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Local Volume Tables for Young-Growth Conifers on a High Quality Site in the Northern Sierra Nevada

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Local volume tables for ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*), sugar pine (*Pinus lambertiana* Dougl.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), California white fir (*Abies concolor* var. *lowiana* [Gord.] Lemm.), and incense-cedar (*Libocedrus decurrens* Torr.) are presented by 1-inch diameter classes in the range of 3 to 40 inches for ponderosa pine, Douglas-fir, California white fir, and incense-cedar. Sugar pine is presented to 45 inches. Trees were measured by an optical dendrometer. Tables are presented for each species in terms of cubic volume to a 0- and 6-inch top, and Scribner board feet to a 6-inch top. The tables are applicable to trees growing on land of high site quality in the northern Sierra Nevada of California at low to mid elevations.

Retrieval Terms: ponderosa pine, sugar pine, Douglas-fir, California white fir, incense-cedar, local volume tables

Intensive forestry requires that foresters be able to estimate tree volume accurately for such phases of timber management as timber sales, forest surveys, appraisals for land exchanges, evaluations of damage, advance planning, and growth and yield studies. The private land appraiser and even the tax assessor often find such information useful as well. Needed in particular are volume data for young trees in small-tree growth models.

To be of value, estimates of tree volume should be expressed in units of measure that relate to the products derived from the tree and that are expressed in terms familiar to the user. The board foot and cubic foot are traditional units of measure, although the cubic foot is increasing in importance as utilization of the total tree becomes more common. Consequently, future users will find volume tables more applicable if they contain both units of measure.

Future users also will find volume tables more useful if they present estimates for the species that make up the typical westside Sierra Nevada [California] conifer forest. The large number of species provides raw material for a wide variety of wood products. Future managers are likely to retain the mixed-conifer forest in order to have the flexibility to capitalize on high-yielding "markets of opportunity" and to respond to the ever-changing marketplace.

From the late 1940's through the 1970's, volume estimates in California were based largely on form-class volume tables derived from logged stands.[1,2] But even with the availability of such tables, those desiring a volume estimate for a specific area or range of tree size often had to construct their own local volume tables. In the mid-1970's two volume tables for softwood species in California were published.[3,4] Data in them vary as to source (inventory and noninventory data) and sample size, particularly with regard to trees smaller than 11 and 10 inches (28 and 25 cm), respectively, in diameter at breast height (d.b.h.). In both publications, volumes for small trees are for the most part extrapolations. Needed are volume estimates, based on a full range of tree sizes, that are specific to the young-growth, mixed-conifer forest on sites of high quality in the northern Sierra Nevada of California.

This note offers *local* volume tables that are convenient to use because the user can compare the measurements of a few trees to the values in the height-diameter figures and volume tables. If the values are close, then the tables are applicable; if not, other means of estimating volume will be needed. The local volume tables that follow contain information to a 0-inch top (total stem), and 6-inch (15-cm) top for cubic feet and to a 6-inch top for Scribner board feet. The tables are based on a large sample (510 trees total) that reflects a special effort to sample trees in the 3- to 14-inch (8- to 36-cm) d.b.h. range (89 trees). They also present volume estimates for a full range of conifer species and tree sizes typically found in a young-growth forest in the northern Sierra Nevada at elevations from 2000 to 3500 feet (610 to 1068 m).

SITE AND STAND

This study took place on the Challenge Experimental Forest and surrounding area in eastern Yuba County, about 26 miles (42 km) northeast of Oroville, California, on land located between the south fork of the Feather River and the north fork of the Yuba River. Research on the Experimental Forest applies to about 1.5 million acres (607,035 ha) of highly productive timberland along the west slopes of the Sierra Nevada.[5] These young-growth conifer and hardwood forests at low to mid-elevations form a transition zone between the chaparral and mixed hardwoods at lower elevations and the California white fir forest at higher elevations. Within this zone, and often in complex mixture, the Douglas-fir—tanoak—Pacific madrone, Pacific ponderosa pine, Pacific ponderosa pine—Douglas-fir, and Sierra Nevada mixed-conifer forest cover types are found.[6]

An important attribute of the Experimental Forest is its high site quality. Dominant and codominant ponderosa pines average 110 feet (33 m) in 50 years.[7] Soils often are more than 30 feet (9 m) deep as seen in road cuts, mean annual temperature is 55 °F (13 °C), and annual precipitation averages 68 inches (1727 mm). Frost-free days average about 190 each year.

