Forest Service Handbook
Service Wide (WO)
Washington, DC

Forest Service Handbook 2409.12 – Timber Cruising Handbook

Chapter 20 – Estimating Tree Volume

Amendment Number: 2409.12-2024-1

Effective date: October 16, 2024

Duration: This amendment is effective until superseded or removed

Superseded Directive: 2409.12 Estimating Tree Volume and Weight, 2409.12-1993-1

Approved by: Christopher French, Deputy Chief National Forest System.

Date approved: May 28, 2024

Responsible Staff: Forest Management, Rangelands Management, and Vegetation Ecology (FMRMVE)

Digest: Following is an explanation of the changes throughout the directive by section.

Section 20.05: Adds definitions section.

Section 22.22c: Removes Tarif volume estimators.

Section 23: Weight determination references Chapter 80, Weight Factor Determination.

Table of Contents

This chapter includes general guidelines for using tree volume and tree product estimators and defines acceptable direct tree volume and product determination techniques. Guidelines for estimating the weight of trees and components of trees are also given.

20.5 Definitions

Tree volume estimator. An equation or its tabular representation for estimating the cubic content, or volume, of a tree.

Tree product estimator. An equation or its tabular representation for estimating the product of tree. Sawtimber product may be expressed in board feet, poles may be in lineal feet, pulpwood in cords or units, and peeler blocks may be board feet or square feet. Cubic feet may be used to express the solid wood content for any wood product.

21 - Log Rules and Cubic Formulas.

21.1 - Log Rules

A log rule is a table of estimated volume or lumber which might be sawn from logs of different sizes under assumed conditions. The Scribner Decimal c, and International 1/4-inch rules are used by the Forest Service to estimate board-foot contents in roundwood.

21.2 - Cubic Formulas.

A cubic-foot formula expresses roundwood volume without reference to product class. Use the Smalian formula to determine the cubic volume of roundwood. The Smalian formula, in general terms, is:

$$V = \frac{A + a}{2} \times L$$

Where: V = Volume in cubic feet (ft^3)

A = Large end cross section area (ft^3)

a = Small end cross section area (ft^3)

L = Log Length (ft)

22 - Tree Volume Determination.

See FSH 2409.12a, Volume Estimator Handbook, for detailed descriptions of all phases of developing tree volume and product estimators, stem profile models, model verification, model validation, and model calibration.

22.1 - Utilization Limits.

Determine volume to utilization limits applicable to the place and time when the timber sale will be sold. These limits are usually expressed in terms of height and diameter. Calculate or-measure a merchantable height, which is the height from a specified stump to a specified top diameter. The advent of whole-tree chipping may extend utilization to include the entire main stem and the branches as well. Under these conditions, call the entire stem merchantable. For sawtimber trees, utilization may not necessarily end with the sawlog portion, but may include the chippable portion above the sawlog. Merchantability criteria for the sawlog portion can change over time, affecting not only the smallest tree diameter considered merchantable, but also extending utilization farther up the stem.

22.2 - Tree Volume and Product Estimators.

Apply the term "tree volume estimator" (sec. 20.5) to either an equation or its tabular representation, or both, for estimating the cubic content of a tree. Compute tree volumes from equations or from stem profile models. Use volume tables only when hand summary of volumes is necessary.

The term "product estimator" (sec. 20.5) is similar to the volume estimator, except cubic feet may not be the unit of measure.

22.21 - Tree Stem Components.

Measure the dimensions necessary for calculating volume. The most common measurements are diameter at breast height (DBH) and height to a specific point on the stem, or to the tip of the tree. To the extent possible, partition the tree into product components. Product feasibility is based on local utilization practices and markets for the various products.

The main stem components are:

1. The sawlog portion to a specified top limit.

2. The topwood portion from the top of the sawlog to a specified top limit, such as 4 inches diameter outside bark (DOB) or diameter inside bark (DIB), or to the tip of the tree when only the main stem is considered.

3. The crownwood portion includes all branches and that portion of the main stem above the merchantable limit.

The components mentioned in paragraphs 2 and 3 are often classed as chippable material.

