Tree Volume Equations for 10 Urban Species in California[1]

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Abstract: *This study is the first phase of a three-phase urban forest utilization project at California Polytechnic State University, San Luis Obispo. Selected samples of 10 urban species were carefully measured in order to develop tree volume equations. These species include Chinese elm, holly oak, camphor tree, jacaranda, American sweet gum, Monterey pine, blue gum, Monterey cypress, acacia (golden wattle), and carob. Equations for species in three regions of California will ultimately be developed. The results of two regions are completed and reported here. Local and standard volume equations were developed for use by urban foresters needing to calculate tree volumes.*

Cities throughout California are facing tremendous challenges in funding and sustaining urban forestry programs. Some of the costliest operations are tree care and removal, and disposal of wood residues. Urban foresters can no longer afford to operate in a manner that treats urban forest wood residues as a costly disposal problem. Recycled uses for these wood residues could generate significant savings in handling and landfill costs, costs that are growing rapidly. Even more attractive is the prospect that these wood residues could actually generate net revenues if markets for energy and high-quality woods could be identified and developed.

In order to move urban forestry programs from the costly status quo to a more sustainable state, where wood residues are valued, a more comprehensive inventory of the urban forest is required. Many communities have developed a "street tree inventory" which typically describes the location and health condition of trees by species. Such an inventory is an important first step in understanding the composition of the urban forest. However, much more information is needed to begin managing the urban forest in a sustainable fashion.

For an inventory to serve as a management tool, it should describe the structure, composition and "volumes" of the urban forest with reasonable accuracy. To achieve these results, data must be collected on tree size (i.e., diameter at breast height and total height), and age (date planted) in addition to species, location, and health or damage rating. Data on maintenance activities, costs, and timing would make the inventory even more useful. Because developing such comprehensive inventories requires a considerable investment in time and resources, standardized methods are needed to assist urban foresters in data collection, analysis, and inventory assessment.

Overview of Goals of the Urban Forest Utilization Project

This section is presented for the reader to understand how this study fits into the multi-year Urban Forest Utilization project and its role in enhancing the sustainability of urban forests. The goal of this project is to conduct a series of volume and utilization studies of the major urban forest species to further the

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[1]A modified version of this paper was presented as a video ("Cal Poly Urban Forest Utilization Project") at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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development of management inventories in each California city for the purpose of promoting sustainable urban forests. To accomplish this goal, the project has been broken down into three phases:

- **Phase I** - Development of Tree Volume Predictions - The first phase involves biometric studies to enable the urban forester to predict the volume of various tree species for the future sustainable urban forests (Pillsbury and Thompson 1995). Detailed measurements are made of sample trees in order to create a statistical model for each predetermined species. Volume prediction equations are developed. It is this phase that is presented in this report. Results of Phases II and III will be reported separately.

- **Phase II** - Development of Community Forest Inventories - Using the prediction models from Phase I, cities can expand their current *street tree inventory* and begin to create a *management inventory*. Collecting data on tree diameter in addition to data on species, location, planting date, and tree condition is all that is necessary for estimating total inventory. Other data on maintenance activities, tree heights, useful life, growth rate, value, and product utilization are needed to create a *comprehensive inventory*. A comprehensive inventory can be used to manage by rotation and develop product and sustainable budgets (see Phase III).

- **Phase III** - Information Management for Budgeting and Product Development - As urban forest management inventories are established, a whole range of management functions can be enhanced and new opportunities explored. Cities can use such inventories to design the urban forest to normalize its species composition and structure; better plan and organize planting, care, trimming and removal activities; and establish new uses and markets for the regularized flows of wood residues. Combined with a GIS database, new ways of integrating the urban forest into the city infrastructure and interacting with the public can be developed.

Study Design and Criteria

As discussed earlier, the objective of this study is to develop equations that can be used to predict or estimate tree volume for urban forest species from various geographical regions and communities in California. The following sampling design was used to develop prediction equations for urban forest species in California.

Selecting Communities with Urban Forestry Programs

California was first divided into three broad geographic regions: Southland, Coastal, and the Central Valley (*fig. 1*). The rationale for this initial stratification is to ensure that species selected represent major climatic conditions found in the State.

