component weights, the three horizontal live crown sections were analyzed separately and then combined. The sample branches, which represented all branches in their sections, were separated into component classes. Using total green weights of sample branches as the base, accumulative proportions[4/] were developed for each sample branch.

Accumulative proportions are the progressively summed component weights divided by their sum of all component weights. These proportions when subtracted one from the other yield the proportion for individual components.

These individual proportions were multiplied by their respective section total green weight, yielding estimates of their total component green weights. The moisture samples from each crown section were used to convert component green weights of crown sections to ovendry weights. The individual ovendry components were totaled for the three crown sections to get an estimate of total weight of tree components. By adding the totals for each tree, an estimate was obtained of total ovendry live crown weight. With this total as the base, accumulative proportions, which applied to the entire tree, were developed for each sample tree.

The data used for this study were classified as being from either the east or west side of the summit of the Cascade Range. Data from the same side--although from different investigators--were considered to represent the same population and were pooled into one data set. As mentioned earlier, analysis of covariance was used as an objective means to test whether tree data from the east side (inland data set) or west side (coastal and Shelton data sets) could be pooled.

The regression models used in the covariance analysis were selected from a computer program (REX) (Grosenbaugh 1967). Three criteria were used to select the models for the analysis of covariance: (1) They had the lowest ratio of mean squared residuals (RMSQR) (Grosenbaugh 1967) of all models examined. (2) When plotted against a scatter of their raw data they visually fit the data best. (3) They were examined to see how logically they predicted beyond the limits of their data, and those models that obviously predicted erroneously were discarded. These three criteria were used to select several models for each data set (inland and coastal), and those models that were common between them were used in the analysis of covariance and are shown in table 1.

4/Proportion 1 (P1) = foliage weight divided by total branch weight (t.b.w.); P2 = P1 + (0.0- to 0.24-inch-diameter branchwood weight (d.b.w.) divided by t.b.w.); P3 = P2 + (0.25- to 0.99-inch-d.b.w. divided by t.b.w.); P4 = P3 + (1.0- to 2.99-inch-d.b.w. divided by t.b.w.).

Table 1 --Covariance analysis statistics comparing regression slope coefficients between data sets for inland and coastal Douglas-fir and western hemlock[1]

Species[2]	Model number[3]	Sample size (n)	[4] R^2	MSE[5]	F-statistic for slope[6]
		LIVE CROWN WEIGHT			
Inland DF	1	56	0.91	0.2797	3.03
Coastal DF	1	112	.90	.3986	
Inland DF	2	56	.94	.1841	5.79**
Coastal DF	2	103	.94	.2506	
Inland WH	1	27	.98	.0561	6.83
Coastal WH	1	28	.92	.3079	
Inland WH	3	27	.98	.0581	5.41**
Coastal WH	3	28	.96	.1669	
		DEAD CROWN WEIGHT			
Inland DF	4	33	.91	683.4	621.48**
Coastal DF	4	74	.95	147.3	

[1] Inland data is from Brown (1978) who conducted studies in western Montana and northern Idaho. Coastal data are from Grier (see footnote 2 of text) and Woodard (1974) for west of the summit of the Cascade Range.

[2] DF = Douglas-fir, WH = western hemlock.

[3] Model 1, $\ln(W)= B1 + B2 \ln(d)$; model 2, $\ln(W)= B1 + B2 \ln(d) + B3 (h/d)$; model 3, $\ln(W)= B1 + B2 \ln(d) + B3 \ln(h)$; model 4, $DW = B1 + B2 (d^3)$; where ln = natural logarithm; W = live crown weight in ovendry pounds; B1, B2, and B3 = regression coefficients; d = d.b.h. in inches; h = total tree height in feet; and DW = dead crown weight in ovendry pounds.

[4] Coefficient of determination.

[5] MSE = mean square error of residuals.

[6] Two asterisks indicate a significant difference at the 0.01 level between regression coefficients of the two data sets.