Topwood in the main stem may be estimated by a separate product volume equation having DBH as one of its variables. It may also be estimated using a stem profile model by specifying the sawlog top limit and a topwood limit of either height or diameter. Crownwood volume may be estimated as the difference between total tree cubic volume, including branches, and the main stem volume to the defined merchantable height.

22.22 - Types and Use of Tree Volume and Product Estimators.

Use the appropriate type of estimator from those available. Before starting a cruise, know the specific variables to be measured as required by the product or volume estimator. Select the most appropriate volume estimators for each species and product class to be cruised. For each applicable product or volume estimator know the top limits and stump heights, and whether use of a form factor is needed. Not having such information, or failing to apply it properly, will lead to a bias in the tract product volume or estimate.

22.22a - Standard Tree Volume Estimators--Volume and Stem Profile Models.

Standard volume estimators use diameter breast height (DBH) and either total height from ground to tip, height to a specified diameter limit, or height to a point otherwise defined as independent variables. An upper stem DIB or DOB is used to define the merchantable diameter limit for various forest products. If measured in the field, DOB is the preferred variable since this can be accurately determined.

When using standard volume estimators:

1. Understand the criteria that define the height for the applicable volume estimator. Heights other than total height are called reference height or merchantable height and define the stem section for estimating volume.

2. Measure heights to the specified diameter limit if required by the volume estimator. When volume estimators specify DIB limit, use a standard DOB equivalent for a particular species or assume a bark thickness to determine height where the DIB occurs.

3. Observe the stratification (site, product, species, other) on which the volume estimator is applicable.

4. Properly apply defect deduction methods in keeping with the basic premises of the volume estimator(s) being used (sec 22.3). For example, if the volume estimator is based

on measuring the entire stem length to a specified reference diameter, make the suitable percentage deduction from tree volume for any defective segments below the reference diameter. Do not measure a shorter height or record fewer logs for the tree to account for the defect.

22.22b - Local Tree Volume Estimators.

Local volume estimators use only DBH as a predictor. They are constructed using sample tree data from the population of trees whose volume is to be estimated. Use of local volume estimators requires approval by the Regional Forester (FSH 2409.12a, sec. 04.21).

Evaluate the use of local volume estimators by considering the purpose of the cruise estimate and the level of accuracy required. The chance for bias is increased by the loss of the height variable, and a local volume estimator's usefulness is limited to stands having uniform height conditions within DBH classes, or where it is practical to stratify site conditions.

22.22c - Stem Profile Models.

A stem profile model expresses the form of the tree stem. It can also function as a volume estimator with greater versatility than conventional volume equations. Not all profile models use the same form or independent variables, so collect data for the variables defined in the profile model to be used. Generally, profile models require DBH and total height, although some profile models also require a form class measurement or a height to specific upper stem diameter.

In cruising, profile models may be used to estimate:

1. Diameter at desired heights on the stem.

2. Height to a given diameter.

3. Volume for the entire stem or in a given portion of the stem.

22.23 - Validation of Tree Volume Estimators.

Validate the volume estimators for first-time use. A validation check serves two purposes:

1. to validate the ability of the equation to predict volume within the constraints of the initial assumptions, and

2. to check the validity of the actual assumptions.

Statistical precision for a tree volume estimator only applies to the data used in its derivation. Validation using an independent sample is a measure of how well the equation estimates

volume of trees from applicable stands. See the Timber Volume Estimator Handbook, FSH 2409.12a, for details of validation.

22.3 - Estimating Tree Defect and Net Tree Volume.

The standard practice in National Forest volume determination is to sell only merchantable wood volume. Partition roundwood volume into two components: gross and net. Gross is the total volume in the tree to a specified top limit, while net is the residual volume after deducting wood loss (defect) from gross volume. Requirements for specifying measurement limits for net are the same as for gross volume.

Defect is any tree condition that reduces either product yield (lumber or veneer, for example) or wood fiber yield. Examples of defect include soft rots, crook, sweep, heart check, and fire scars. All of these defects can reduce product yield, but of the examples given, only soft rots and fire scar reduce fiber yield. Refer to detailed defect information in the National Forest Log Scaling Handbook, FSH 2409.11, and the Cubic Scaling Handbook, FSH 2409.lla.

22.31 - Defect Deduction Methods.

