Reference: Georgia FFA ENR CDE Ecosystems Team Activity Pages 26-36

TIMBER CRUISING HANDBOOK

FOREST SERVICE HANDBOOK
WASHINGTON

FSH 2409.12 - TIMBER CRUISING HANDBOOK

Amendment No.

Effective

POSTING NOTICE. Amendments are numbered consecutively by title and calendar year. Post by document name. Remove entire document and replace with this amendment. Retain this transmittal as the first page of this document. The last amendment to this Handbook was **2409.12** the original handbook.

Document Name	Superseded (Number of Pages)	New (Number of Pages)
00-05		5
11-15.3		15
21-23.22		21
30.5-38.5		84
41-43.6		12
51-53.23		8
61-63.5		12
71-73.2		5
81-81.2		3

Digest: Revises and updates entire handbook. Significant changes in direction are as follows:l

05 Adds new definitions.
08 Adds reference section to zero code.
13.28 Adds information on laser cruising equipment.
21-23.22 Updates and adds instructions for volume estimators, adds reference to FSH 2409.12a, Timber Volume Estimators Handbook.
30.5 Adds definitions of statistical terms.
31-38.3 Adds example calculations of cruise statistics.
41-43.6 Updates direction for selecting cruise methods, timber cruise planning, data recording and cruise records.
41.4-41.45 Adds direction on stratification of samples.
51-53.35 Adds direction for global positioning system traverses
61-66.1 Updates and adds direction for certification of cruisers and cruises.
72-72.2 Adds direction for marking to reduce likelihood of trespass and for use of tracer paint.
81-81.2 Updates direction for trespass cruises.

F. DALE ROBERTSON

Chief

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

FSH 2409.12

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TIMBER CRUISING HANDBOOK

ZERO CODE

01 - AUTHORITY. Timber use laws are cited in Title 36 of the Code of Federal Regulations (CFR), Part 223, Subpart A.

02 - OBJECTIVE. The objective of timber cruising is to provide reliable estimates for timber appraisals. The timber volume estimate serves as the basis for payment on tree measurement sales or for bidding on scaled sales.

03 - POLICY. Regions and Forests shall use the procedures provided in this Handbook when cruising timber for sales, free use, exchange, or in trespass cases.

04 - RESPONSIBILITY. It is the responsibility of the Regional Forester to:

1. Issue direction, as needed, to accommodate specific Regional and local conditions.

2. Approve the use of local and aerial volume estimates. This authority may not be redelegated.

05 - DEFINITIONS. The following are special terms used throughout the text. See FSH 2409.14 for standards for data elements.

Bark--All the tissues, including the cambium, taken collectively and forming the exterior covering of the xylem of a tree.

Bole--A tree stem that has grown to substantial thickness; generally capable of yielding sawtimber, veneer logs, large poles, or pulpwood.

Bolt--Any short log cut to a specific length.

Butt end--The end of a tree length originally connected to the stump.

Butt log - The lowest log on a bole.

Butt rot - Any decay or rot developing in and sometimes characteristically confined to the base or lower stem of a tree.

Butt swell - That part of a log outside its normal taper, extending from where the normal taper ends and the flare begins to the large end of the log. It is usually manifest only in butt logs, due to the self-buttressing growth of the tree near its base.

Caliper - An instrument for determining tree and log diameters by measurement of their rectangular projection on a straight graduated rule via two arms at right angles to (and one of them sliding along) the rule itself.

Catface - A defect on the surface of a tree or log resulting from a wound where healing has not reestablished the normal cross section.

Charred wood - Wood converted to charcoal as a result of incomplete combustion.

Conk - The fruiting body of a fungus denoting the presence of rot. The conk may be of various shapes and sizes.

Cull log - A log not meeting the specified product requirements due to defect.

DBH - Abbreviation for Diameter Breast Height; diameter at breast height is measured at 4.5 feet above the ground on the high side of the tree.

Decay - The decomposition of wood substance caused by the action of wood-destroying fungi, resulting in softening, loss of strength and mass, and often in change of texture and color. Examples of decay are:
heart rot, sap rot, stump rot, and rotten knots.

Defect - Any imperfection occurring in and affecting the quantity of products for which the log is being scaled.

Diameter, small end - The average diameter, inside bark, at the upper end of the tree length or log segment.

Diameter tape - A circumference tape measure specially graduated so the diameter may be read directly when the tape is placed around a tree stem, bole, or piece of roundwood.

DIB - Abbreviation for Diameter Inside Bark, a measurement of the diameter at a point on a tree or log that includes the wood only.

DOB - Abbreviation for Diameter Outside Bark, a measurement of the diameter at a point on a tree or log that includes the wood and bark.

Fire scar - A healing or healed-over injury on a woody plant, caused or aggravated by fire.

Firm red heart - A form of incipient decay characterized by a reddish color produced in the heartwood, which does not render the wood unfit for the majority of uses. Firm red heart contains none of the white pockets characterizing the more advanced stage of decay.

Flare - A rapid increase in the taper of a log at the butt end due to swell (See "butt swell").

Fork - A division of a log or a stem of a tree into two or more prongs.

Gross volume - Total volume including defects.

Heart check - A check or separation originating at the pith and extending across the annual rings.

Heart rot - Any rot characteristically confined to the heartwood. It generally originates in the living tree.

Height - The measured length of the bole from a specified point at or near the ground to a specified point higher on the bole of tree. (FSH 2409.14)

Heartwood - The inner core of a woody stem wholly composed of nonliving cells and usually differentiated from the outer enveloping layer (sapwood) by its darker color.

Incipient decay - The early stage of decay in which the decomposition has not proceeded far enough to soften or otherwise change the hardness of the wood perceptibly. It is usually accompanied by a slight discoloration of the wood. (See "firm red heart.")

Intermediate decay - A more advanced stage of decay than incipient decay, characterized by a change in the color of the wood and some slight decomposition and loss of strength which does not render the wood unfit for general purposes. (See "white specks.")

Knot - A portion of a branch enclosed in the xylem by the natural growth of the tree.

Linear measure - A measure of length.

Log - A section of the bole of a felled tree, after trimming and cross-cutting.

Log rule - A table or equation that estimates product yield contained in logs of given length, form, and end diameter inside bark.

Merchantable Height - The measured length of the bole from a specified point at or near the ground to a point higher on the bole where it is too small or defective to meet a specified product utilization standard, such as pulpwood or sawlog.

Missing wood - Wood absent from a log or part of a log that otherwise would usually be regarded as naturally complete. It may be caused by advanced decay, fire, or the operation of a machine or tool.

Net volume - The volume remaining after all deductions for defects from gross volume have been made.

Out of round - Describes a shape that departs from circular.

Ovendry - A condition in which the wood has ceased to lose moisture after being subjected to a temperature of 103 $\pm 2^{\circ}$C in a ventilated oven, for purposes of determining moisture content.

Piece - A part of a whole (as of a tree); it also means an object regarded as a unit of a kind (as one of a number of products of the group).

Pocket rot - In wood, any rot localized in small areas, generally forming round or lens-shaped cavities.

Product - A commodity manufactured from a portion of a tree.

Product estimator - A procedure, equation, or table used to estimate the product volume of a tree or tree segment. Potential sawn lumber measured in board feet is the most common product estimated. Product estimators are frequently misclassified as volume estimators.

Product Volume - A statement of the potential amount of a manufactured product; board feet, cubic feet, square feet, lineal feet and so forth.

Pulpwood - Wood cut and prepared primarily for manufacture into wood pulp.

Punky wood - A soft, weak, often spongy wood condition caused by decay.

Ring rot - Any rot localized mainly in the earlywood of the annual rings, giving a concentric pattern of decayed wood in cross-section.

Reference diameter - The specified bole diameter to which height is measured.

Reference height - The height measured to a specified point on the tree bole.

Ring shake - A shake that separates between the annual rings and partially or completely encircles the pith.

Roundwood - Any section of the stem or of the thicker branches, of a tree of commercial value that has been felled or cut but has not been processed beyond removing the limbs, or bark, or both.

Sample - A subset of a population, being representative of that population.

Sample size - The number of sampling units included in a sample.

Sample tree - An individual tree included in a sample for the purpose of measurement.

Sampling group - One of the units, groups or strata into which a population is subdivided for purposes of sampling.

Sap rot - Any rot characteristically confined to the sapwood.

Sapwood - The living wood of pale color near the outside of the log.

Scale (verb) - To measure or estimate the quantity, expressed as the volume, or area, or length, or mass, or number of products obtained from trees after they are felled. See National Forest Log Scaling Handbook, FSH 2409.11 and FSH 2409.11a for scaling practices and procedure.