In stand volume, ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) is the dominant species, followed by Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), with lesser amounts of sugar pine (*Pinus lambertiana* Dougl.), California white fir (*Abies concolor* var. *lowiana* [Gord.] Lemm.), and incense-cedar (*Libocedrus decurrens* Torr.). Hardwoods, principally California black oak (*Quercus kelloggii* Newb.), tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.), and Pacific madrone (*Arbutus menziesii* Pursh), are scattered throughout as individual trees, clumps, or groves. Average stand density in conifer and hardwood trees larger than 3.5 inches (8.9 cm) d.b.h. is 248 per acre (613/ha); basal area is 270 ft^2 per acre (62 m^2/ha). The forest is made up of a mosaic of even-age stands, depending on fire history, with the oldest dominant and codominant trees being about 120 years old.

Sample trees were those of a forest and did not include open-grown trees in meadows or in areas with only a few remaining seed trees. Sampled trees did include those on ridges and in draws and in stands having a wide variety of densities and species. Trees in dense stands or growing in draws or ravines often are straight and tall with gently tapering boles, whereas trees in openings or on ridgetops often are shorter with greater taper.

MEASUREMENTS

Because the goal was to produce an accurate local volume table representative of the Experimental Forest and surrounding area, a large, well distributed sample and an accurate instrument were needed. Sample trees on ridges, in draws, among hardwoods, and in stands of varying density were measured with the Barr and Stroud optical dendrometer.[8] Sampling followed a stratified random design. A table of diameter classes in increments of 4 inches (10 cm) was constructed for each species to ensure that a full range of trees was included in the sample.

The smallest diameter measured was 3 inches (8 cm) and the largest was 40 inches (102 cm), except for sugar pine, which grows rapidly on good sites, and was measured to 45 inches (114 cm) d.b.h. Such diameters reflect the young-growth nature of the stands. Old-growth trees were excluded from the sample. Sampling intensity (number of trees) by species was:
ponderosa pine, 139; sugar pine, 49; Douglas-fir, 154; California white fir, 80; and incense-cedar, 88.

For each tree, dendrometer measurements were taken at d.b.h., at one half of the branch-free bole, at the base of the live crown, at midcrown, and at the top of the tree. In addition, stump height (taken at 12 inches or 30 cm) was measured manually. Occasionally, additional measurements of the tree bole were taken to ensure accurate volume estimates. All data were checked manually, entered on tape, and run through the STXMOD computer program which transforms tree measurements into heights, volumes, and other parameters.[9] Bark thickness initially was measured directly after chopping into opposite sides of the tree. Because it conformed to values in the bark thickness tables used by the Forest Service in California, these values were adopted.

Bole volumes were computed for each species to three utilization standards: (1) cubic foot volume to top of tree (0-inch top), less a 12-inch stump, (2) cubic foot volume to a utilized top (6 inches or 15 cm in diameter), less a 12-inch stump, and (3) Scribner board-foot volume to a 6-inch top, less a 12-inch stump. Six inches was selected as the utilized top because this is the standard used in the majority of timber sales. Defects, including rot, crook, and sweep, were virtually absent in sampled trees, and were not considered in calculating volume. The minimum log length was 10.0 feet (3.3 m).