Table 2 --Regression equations for predicting live crown weight of Douglas-fir and western hemlock

Species[1]	Prediction equations[2]	Sample size (n)	[3] R^2	$\sqrt{MSE}$[4]
DF	W = Exp(0.0623+1.949 ln(d))[5]	173	0.91	227.1
DF	W = Exp(-0.7224+1.888 ln(h)-0.3873 (h/d))[5]	108	.97	237.8
WH	W = Exp(0.3157+1.907 ln(d))[5]	58	.94	196.0
WH	W = Exp(4.577+3.228 ln(d)-1.760 ln(h))	32	.97	131.7

[1] DF = Douglas-fir; WH = western hemlock.

[2] W = live crown weight in ovendry pounds; Exp = 2.7183 to the power enclosed in parentheses; ln = natural logarithm; d = d.b.h. in inches; h = total tree height in feet.

[3] Coefficient of determination.

[4] For logarithmic functions, the mean square error of residuals (MSE) was calculated as $\sum(P-O)^2/df$, where P and O are predicted and observed values, respectively, transformed to arithmetic units and df is the residual degrees of freedom.

[5] The (mean square error of residuals from transformed data)/2 was added to the intercept regression coefficient (Baskerville 1972) to correct for log bias inherent in dependent log transformations.

Models 2 and 3 suggest that a slight but noticeable reduction in mean square error can be gained over model 1 by adding a transformation which includes height. Since height is not always available, however, model 1 with d.b.h. as the only independent variable was also compared with covariance analysis.

As shown in table 1, no significant difference was found between inland and coastal slope coefficients for model 1. Based on this information, the inland, coastal, and Shelton data sets were pooled to develop one live crown weight equation that can be used on either side of the Cascade Range for Douglas-fir with less than 87-inch d.b.h. and western hemlock with less than 47-inch d.b.h. The equations are presented in table 2. Conversely, when the inland and coastal data sets were compared for models 2 and 3 (which contain a transformation with height and apply to Douglas-fir and western hemlock respectively), a significant difference was found between their slope coefficients. Therefore, only the coastal and Shelton data sets were pooled (both are west-side data sets) to develop weight equations for the west side of the Cascade Range.

Dead Crown Analysis.--The only data available for analysis of dead crown weight was for Douglas-fir. When weighted regression was used through the REX (Grosenbaugh 1967) computer program, the following common model fit both the coastal and inland Douglas-fir data sets better than other models examined:

Model 4 $\quad DW = B1 + B2\ (d^3),$

where

DW = dead branchwood weight in oven-dry pounds

B1 and B2 = regression coefficients

d = d.b.h. in inches.

When covariance analysis was used, a significant difference was found between the slope coefficients of model 4 when they were fitted to the two data sets.

Since the slope coefficients were different, the coastal and inland data were not combined. Only the coastal and Shelton data were used to develop the dead crown weight equation. Since the inland data was not included, there was a gap in the data between 10- and 30-inch d.b.h. making it difficult to fit a curve to the remaining data points. A visual examination of the probable slopes for the data between 1- to 10- and 30- to 90-inch d.b.h. revealed that they would differ noticeably. Therefore, segmented polynomial regression was used to fit a curve to the data. The slopes of the two segmented curves intersected at 9.8-inch d.b.h. The resulting model is shown below and is further illustrated in figure 1.

$$DW = 22.46 + 0.0010(X) + 0.2425(Z)$$

where

DW = dead crown weight in ovendry pounds

If d.b.h. is equal to or less than 9.8 inches, $X = 9.8^3$.

If d.b.h. is greater than 9.8 inches, $X = d^3$.

If d.b.h. is equal to or less than 9.8 inches, $Z = d^2 - 9.8^2$.

If d.b.h. is greater than 9.8 inches, $Z = 0.0$.