Scale stick - A graduated stick for measuring the end diameters of logs or felled trees inside bark.

Shake - A separation along the grain and occurring between or across the annual rings, but not extending from one surface to another.

Soundwood - Wood free from structural defect.

Stem - The principal axis of a plant from which buds and shoots develop. Larger tree stems are called boles.

Stem profile model - A mathematical respresentation of a tree's profile or shape. (Also referred to as a stem profile equation.)

Sweep - A gradual curve in the length of a log, as distinct from an abrupt bend or curvature.

Taper equation - See stem profile model.

Taper, log - The progressive change in the diameter of a log from one end, or point on its length, to another.

Taper, tree - The progressive decrease in the stem or bole diameter of a tree from the ground or a specified point on the lower bole to the tip or a specified point on the upper bole.

Tarif - A word of Arabic origin meaning tabulated information; applied to a specific type of volume table.

Tree profile model - See stem profile model.

Tree volume, merchantable - The portion of tree volume that can be sold and utilized in a manufacturing process.

Tree volume, total - The cubic content of a tree from ground to tip. This might or might not include the cubic content of limbs.

Variable - A characteristic of a population that may vary from one sampling unit to another. Variables are classed as:

> Continuous variable is related to some numerical scale of measurement, any interval of which may be subdivided into an infinite number of values such as length, height, volume, mass.
>
> or
>
> Discrete variable can assume only a specified number of values.

Variable of Interest - The variable used to develop an estimate of the average and the variation in the desired characteristic for the population being sampled. The variation is used to estimate the reliability of the estimated characteristic for the population and to determine how many members of a population must be sampled to achieve a desired level of reliability. The variable of interest is relevant only to the characteristic being sampled in a sample group or strata, and in the case of two-stage sampling, to the stage of the sample.

<u>Volume estimator</u> - An equation or series of equations used to estimate the average cubic content of a log or tree.

<u>White specks</u> - Small white pits or streaks in the wood, characteristic of the intermediate stage of Phellinus Pini (Fomes) decay.

<u>Woodchip</u> - A small, thin, and flat piece of wood cut from a larger piece of wood by knife action. A woodchip shall show two knife cuts and its width is always greater than its thickness.

<u>08</u> - <u>REFERENCES</u>. The following references contain additional detail and theoretical information used in the development of this handbook. Users seeking additional background on specific aspects of timber cruising may refer to the following:

Aho, Paul E. 1966. Defect estimation for grand fir, Engelmann spruce, Douglas-fir and western larch in the Blue Mountains of Oregon and Washington. U.S. Forest Service, Pac. N.W. For. and Range Exp. Sta.

Avery, Thomas Eugene and Harold E. Burkhart 1983. Forest Measurements. McGraw Hill Book Co., New York. 3rd Edition 349p.

Beers, T. W. and C. I. Miller. 1964. Point Sampling: Research results, theory and applications. Purdue University Agr. Exp. Sta. Res. Bulletin 786.

Bitterlich, W. 1947. Die Winkelzahlmessung (Measurement of basal area per hectare by means of angle measurement). Allg. Forst. Holzwirtsch. Ztg. 58:94-96.

Bruce, Donald. 1961. "Prism cruising in the western United States and volume tables for use therewith." Portland, Oregon: Mason, Bruce and Girard.

Dilworth, J. R. and J. F. Bell. 1980. Variable plot cruising. Oregon State Univ. Book Stores, Inc. Corvallis, OR.

Freese, Frank. 1962. Elementary forest sampling. U.S.D.A. Agr. Handbook No. 232. U.S. Gov't Printing Office.

Freese, Frank. 1967. Elementary statistical methods for foresters. U.S.D.A. Agr. Handbook No. 317. U.S. Gov't Printing Office.

Gregoire, Timothy G. 1982. The unbiasedness of the mirage correction procedure for boundary overlap. Forest Sci. 28(3): 504-508.

Grosenbaugh, L. R. 1952. Plotless timber estimates--new, fast, easy. Jour. For. 50:32-37.

Grosenbaugh, L. R. 1958. Point-sampling and line-sampling: probability theory, geometric implications, synthesis. South. For. Exp. Sta. Occ. Paper 160.

Grosenbaugh, L. R. 1964. Some suggestions for better sample-tree-measurement. Soc. Amer. Foresters Proc. 1963:36-42, illus.

Grosenbaugh, L. R. 1965. Three-pee sampling theory and program THRP. U.S. Forest Service, Pac. S.W. For. and Range Exp. Sta. Res. Paper. PSW-21.

Grosenbaugh, L. R. 1967. STX-Fortran-4 program for estimates of tree populations from 3P sample tree measurements. U.S. Forest Service, Pac. S.W. For. and Range Exp. Sta. Res. Paper. PSW-13.

Grosenbaugh, L. R. 1974. STX 3-3-73: Tree content and value estimation using various sample designs, dendrometry methods, and V-S-L conversion coefficients. U.S. Forest Service, S.E. For. Exp. Sta. Res. Paper. SE-117.

Husch, Bertram, Charles Miller and Thomas Beers. 1982. Forest Mensuration. John Wiley and Sons, Inc., New York. 3rd Edition, 402p.

Johnson, Floyd A. 1965. Sample sizes for timber cruises. U.S. Forest Service, Pac. N.W. For. and Range Exp. Sta. Res. Note. PNW-30.

Mesavage, Clement. 1964. Aids for using Barr and Stroud dendrometers. Soc. Amer. Foresters Proc. 1964:238-244, illus.

Mesavage, Clement. 1968. Revised calculator for Barr and Stroud dendrometers. U.S. Forest Service, So. For. and Range Exp. Sta. Res. Note. S0-84.

Mesavage, Clement. 1971. STX timber estimating with 3P sampling and dendrometry. U.S.D.A. Agr. Handbook No. 415. U.S. Gov't Printing Office.

Turnbull, K. J. and G. H. Hoyer. 1965. Construction and Analysis of Comprehensive Tree-Volume Tarif Tables. State of Washington, Department of Natural Resources, Olympia, Washington. Resource Management Report
No. 8.

Van Wagner, C. E. 1968. The line intersect method in forest fuel sampling. Forest Science 14(1): 20-26.

CHAPTER 10 - PRINCIPLES OF MEASURING TREES

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CHAPTER 10 - PRINCIPLES OF MEASURING TREES

Timber cruising is the determination of the gross and net product volume and value (timber quality) for a tract of timber. It involves measuring tree diameters and heights, estimating defects, and making other determinations, such as grade and form class, that may be specified by the cruise plan. This chapter deals with the technical aspects of making tree measurements and the tools required.

11 - SPECIES IDENTIFICATION. Each timber cruiser must properly identify tree species. Stumpage rates, merchantability specifications, and many product volume references are species related. Species may be identified by bark characteristics, form, type of fruit, cones, needles, leaves, and other features.

12 - TREE MERCHANTABILITY SPECIFICATIONS. Develop the minimum tree and piece merchantability specifications in the cruise design phase and document in the cruise plan. These specifications will be included in the Timber Sale Contract to identify material to be removed. Knowledge of the minimum piece and tree specifications for each end product category is required. The cruiser must recognize and record the end product potential for cruised materials. End products are subdivided into three categories:

1. Material suitable for the manufacture into lumber or veneer.
2. Material suitable for conversion into chips.
3. Material suitable for conversion into other products such as poles, pilings, rails, ties, and house logs.

The minimum piece specifications are described by:

1. Length.
2. Diameter inside bark at the small end.
3. Net product volume as a percent of gross product volume.
4. Other timber sale specifications.

The minimum tree specifications are described by:

1. Minimum number of pieces a tree must contain to be merchantable.
2. Minimum diameter breast height.
3. Piece net volume.