RESULTS AND DISCUSSION

Tree Height

The first concern that potential users of a local volume table have is the relationship of their trees to the trees in the table. Users often have a good idea of the diameter-height relationship of their trees. Consequently, graphs of height as a function of diameter (*figs. 1-5*) and tree height-diameter equations are presented here as a means for users of the volume tables to ascertain their applicability. Heights from the STXMOD program, plus 12 inches for stump height, were plotted against d.b.h. The relationship was tentatively expressed in several mathematical equations and examined for goodness of fit by a computer-based least-squares curve-fitting technique. The most representative equation relating total tree height (0-inch top) to d.b.h. for all species was

$$Y = a + bX + cX^2,$$

in which

Y = height in feet, and

X = d.b.h. in inches.

Best-fit regression coefficients were:

Ponderosa pine	$Y = 10.0333 + 6.3269x - 0.061x^2$,
Sugar pine	$Y = -3.1144 + 6.8060x - 0.069x^2$,
Douglas-fir	$Y = 2.2668 + 6.8694x - 0.075x^2$,
California white fir	$Y = -5.5515 + 7.4811x - 0.082x^2$, and
Incense-cedar	$Y = 3.3860 + 4.8545x - 0.044x^2$.

Correlation coefficients and standard error (in parentheses) are presented to show the goodness of fit of the regressions. Correlation coefficients, significant at the 1 percent level, were 0.85 (15.8 ft) for ponderosa pine, 0.93 (13.1 ft) for sugar pine, 0.93 (11.9 ft) for Douglas-fir, 0.95 (12.3 ft) for California white fir, and 0.94 (11.2 ft) for incense-cedar.

Tree Volume

After volume as a function of d.b.h. was plotted and the general curve defined, the best mathematical expression of it was determined by a least-squares curve-fitting procedure similar to that used for tree height. Because variation in volume increased with increasing diameter, natural log d.b.h. was used to weight the regressions. The bias associated with log transformation was corrected by the equation developed by Baskerville.[10] This correction was built into all the volume equations that follow. The most representative regression equation relating cubic volume to diameter was

$$\text{Ln } Y = \text{a} + \text{b Ln } X,$$

in which

Y = cubic foot volume (0-inch top), and
X = d.b.h. in inches.

The best expressions of the relationship between cubic volume to a 0-inch top and d.b.h. were

Ponderosa pine: Ln vol = -4.0865 + 2.7826 ln d.b.h.,
Sugar pine: Ln vol = -3.9278 + 2.7347 ln d.b.h.,
Douglas-fir: Ln vol = -3.6083 + 2.6516 ln d.b.h.,
California white fir: Ln vol = -3.9320 + 2.7749 ln d.b.h., and
Incense-cedar: Ln vol = -3.6997 + 2.5111 ln d.b.h.

Natural logarithms were used because they displayed better; data points were more spread out on graphs of the relationship. Correlation coefficients, significant at the 1 percent level, were 0.99 or better for all species. Mean squared errors, calculated from the regressions above, were 0.0224 for ponderosa pine, 0.0297 for sugar pine, 0.0346 for Douglas-fir, 0.0286 for California white fir, and 0.0250 for incense-cedar.

During development of the equation for volume to a 6-inch top, the estimated volume equation for the 6-inch top crossed that of the 0-inch top; in effect giving more volume to a shorter tree. Plainly, these equations had to be developed in a slightly different manner. Close examination indicated that the difference in volume between the 0-inch top and the 6-inch top was roughly constant. Linear regressions of the volume difference between 0-inch and 6-inch values on d.b.h. indicated slope coefficients that did not differ significantly from zero for all species ($p > 0.05$). Additional calculations indicated the mean volume difference to be 1.61 cubic feet (0.04 m^3) for ponderosa pine, 1.51 cubic feet (0.04 m^3) for sugar pine, 1.65 cubic feet (0.04 m^3) for Douglas-fir, 1.58 cubic feet (0.04 m^3) for California white fir, and 1.83 cubic feet (0.05 m^3) for incense-cedar. Standard errors of these differences ranged from 0.06 to 0.09. A useful general rule of thumb for these young-growth species is that cubic volume to a 6-inch top is about 1.7 cubic feet (0.05 m^3) less than to a 0-inch top.

