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Cubic-Foot Tree Volume Equations and Tables for Western Juniper

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Abstract

This note presents cubic-foot volume equations and tables for western juniper (*Juniperus occidentalis* Hook.). Total cubic-foot volume (ground to tip, excluding all branches (CVTS)) is expressed as a function of d.b.h. and total height. Utilizable cubic-foot volume (top of 12-inch stump to a 4-inch top, excluding all branches (CV4)) is expressed as a function of CVTS and d.b.h.

Keywords: Cubic-foot volume tables, western juniper, *Juniperus occidentalis*.

Introduction

Rising costs of energy have stimulated an interest in western juniper as a potential source of energy. In response to this interest, the Forest Inventory and Analysis Work Unit of the Pacific Northwest Forest and Range Experiment Station in Portland, Oregon, is expanding its inventory program[1] to include an assessment for western juniper (*Juniperus occidentalis* Hook.) wood supply. But no volume equations or tables have been available.

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[1] Regional forest inventories are conducted nationwide by the U.S. Department of Agriculture, Forest Service. The Pacific Northwest Forest and Range Experiment Station conducts surveys in Alaska, California, Hawaii, Oregon, and Washington.

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We have developed an equation for estimating the total volume (CVTS) of western juniper trees, expressed as a function of two independent variables: diameter at breast height (d.b.h.) and total height. A second equation is presented to convert total volume to utilizable cubic volume (CV4).

The Basic Data

We needed a volume equation suitable for use on western juniper trees throughout eastern Oregon and northeastern California. Although we would have preferred using measurements from a large sample of trees representing the complete range of forest conditions found in the region, time and funding restrictions limited us to using available tree measurement data plus a small sample for testing the results from our original data set.

Available data were limited to measurements from 52 trees that were felled and sectioned for a western juniper site index study (Sauerwein 1982). The data were gathered in central, southern, and southeastern Oregon and from one plot in northeastern California. The trees are believed to sample all site indexes throughout the range of western juniper--southwestern Idaho, eastern Oregon, northeastern California, and western Nevada. Juniper trees at higher altitudes in the Sierra Nevada are not represented. Although the trees selected were all dominants, western juniper grows in such open stands that the relative social position of individual trees is not well defined. We are, therefore, assuming that these data are representative of the population and are usable for developing western juniper volume equations.

Second-growth stands were selected representing well-stocked sites free from cutting, excessive grazing, and fire. The three tallest trees per one-fifth acre were cut and measured. Data were recorded on the felled trees at ground line, 1 foot, 4.5 feet, and every 3 feet thereafter to the tip. Inside and outside bark diameters were taken to tenths of inches and heights to tenths of feet. The STX program (Grosenbaugh 1967) was used to calculate CVTS and CV4 for each of the sample trees.

The test set consisted of 24 trees from the area around Madras and Sisters in central Oregon. Trees were selected to bracket the range of diameters and heights common to the species. Only a few trees were found, however, with diameters over 20 inches. Table 1 shows the distribution of both data sets by 4-inch diameter class.

Table 1--Number of western juniper trees used to develop volume equation, by 4-inch diameter class

Diameter class	Site index study 1/	Test sample 2/	Total
Inches			
5.0-8.9	10	6	16
9.0-12.9	26	9	35
13.0-16.9	9	5	14
17.0-20.9	4	1	5
21.0-24.9	--	1	1
25.0-28.9	--	--	--
29.0-32.9	--	2	2
Total	49	24	73

1/From central, southern, and southeastern Oregon, and from northeastern California.

2/From Madras and Sisters areas, central Oregon.

Developing the Equations

An important assumption of least squares regression is homogeneity of variance. To satisfy this condition, cubic volume was transformed with the method used by Bruce and DeMars (1974). The dependent variable chosen was form factor (F), obtained by dividing total cubic volume including stump by the volume of a cylinder with a basal area and height equal to that of the sample tree (F=CVTS/(BA*H)). This model had been successfully used in developing volume equations for California species (MacLean and Berger 1976).