The sample size (n), coefficient of determination (R^2), and the square root of the mean square error of residuals (MSE) are 90, 0.97, and 17.74, respectively. This model consists of two curve segments that join at 9.8-inch d.b.h. It was constrained to be continuous at 9.8-inch d.b.h.; but its first derivative was not constrained to be continuous at the point where they join, causing an irregular curve. Until additional data become available, it seems reasonable from the data presented in figure 1, to assume that dead weight increases only slightly between 10- and 30-inch d.b.h.

Accumulative proportions.--Accumulative proportion equations (see footnote 4) were developed for the live crown weight of Douglas-fir; the equations are presented in table 3 and illustrated in figure 2. Most of the coastal data could not be used in these analyses because the crown weight of sample trees had not been separated into components (see footnote 1) except for Woodard's (1974). Since the Woodard (1974), inland, and Shelton data were all dominant/codominant trees, and they all had the same crown component separations, these data were pooled to develop the Douglas-fir accumulative proportions equations.

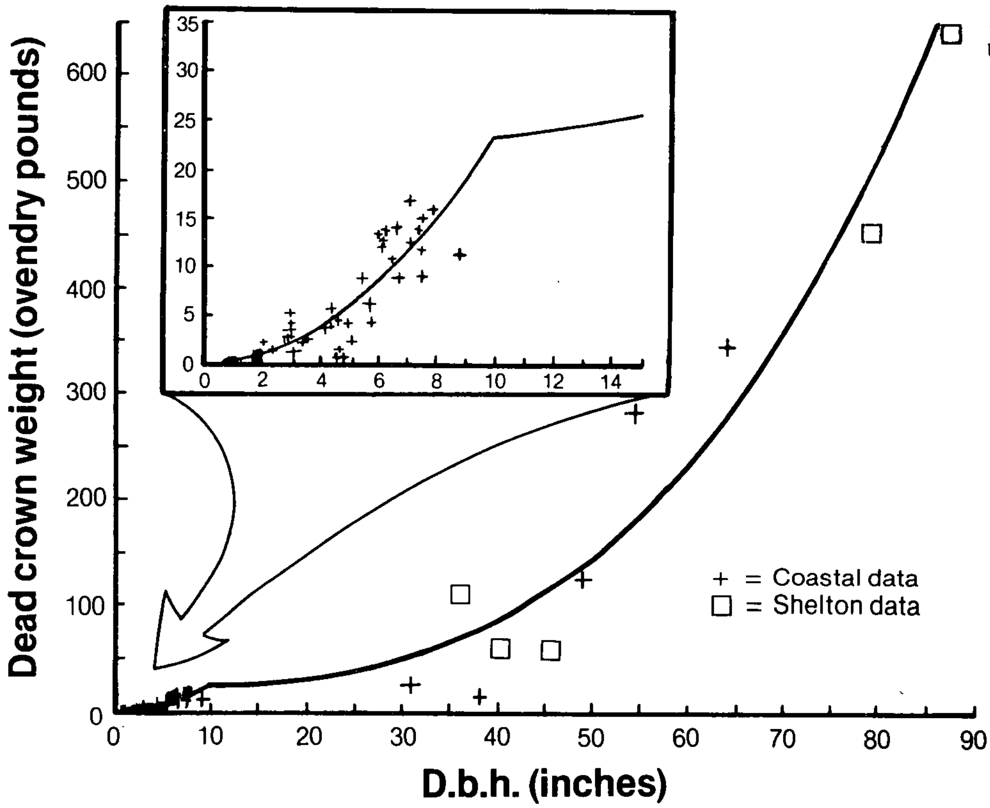

Figure 1.--Dead crown weight of Douglas-fir.