The mathematical expression of the relationship between cubic volume to a 6-inch top and d.b.h. is

$$Y = \exp(\text{a} + \text{b} \ln X) - \text{c},$$

in which

Y = cubic volume (6-inch top),
exp = exponent of,
a = intercept,
b = constant for volume to 0-inch top,
X = d.b.h. (inches), and
c = a constant which is the mean volume difference between utilization standards.

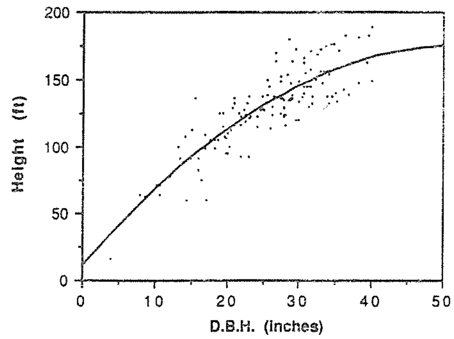

Figure 1— Relationship of height to diameter for ponderosa pine on the Challenge Experimental Forest, northern California.

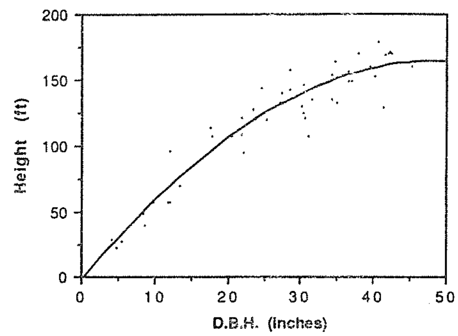

Figure 2— Relationship of height to diameter for sugar pine on the Challenge Experimental Forest, northern California.

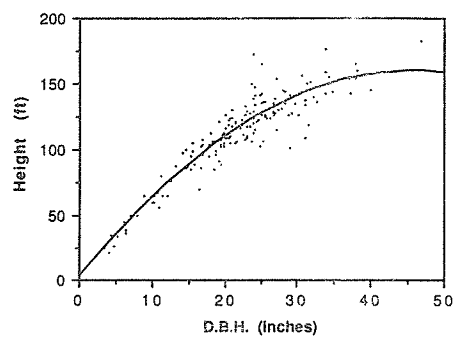

Figure 3— Relationship of height to diameter for Douglas-fir on the Challenge Experimental Forest, northern California.

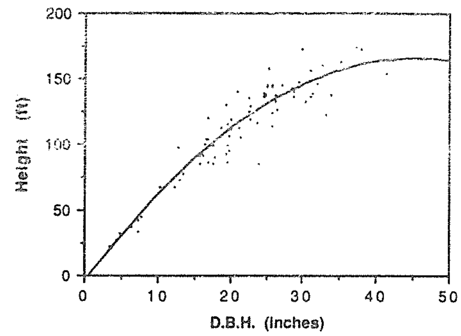

Figure 4— Relationship of height to diameter for California white fir on the Challenge Experimental Forest, northern California.

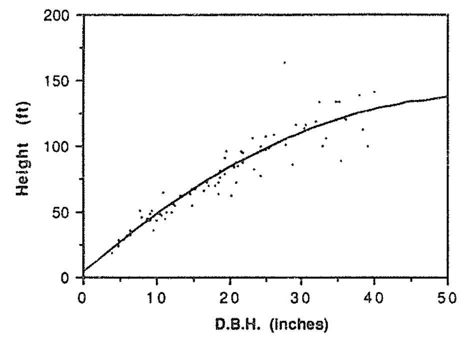

Figure 5— Relationship of height to diameter for incense-cedar on the Challenge Experimental Forest, northern California.

Correlation coefficients, significant at the 1 percent level, were 0.98 for ponderosa pine, 0.98 for sugar pine, 0.97 for Douglas-fir, 0.98 for California white fir, and 0.98 for incense-cedar.