Least squares regressions were fit using independent variables of total height and d.b.h. outside bark, their powers, and crossproducts. A problem was encountered in fitting short squat trees. Three trees under 18 feet in height were dropped from the data set when the transformation failed. Their omission had negligible effect on our ability to estimate their volumes. After consultation with Bruce,[2/] we added a further transformation: the basal area of all trees (BA) was multiplied by $(H/(H - 4.5))^2$, thereby improving the fit for short trees. After the final model was selected using 49 trees, we ran a covariance analysis to see if the 49 trees and the test sample of 24 trees could be combined to obtain a final equation by least squares regression. The covariance analysis showed no significant difference between the slopes, so the sets were combined to obtain the final equation.

To convert CVTS to CV4, we turned to the tarif system developed by the Department of Natural Resources (DNR), State of Washington. We had CV4 computed by the STX program for 51 of the 52 trees from the site index study. When the most recent CV4/CVTS tarif ratios (Chambers and Foltz 1979) were plotted against the study trees, the results were substantially biased, probably because of the heavy taper typically found in western juniper stumps. To correct this bias, we recalibrated the equation, following the model described by Turnbull and Hoyer (1965).

The form factor equation is:

$$F = 0.307 + 0.00086*H - 0.0037*D*H/(H-4.5).$$

The volume equations are:

$$CVTS = BA*F*H*(H/(H-4.5))^2, \text{ and}$$

$$CV4 = (CVTS + 3.48)/(1.18052 + 0.32736*e^{(-0.1*D)}) - 2.948;$$

where:

D = diameter at breast height outside bark (inches),
H = total height including stump and tip (feet),
BA = $0.005454154 * D^2$ (square feet),
F = CVTS/(BA*H),
CVTS = total cubic volume from ground to tip, excluding all branches (cubic feet), and
CV4 = utilizable cubic volume from top of 12-inch stump to a 4-inch top, excluding all branches (cubic feet).

The root mean square error for F was 3.8 percent.

[2/] Personal communication with David Bruce, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR, December 1982.

Discussion and Conclusions

Measured volumes were plotted against estimated volumes for CVTS and CV4 (figs. 1, 2). The figures illustrate the lack of bias in the equations as well as the lack of data for large volume trees.

The small samples and the few number of large trees were major difficulties in the development of these equations. Of the 73 trees used to obtain the final equation, only 3 had a d.b.h. greater than 20 inches. Although the volume tables (tables 2, 3) provide reasonable extrapolations, the user should be cautious when applying them to trees above 20 inches d.b.h.

The study is limited to trees in eastern Oregon and northeastern California. Site index curves developed from these data, however, are suitable for the entire range of western juniper (Sauerwein 1982). We think the equations and volume tables presented here will also be valid for the entire range.