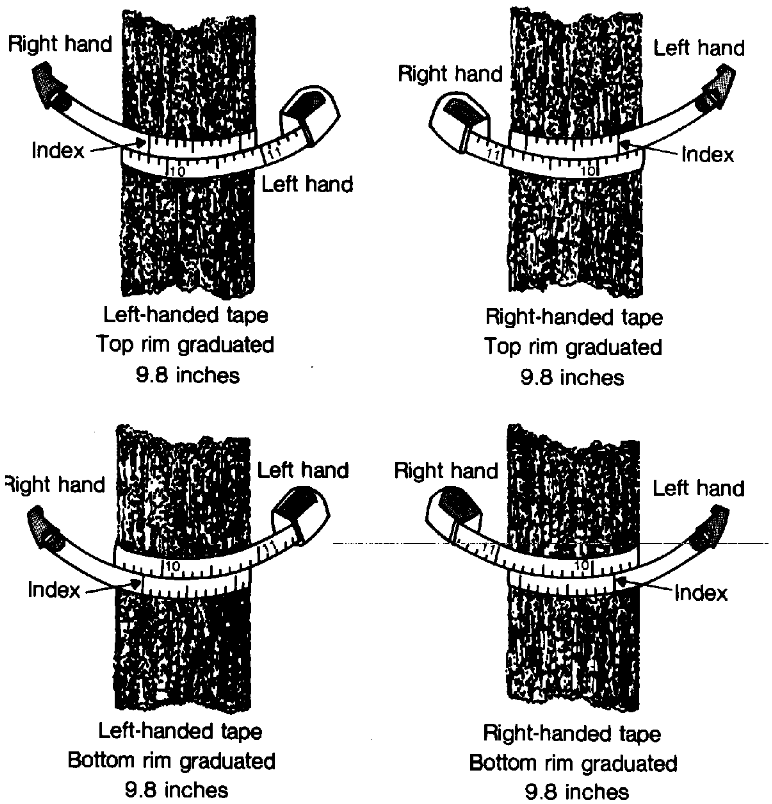
13 - TREE MEASURING INSTRUMENTS.

13.1 - Diameter Measuring Instruments.

13.11 - Diameter Tape. The diameter tape is the most common device used in measuring tree diameters. Tapes are either 20-feet or 50-feet long, are made of steel, usually have a bark hook on the zero end, and are graduated on the outside surface in inches and tenths of inches of diameter equivalents (3.1416 inches) of circumference. Tapes may also have linear graduation in feet or meters on the inside surface. Many logger's tapes are graduated, on the backside, in diameter equivalents of circumference.

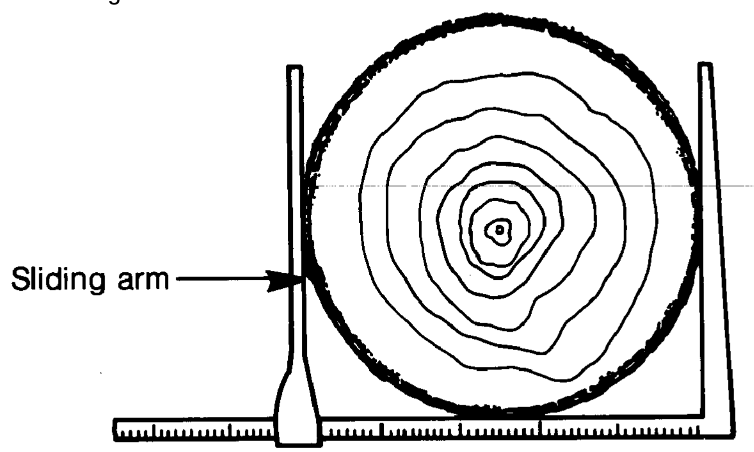
Diameter tapes come in right-handed and left-handed models. This refers to the hand in which the tape case must be held so, with the tape around a tree, the numbers are reading right side up.

In correct use, the diameter tape numbers are right side up and the tape is crossed on the face of the tree, so the index or zero mark lays along the graduated edge of the tape. Tapes may be graduated on either the upper or lower edge. Figure 01 illustrates the correct use of left-handed and right-handed tapes.



13.11 - Figure 01
Correct use of left-handed and right-handed tapes

13.12 - Tree Calipers. Tree calipers, available in either wood or metal and graduated in English or metric graduations, may be used for measuring tree diameters. English graduations are in tenth inches and metric graduations are in centimeters. Caliper sizes range from 18 to 60 inches, and the arm is attached at right angles to the beam. When using tree calipers, take two measurements at right angles and average the readings.



13.12 - Figure 01
Tree Calipers

13.13 - Dendrometers. Dendrometers are classified as optical forks, optical calipers, or short-base rangefinders, depending on the trigonometric principles of their design. Three dendrometers, two optical forks, and one optical caliper are commercially available. The most common optical fork is the Spiegel-Relaskop. A more sophisticated version, the telerelaskop is basically a Spiegel-Relaskop with magnification. The only optical caliper, the Wheeler penta prism caliper, has no magnification.

13.13a - Optical Fork (Relaskop, Telerelaskop). The optical fork measures stem diameter with a fork angle formed by two intersecting lines of sight with the apex at the observer. Optical forks depend on the observer to measure the distance (baseline) to the tree. Optical forks are further classified as fixed and variable. In use, the fixed fork is aligned with the tree, varying the distance (baseline) from the tree. With variable forks, of which the two relaskops are examples, the fork is aligned with the tree by varying the fork angle. These devices have the added advantage of having the fork-angle linked to the vertical angle by means of cylindrical cosine graphs. This enables a given diameter to be located at any height for a given distance from the tree. For example, the width of one vertical stripe on the relaskop drum defines a 4-inch diameter at 66 feet from the tree, regardless of its height, and a 2-inch diameter at 33 feet from the tree, regardless of its height.

When measuring diameters of a swaying tree, move the device with the sway of the bole to keep the fork angle in alignment with the bole. Failure to do this results in biased diameter estimates. If a tree is leaning either toward or away from the observer, erroneous readings will result. Readings on a tree leaning toward the observer will be high and readings on a tree leaning away from the observer will be low. Therefore, when measuring stem diameters of leaning trees, make all sightings at right angles to the lean.

The instruments mentioned here should be mounted on a tripod or staff to facilitate accurate measurements. Failure to do so may increase measurement variation and increase the number of measurements necessary to attain the desired precision.

To avoid bias from the revolving drum of the relaskop being out of alignment, periodically check the device against a target of known width.

13.13b - Optical Calipers (Wheeler penta-prism caliper). The optical caliper measures stem diameter with two parallel lines of sight separated by a sliding measurement scale at the observer. It is an optical analog of the conventional mechanical tree caliper. There is currently no commercial optical caliper equipped with magnification. The commonly used Wheeler model is, however, equipped with a clinometer to measure height. This instrument requires a measured baseline from the observer to the tree when used with the clinometer to measure height. If only used for measuring diameters anywhere on the stem, the distance to the tree (baseline distance) does not have to be known.

The chief advantage of this instrument is that while tree lean in the line of sight affects height measurement, it does not affect diameter measurement. This is an advantage over all other dendrometers. Tree lean at right angles to the line of sight, however, does not affect either height or diameter measurement if the instrument is properly tilted and sight lines are parallel to the lean.

Use of the penta-prism caliper requires focusing simultaneously on the halving line of the prism and on the distant tree stem. This tends to make the halving line appear fuzzy instead of sharp, making accurate alignment of the two vertical images difficult. Since the instrument is in one-to-one correspondence with the diameter being measured, the baseline of the instrument must be wide enough to accommodate the working range of tree diameters. A 36-inch diameter seems to be the practical limit for a hand-held device; use a support staff or tripod for anything larger.

To avoid bias from the prism being out of alignment, periodically check the instrument against a target of known width.

13.13c - Short-Base Rangefinder Dendrometer. This type of device is represented by Barr and Stroud Dendrometers, Models FP-12, FP-15. These are precision instruments but their manufacture has been discontinued. They are self-contained instruments producing coincident images of tree stems by means of counter-rotating circular wedge prisms. The coincident image retains the same relation to the tree stem whether the tree is motionless or swaying in the breeze. The instrument setting in the coincident position is used to compute the distance (range), as well as the diameter outside bark (DOB), by means of complex trigonometric relationships applicable to the specific instrument. The dendrometer is equipped with 8X magnification, enabling precise definition of coincidence by providing a sharp halving line. An inclinometer with micrometric head is used for readings of elevation and depression that are translated into vertical height. The instrument weights about 5 pounds.

The Barr and Stroud is not a direct-reading device. The user records instrument readings in units that must be processed by a computer program like STX (Grosenbaugh, 1967). Mesavage (1964, 1968) devised a slide rule-like field calculator to convert instrument readings to standard units.

13.2 - Height Measuring Instruments.

13.21 - Telescoping Measuring Rod. Telescoping measuring rods consist of a number of progressively smaller sections which telescope inside each other. One or multiple sections may be pulled out since each section is locked in place independently. Rods are available in extended lengths of 17 to 50 feet. Rods are made of sturdy fiberglass and come graduated in either feet, inches, half inches; feet, tenths foot, hundredths foot; or meters, decimeters, centimeters. The height rod is an extremely useful instrument in timber less than 50 feet tall. It is also an excellent instrument to use as a standard when checking the calibrations of other height measuring instruments such as Relaskops and clinometers.