Sometimes, steps need to be taken to control the board-foot Scribner curve in the region of zero volume. Control near zero volume was necessary, for example, to develop the Scribner board-foot volume equations for California black oak, tanoak, and Pacific madrone in the northern Sierra Nevada.[11] Specifically, it was necessary to determine the diameter at which each species had zero board-foot volume. Although the coefficient representing the Y intercept fell below zero (was negative) in the current study, this occurs only in trees that are well below the lower diameter limit for merchantable volume, and no steps to control volume near zero were attempted. The most representative Scribner board-foot volume equation for the five species proved to be

$$\ln Y = a + b \ln X,$$

in which

Y = Scribner board-foot volume, and

X = d.b.h. in inches.

The best expression of the relationship between Scribner board-foot volume to a 6-inch top and d.b.h. for each species was

Ponderosa pine	Ln vol = -4.6408 + 3.4351 ln d.b.h.,
Sugar pine	Ln vol = -4.4806 + 3.3703 ln d.b.h.,
Douglas-fir	Ln vol = -3.2292 + 3.0175 ln d.b.h.,
California white fir	Ln vol = -4.0068 + 3.2944 ln d.b.h., and
Incense-cedar	Ln vol = -5.6510 + 3.5357 ln d.b.h.

Correlation coefficients, significant at the 1 percent level, by species, and mean squared errors (in parentheses), calculated from the regression equations above, were ponderosa pine 0.98 (.0519), sugar pine 0.98 (.0874), Douglas-fir 0.96 (.0701), California white fir 0.97 (.0711), and incense-cedar 0.98 (.0842).

Volume tables by 1-inch (2.5 cm) diameter intervals are provided for the five conifer species (*tables 1-5*). Coefficients of variation (CV) associated with predicted volume, which aid in evaluating the reliability of the volume tables, are shown as a footnote for each table. For the 0-inch cubic and

Table 1—*Local volume table for ponderosa pine to three utilization standards, Challenge Experimental Forest, California*

D.b.h.	Volume: 0-inch top	Volume: 6-inch top	Volume: 6-inch top
inches	*ft³*	*ft³*	*Scribner board feet*
3	0.357	—	—
4	0.795	—	—
5	1.480	—	—
6	2.458	—	—
7	3.774	—	—
8	5.472	3.862	12.21
9	7.594	5.984	18.30
10	10.181	8.572	26.29
11	13.273	11.664	36.47
12	16.909	15.301	49.17
13	21.128	19.520	64.74
14	25.966	24.359	83.50
15	31.462	29.856	105.84
16	37.651	36.046	132.11
17	44.569	42.965	162.69
18	52.253	50.650	197.99
19	60.736	59.135	238.40
20	70.054	68.454	284.33
21	80.240	78.643	336.21
22	91.329	89.734	394.47
23	103.354	101.761	459.55
24	116.348	114.757	531.90
25	130.343	128.755	611.97
26	145.374	143.788	700.24
27	161.470	159.888	797.17
28	178.666	177.087	903.24
29	196.991	195.416	1018.96
30	216.479	214.907	1144.81
31	237.159	235.592	1281.30
32	259.064	257.501	1428.95
33	282.223	280.665	1588.27
34	306.668	305.115	1759.80
35	332.428	330.881	1944.05
36	359.534	357.992	2141.58
37	388.017	386.481	2352.94
38	417.906	416.376	2578.68
39	449.229	447.706	2819.35
40	482.019	480.502	3075.54

Coefficient of variation of predicted tree volume is:

	0-inch top	6-inch top	6-inch top
	15.05	21.39 to 15.10	23.09

6-inch Scribner board-foot volume tables, the coefficients were calculated by the formula

$$CV = SQRT\ exp[MSE]-1 * 100,$$

where

MSE = SSE/(n-2) from the log form,

and

SQRT = Square root,

MSE = Mean square error, and

SSE = Error sum of squares.

