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# Local Volume Tables for Pacific Madrone, Tanoak, and California Black Oak in North-Central California

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Native California hardwoods constitute a potentially rich resource for wood products and energy that currently is unmanaged and scarcely utilized. The first step toward management of a resource is to develop quantitative information about its potential productivity. Volume tables are one way to estimate the magnitude and value of the resource.

But volume tables for native California hardwoods are scarce. Hornibrook and others<sup>1</sup> provided tables for four California hardwoods, and Wiant and Berry<sup>2</sup> derived volume and tariff tables for tanoak in Humboldt County, California. More recently, Pillsbury and Stephens<sup>3</sup> published volume and weight tables that apply to California's central coastal counties for tanoak, Pacific madrone, and other local hardwoods.

This note provides estimates of the volume of three species—Pacific madrone (*Arbutus menziesii* Pursh), tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.), and California black oak (*Quercus kelloggii* Newb.)—the hardwood species in California having the most economic promise<sup>4</sup> and the most volume.<sup>5</sup> Cubic volume tables are given for each species to treetop and to a 4-inch diameter top. Scribner board-foot volume tables are similar and are given to a 4-inch top.

The tables were developed from data recorded by an optical dendrometer and

are given in 1-inch diameter classes in the range of 3 to 30 inches. The tables apply to areas having high site quality in the north-central Sierra Nevada. Stands on such land correspond to Site Index<sub>55</sub> or above for California black oak.<sup>6</sup> As site index decreases below this value, use of these tables becomes increasingly risky.

## STUDY ENVIRONMENT

The study site was located on and near the Challenge Experimental Forest in Yuba County, California. Here, because of a combination of high site quality and plentiful rainfall, extensive stands of tanoak and Pacific madrone have developed, after severe disturbance, chiefly fire. California black oak often is a significant component of mixed hardwood stands of the three species. Tanoak, Pacific madrone, and California black oak also are found as single trees, in clumps, or in groves, often intermingled with conifers native to the area.

The elevational range of the sampled trees lies between 2500 and 3200 ft (760 and 976 m). Summers are hot and dry, and winters cool and wet. The average midsummer maximum temperature (43-year record) is 90° F (32° C); the midwinter minimum is 30° F (-1° C). The growing season is about 200 days. Annual precipitation, also based on 43 years of record, averages 68 inches (1727 mm),

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Local volume tables for Pacific madrone (*Arbutus menziesii* Pursh), tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.), and California black oak (*Quercus kelloggii* Newb.), developed from data recorded by an optical dendrometer, are presented by 1-inch diameter classes in the range of 3 to 30 inches. Cubic volume tables are given for each species to treetop, and to a 4-inch diameter top. For Scribner board-foot volume, a similar table to a 4-inch top is provided. The tables apply to trees in the northern Sierra Nevada and, possibly, in the southern Cascade Range where site quality generally is good; corresponding, for example, to Site Index<sub>55</sub> for California black oak.

*Retrieval Terms:* Pacific madrone, tanoak, California black oak, volume tables



**Figure 1**—California black oak and tanoak trees with gently tapering boles on the Challenge Experimental Forest, Yuba County, California.

with about 98 percent falling between October and May.

On the Experimental Forest, the soil is deep, well-drained, quite fertile, reddish in color, and of clayloam-clay texture. Principal established soil series in the area are Sites, Aiken, Josephine, and Tish Tang. These series are found extensively throughout the Sierra Nevada, Cascade, and Coast Ranges at low to middle elevations.

Stand age ranged from 42 to 120 years in 1975, when this study began. Nearly all trees became established as sprouts. At a breast-height age of 60 years and mean height of 70 feet (21 m), site index for California black oak is 60 at a base age of 50 years.<sup>6</sup> Measures of site index are not available for tanoak and Pacific madrone.