13.22 - Haga Altimeter. The Haga altimeter is a hand-held instrument used to measure vertical heights. The instrument has six different scales. Its scale values indicate height directly for various known base length distances. The first four scales (15, 20, 25, and 30) may be used with base length distances in feet, meters, or yards. The fifth scale (%) indicates height as a percent of the baseline distance. The sixth scale (topographic) indicates height directly in feet for a base length distance of 66 feet.

13.23 - Blume-Leiss Altimeter. The Blume-Leiss altimeter is a hand-held instrument used to measure vertical heights. The instrument has four different scales, each of which corresponds to a specific baseline distance of 45, 60, 90 and 120 feet. All readings are directly in feet. Height measurement range is up to 180 feet.

13.24 - Clinometer. The clinometer is a light, compact, and rugged hand-held instrument. Its primary function is to measure vertical angles above and below the horizontal. The instrument is available in either topographic or percent scales. Height measurements are easily made with this instrument. Because of its relatively low cost, it is probably the most common height instrument used by the Forest Service timber cruiser.

13.25 - Abney Level. The Abney is a light, compact hand-held instrument. Its primary function is to measure vertical angles above and below the horizontal. The instrument has both topographic or percent scales.

13.26 - Spiegel-Relaskop. The Spiegel-Relaskop described in 13.13a, is a versatile instrument. It is used to measure tree and limb diameters, tree height, slope and horizontal distances, and as an angle gauge in point sampling. Used as a height measuring instrument, the Relaskop indicates height in feet for known horizontal distances.

13.27 - Telerelaskop and Barr and Stroud Dendrometers. The Telerelaskop and Barr and Stroud dendrometers described in section 13.13 are used for making height measurements.

13.28 - Laser Measuring Devices. Laser measuring devices are being developed to measure heights and other characteristics of the trees as needed for timber cruising. Maintain awareness of the potential and limitations of this equipment for improving accuracy and reducing costs.

14 - MEASURING THE TREE. Measuring individual tree variables in a consistent and prescribed manner is essential. All volume estimation procedures require some or all of the following measurements:

1. Diameter breast height (DBH).

2. Reference height (measured to a specific diameter inside bark (DIB) or diameter outside bark (DOB)).

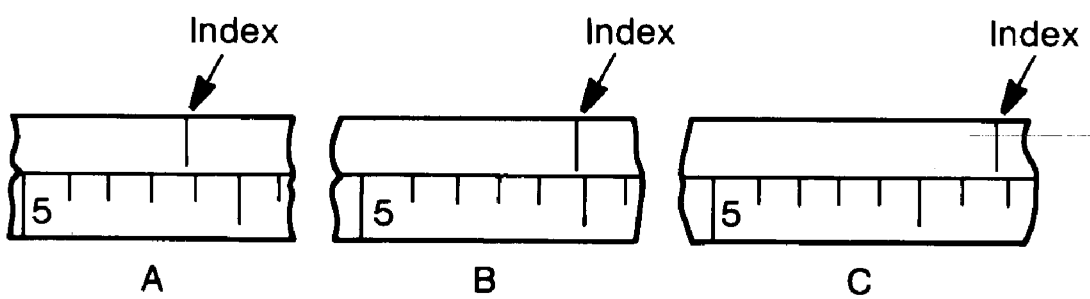
3. Total height.

4. Stump height.

5. Tree form class.

14.1 - Measuring Tree Diameter.

14.11 - Reading the Diameter Tape. If the diameter reading is not exactly on a tenth, take diameter tape readings to the next lower one-tenth inch. This compensates for the positive bias incurred by measuring out-of-round trees with a tape. Figure 01, example A is read as 5.3, example B as 5.4, and example C as 5.6.



14.11 - Figure 01
Diameter Tape Measurement Readings

There are situations where diameter measurements are made and recorded to the nearest 1- or 2-inch diameter class. This may occur when the precision of the measuring instrument can only be to the closest 1 or 2 inches or specified product volume estimation procedures are based on 1- or 2-inch DBH classes. Standard 1- and 2-inch classes are:

1. Examples of 1-inch diameter class are: 5-inch class = 4.6 - 5.5 inches; 9-inch class = 8.6 - 9.5 inches, and so on.

2. Examples of 2-inch diameter class are: 12-inch class = 11.0 - 12.9 inches; 14-inch class = 13.0 - 14.9 inches, and so on.

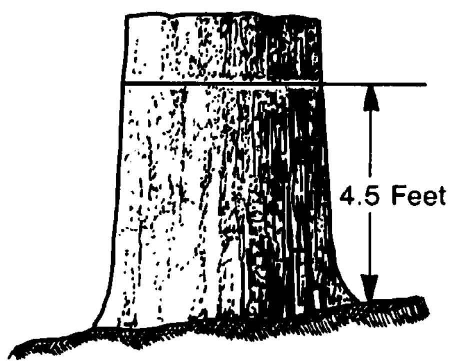
There are situations where diameter measurements are not rounded. This situation occurs when absolute measurements are specified. Timber sale contract minimum tree DBH and minimum piece specifications are absolute.

Example:

1. Minimum tree DBH specification = 7.0 inches. This means 6.95 would not be rounded to 7.0 inches.

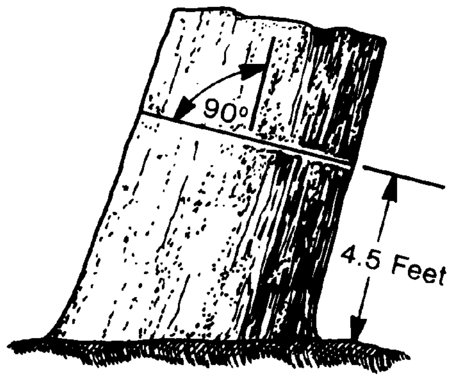
2. Minimum piece specification = 7.6 inches DIB. This means 7.55 would not be rounded up to 7.6 inches.

14.12 - Measuring Tree Diameter at Breast Height (DBH). Measure DBH from the high ground side of the tree at 4.5 feet above the forest floor (fig. 01). If tree diameter cannot be measured at 4.5 feet because of abnormalities, measure as described in section 14.12d.



14.12 - Figure 01
Measuring DBH - Normal Case

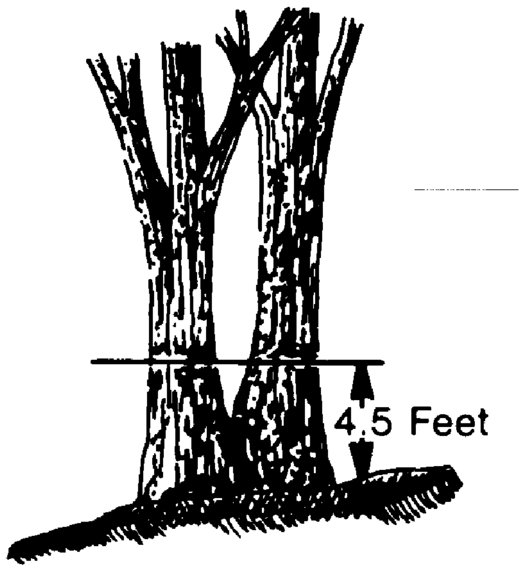
14.12a - Leaning Trees. Measure DBH on leaning trees at a right angle to the center line of the tree as shown in figure 01.



14.12a - Figure 01
Measuring DBH - Leaning Trees

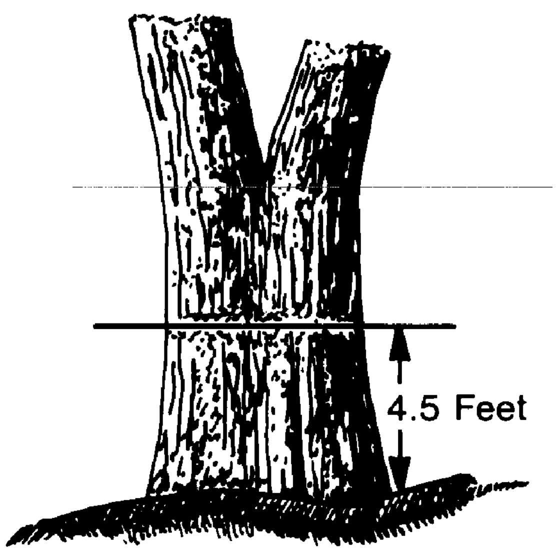
14.12b - Forked Trees. A forked tree is a tree with two or more stems originating from one stump. Consider forking to start at the point where daylight is seen.

When a tree forks below 4.5 feet, consider as two trees and measure DBH on each stem at 4.5 feet above the ground on the high side (fig. 01). If either stem at this point is abnormal, measure as described in section 14.12d.