Table 2—*Local volume table for sugar pine to three utilization standards, Challenge Experimental Forest, California*

D.b.h.	Volume: 0-inch top	Volume: 6-inch top	Volume: 6-inch top
inches	*ft³*	*ft³*	*Scribner board feet*
3	0.397	—	—
4	0.872	—	—
5	1.606	—	—
6	2.644	—	—
7	4.030	—	—
8	5.806	4.293	12.52
9	8.012	6.500	18.63
10	10.688	9.175	26.57
11	13.870	12.357	36.63
12	17.596	16.084	49.12
13	21.902	20.389	64.33
14	26.823	25.310	82.58
15	32.392	30.879	104.20
16	38.645	37.132	129.51
17	45.614	44.100	158.87
18	53.331	51.817	192.63
19	61.829	60.316	231.13
20	71.139	69.626	274.75
21	81.294	79.780	323.85
22	92.322	90.809	378.82
23	104.256	102.742	440.05
24	117.125	115.611	507.92
25	130.957	129.443	582.83
26	145.784	144.270	665.20
27	161.634	160.120	755.43
28	178.536	177.022	853.93
29	196.518	195.004	961.14
30	215.608	214.094	1077.48
31	235.835	234.321	1203.38
32	257.227	255.712	1339.29
33	279.809	278.294	1485.64
34	303.611	302.097	1642.90
35	328.658	327.144	1811.50
36	354.978	353.464	1991.92
37	382.598	381.083	2184.62
38	411.543	410.029	2390.07
39	441.840	440.326	2608.73
40	473.516	472.001	2841.11
41	506.595	505.080	3087.66
42	541.104	539.589	3348.89
43	577.067	575.552	3625.29
44	614.513	612.997	3917.35
45	653.462	651.948	4225.57

Coefficient of variation of predicted tree volume is:

	0-inch top	6-inch top	6-inch top
	17.39	23.50 to 17.40	30.23

To account for the error introduced by the use of the correction factor in calculating the 6-inch cubic foot volumes, the coefficient of variation was calculated by

$$CV = 100 * SQRT\ [N1^2 (expN2-1) + N3^2] / N4 \text{ at d.b.h. of } N0,$$

Table 3—*Local volume table for Douglas-fir to three utilization standards, Challenge Experimental Forest, California*

D.b.h.	Volume		
	0-inch top	6-inch top	6-inch top
inches	*ft³*	*ft³*	*Scribner board feet*
3	0.499	—	—
4	1.070	—	—
5	1.933	—	—
6	3.135	—	—
7	4.718	—	—
8	6.723	5.077	21.02
9	9.187	7.542	29.99
10	12.149	10.503	41.22
11	15.642	13.996	54.95
12	19.701	18.055	71.45
13	24.359	22.714	90.97
14	29.648	28.003	113.77
15	35.599	33.955	140.10
16	42.244	40.600	170.22
17	49.611	47.967	204.39
18	57.730	56.086	242.86
19	66.629	64.986	285.90
20	76.336	74.693	333.76
21	86.879	85.237	386.70
22	98.284	96.643	444.98
23	110.579	108.938	508.85
24	123.790	122.150	578.58
25	137.941	136.301	654.43
26	153.059	151.420	736.65
27	169.169	167.531	825.50
28	186.294	184.657	921.25
29	204.460	202.824	1024.15
30	223.691	222.056	1134.46
31	244.011	242.377	1252.45
32	265.442	263.809	1378.37
33	288.008	286.377	1512.49
34	311.733	310.104	1655.06
35	336.639	335.010	1806.35
36	362.748	361.120	1966.61
37	390.082	388.457	2136.12
38	418.665	417.041	2315.12
39	448.517	446.895	2503.88
40	479.661	478.042	2702.67

Coefficient of variation of predicted tree volume is:

	18.75	24.89 to 18.83	26.96

Table 4—*Local volume table for California white fir to three utilization standards, Challenge Experimental Forest, California*