On the Experimental Forest and surrounding area, these hardwood species typically have the form of trees growing

in a forest, as contrasted with those growing alone or as a single clump in an open field. Such open-grown trees may develop crown widths equal to or even larger than tree heights. Crown widths of trees on the Experimental Forest rarely exceed one-half of tree height, with one-third being more common. Even in the forest environment, however, the more open-grown trees—especially Pacific madrone and California black oak—can develop forks.

Tree height and form vary with topography and stand density. Trees in dense stands or growing in draws or ravines often are straight and tall with gently tapering boles (*fig. 1*). Trees in larger openings or on ridgetops often are shorter and have greater taper. Tree heights also vary with aspect, as has been shown for California black oak.<sup>7</sup>

A load of hardwood logs from the north-central Sierra Nevada often con-

tains a fairly wide range of diameters, including those from both large and small trees. Currently, logs are graded by a local system that uses a few simple grades and log weights. Standard hardwood factory log grade rules have not yet been applied to any extent for California hardwoods. Nevertheless, one experienced buyer of California black oak logs stated that a typical mix of logs would be 33 to 40 percent factory logs, 40 to 50 percent construction logs, and the remainder chip logs. Current market conditions, however, result in a variety of uses. When the market is strong, parts of construction-grade logs are used for blocking, large construction timbers, and pallet stock; when weak, some construction-grade logs become chip logs.

For tanoak, the percentage distribution by grade, although unknown, may be similar to California black oak, or even reflect a slightly higher proportion of factory-grade logs and construction-grade logs; for Pacific madrone logs, the average quality probably would be lower than for California black oak logs, because of crook and sweep.

## SAMPLING

Because growth and form of Pacific madrone, tanoak, and California black oak are sensitive to relatively minor changes in stand density and topography, a large and well-distributed sample was necessary to quantify accurately the amount of wood in trees in the area. Trees were sampled throughout the Experimental Forest and adjacent area and measured precisely by the Barr and Stroud optical dendrometer.<sup>8</sup> Sampling followed a stratified random design and included a good representation of species, diameters, and topographic settings. Stand tables by 4-inch (10-cm) diameter classes were constructed for each species as sampling progressed to aid in obtaining a representative and well-distributed sample.

Altogether, 333 trees from 3 to 30 inches (8 to 76 cm) in diameter were measured with the optical dendrometer. Sample size was: Pacific madrone, 85 trees; tanoak, 144; and California black

oak, 104 trees. The proportions of forked trees were 18 percent for madrone, 16 percent for California black oak, and none for tanoak. These proportions are similar to those for forked trees in natural stands in the area.

## BARK THICKNESS

To estimate the amount of solid wood in each tree, bark thickness was determined for each species and size of tree. It was measured on 136 trees in the diameter range of 4.8 to 40.0 inches (12 to 102 cm) by chopping into the bark at diameter-at-breast-height (d.b.h.) on opposite sides of each tree.

## TREE VOLUME

Dendrometer readings were recorded at stump height, d.b.h., midway between d.b.h. and base of live crown, near base of live crown, midway in crown, and at top of tree. Abrupt changes in bole diameters, often caused by large branches or forking, required many additional measurements. Every tree bole was defined by at least six measurements. Multiple-forked trees, however, required up to 14 measurements, with several along each limb beyond the fork to terminal end of upright stems, and to about a 2-inch (5-cm) end diameter for laterals. In many instances, the bases of live crowns were poorly defined because crowns were one-sided. Abrupt changes in taper often were noticed here. For these reasons, measurements at bases of live crowns often were omitted.