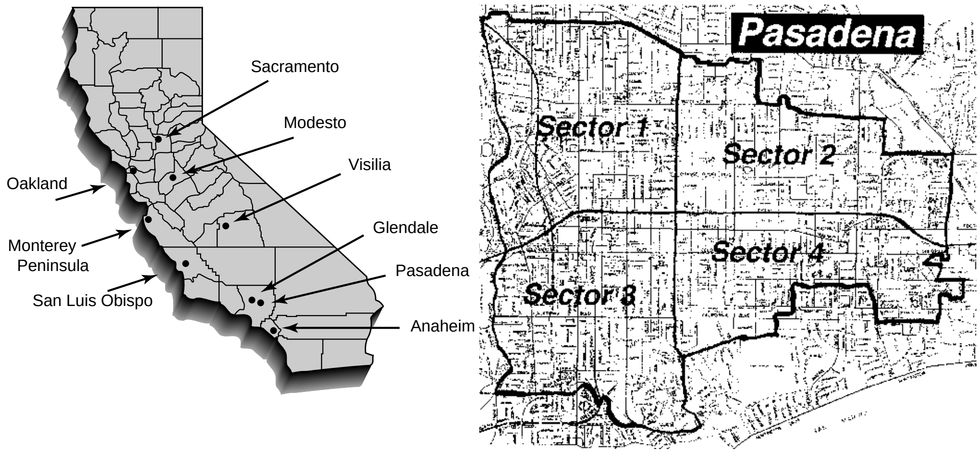

Figure 1—Cities studied for volume table development of urban forest species.

Three communities in each geographic region were identified that could benefit from an evaluation of the volume potential of their urban forest. Communities were selected on the basis of the following criteria:

1. The community must have an active urban forestry program. The program must be prominently visible in the cities' organizational structure and have an identified urban forester in charge.
2. The urban forestry program must be able to demonstrate a commitment to long-term urban forest development and be on the road to sustainability. The four core elements of sustainability are: species selection and diversity, inventory and landscape planning, tree care and wood utilization, and public relations and support. For more information on sustainability, see *The Elements of Sustainability in Urban Forestry* by Thompson and others (1994).
3. The community must at least have the beginnings of a street tree inventory. The inventory must be computer-based and accessible for future studies discussed in Phase II, Development of Community Forest Inventories.
4. Within each geographic area of the State, urban foresters must agree on the species that will be sampled.
5. Communities having large, old trees that are facing removal in the next 5-10 years were favored because prediction equations would be more relevant in the near term.

Communities selected for study are shown below:

Region	*Community*	*Year of sample*
Southland	Anaheim	1994
	Glendale	1994
	Pasadena	1994
Coastal	San Luis Obispo	1995
	Monterey Peninsula	1995
	Oakland	1995
Central Valley	Modesto	1996
	Sacramento	1996
	Visalia	1996

Clearly many other communities could be included in the sample, and as the need and support arise, they can be added. The intent here is to provide specific information on selected communities from different parts of California rather than intensively sample in one or two cities. It is our hope that the value of these results will encourage equation development of additional species in the same or other communities. However, the information collected for the communities that were sampled will allow "preliminary" estimates of volume for other cities as well.

Species Selection

Five species in each geographic region were selected for study. Species were selected on the basis of the following criteria:

1. Species had to be well represented in each community of the geographic region. This was evaluated by urban foresters and from street tree inventories.
2. Trees marked for removal in the next decade were given higher priority. We decided that the prediction equations developed in this study should represent species most likely to be harvested in the near future, rather than species recently planted that will not be removed soon.
3. Species that attain larger sizes were favored in the selection process, as they provide greater volumes for use and represent greater savings of disposal costs.
4. Species were favored for selection that were of higher wood quality and value.
5. Five species were selected from each geographic region with the restriction that species not be duplicated among regions to increase the number of trees evaluated.
6. Species were ranked lower on the list if equations were available from other studies, even if the studies did not include trees from an urban environment. An example of this is coast live oak (*Quercus agrifolia*) which has been reported in several publications, including Pillsbury and Kirkley (1984).

The selection process involved much discussion among the authors and urban foresters from these communities, and many additional species were considered. The species selected, by geographic region, are as follows:

Region	*Species*	
Southland	Chinese elm	*Ulmus parvifolia chinensis*
	Holly oak	*Quercus ilex*
	Camphor tree	*Cinnamomum camphora*
	Jacaranda	*Jacaranda mimosifolia*
	American sweet gum	*Liquidambar styraciflua*
Coastal	Monterey pine	*Pinus radiata*
	Blue gum	*Eucalyptus globulus*
	Monterey cypress	*Cupressus macrocarpa*
	Acacia (golden wattle)	*Acacia longifolia*
	Carob	*Ceratonia siliqua*
Central Valley	Japanese zelkova	*Zelkova serrata*
	Southern magnolia	*Magnolia grandiflora*
	London plane	*Platanus acerifolia*
	Chinese pistache	*Pistacia chinensis*
	Modesto ash	*Fraxinus velutina* 'Modesto'

Procedures and Data Collection Methods

Sample Size

In similar volume studies [3] we found that a sample size of approximately 50 trees is the minimum number necessary to develop a statistically reliable estimate of the equation parameters. Based on these studies, a sample size of 50 trees per species was adopted.