14.12b - Figure 01
Fork Occurs Below 4.5 Feet

When a tree forks at or above 4.5 feet, consider as one tree and record the smallest diameter at 4.5 feet or below (fig. 02).

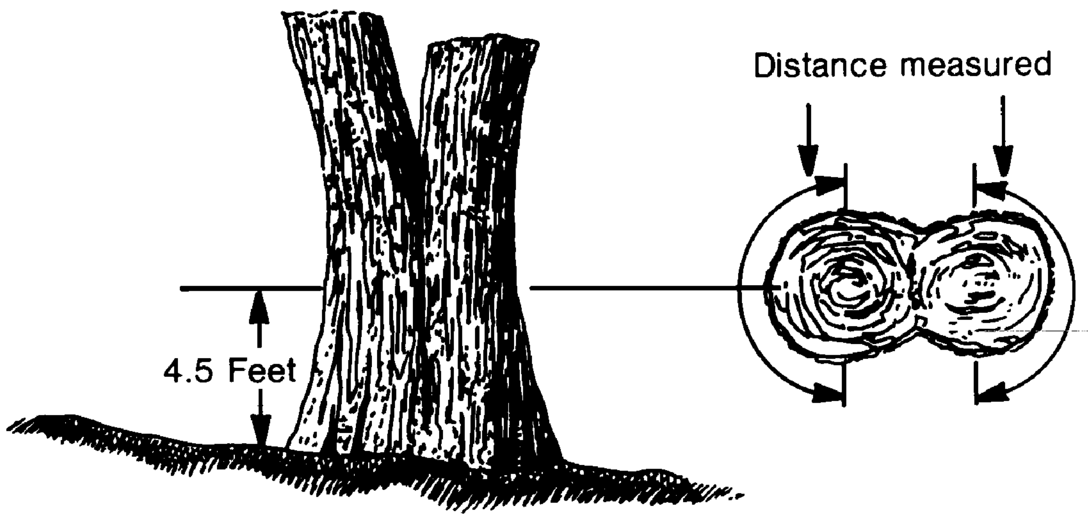


14.12b - Figure 02
Fork Occurs Above 4.5 Feet

14.12c - Trees Growing Together. Two methods may be used to determine DBH on trees growing together.

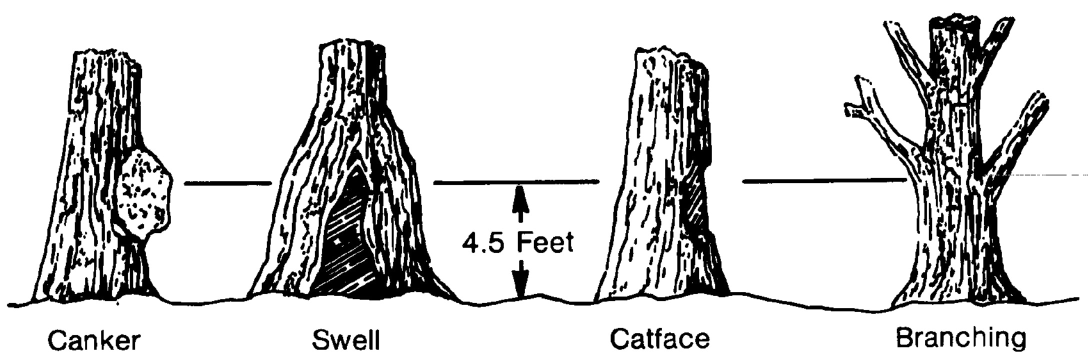
1. If calipers are available, measure each tree at normal DBH point, 4.5 feet above high ground side.

2. To use one-half diameter method, make two marks opposite each other on the stem at 4.5 feet. Measure the distance between the marks with a diameter tape; double the measurement to determine DBH.



14.12c - Figure 01
Measuring DBH on Trees Growing Together

14.12d - Trees With Abnormalities at 4.5 Feet. Figure 01 illustrates examples of trees with abnormalities such as canker, swell, catface, or excessive branching.



14.12d - Figure 01
Abnormalities at 4.5 Feet

Use one of the following procedures when DBH measurement cannot be taken at 4.5 feet:

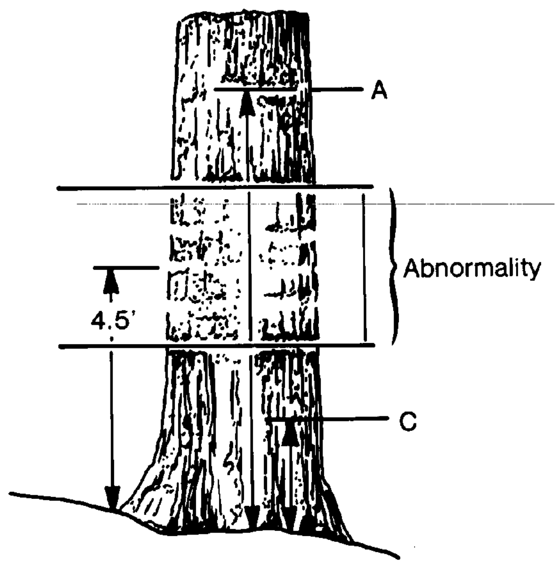
1. If the tree can be measured at normally formed points above and below the abnormality, take measurements for "A" and "C" where tree exhibits normal taper and is free from influences of abnormality. (figure 02).

   a. Measure diameter above DBH, point "A."
   b. Measure diameter below DBH, point "C."

If these measurements are at equal distances from 4.5 feet, average A and C to arrive at DBH measurement.

Example:
Diameter "A" = 16 inches
Diameter "C" = 18 inches

$$DBH = \frac{16 + 18}{2} = 17 \text{ inches}$$



14.12d - Figure 02
Techniques for Determining DBH
with Abnormalities at 4.5 Feet

If point A and point C are at unequal distances from 4.5 feet, interpolate the distances to arrive at DBH measurement.

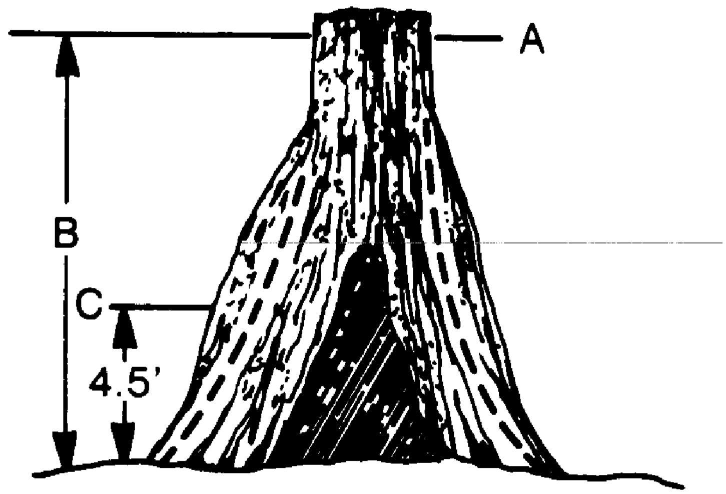
Example:
Diameter "A" = 16 inches
Diameter "C" = 22 inches
Height of "A" above ground = 12 feet
Height of "C" above ground = 2 feet

$$\text{Normal taper} = \frac{22" - 16"}{12' - 2'} = 0.6 \text{ inches/foot}$$

DBH = 22" - [(4.5' - 2') x 0.6"/ft.] = 20.5 inches
or

DBH = 16" + [(12' - 4.5') x 0.6"/ft.] = 20.5 inches

2. If the tree cannot be measured at normal points above and below the abnormality, measure above the abnormality and apply taper from comparable trees of the same species (figure 03).



14.12d - Figure 03
Abnormal Butt Swell

a. Measure diameter above DBH where shape is normal, point "A."

b. Measure height to point "A," length "B."