Tree data were processed by the STXMOD computer program, which provides an efficient and accurate method for deriving various descriptors of standing trees, especially volume.<sup>9</sup> Volumes were computed for each species for different utilization standards. These standards were (1) cubic foot volume of main bole and major forks to top of tree (0-inch top) less a 1-ft (30-cm) stump, (2) cubic foot volume of main bole and major forks to a utilized top (4 inches or 10 cm in diameter) less a 1-ft stump, and (3) Scribner board-foot volume of main

bole and major forks to a 4-inch (10-cm) top. Four inches (10 cm) was selected as the utilized top because results of a local survey showed that this value currently was being used most and would continue to be in the future. For Scribner values, the normal Scribner rule has been extrapolated from a minimum 8-inch (20-cm) diameter to apply to approximately a 4-inch (10-cm) minimum. Defect, including crook and sweep, was considered minor and did not enter into volume calculations. Minimum log length was 8.0 ft (2.4 m).

## TREE HEIGHT

Tree heights were provided by the STXMOD program. Total height included the length of the main stem plus 1 ft (30 cm) for stump height.

## RESULTS AND DISCUSSION

### Bark Thickness

Graphs of bark thickness plotted against d.b.h. indicated a curvilinear relationship for the three species studied. This relationship was tentatively expressed in three mathematical equations and examined for goodness-of-fit. A computer-based least-squares curve-fitting technique was used. The most representative equation relating average single-bark-thickness to d.b.h. for each species was the following:

$$Y = a + bX + cX^{-1}$$

in which

Y = average single-bark thickness in inches and

X = d.b.h. in inches (*fig. 2*)

Best-fit equations by species were these:

Pacific madrone

$$Y = -0.1693 + 0.0219X + 1.2813X^{-1}$$

Tanoak

$$Y = 0.9532 + 0.0086X - 4.2156X^{-1}$$

California black oak

$$Y = 1.0377 + 0.0102X - 7.0044X^{-1}$$

Correlation coefficients, significant at the 1 percent level, by species, were 0.74 for Pacific madrone, 0.73 for tanoak, and 0.84 for California black oak.

On Pacific madrone, sloughing prevents bark from becoming much thicker than 0.6 inches (1.5 cm). On tanoak, bark thickness increased as diameter increased, with the increase becoming smaller after about 12 inches (30 cm). Increases of bark thickness for California black oak showed a trend similar to tanoak.

### Tree Volume

After plotting indicated the general volume-d.b.h. curve, the best mathematical expression of it was determined by a least-squares curve-fitting procedure similar to that used for bark thickness. The most representative regression equation relating cubic volume to diameter was the following:

$$\log \text{ volume} = a + b \log \text{ d.b.h.}$$

Because variation in volume increased with increasing diameter, log d.b.h. was used to weight the regressions. The best expressions of the cubic volume-d.b.h. relationships to a 0-inch top were these:

Pacific madrone

$$\log Y = -1.4049 + 2.5298 \log X$$

Tanoak

$$\log Y = -1.3237 + 2.3612 \log X$$

California black oak

$$\log Y = -1.1981 + 2.3329 \log X$$

in which

Y = volume in cubic feet, and

X = d.b.h. in inches

Correlation coefficients, significant at the 1 percent level, by species, were 0.97 for Pacific madrone, 0.99 for tanoak, and 0.99 for California black oak.

For cubic-foot volume to a 4-inch (10-cm) top, the amount of wood excluded originally was thought to be proportional to diameter. The log-log equation, however, gave a poor fit; in fact, the estimated equation for the 4-inch (10-cm) top crossed that of the 0-inch top. Attempts

to combine the two equations did not give plausible results. This was because the log-log equation was not sufficiently flexible and forced a proportional relationship between the 0-inch and 4-inch volumes. Close examination indicated that the relationship was not proportional, but roughly constant. Linear regressions of volume difference between 0-inch and 4-inch (10-cm) values on d.b.h. indicated slope coefficients that did not differ significantly from zero ( $p = 0.05$ ). And this was true for all three species. Calculations indicated that the mean volume differences between volumes to 0-inch tops and 4-inch (10-cm) tops for each species to be 0.73 ft<sup>3</sup> (0.02 m<sup>3</sup>) for Pacific madrone, 0.96 ft<sup>3</sup> (0.03 m<sup>3</sup>) for tanoak, and 1.27 ft<sup>3</sup> (0.04 m<sup>3</sup>) for California black oak. A useful general rule of thumb, then, is that cubic volume to a 4-inch (10-cm) top is about 1 ft<sup>3</sup> (0.03 m<sup>3</sup>) less than that to a 0-inch top. The mathematical expression of the relationship between cubic volume to a 4-inch (10-cm) top and d.b.h. was the following:

$$\log \text{ volume} = a + b \log \text{ d.b.h.} - C$$

in which  $C$  = the mean volume difference between utilization standards.