[3]Full citations are provided in the References: Pillsbury 1994, Pillsbury and Pryor 1994, Pillsbury and Hermosilla 1993, Pillsbury and Pryor 1992, De Lasaux and Pillsbury 1988, Pillsbury and Pryor 1989, Pillsbury and others 1989, and Pillsbury and Kirkley 1984.

Geographic Stratification

Each geographic area is represented by three cities or communities, and the number of sample trees per species was proportioned among their urban forests. To further make certain that the sample design fully represents the geographic area, each community was stratified into three to five sectors of approximately equal area (in communities where species were widely spread), and trees were sampled equally among sectors. This design, illustrated in *fig. 1* for the City of Pasadena, ensured that all sectors were sampled with similar intensity.

Diameter Distribution

In addition to sample size and geographic stratification concerns, trees must be at least 5.0 inches dbh (diameter at breast height) and 15 feet tall to be included in the sample. Because volume is closely correlated to tree diameter, an accounting of diameters was kept. As trees were measured, their diameters were plotted on a d-line (diameter line). This was an easy method to be certain that the full range of tree sizes of each species was represented. In addition, we checked each sector carefully to be sure that representatives of the largest trees were included in the sample.

Tree Data Collected

The data collected for each sample tree are summarized in *table 1*. The variables collected are listed and discussed below.

Species

The common name was recorded on the data form. Trees having major defects, unusually large damaged areas, or that were abnormally shaped or pruned were not included in the sample.

Diameter at Breast Height

Diameters are used in volume equation development. Diameter at breast height outside bark (dbhob) was measured with a diameter tape at a point 4.5 feet above the ground on the uphill side. If the tree was leaning, the 4.5 feet were measured along the central stem axis. For trees that forked at breast height or lower, the tree was considered to be two trees; however, trees of this type were not included in the sample, unless otherwise noted. If forking occurred just above breast height, a single dbh measurement was made below joint swelling. This means that dbh measurements could vary anywhere from about 2 to 6 feet on the stem, although almost all measurements were at 4.5 feet. It is important that use of the equations presented later in this report follow these “rules” for greatest accuracy.

Diameter Outside Bark at 1 Foot

Diameter outside bark (dob) was also measured at 1 foot to compute the volume of the base segment. If butt swell was present, the measurement was taken where the tree taper was normal, usually no higher than 2 feet. A diameter tape was used.

Table 1—Data collected from urban tree species.

Characteristic	Units	Description	Used in development of equations by the authors	Data the urban forester will collect
A. Tree Information*:*				
Species	Code	A = Acacia (Golden wattle) BG = Blue gum C = Carob CA = Camphor CE = Chinese elm HO = Holly oak JA = Jacaranda LA = Liquidambar MC = Monterey cypress MP = Monterey pine M = Southern magnolia MA = Modesto ash CP = Chinese pistache LP = London plane Z = Japanese zelkova	Yes	Yes
Dbh	Inches	Diameter at breast height, to the nearest 0.1 inch.	Yes	Yes
Dob at 1 foot	Inches	Diameter to the nearest 0.1 inch.	Yes	No
Total height	Feet	Estimated total height to top of terminal leader.	Yes	Yes
Average crown diameter	Feet	Average of long and short axis, to the nearest foot.	Yes	No
Number and average length of terminal branches	No., Feet	Count of the number of terminal branches; average length determined by measuring a sample for average of long and short axis.	Yes	No
B. Tree Identification Information*:*				
Date	n/a	Date of field measurement.	Yes	Yes
Photo number	n/a	Roll number and photo number.	Yes	No
Tree location and tree number	n/a	Located by street address. If more than one tree at the same address, trees were numbered in the direction of increasing address numbers.	Yes	Yes

Total Height

Total tree height was measured from the tree base on the uphill side to the tip or tallest live portion of the crown. Heights of leaning trees were calculated using the vertical height to the tree tip and the angle of the bole. Heights are used in volume equation development. An example is shown in *figure 2a*.