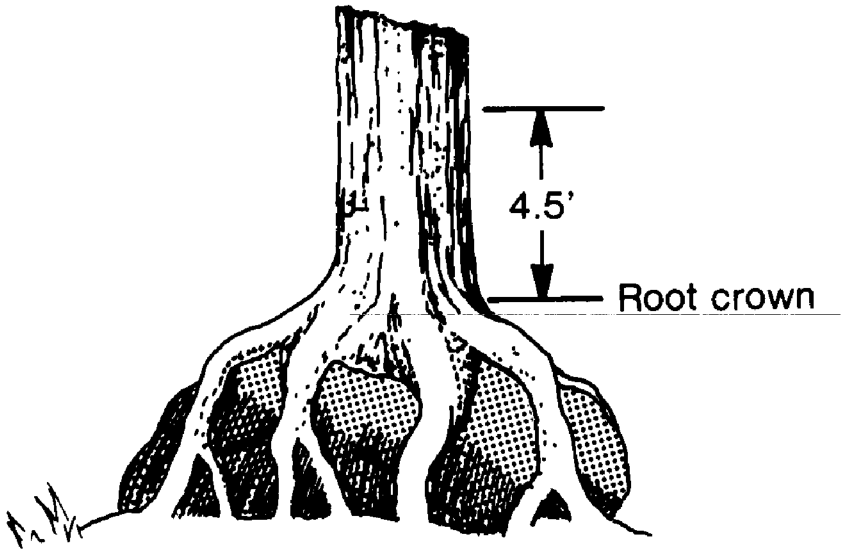
c. Determine average taper from comparable trees of the same species in immediate area.

d. Interpolate DBH measurement "C" based on diameter measurement "A," the estimated average taper, and length "B."

Example:

Diameter "A" = 18.0 inches
Length "B" = 12 feet
Estimated taper = 2 inches in 8 feet or .25 inches per foot
DBH = 18 + ((12 - 4.5) x .25) = 19.88 inches or 19.9 inches

14.12e - Trees Growing on Objects. When trees are growing on objects, such as rocks or logs, measure at 4.5 feet above the root crown rather than above the forest floor.



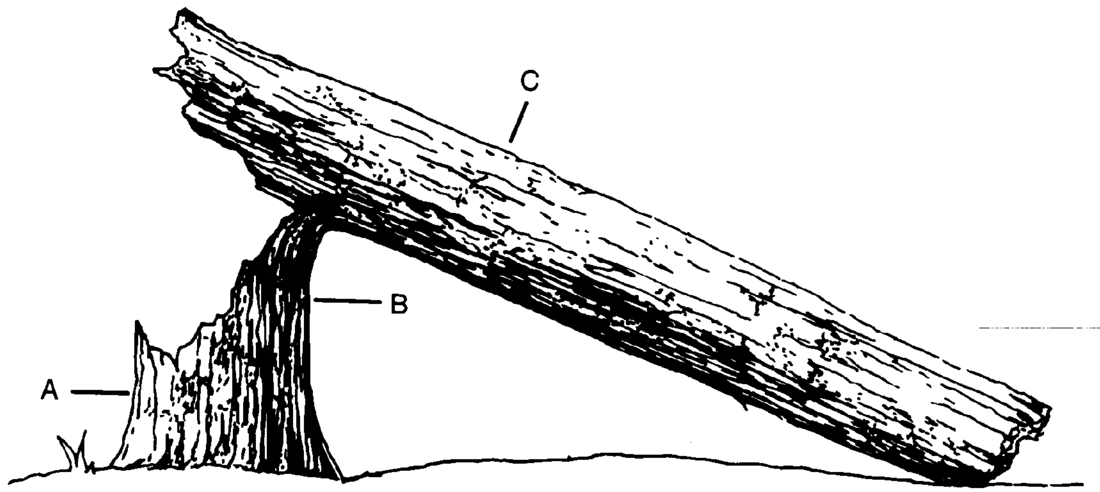
14.12e - Figure 01
Measuring DBH on Trees Growing on Objects
(Rocks, Logs)

14.12f - Coppice Growth. To measure DBH on coppice growth or on trees growing in clumps, follow the procedures described in section 14.12b - 14.12c.

14.12g - Broken Trees. Use one of the following procedures to determine DBH on broken trees:

1. If DBH occurs either below the break (A) or above the break (C), measure normally using calipers or diameter tape (fig. 01).

2. If DBH occurs at the break (B) as shown in figure 01, use procedures outlined in section 14.12d.



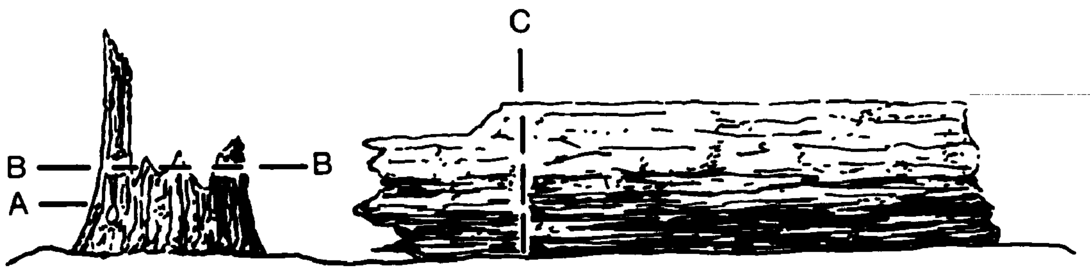
14.12g - Figure 01
Measuring DBH on Broken Tree

<u>14.12h</u> - <u>Broken Off Trees</u>. Use one of the following procedures for determining DBH on broken off trees. Figure 01 illustrates these procedures.

1. If DBH occurs below the break (A), measure normally using calipers or diameter tape.

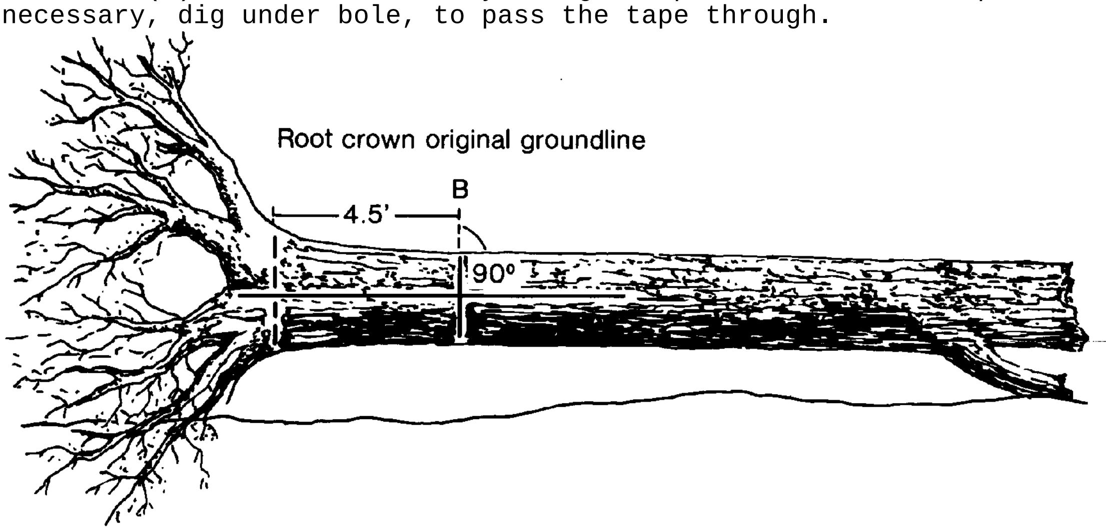
2. If DBH occurs at the break (B), and if bole is not shattered badly, make the DBH measurement at the break point. If bole is shattered, use procedures in section 14.12d.

3. If DBH occurs above the break (C), measure normally using calipers or diameter tape. If necessary, dig under bole, to pass the tape through.



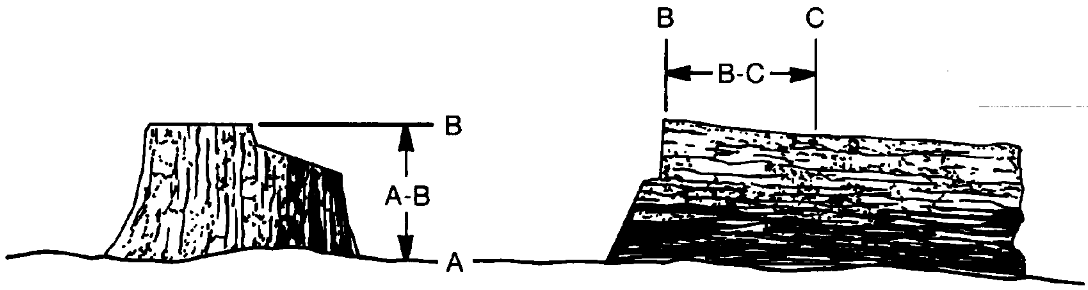
<u>14.12h</u> - <u>Figure 01</u>
<u>Measuring DBH on Broken Off Tree</u>

<u>14.12i</u> - <u>Down Trees</u>. On down trees measure DBH at 4.5 feet above original high side ground line at right angles to the center line of the bole (B). Measure normally using calipers or diameter tape. If necessary, dig under bole, to pass the tape through.