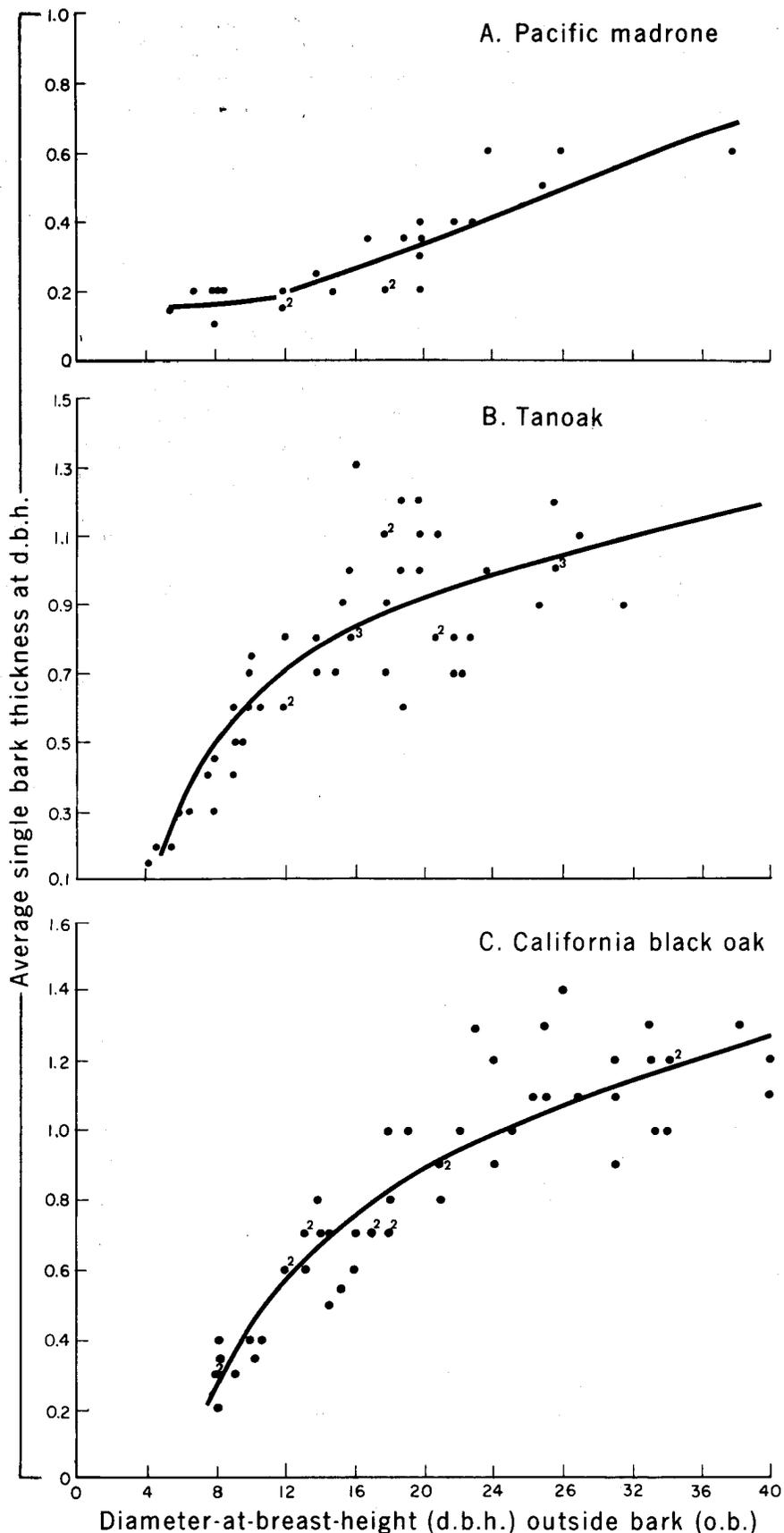
Correlation coefficients, significant at the 1 percent level, by species, were 0.97 for Pacific madrone, 0.98 for tanoak, and 0.99 for California black oak.