Average Crown Diameter

Crown diameter was determined by averaging measurements of the long axis with a diameter taken at 90 degrees. Readings were taken with a 100-foot cloth tape. Data can be used to correlate with tree volume.

Number and Length of Terminal Branches

Terminal branches, 4 inches in diameter at the large end, were included in the calculation of tree volume. For each sample tree, 5 or 6 terminal branches were measured for length. In all cases, lengths were consistent within 2-3 feet, and an average was obtained. The total number of terminal branches was counted for each sample tree.

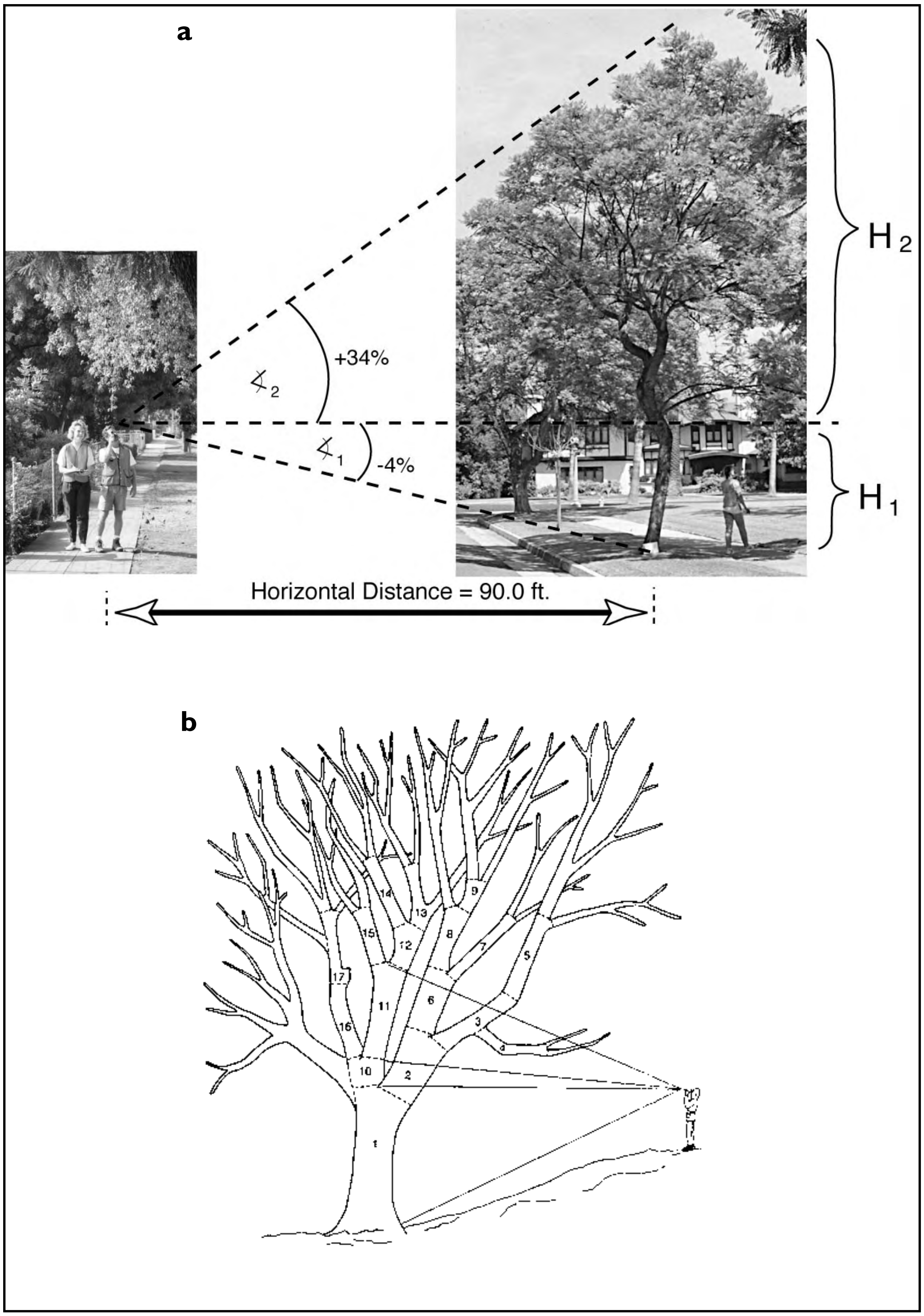

Figure 2—Tree height and segment measurement. (a) The use of Standard Volume equations (or tables) requires total tree height. A clinometer or abney can be used to measure the vertical angle to the tree top and base. For this example, total tree height (H_1 + H_2) is: ((4+34)x90)/100 = 34.2 ft. (b) Sample trees were measured on a segment-by-segment basis to determine volume. Numbers on tree indicate tree segments.