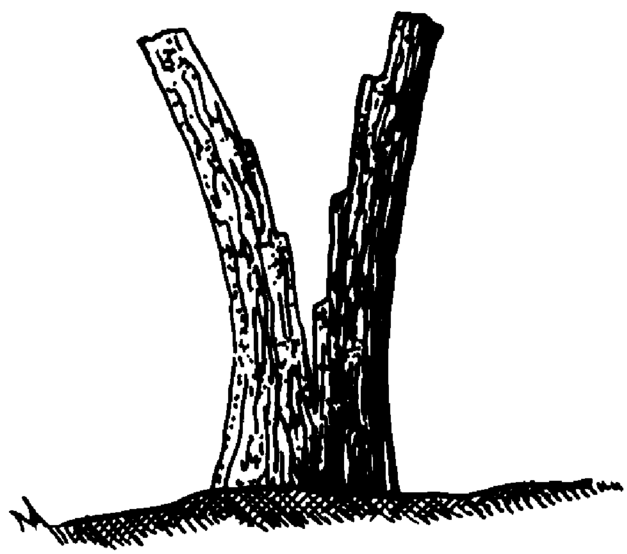
<u>14.12i</u> - <u>Figure 01</u>
<u>Measuring DBH on Down Trees</u>

14.12j - Severed, Down Trees. Measure from the ground on the high side to the saw cut on the stump (AB) and then from the saw cut on the end of the log up the bole (BC) to determine where 4.5 feet above the ground would be (fig. 01). Measure diameter at this point, normally using calipers or diameter tape. If necessary, dig under bole, to pass the tape through.



14.12j - Figure 01
Measuring DBH on Severed Trees

14.12k - Split Trees. Measure DBH with calipers or use the one-half diameter technique described in section 14.12c.



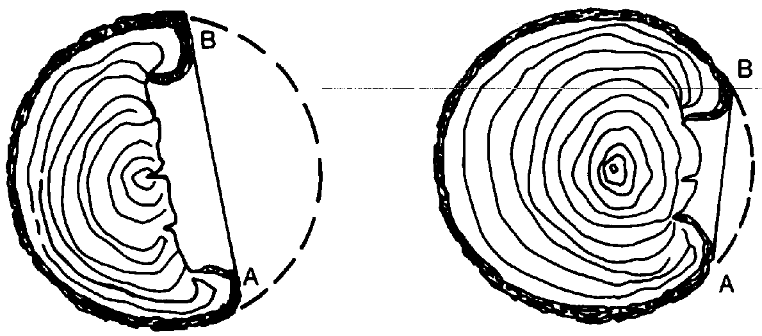
14.12k - Figure 01
Measuring DBH on Split Trees

14.12l - Trees Having a Large Catface. Use the most appropriate of the following procedures when measuring trees abnormally formed by a catface at 4.5 feet:

1. Use calipers. Measure DBH at right angle to catface.

2. Use a diameter tape. Adjust the tape to a normally rounded position to allow for the catface portion missing. If the tape is not adjusted but is pulled tight, the tape will be straight across the missing portion and the diameter read will be less than it should be (fig. 01).

3. Use the one-half diameter technique described in section 14.12c.



14.12l - Figure 01
Measuring DBH on Trees With Large Catface

14.12m - Trees Without Bark. Volume estimation procedures assume Diameter Breast Height (DBH) will be measured outside bark. The DBH measurement for trees with no bark or only partial bark at 4.5 feet must be increased to reflect the contribution of the missing bark.

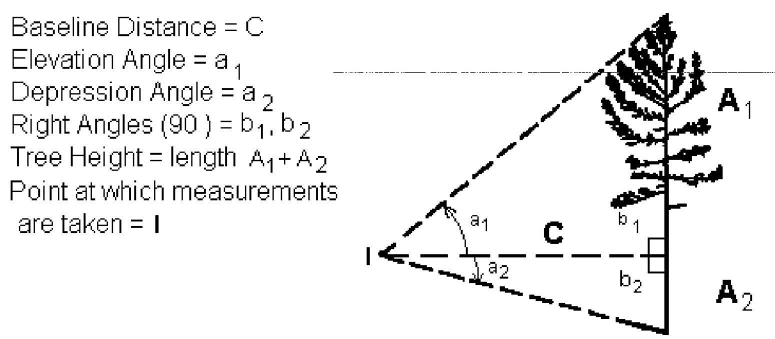
If a tree has no bark at 4.5 feet, add two times the average bark thickness (developed using data from trees with bark, of the same species, size, and geographic location) to the tree's DBH. If a tree has a partial bark covering at 4.5 feet, the individual making the measurement must use their best judgment in determining an accurate DBH.

14.2 - Measuring Tree Heights. Most volume estimation procedures require accurate tree heights to provide an accurate estimate of tree volume. An error in tree height can result in an erroneous tree volume and by extension an erroneous sale volume.

The procedures described in this section apply to all height measuring instruments.

Heights of standing trees are calculated using measurements of baseline distance, elevation angle, and depression angle. An error in any one of these measurements will result in the calculation of an erroneous tree height.

The calculation of tree height is based on the "Law of Sines" which states, in part, for any triangle, if two angles and one side are known, then the remaining angle and two sides of the triangle may be found. The known side of the triangle is the baseline distance. The known angles are the right angle formed where the baseline intersects the tree bole and the measured elevation/depression, angle. Determine the length (height) on the tree bole from the baseline intersection to the sight point used for the elevation/depression angle (fig. 01).



14.2 - Figure 01
Measuring Tree Heights

It is usually more accurate to measure height from a point uphill from the tree or on the same contour line as the tree. Avoid measuring height downhill from the tree whenever possible.

Measure tree height to the tip of the tree and/or to specified reference heights, such as total merchantable height, or sawlog height. Depending on the volume estimation procedures used, a standard stump height may or may not be considered as part of the total or reference height measurement.

1. Total tree height. Measure from the base of the tree on the high ground side to the tip of the tree leader. Record total tree height to the nearest foot.

2. Reference heights. Measure using one of the following:

a. To a specified diameter. Measure from the base of the tree on the high ground side to a specific reference diameter (minimum DIB or DOB).

b. To a merchantability limit. Measure from the base of the tree on the high ground side to a point above which the bole is too small or defective to meet the specified product utilization standards.

14.21 - Baseline Distance. Baseline distance is the horizontal distance from the face of the tree to a manufacturer's specified point on the height (angle) measuring instruments. Many instruments used to measure tree height are calculated for specific baseline distances.

When using a tape to measure baseline distance, attach the tape at a convenient height on the tree and back off the required distance, pulling the tape tight. With a clinometer, find the percent slope of the tape going back to the tree. If the slope is over 10 percent, an adjustment to the measured slope distance is necessary to prevent a bias in the height calculation. Calculate the slope distance by multiplying the desired baseline distance by the slope correction factor (ex. 01). Back off the slope distance and measure the tree height from this distance, the desired baseline distance.

Example:
Initial measured base distance (desired horizontal distance) = 66 feet
Percent slope to tree = 25
Indicated slope distance for 66 feet = 68 feet (66 x 1.03)

This adjustment is necessary to ensure the desired horizontal distance is maintained.

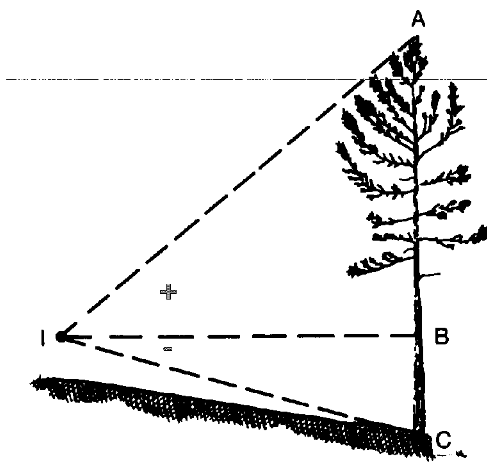
14.21 - Exhibit 01
Slope Correction Factor
(Corrects Horizontal to Slope Distance)

Slope Correction Factor

Percent of Slope	Slope Correction Factor	Percent of Slope	Slope Correction Factor
0 to 9	1.00	70	1.22
10 to 17	1.01	71 to 72	1.23
18 to 22	1.02	73 to 74	1.24
23 to 26	1.03	75	1.25
27 to 30	1.04	76 to 77	1.26
31 to 33	1.05	78 to 79	1.27
34 to 36	1.06	80	1.28
37 to 39	1.07	81 to 82	1.29
40 to 42	1.08	83	1.30
43 to 44	1.09	84 to 85	1.31
45 to 47	1.10	86	1.32
48 to 49	1.11	87 to 88	1.33
50 to 51	1.12	89	1.34
52 to 53	1.13	90 to 91	1.35
54 to 55	1.14	92	1.36
56 to 57	1.15	93 to 94	1.37
58 to 59	1.16	95	1.38

60 to 61	1.17	96 to 97	1.39
62 to 63	1.18	98	1.40
64 to 65	1.19	99 to 100	1.41
66 to 67	1.20	101	1.42
68 to 69	1.21		

14.22 - Vertical Trees. Measure the height of a vertical tree whenever possible from either level ground or from the uphill side. Use elevation and depression angle measurements from horizontal to get the height. In figure 01, the elevation angle from the horizontal line to the tree top is shown by a (+); the depression angle from the horizontal to the ground by a (-).