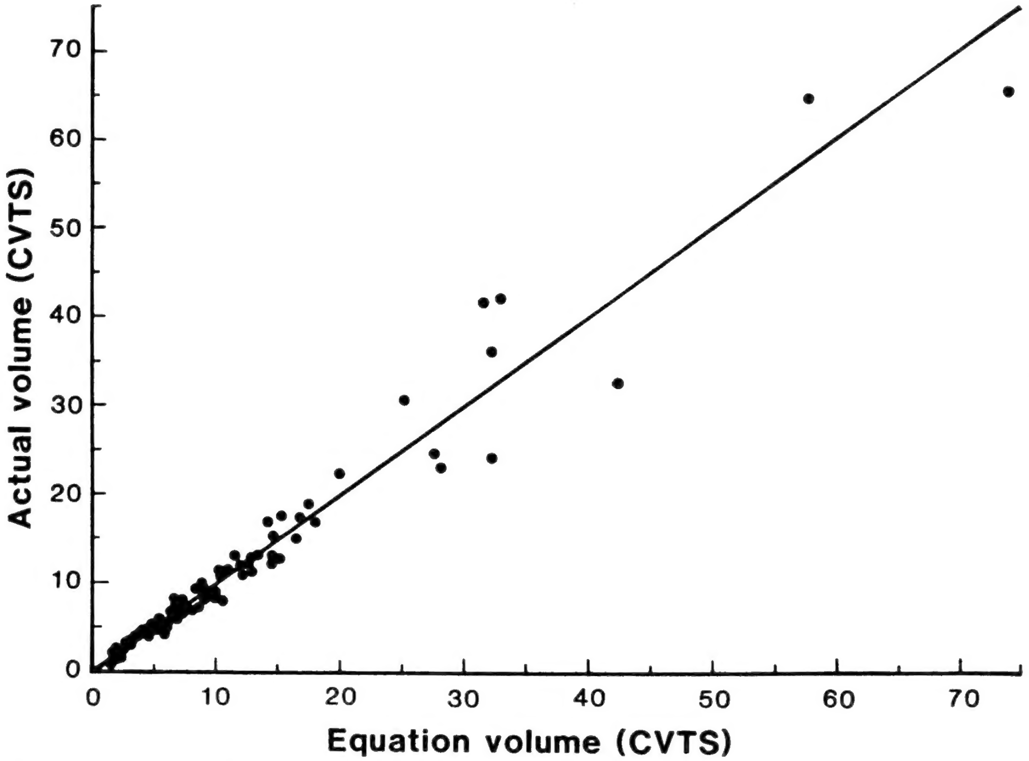

Figure 1.--Relationship between measured cubic-foot volume (CVTS) of 73 western juniper trees and estimates calculated with the equation.

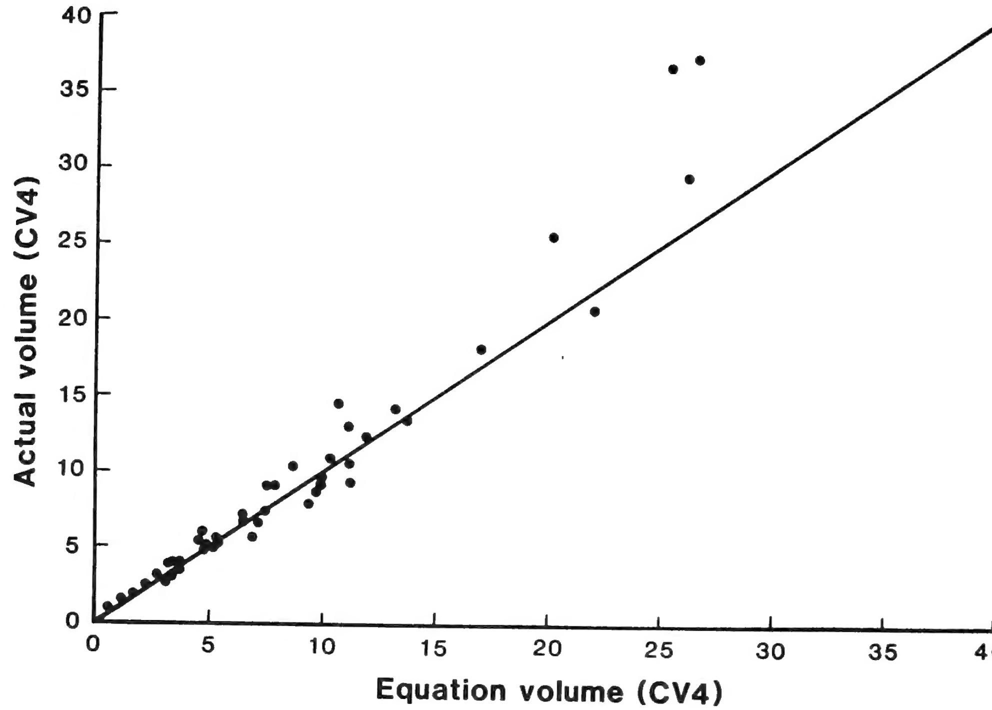

Figure 2.--Relationship between measured utilizable cubic-foot volume (CV4) of 51 western juniper trees and estimates calculated with the equation.