Tree Location and Number

Trees were located by house and street address. If more than one tree was growing at an address, the trees were numbered sequentially following the direction of house numbers.

Photo and Sketch

Each tree was photographed with a 35-mm camera using slide film. A placard was held to identify the tree. Also, as the segment data were collected, a sketch was drawn showing the relative location of each segment. This information was used for illustration and in a few cases when field notes were unclear.

Tree Volume Calculation

Any level of use or management involving the cutting and removal of urban trees requires that accurate volume prediction equations be used. Volume equations can be used to determine tree removal volume, inventory, and for growth and yield studies. Reliable estimates of urban tree volume depend, in part, on the accuracy of the equations developed. Also, they are more reliable within the geographic area from which the field data were collected; the greater the distance from the collection area, the less reliable.

For volume measurement, the branching pattern was defined on a segment basis. Segment length and the diameters at each end were measured using a Spiegel Relaskop (Pillsbury and Kirkley 1984). Segment length was determined from coordinates measured at both ends of each segment. Each tree was divided into segments based on four criteria:

1. Segments were defined as the distance from fork to fork in trees with very complex branching pattern, such as segment 11 in *fig. 2b*.
2. If a branch had a sweep or crook, segments were measured to obtain a straight log length such as in segments 3 and 5.
3. Segments were defined if abrupt changes in taper were apparent such as in segments 16 and 17.
4. If a tree had an excurrent growth form, such as liquidambar, the maximum segment length measured was approximately 10 feet.

If swelling was present on the stem, a common occurrence, relaskop diameter readings were taken slightly above or below the abnormality. A two-step process was used for branches not growing vertically. First the vertical distance between the ends was calculated on the basis of relaskop coordinates. Secondly, an angle, to the nearest 1 degree from horizontal, was measured with a clinometer, and segment length was computed. Segments growing less than 30 degrees from horizontal were measured by projecting their length to the ground and measuring it with a cloth tape held parallel to the branch angle.

Cubic foot volume was calculated for each tree using three equations for determining the cubic volume of a solid. The stump (base segment) was treated as a cylinder (equation 1), the tip was treated as a cone (equation 2), and the remaining segments were treated as a paraboloid frustrum, and Smalian's formula was used (equation 3).

$$V_1 = A_u L \qquad [1]$$

$$V_2 = \frac{L}{3}\left(A_b\right) \qquad [2]$$

$$V_3 = \frac{L}{2}\left(A_u + A_b\right) \qquad [3]$$

where:
V = volume outside bark in cubic feet to 0-inch top,
A_b = cross-sectional area outside bark at base in square feet,
A_u = cross-sectional area outside bark at top in square feet, and,
L = length of segment in feet.

Utilization Standards

Total tree volume includes the volume of all stem segments from ground level including terminal branches and bark. It does not include the volume of roots and foliage. A spreadsheet formulated in Microsoft Excel®[4] was developed to calculate individual tree volumes using Equations 1-3. Because markets for urban wood are limited, it is not known what branch or stem size will be needed by existing and developing wood manufacturing industries. For example, some companies might be equipped to handle large diameter, 8-foot bolts, while others may operate in the small mulching market. In order to provide estimates for a variety of uses, the spreadsheet was created to calculate wood volume in the following diameter size classes: less than 4 inches, 4-8 inches, 8-12 inches, 12-16 inches, 16-20 inches, greater than 20 inches as well as total volume. The average diameter of each segment was used to determine its diameter class. Further, these size classes were set as variables and can be changed to obtain volume proportions based on different diameter groupings. For instance, if one were interested in firewood potential, the volumes of all segments in the 4- to 8-inch and 8- to 12-inch diameter classes would be combined. Based on field measurements, the average percent volume for the segment diameter classes discussed above are shown in *figure 3*.