Defect is estimated in standing trees by the following methods:

1. Seen Defect: Visually estimate the extent and position of defect(s) in the tree, then refer to a table of percentages of stem volume (sec. 22.31a, ex. 01 and 02). Where only a part of a standard segment length is affected by the defect, multiply the tabular volume percent by the fraction affected.

2. Hidden Defect: A standard deduction to account for non-visible defects based on past observations of logging data for the area. The result is an average net volume estimate based on specific species in a specific geographical area

Both seen and hidden defects apply to individual trees. In using seen defect methods, decide on the suitable deduction from an ocular assessment of stem condition. Tailor these methods to specific regions or sub-regions to allow for the differing defect characteristics of species. Most methods require tables that show the average percentage distribution of tree volume for each log based on the log position in the tree.

Successful application of seen defect estimation methods demands considerable skill by the cruiser and a knowledge of rot characteristics for the species being cruised. Each cruiser must continually update their skills by periodically visiting sawmills and logged areas to relate the extent of rot to surface indicators.

22.31a - Volume Distribution in Trees.

Where the cruiser must make ocular assessments of defect in-standing trees, use tables that show the percent of tree volume in different parts of a tree. These tables show percentage of volume by 16-foot segments within the merchantable length, although other segment lengths may also be used (ex. 01, 02). Tables showing volume distribution in trees should specify the area of applicability and species or species group to which they apply.

22.31a - Exhibit 01

Percent of Tree Product Volume by 16-foot logs, Scribner Dec. C Log Rule

		Log Number									
MERCH HT.1/ (feet)	**LOG HT.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
9-25	1	100									
26-42	2	68	32								
43-59	3	47	36	17							
60-75	4	38	29	22	11						
76-92	5	33	27	20	14	6					
93-108	6	28	25	20	16	7	4				
109-125	7	26	23	19	17	8	3	3			
126-141	8	24	21	18	15	10	6	4	2		
142-158	9	19	17	15	14	13	10	6	4	2	
159-174	10	19	17	15	14	13	9	6	4	2	1

1/ Not total tree height

22.31a - Exhibit 02

Percent of Tree Product Volume by 16-foot Logs, Smalian Cubic Volume

		Log Number									
MERCH HT.1/ (feet)	**LOG HT.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
9-25	1	100									
26-42	2	63	37								
43-59	3	45	33	22							
60-75	4	37	28	21	14						
76-92	5	32	25	19	15	9					
93-108	6	27	22	19	14	11	7				
109-125	7	24	21	19	17	11	5	3			
126-141	8	22	19	17	15	11	8	5	3		

142-158	9	20	16	14	13	12	10	7	5	3
159-174	10	19	16	14	13	12	10	7	5	3	2

1/ Not total tree height

When volume estimators are based on measuring entire stem length to a specified reference diameter and it becomes necessary to reduce merchantable length because of defect, express this as a percentage deduction from tree volume, rather than by tallying the tree as being shorter than it is.

22.31b - Rots.

Where ocular deduction methods are used, the extent of rot in a standing tree requires a knowledge of indicators. Since the cruiser can only base any judgment of rot on indicators visible on the standing tree, use local defect guides for determining the average distances up and down the stem a particular rot extends from an indicator. Since rot characteristics can vary by species, separate guides are needed. When site index affects extent of rot, prepare site index-specific guides.

22.31c - Sweep and Crook.

Sweep is a stem deflection which, compared to crook, is less abrupt and more continuous. Sweep is generally counted deductible where it is excessive within a product length in the stem. Crook is a more abrupt deflection in the stem. Refer to FSH 2409.lla, Chapter 40 for detailed information about sweep and crook.

22.31d - Missing Wood.

Missing wood includes such things as missing parts of trees, catface, and fire scar. Cases also occur where the top of the tree is missing. If the volume estimator requires measuring height to a fixed top diameter, estimate where that point would have been if the stem remained intact. To do otherwise is to incur estimating bias from a miscalled height. Also, handle the missing stem portion as a deduction from gross volume by assigning it a suitable percentage deduction.

22.31e - Breakage and Hidden Defect.

Estimate this defect where appreciable breakage from felling is a normal occurrence. Ordinarily, deductions for breakage need to be applied only to the sawlog portion of the tree since the recovery of fiber volume is not greatly affected unless shattered breakage occurs.

