Demand for eucalyptus wood products since the 1970s has led to the management of some blue gum stands. Being able to make reliable estimates of total wood volume is essential in managing these stands.

Wood volume equations for central coast blue gum

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Owners and managers of blue gum eucalyptus stands will be able to use the equations to estimate the total wood volume for paper chips, biomass chips, or fuelwood. The equations were developed specifically for California's central coast.

In the late 1800s several thousand acres of eucalyptus (principally blue gum, *Eucalyptus globulus*) were planted along the central coast. The U.S. Forest Service estimates that there are now about 96,000 acres of mature eucalyptus in California. Many of these plantings have been left unmanaged because of little demand for eucalyptus wood products. Since the 1970s, however, the demand for eucalyptus fuelwood has increased, and some stands are now being managed for wood products.

To manage timber stands, it is important to know their wood volume. The usual method is to measure trees and refer to a volume table, but there has been no reliable table for eucalyptus species in California. In 1974, the California Department of Forestry developed a volume table for blue gum in Jackson State Forest. This table presents data for windbreak trees in board feet and cubic feet to a 6-inch top by number of merchantable logs. It is inadequate for estimating total wood volume of blue gum, as needed for paper chips, biomass chips, or fuelwood. We therefore conducted a study to develop a table that forest managers could use to estimate wood volume in mature eucalyptus stands growing along California's central coast.

Such a table may also be used to estimate wood volume in new plantations. A Cooperative Extension survey found that more than 1,000 acres of eucalyptus were planted in 1985. Managers of these plantations will need to estimate wood volume as their stands mature.

Procedures

Our study took a total of 358 individual tree observations from five eucalyptus stands of 40 to 300 acres. Blue gum was the only species sampled. Samples included a full range of diameters and heights at each location. Edge trees were not sampled to avoid abnormal growth patterns.

Site locations provided a diversity of stand types, ages, climatic conditions, diameters, and heights from which to develop a representative volume table for the central coast:

Point Pinole. An even-aged blue gum stand in Contra Costa County east of San Francisco.

El Granada . A mixed-age, 300-acre stand in San Mateo County, about a mile inland from the coast.

Aromas. A predominantly second-growth stand under intensive even-age management in Monterey County, approximately 11 miles from the coast.

Montana de Oro. A 60- to 80-year-old, 200-acre stand along the coast in San Luis Obispo County.

Nipomo. An even-aged, second-growth stand from stump sprouts in southern San Luis Obispo County, about 10 miles inland.

Volume equations

Wood volume equations are commonly developed from measurements of tree height and diameter at a number of points along the main stem. Volume is calculated using Smalian's formula [Volume = $(A_1 + A_2)\frac{L}{2}$. Volume is cubic-foot volume, A_1 and A_2 are the cross-sectional areas of the ends of the segment in square feet, and L is the segment length in feet.]

Total tree volume is found by adding the volumes of individual log sections in a tree. Tree volumes are then correlated with height and diameter measurements by means of a regression analysis. The regression analysis generates coefficients for volume equation variables. The equation that results is used to construct a volume table. This table can be used by forest managers to estimate wood volume in a stand.

We used a multiple regression of cubic volume versus diameter at breast height (dbh) and total height to obtain both inside and outside bark volume equations. The variables of dbh, total height, and cubic volume were expressed in English and metric units.

Measurements

In this study, we used two measurement methods to collect volume data from the sample trees: a cut tree and a standing tree method.

Cut tree method. We measured dbh for individual trees in a stand. Trees were felled and total height was measured with a tape. Diameter outside bark was measured at various heights on the tree; usually at least one diameter was taken every 3 meters. Dbh was measured to the nearest 0.1 centimeter and total height to the nearest 0.1 meter. Volume of the main stem was calculated from a 1-foot (30.5-cm) stump to a 2-inch (5-cm) merchantable top. Where main forks occurred and there was no central leader, both sides of the fork were meas-

ured. Side branches were not measured. This method was used to measure a total of 253 trees.

Standing tree method. At some locations (Aromas, Montana de Oro, and Nipomo), we could not obtain permission to cut large numbers of sample trees. We therefore used a simple linear regression equation relating standing tree volume to cut tree volume. This method was developed at California Polytechnic State University, San Luis Obispo, by N. H. Pillsbury, J. A. Stephens, and M. L. Kirkley. Dbh and stump diameter at 1 foot (0.3 m) of 105 standing trees were measured. Total height, section lengths, and upper stem diameters were then obtained with a Relaskop, an optical tree-measuring instrument. Segment volumes were computed from the Relaskop coordinates and diameter measurements using Smalian's formula.

To develop the relationship between volumes obtained by the cut and standing tree methods, we measured a subsample of 25 trees while they were standing and again later after they were felled.