D.b.h.	Volume		
	0-inch top	6-inch top	6-inch top
inches	*ft³*	*ft³*	*Scribner board feet*
3	0.413	—	—
4	0.918	—	—
5	1.706	—	—
6	2.829	—	—
7	4.339	—	—
8	6.285	4.703	17.18
9	8.715	7.133	25.33
10	11.675	10.092	35.83
11	15.209	13.627	49.05
12	19.363	17.781	65.34
13	24.179	22.596	85.05
14	29.699	28.117	108.57
15	35.965	34.383	136.27
16	43.019	41.437	168.56
17	50.900	49.319	205.82
18	59.649	58.067	248.47
19	69.304	67.723	296.91
20	79.905	78.324	351.57
21	91.490	89.909	412.87
22	104.096	102.516	481.25
23	117.762	116.182	557.15
24	132.524	130.944	641.01
25	148.419	146.839	733.28
26	165.484	163.905	834.42
27	183.754	182.176	944.89
28	203.266	201.688	1065.16
29	224.055	222.477	1195.70
30	246.155	244.578	1336.98
31	269.603	268.027	1489.50
32	294.433	292.857	1653.73
33	320.678	319.103	1830.16
34	348.375	346.801	2019.31
35	377.554	375.980	2221.65
36	408.252	406.679	2437.70
37	440.502	438.930	2667.97
38	474.337	472.765	2912.98
39	509.788	508.218	3173.22
40	546.891	545.322	3449.25

Coefficient of variation of predicted tree volume is:

	17.03	22.79 to 17.08	27.15

Table 5—*Local volume table for incense-cedar to three utilization standards, Challenge Experimental Forest, California*

D.b.h.	Volume		
	0-inch top	6-inch top	6-inch top
inches	*ft³*	*ft³*	*Scribner board feet*
3	0.390	—	—
4	0.804	—	—
5	1.407	—	—
6	2.225	—	—
7	3.276	—	—
8	4.581	2.756	5.48
9	6.158	4.333	8.31
10	8.023	6.198	12.07
11	10.193	8.367	16.90
12	12.682	10.856	22.99
13	15.505	13.679	30.51
14	18.677	16.851	39.65
15	22.210	20.383	50.61
16	26.117	24.291	63.58
17	30.412	28.585	78.78
18	35.106	33.279	96.42
19	40.211	38.383	116.73
20	45.739	43.911	139.95
21	51.700	49.872	166.30
22	58.106	56.278	196.03
23	64.968	63.139	229.39
24	72.296	70.467	266.64
25	80.100	78.270	308.04
26	88.391	86.560	353.87
27	97.178	95.346	404.38
28	106.470	104.638	459.87
29	116.278	114.445	520.62
30	126.610	124.776	586.92
31	137.476	135.642	659.07
32	148.885	147.050	737.37
33	160.846	159.010	822.12
34	173.368	171.530	913.65
35	186.458	184.619	1012.26
36	200.125	198.286	1118.27
37	214.379	212.539	1232.03
38	229.227	227.386	1353.86
39	244.678	242.835	1484.09
40	260.738	258.894	1623.07

Coefficient of variation of predicted tree volume is:

	15.91	26.68 to 16.02	29.64

in which

N0 = d.b.h. (CV must be calculated for each breast height value separately),
N1 = 0-inch volume at d.b.h. N0,
N2 = MSE calculated for the 0-inch regression for each species,
N3 = Standard error of the correction factor for volume to a 6-inch top, and
N4 = 6-inch volume at d.b.h. N0.

Because the coefficient of variation for the 6-inch cubic foot volumes is calculated at each d.b.h., it is shown as a range of values. For each species the coefficient of variation within the stated range decreases as d.b.h. increases.

The tabular values apply solely to trees having the site and stand characteristics noted earlier. The tables apply particularly to trees on sites of high quality. Deviation from high-quality sites increases the likelihood that the values will become less applicable.

END NOTES AND REFERENCES

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[8]Trade names are used for information only; no endorsement by the U.S. Department of Agriculture is implied.

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