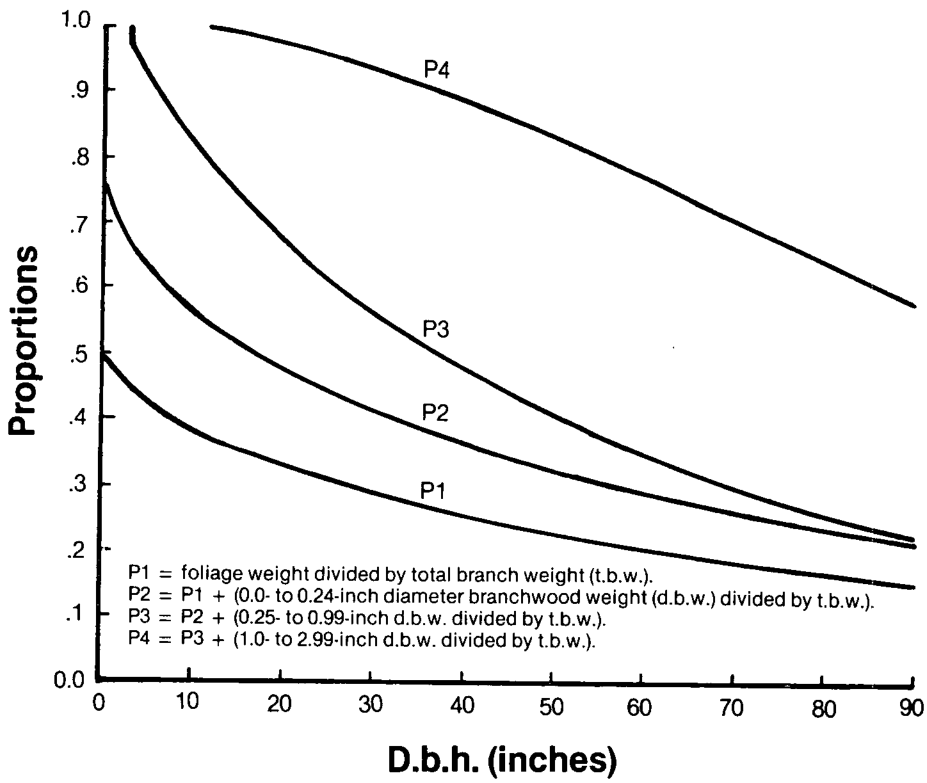

Figure 2.--Accumulative proportions for live crown weight of Douglas-fir.

There were insufficient data for regression analysis of the accumulative proportions for west-side western hemlock.

Table 3 --Accumulative proportion equations for live crown weight of coastal Douglas-fir

$$P = Exp(B1 + B2\ (d)^{B3})$$ [1]

P	Regression coefficients B1	B2	B3	Number of observations	MSE[2]	Conditions
1	-0.6916	-0.0546	0.6842	33	0.0021	
2	- .2676	- .0683	.6482	33	.0037	
3	.0693	- .0415	.8050	33	.0071	If d is less than 2 inches, P3 = 1.00.
4	.0122	- .0002	1.7623	18	.0015	If d is less than 11 inches, P4 = 1.00.

[1] P = accumulative proportion; Exp = 2.7183 to the power enclosed in parentheses; B1, B2, and B3 = regression coefficients; and d = d.b.h. in inches.

[2] MSE = mean square error of residuals.

Results and Discussion

For model 1, no difference was found between slope coefficients for either Douglas-fir or western hemlock. Therefore, the data were pooled for each species and refitted to model 1. The equations developed from these pooled data (see table 2) provide land managers in the Pacific Northwest with equations for predicting live crown weight using d.b.h. as the only independent variable. These can be used for Douglas-fir and western hemlock up to 87- and 47-inch d.b.h., respectively.

A significant difference was found between slope coefficients for models 2 and 3 of the inland and coastal data sets. Therefore, the inland and coastal data sets were not combined for either species. The Shelton and coastal data sets were combined and fitted to a regression model, however, since they were both west-side data sets (see table 2). By including the Shelton trees and excluding the inland trees when the data were refitted for Douglas-fir, the MSE changed from being smaller to being larger than the MSE of model 1. This anomaly was unfortunate but further illustrates the need for more work to identify the correct model(s) for predicting crown weight.