The most representative Scribner volume equation for the three species proved to be the following:

$$\text{volume} = a(\text{d.b.h.} - d) + b(\text{d.b.h.} - d)^2 + c(\text{d.b.h.} - d)^3$$

in which  $d$  = the estimated d.b.h. at which each species has zero board-foot volume.

For Pacific madrone the estimated d.b.h. was 5.5 inches (13 cm), for tanoak 5.0 inches (14 cm), and for California black oak 5.0 inches (13 cm). To control the curve in the region of zero volume, it was necessary to define the estimated d.b.h.'s and use them in the regression equations. Estimating each of the critical d.b.h.'s separately from the regression



**Figure 2**—Bark thickness as related to diameter-at-breast-height (d.b.h.) on the Challenge Experimental Forest, Yuba County, California: (A) Pacific madrone, (B) tanoak, and (C) California black oak.

was necessary. The best expressions of the Scribner board-foot volume -d.b.h. relationships to a 4-inch top were these:

Pacific madrone

$$Y = -0.0494X + 1.3078X^2 + 0.0115X^3$$

Tanoak

$$Y = 2.1229X + 0.5162X^2 + 0.0197X^3$$

California black oak

$$Y = 0.5319X + 1.1302X^2 + 0.0106X^3$$

Correlation coefficients, significant at the 1 percent level, by species, were 0.93 for Pacific madrone, 0.98 for tanoak, and 0.98 for California black oak.

Volume tables by 1-inch diameter intervals for three utilization standards are provided for Pacific madrone, tan-

oak, and California black oak (tables 1, 2, 3). For each of the tables, the root mean square error of predicted tree volumes are shown as footnotes. These values are equal to or slightly below similar values in other volume tables used currently.<sup>10</sup>

### Tree Height

When height is plotted against d.b.h., the relationship formed is a useful descriptor of the trees. Heights were tested in a manner similar to that for volume and diameter. The most representative equation relating total tree height (0-inch top) to d.b.h. for all species was the following:

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

in which

Y = height in feet, and

X = d.b.h. in inches

This equation, like the volume tables, applies to trees up to 30 inches (76 cm) d.b.h. Projection beyond 30 inches is not recommended because of the small sample size of larger trees. Best-fit regression coefficients were these:

Pacific madrone

$$Y = 20.51 + 4.49 X - 0.068X^2$$

Tanoak

$$Y = 9.62 + 6.87X - 0.140X^2$$

California black oak

$$Y = 24.59 + 5.33 X - 0.096X^2$$

Correlation coefficients, significant at the 1 percent level, by species, were 0.81 for Pacific madrone, 0.89 for tanoak, and 0.86 for California black oak.