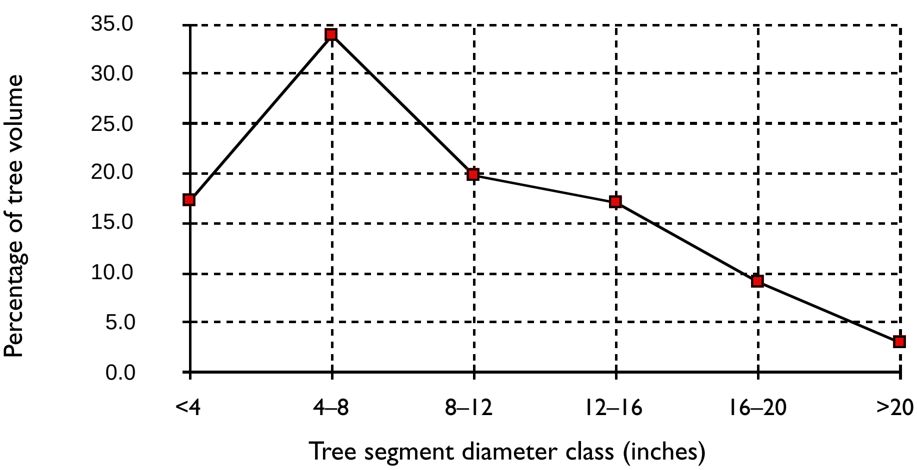

Figure 3—Approximate percentage of tree volume by diameter class for holly oak.

Volume Equations

Two types of equations are commonly used to predict tree volume, local and standard volume equations. Local volume equations use one variable, diameter at breast height (dbh), to estimate tree volume, while a standard volume equation uses both dbh and height. Including height in the equation generally provides a better estimate as it helps account for soil, climate, and some cultural variations. Because not all street tree inventories include height, both types of equations are presented here to provide flexibility for the user.

The relationship between volume and dbh and height is a power function that can be linearized as described by equations 4 and 5.

$$V = b_0 (\text{Dbh})^{b_1} \quad [4]$$

$$V = b_0 (\text{DBH})^{b_1} (\text{Ht.})^{b_2} \quad [5]$$

where:

V = volume outside bark in cubic ft,

Dbh = diameter outside bark at breast-height in inches,

Ht. = total tree height in feet, and,

b_i = regression coefficients.

Simple and multiple regression analysis (equations 4 and 5, respectively) were used to develop the volume prediction equations (*table 2*). A logarithmic transformation of volume, dbh, and height was used to linearize the data and to equalize the variation about the regression line. The data were converted to the logarithmic form to compute the regression coefficients b_0, b_1, and b_2. This is the normal procedure when fitting nonlinear tree volume equations because the logarithmic forms tend to reduce variance in homogeneous samples (Husch and others 1982).

Table 2—Local and standard volume equations for selected urban forest species

Species	Local Volume Equation	Adj. R^2	n	SE	Avg pct deviation	Pct aggregate difference
Blue gum	Vol (cf) = 0.055113 ($dbh^{2.436970}$)	0.968	50	1.27	18.6	0.6
Acacia	Vol (cf) = 0.048490 ($dbh^{2.347250}$)	0.938	50	1.24	15.8	-3.0
Monterey pine	Vol (cf) = 0.019874 ($dbh^{2.666079}$)	0.969	50	1.27	18.9	-1.7
Monterey cypress	Vol (cf) = 0.035598 ($dbh^{2.495263}$)	0.980	50	1.23	15.7	1.9
Carob	Vol (cf) = 0.066256 ($dbh^{2.128861}$)	0.910	50	1.29	18.9	-2.3
Camphor	Vol (cf) = 0.031449 ($dbh^{2.534660}$)	0.970	50	1.17	12.5	-1.2
Chinese elm	Vol (cf) = 0.028530 ($dbh^{2.639347}$)	0.903	50	1.22	16.6	-2.3
Holly oak	Vol (cf) = 0.025169 ($dbh^{2.607285}$)	0.938	50	1.24	17.0	-1.3
Jacaranda	Vol (cf) = 0.036147 ($dbh^{2.486248}$)	0.949	49	1.19	13.9	0.0
Liquidambar	Vol (cf) = 0.030684 ($dbh^{2.560469}$)	0.979	50	1.15	10.5	-0.5
Species	**Standard Volume Equation**	**Adj. R^2**	**n**	**SE**	**Avg pct deviation**	**Pct aggregate difference**
Blue gum	Vol (cf) =0.003089 ($dbh^{2.151822}$)($ht^{0.835731}$)	0.983	50	1.19	10.9	-1.0
Acacia	Vol (cf) = 0.014058 ($dbh^{2.186485}$)($ht^{0.467357}$)	0.976	50	1.14	14.5	-2.7
Monterey pine	Vol (cf) = 0.005325 ($dbh^{2.226808}$)($ht^{0.668993}$)	0.979	50	1.22	16.0	-1.1
Monterey cypress	Vol (cf) = 0.005764 ($dbh^{2.260353}$)($ht^{0.630129}$)	0.989	50	1.16	11.9	2.2
Carob	Vol (cf) = 0.008573 ($dbh^{1.795854}$)($ht^{0.926668}$)	0.933	50	1.24	17.8	-1.4
Camphor	Vol (cf) = 0.009817 ($dbh^{2.134803}$)($ht^{0.634042}$)	0.976	50	1.15	10.9	-1.3
Chinese elm	Vol (cf) = 0.010456 ($dbh^{2.324812}$)($ht^{0.493171}$)	0.915	50	1.21	14.8	-1.9
Holly oak	Vol (cf) = 0.004307 ($dbh^{1.821580}$)($ht^{1.062691}$)	0.976	50	1.15	10.4	0.3
Jacaranda	Vol (cf) = 0.011312 ($dbh^{2.185780}$)($ht^{0.548045}$)	0.956	49	1.17	12.7	0.1
Liquidambar	Vol (cf) = 0.011773 ($dbh^{2.315815}$)($ht^{0.415711}$)	0.982	50	1.13	9.2	-0.6