Accumulative proportion data were insufficient to develop regression equations for the coastal trees; therefore, statistical comparisons between inland and coastal regression coefficients were not possible. The Shelton and Woodard (1974) trees were, however, separated into components (see footnote 1); and although their d.b.h. ranges did not overlap with the inland trees, it was possible to plot these data for visual comparisons. It was our opinion the data sets fitted together logically and could be pooled. Accumlative proportion functions were fitted to these pooled data for Douglas-fir (see table 3 and footnote 4); but since the data were too scant for western hemlock, regression equations were not developed. For small western hemlock (less than 30-inch d.b.h.), Brown (1978) provides proportion equations; but for larger western hemlock, the averages of proportions developed from the three Shelton trees (average d.b.h. of 45.6 inches), may be helpful--P1, P2, P3, and P4 are 0.23, 0.35, 0.47, and 0.85, respectively (see footnote 4).

Until more data are available, these accumulative proportions should yield reasonable estimates of crown component proportions for large coastal western hemlock.

Note that the proportion equations were developed from dominant/codominant trees; if applied to intermediate/suppressed trees, additional error could result.

Comparisons were also made between slope coefficients for dead branchwood of inland and coastal Douglas-fir; a significant difference was found in the regression slopes of the two data sets. Therefore, only the Shelton and coastal data were combined and fitted to a segmented polynomial model. Data were not available to develop equations for weights of dead branchwood of west-side western hemlock.

Although more data on Douglas-fir dead branchwood are needed, an interesting phenomenon appeared in comparisons of weights of inland and coastal Douglas-fir dead branchwood. For a given d.b.h. (especially above 10-inch d.b.h.), the dead branchwood weight of the inland tree is notably greater than that of the coastal tree. Evidently, dead branches do not persist as long in a moist climate as they do in a drier inland climate. Although the weight of live branchwood of coastal and inland trees is similar, the weight of dead branchwood appears greatly different.

Although crown weight and proportion equations were developed for coast Douglas-fir and western hemlock, more data are needed to strengthen them. To estimate the crown weights of other west coast conifers see Snell and Brown (1980).

Metric Conversions

When you know	multiply by	to find
inches	2.540	centimeters
feet	0.305	meters
pounds	0.454	kilograms
pounds per square foot	4.883	kilograms per square meter
tons per acre	2.242	metric tonnes per hectare
cubic feet per acre	0.070	cubic meters per hectare
degrees Fahrenheit	$(5/9)(^{o}F-32)$	degrees Celsius

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Appendix

Table 4 --Crown weight data by foliage and branchwood component for five dominant Douglas-fir and three dominant western hemlock trees sampled on the Shelton Ranger District of the Olympic National Forest

D.b.h.	Total tree height	Live crown length	Ovendry weight of live crown components						Ovendry weight of dead crown components		
			Needles	0-0.24 inch	0.25-0.99 inch	1.00-2.99 inches	3.00+ inches	Total	1.00-2.99 inches	3.00+ inches	Total
Inches	Feet	Feet	Pounds						Pounds		
					DOUGLAS-FIR						
36.1	180	82	245.2	96.2	205.8	614.9	172.4	1334.5	112.7	0	112.7
40.6	176	110	301.0	122.7	261.3	437.9	307.3	1430.2	63.4	0	63.4
45.3	185	82	491.2	188.3	400.7	606.9	195.4	1882.5	59.8	0	59.8
78.9	218	116	659.8	265.5	326.1	1004.5	1352.6	3608.5	459.9	0	459.9
86.9	255	140	1009.6	383.9	707.8	1848.1	2244.4	6193.8	74.5	568.7	643.2
					WESTERN HEMLOCK						
45.0	204	127	518.9	276.6	233.2	742.3	178.0	1949.0	39.2	0	39.2
45.3	165	90	661.4	354.1	366.9	1183.3	488.8	3054.5	0	83.8	83.8
46.5	187	123	491.2	201.3	291.9	832.5	431.3	2247.2	147.2	0	147.2

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