Table 1—Local volume table for Pacific madrone to three utilization standards, Challenge Experimental Forest, California

Diameter-at-breast-height (inches)	Utilization standard		
	0-inch top <sup>1</sup> (ft <sup>3</sup> )	4-inch top <sup>2</sup> (ft <sup>3</sup> )	4-inch top <sup>3</sup> (board-feet Scribner)
3	0.6	—	—
4	1.3	0.6	—
5	2.3	1.6	—
6	3.7	3.0	—
7	5.4	4.7	2.9
8	7.6	6.9	8.2
9	10.2	9.5	16.3
10	13.3	12.6	27.3
11	17.0	16.3	41.2
12	21.2	20.4	58.1
13	25.9	25.2	78.1
14	31.2	30.5	101.2
15	37.2	36.5	127.4
16	43.8	43.1	157.0
17	51.0	50.3	189.0
18	59.0	58.3	226.3
19	67.6	66.9	266.1
20	77.0	76.3	309.4
21	87.1	86.4	356.4
22	98.0	97.3	407.0
23	109.6	108.9	461.5
24	122.1	121.4	519.7
25	135.4	134.7	581.8
26	149.5	148.8	647.9
27	164.5	163.8	718.1
28	180.4	179.7	792.3
29	197.1	196.4	870.7
30	214.7	214.0	953.4

Root mean square error of predicted tree volumes are:

- <sup>1</sup> 6.67
- <sup>2</sup> 6.86
- <sup>3</sup> 48.07

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

Diameter-at-breast-height (inches)	Utilization standard		
	0-inch top <sup>1</sup> (ft <sup>3</sup> )	4-inch top <sup>2</sup> (ft <sup>3</sup> )	4-inch top <sup>3</sup> (board-feet Scribner)
3	0.6	—	—
4	1.3	0.3	—
5	2.1	1.1	—
6	3.3	2.3	2.7
7	4.7	3.7	6.5
8	6.4	5.4	11.5
9	8.5	7.5	18.0
10	10.9	9.9	26.0
11	13.7	12.7	35.6
12	16.8	15.8	46.9
13	20.3	19.3	60.1
14	24.1	23.1	75.3
15	28.4	27.4	92.5
16	33.1	32.1	112.0
17	38.2	37.2	133.8
18	43.7	42.7	158.1
19	49.6	48.6	184.9
20	56.0	55.0	214.5
21	62.9	61.9	246.8
22	70.2	69.2	282.0
23	77.9	76.9	320.3
24	86.2	85.2	361.8
25	94.9	93.9	406.5
26	104.1	103.1	454.6
27	113.8	112.8	506.2
28	124.0	123.0	561.5
29	134.7	133.7	620.5
30	145.9	144.9	683.4

Root mean square error of predicted tree volumes are:

- <sup>1</sup> 4.95
- <sup>2</sup> 5.15
- <sup>3</sup> 32.11

Table 3—Local volume table for California black oak to three utilization standards, Challenge Experimental Forest, California

Diameter-at-breast-height (inches)	Utilization standard		
	0-inch top <sup>1</sup> (ft <sup>3</sup> )	4-inch top <sup>2</sup> (ft <sup>3</sup> )	4-inch top <sup>3</sup> (board-feet Scribner)
3	0.8	—	—
4	1.6	0.3	—
5	2.7	1.4	—
6	4.1	2.8	—
7	5.9	4.6	5.7
8	8.1	6.8	12.1
9	10.7	9.4	20.9
10	13.6	12.3	32.2
11	17.0	15.7	46.2
12	20.9	19.6	62.7
13	25.2	23.9	82.0
14	29.9	28.6	104.1
15	35.1	33.8	129.0
16	40.8	39.5	156.8
17	47.0	45.7	187.5
18	53.7	52.4	221.9
19	61.0	59.7	258.1
20	68.7	67.4	298.2
21	77.0	75.7	341.4
22	85.8	84.5	387.9
23	95.2	93.9	437.8
24	105.1	103.8	491.0
25	115.6	114.3	547.8
26	126.7	125.4	608.1
27	138.4	137.1	671.9
28	150.6	149.3	739.5
29	163.5	162.2	810.8
30	176.9	175.6	885.8

Root mean square error of predicted tree volumes are:

<sup>1</sup> 5.60

<sup>2</sup> 5.73

<sup>3</sup> 36.04

## NOTES

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<sup>8</sup>Trade names are used for information only; no endorsement by the U.S. Department of Agriculture is implied.

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