Note: For an explanation of terms used here, see the discussion in the text.

Tests of Equation Fit, Reliability, and Measures of Accuracy

There is no one measure of the adequacy of volume equations. We examined several of the more common tests to determine the overall fit and reliability of the equations. In *table 2*, several statistics are provided that help the reader understand the relative precision of the relationships that have been developed. *Standard Error of the Estimate* (SE) is the abbreviation used in these tables for this measure of reliability. The standard error of the estimate indicates, in volume units, the error associated with the mean volume of each species. *Average Percentage Deviation* measures the extent to which the individual observations of sample tree volume deviate from the regression surface. This percentage gives an idea of the amount by which any single calculated value (or value read from a volume table) will vary from the actual value. *Percent Aggregate Difference* is the percent difference between the sum of the predicted and the sum of the actual volumes for a given sample.

Error and Outlier Analysis

Concurrent with the development of the prediction equations, the data were carefully checked to determine whether measurement or recording errors were present. We developed computer programs to identify possible errors in diameter, height, and tree segment data. Tree volumes were checked by examining the standardized residual calculated for each tree. Even if a tree showed an unusual relationship between the dbh and height values and volume, the tree was checked against the sketch and photograph for legitimacy. After all checks were performed, only one tree was removed from the data set on the basis of these tests.

Other Measures

In addition to the reliability tests previously discussed, several other tests were conducted. These included analysis of the *F*-value, the root mean squared error (another measure of the residual variation), and plots of residuals to check for nonlinearity and nonconstant error variance. In no case did we find reason to believe a problem in the database existed.

Limitations of Equations

It must be emphasized that the measures of reliability and accuracy presented above pertain only to the accuracy of the equations in the context of the data used in their construction. Despite the efforts of the authors to develop and implement a sound sampling design and to carefully evaluate the results, there is still no guarantee that these equations and tables will always apply equally well to an independent sample. However, past experience has shown that equations developed by these rigorous measures will perform well, usually within 10-12 percent, if field procedures follow the methods outlined in this report. When a more accurate estimate is required, say in the case of sale or purchase of standing trees, the equations (or tables) should be checked against the measured volumes of a representative sample of trees obtained from the area of interest.

Volume equations will best represent the communities where the data were originally collected. To apply the equations in a different portion of the State runs the risk of unacceptable errors (Pillsbury and others 1995). The question of "how well will they do" in a new environment cannot be answered without additional study. Often equations are used out of their geographic area simply because they are the "best" equations available. Clearly the user takes the responsibility for the results.

Of the two types of equations presented, generally the standard volume equations (using both dbh and height) are considered more accurate, as the height variable adds more precision to the estimate. However, in the case of trees that have been recently topped, the correlation of dbh and height to volume will have been significantly altered. In this situation, the local volume equation (use of dbh only) may provide a better volume estimate.