Certain defects, such as ring shake, heart check, and some rots are internal in the tree and cannot be seen by the cruiser. All of these defects can reduce lumber yield and are, therefore, important in estimating sawlog volume. Soft rots reduce wood fiber volume but shake and checks do not.

Account for breakage and hidden defect by applying a factor, based on experience, to the cruise volumes. Determine loss from breakage and hidden defect for specific timber types and localities.

22.31f - Net Volume Estimators.

In younger timber, when the occurrence of defects are infrequent or are uniformly found, their effects can be accounted for directly in the volume equation. In such applications, the equation predicts net volume of the tree.

Obtain greater precision for the net volume predictor by stratifying stems into classes better correlated to the incidence of defect. For example, if it is found that defect percentage tends to be lower in trees having no external indicators of rot, and higher in those trees having obvious indicators, trees might be classified as “apparently sound" and "obviously defective." Therefore, classify each tree by the presence or absence of indicators. Compute volume from a separate set of equations for each condition class.

22.4 - Direct Tree Volume Estimation Methods.

For direct measurement, measure felled sample trees (sec. 22. 42) or standing trees with a dendrometer. Direct methods have the advantage of basing volume estimates on measurements of samples taken from the tract being cruised and are, therefore, less prone to the bias inherent in standard volume estimators.

22.41 - Measuring Standing Trees.

For standing trees, estimate volume directly using a type of dendrometer capable of measuring outside bark diameters at selected points on the stem and the heights above ground to those points. A variety of devices are available for doing this. Some devices, such as the Spiegel Relaskop, read directly in standard measurement units. Others, like the Barr and Stroud dendrometer, require translation to get standard units. Estimate defect using the methods described in Section 22.3.

22.42 - Fall, Buck, and Scale.

Another method of direct measurement is to fall a sample of trees on the area being cruised, cut them into logs, and determine their gross and net volumes using standard scaling procedures (FSH 2409.ll; FSH 2409.11a).

1. Use data obtained from such scales to:

    a. Serve as a training experience for cruisers in assessing cull and defect in standing trees.

   b. Check the reliability of tree volume estimators.

   c. Build up data files for developing tree volume regressions.

   d. Serve as a sample in some cruising systems such as 3P (ch. 30).

2. Establish regional standards to produce consistent cruise estimates when using fall, buck, and scale. These standards must cover the following specifications:

   a. Measurement of height (total height, from ground or stump, or merchantable height).

   b. Minimum top scaling diameters.

   c. Minimum scaling lengths and segmentation rules.

   d. Guidelines to account for broken chunks, highly defective material, and extremely knotty material.

   e. Bucking requirements.

   f. Tree species identification.

   g. Data to be recorded.

23 - Weight Determination.

Use weight estimation for tree components such as crownwood or biomass that do not readily lend themselves to volume determination methods. Tree weight estimates are used for planning helicopter logging and timber hauling operations. Weight is much more closely related to cubic volume than board foot units of measure, and weight may be a useful estimator when cubic units of volume are of interest. For information on developing weight factors, see chapter 80.

23.1 - Merchantable Components.

Weight predictors can be derived to estimate weight of various tree components: total tree, tree bole to specified top limit, branches to specified minimum diameters, and foliage and twigs. Weights may be for wood alone, or for wood and bark. Separate bark weight prediction equations are also available. In addition, weight is expressed on an oven-dry or green basis, or both.

Weight equations usually express weights for tree components as a function of species, DBH, and stem height. Therefore, weight estimates can be determined from the regular cruise data collected for conventional volume estimates

23.2 - Residues.

Weight is used to quantify two types of residues that result from timber harvesting.

1. Logging residues are portions of trees not meeting product utilization specifications in the timber sale contract left behind after logging is completed.

2. Standing residues are trees designated to be treated but are left standing as they did not meet merchantability specifications on the timber sale contract for standard products.

23.21 - Logging Residues.

Residues are the tree crowns and unmerchantable segments of the trees. Logging residue prediction equations have been developed for given utilization standards in several species and may be used when precise estimates are not needed.

23.22 - Standing Residues.

Trees considered unmerchantable are not included for removal under the timber sale contract. Tally these trees as separate cruise components and apply weight coefficients as necessary.