Table 2--Cubic-foot volume of western juniper[1/] [2/]

Diameter at breast height outside bark[3/]	Total height (feet) 10	20	30	40	50	60	70	80
Inches								
5	1	1	2					
6	2	2	2	3				
7	2	3	3	4	5	6	7	8
8	3	3	4	5	7	8	9	11
9	4	4	5	7	8	10	12	14
10	4	5	7	8	10	12	14	16
11	5	6	8	10	12	15	17	20
12		7	9	12	14	17	20	23
13		8	11	13	17	20	23	27
14		9	12	15	19	23	27	31
15		10	14	17	21	26	30	35
16		12	15	19	24	29	34	39
17		13	17	22	27	32	38	44
18		14	19	24	29	35	42	48
19		15	20	26	32	39	46	53
20		17	22	29	35	43	50	58
21		18	24	31	38	46	55	63
22		19	26	33	41	50	59	69
23			28	36	45	54	64	74
24			30	38	48	58	68	79
25			32	41	51	62	73	85
26			34	44	54	66	78	91
27			35	46	58	70	83	96
28			37	49	61	74	87	102
29			39	51	64	78	92	108
30			41	54	67	82	97	114
31			43	56	71	86	102	119
32			45	59	74	90	107	125
33			46	61	77	94	112	131
34			48	64	80	98	117	137
35			50	66	83	102	122	143
36			51	68	87	106	127	149
37			53	71	90	110	131	154
38			54	73	93	114	136	160
39			56	75	95	117	141	165
40			57	77	98	121	145	171

[1/]Applies to all western juniper except at higher altitudes in the Sierra Nevada.

[2/]Total tree volume including stump and tip (CVTS). Data set is outlined.

[3/]Diameter classes are midpoint; for example, the 12-inch class includes 11.5-12.4 inches.

Table 3--Cubic-foot volume of western juniper to a 4-inch top[1/] [2/]

Diameter at breast height outside bark[3/]	Total height (feet) 10	20	30	40	50	60	70	80
Inches								
5	0	1	1					
6	1	1	1	2				
7	1	2	2	3				
8	2	2	3	4	5	6	7	8
9	3	3	4	5	6	7	9	10
10	3	4	5	6	8	9	11	12
11	4	4	6	7	9	11	13	15
12	5	5	7	9	11	13	15	18
13		6	8	10	13	15	18	21
14		7	9	12	15	18	21	24
15		8	11	14	17	20	24	28
16		9	12	15	19	23	27	31
17		10	13	17	21	26	30	35
18		11	15	19	24	29	34	39
19		12	16	21	26	32	37	43
20		13	18	23	29	35	41	47
21		15	20	25	31	38	45	52
22		16	21	27	34	41	48	56
23			23	30	37	44	52	61
24			24	32	39	48	56	66
25			26	34	42	51	60	70
26			28	36	45	54	65	75
27			29	38	48	58	69	80
28			31	40	51	61	73	85
29			33	43	53	65	77	90
30			34	45	56	68	81	95
31			36	47	59	72	85	100
32			37	49	62	75	90	105
33			39	51	65	79	94	110
34			40	53	67	82	98	115
35			42	55	70	86	102	120
36			43	57	73	89	106	125
37			45	59	75	92	111	130
38			46	61	78	96	115	135
39			47	63	80	99	118	139
40			48	65	83	102	122	144

[1/]Applies to all western juniper except at higher altitudes in the Sierra Nevada.

[2/]Stump and top excluded; top diameter = 4 inches; stump height = 12 inches. Data set is outlined.

[3/]Diameter classes are midpoint; for example, the 12-inch class includes 11.5-12.4 inches.

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