Since it is useful to know inside-bark volume, especially for pulp chips, bark measurements were made on a subsample of 98 cut trees. An inside-bark versus outside-bark regression equation was developed from these measurements. This equation was then used to calculate inside-bark diameters at upper stem points on trees measured by the standing method.

Calculation of equations

As a first step, to pool the data, the cut tree volume was regressed on the standing tree volume for the 25-tree subsample where both measurement techniques were used. The relationship was highly significant, allowing us to pool the two data collection methods.

Next, outliers from the pooled data set were removed when they exceeded three standard deviations from the mean value. This evaluation removed a total of nine trees (about 2.5%).

Finally, a logarithmic regression of cubic volume versus dbh and total height was used to obtain both inside- and outside-bark volume equations. Of the 349 trees used in the outside-bark analysis, data were available for 228 used in the inside-bark analysis. Table 1 shows the four volume equations calculated.

Conclusions

The volume of an individual blue gum tree can be calculated using the volume equations developed in this study. For example, a tree may have a dbh of 8 inches, and a total height of 75 feet, which means that it would have 10.3 cubic feet outside bark to a 2-inch top.

Tree volume (outside bark) = $0.0015658*(8)^{1.86903}*(75)^{1.13556}$ = 10.3 cubic feet

Another use for these volume equations might be to construct a volume table for a variety of height and diameter combinations. Table 2 shows how such a table would be constructed for total cubic foot volume outside bark.

The relationships developed in this study are applicable only to trees ranging in dbh from 4 to 39 inches (10 to 100 cm), and in total height from 33 to 165 feet (10 to 50 m), in the central coast area from Contra Costa County south to southern San Luis Obispo County.

With reliable volume equations, managers of blue gum stands can accurately estimate standing tree volume by obtaining dbh and total height of trees in plot samples. An accurate assessment of volume will provide a more realistic estimate of the value of crop trees when harvested or of the value they might add to the land. With the growing threat of the longhorned borer, *Phoracantha semipunctata* (Fabr.) (*California Agriculture*, July-August 1986), another potential use of this improved volume information is in maintaining tree health and vigor of stands through patchcutting, coppice silviculture, and fuelwood marketing.

TABLE 1. Standard volume equations for blue gum (*Eucalyptus globulus*) on California's central coast

Units	Volume equation	N	%R^2
English:			
Outside-bark	$Vol = 0.0015658(D)^{1.86903}(H)^{1.13556}$	349	99.4
Inside-bark	$Vol = 0.0010282(D)^{1.93943}(H)^{1.12009}$	228	98.0
Metric:			
Outside-bark	$Vol = 0.0000299(D)^{1.86903}(H)^{1.13556}$	349	99.4
Inside-bark	$Vol = 0.0000181(D)^{1.93943}(H)^{1.12009}$	228	98.0

where:
Vol = cubic volume from a 1-ft (0.3-m) stump to a 2-in (5-cm) merchantable top in cubic feet or cubic meters.
D = diameter at breast height, outside bark in inches or centimeters.
H = total height from base to top in feet or meters.
N = number of observations.
%R^2 = multiple correlation coefficient.

TABLE 2. Blue gum eucalyptus volume table for California's central coast

	Total height in feet:														
DBH	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**	**170**
inches	..... *cubic feet*														
4	1	1	2	2	3	3	3	4	4	5					
6	2	3	4	5	6	6	7	8	9	10					
8	4	5	6	8	10	11	13	14	16	18	19				
10	6	8	10	12	14	17	19	22	24	27	29	32			
12		11	14	17	20	24	27	30	34	37	41	45	48	52	
14		14	18	23	27	31	36	41	45	50	55	59	64	69	74
16		18	24	29	35	40	46	52	58	64	70	76	82	89	95
18			30	36	43	50	58	65	72	80	87	95	103	111	118
20			36	44	53	61	70	79	88	97	106	116	125	135	144
22			43	53	63	73	84	94	105	116	127	138	150	161	172
24				62	74	86	99	111	124	137	150	163	176	189	203
26				72	86	100	114	129	144	159	174	189	204	220	236
28					99	115	131	148	165	182	200	217	235	253	271
30					112	131	150	169	188	207	227	247	267	287	308
32					127	148	169	190	212	234	256	279	301	324	347
34					142	165	189	213	237	262	287	312	337	363	389
36					158	184	210	237	264	291	319	347	375	404	433
38						203	233	262	292	322	353	384	415	447	479
40						224	256	289	321	355	389	423	457	492	527

NOTES: The equation for this table is: Volume (cubic feet) = 0.0015658 x DBH (in)^1.86903 x Tot Ht (ft)^1.13556.
Data shown are gross cubic foot volumes (outside bark) to a 2-inch top.

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