Lastly, trees were not included in the sample when, through extensive trimming, the crown was virtually decimated or when trees were topped. Two options are possible for measuring trees cultured this way. First, the equations can be used, although error is introduced. Fortunately trees of this condition are infrequent and, if they are small, will represent little volume having little effect on the overall estimate. Secondly, the main stem diameter can be obtained by measuring what appears to be the average diameter. The stem height can be measured or approximated. To estimate its cubic-foot volume, use the equation [6] for a cylinder.

$$Volume = 0.005454D^2H \qquad [6]$$

where D is the average stem diameter in inches and H is the stem height (or length) in feet.

Application of Equations to an Independent Inventory

The following discussion outlines the steps necessary to conduct a field inventory for volume and an estimate for trees scheduled for removal from your urban forest.

Your field crews have input inventory data on street trees that show that 200 trees are scheduled for removal in the northeast part of your community during the next 3 years. The species involved are those for which equations have been developed.

Rather than cut and haul the wood to the landfill over a 3-year period, you decide to contact two area-wide hardwood manufacturers and obtain bids on the wood. This strategy, in addition to providing revenue for your urban forestry program, will also reduce the time frame to one summer and relieve the extra burden from your fully committed crews. You and the purchasers agree to sell the wood based on a measure of the cut trees; however, to provide a reasonable estimate of cubic foot quantity available for the bid, you perform the following steps.

1. Field verification: A quick verification of the information in your street tree inventory is needed. A crew is dispatched to check and update the database for location, species, and diameter, and if time is available, for total tree height. Field equipment needed are a diameter tape, clinometer, and a 100 foot tape. A written notice is left on the nearest premise advising residents of the project.
2. Diameter and height should be measured in accordance with the methods discussed in Procedures and Data Collection Methods section. The data should be kept separate by species.
3. Calculations: Use local or standard volume equations to estimate tree volumes. An example of how to obtain tree volume estimates for the equations and tables is presented here.

Use of Volume Equations

A holly oak was measured and found to have a 13.4-inch dbh and a total height of 30.5 feet. Substitute your data into the standard volume equation for holly oak from *table 2*, as follows:

1. Vol (cf) = 0.004307 ($dbh^{1.821580}$) ($ht^{1.062691}$)
2. Vol (cf) = 0.004307 ($13.4^{1.821580}$) ($30.5^{1.062691}$) = 18.4 cubic feet

If height data were not collected, be sure to use the local volume equation (from *table* 2), as follows:

1. Vol (cf) = 0.025169 (dbh $^{2.607285}$)
2. Vol (cf) = 0.025169 (13.4 $^{2.607285}$) = 21.9 cubic feet.

This approach is greatly simplified by setting up a spreadsheet with the regression coefficients referenced as absolute and the tree data referenced as relative.

Use of Volume Tables

Volume tables are normally arranged in diameter classes of 1 or 2 inches and height classes of 5 or 10 feet. Two options are possible, depending on your need. To obtain a rough volume estimate, you can either round diameter and height data to the nearest diameter and height class, respectively, or double interpolate the table to eliminate rounding error. Regardless of the method used, the process is repeated for each tree until finished. Next, volume estimates are summed by species, and again for all species. The proportion of volume by segment diameter can be estimated. An example for holly oak is shown in *figure 3*.

Concluding Remarks

As communities strive for sustainability of their urban forestry programs, increased attention must be paid to the wood resource of the urban forest. To manage for these values, comprehensive inventories and databases are needed. A new level of sophistication and commitment is necessary to build these inventories and to make use of them to further the program's goals.

The urban forester must be capable of properly measuring specific characteristics of a tree such as diameter, height, and age in order to use them in calculating the typical managerial measures (e.g., basal area, volume, and growth rates). These measures can then be combined with other quantitative and qualitative measures such as species, location, health and vigor rating, expected life, and past treatments to establish a database which will form the foundation for wood marketing, policymaking, and public relations activities.

Practicing urban foresters may have already had education and training in forest inventory as part of their bachelor's degree. However, the nuances of measuring native and exotic species in open-grown settings influenced by urbanization require special knowledge and training that is not typical of most forest measurement and inventory course work. To acquire the field and analytical skills needed for this work, urban foresters may need to continue their education through short courses, workshops, and field demonstrations. These continuing education experiences will also facilitate better networking between practicing urban foresters on a broad range of issues, concerns, and potential solutions.

Although considerable resources must be committed to designing and maintaining these comprehensive urban forest inventories, long-term benefits including a healthy urban forest that is both biologically and economically sound will more than justify the expense through improved forest management, regular maintenance, and new funding sources. It is these types of outcomes that the urban forester can point to as evidence of sustainable management.

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