14.22 - Figure 01
Measured on Level Ground or
from the Uphill Side

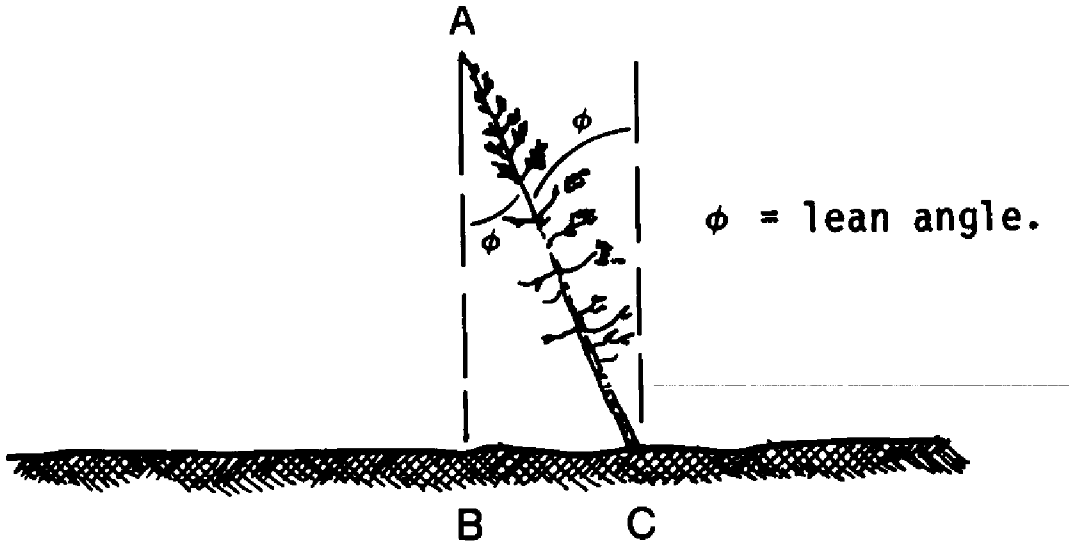
If the two angles from horizontal have different signs (if measured from level or up-slope position), add the absolute values of the two height measurements to determine tree height. If both angles from horizontal have the same sign (if measured from the down-slope position), take the absolute values of the heights and subtract the smaller height reading from the larger one to get tree height.

Examples:

1. Tree measured from up-slope position:
   Instrument elevation to tree top = +40 feet;
   Instrument elevation to ground = -10 feet.
   Tree height = 40 + 10 = 50 feet.

2. Tree measured from down-slope position:
   Instrument elevation to tree top = +65 feet;
   Instrument to ground = +15 feet.
   Tree height = 65 - 15 = 50 feet.

<u>14.23</u> - <u>Leaning Trees</u>. Trees leaning 25 percent (about 15°) or more from vertical require the following special height measuring technique. See figure 01. The angle formed by the intersection of line AB and line BC must be a right (90°) angle.



<u>14.23</u> - <u>Figure 01</u>
<u>Measuring Height of Leaning Trees</u>

1. Determine vertical distance from the ground to the tip of the tree (AB).

2. Determine horizontal distance by measuring from the tree bole to a point directly under the tip of the leaning tree (BC).

3. Determine length of the bole (actual tree height, AC) using the pythagorean theorem for right triangles where

$$Tree\ Height\ (bole\ length) = \sqrt{AB^2 + BC^2}$$

or use table l in chapter 90.

Example:
Vertical Distance, ground to tip (AB) = 65 feet.
Horizontal Distance, stump to point under tip (BC) = 26 feet.

$$\text{Tree Height} = \sqrt{AB^2 + BC^2}$$
$$= \sqrt{65^2 + 26^2}$$
$$= \sqrt{4901}$$
$$= 70 \text{ feet}$$

Alternatively, use the angle-of-lean method:

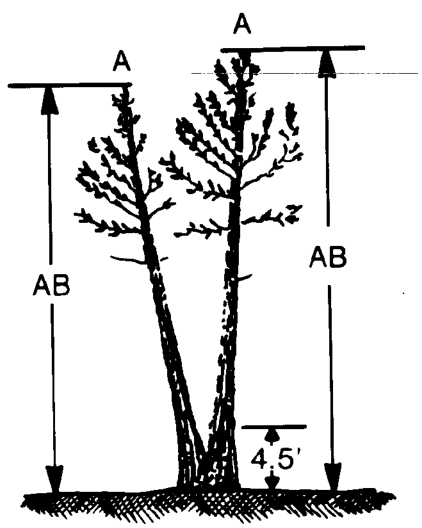
1. Measure Vertical Distance (AB)

2. Determine tree lean angle (ϕ in percent or degrees). The lean angle can be measured in degrees rather than percent, but then a trigonometric table is necessary to find the secant of the measured angle.

3. Multiply Vertical Distance by slope correction factor (sec. 14.21) to obtain bole length or the leaning tree height.

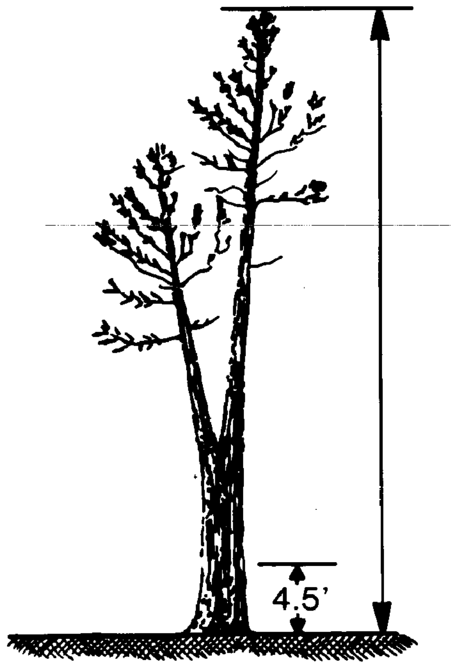
Example:
Lean percent = 40, Factor = 1.08
(Lean angle = 22° Secant = 1.08)
Vertical Distance = 65 feet
Leaning tree height = 65 x 1.08 = 70 feet.

14.24 - Forked Trees. If trees fork below DBH, treat as two trees and measure height of each stem from base of tree to tip of tree.



14.24 - Figure 01
Height of Trees Forked Below DBH

If the fork crotch occurs at or above 4.5 feet on high ground side, the tree is treated as a single tree. Measure height of the best fork.



14.24 - Figure 02
Height of Trees Forked Above DBH

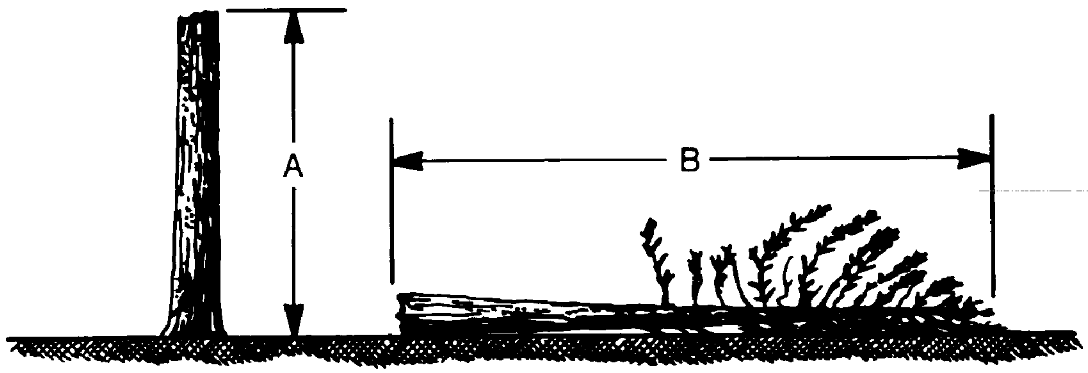
14.25 - Trees Having a Broken or Missing Top. Measure according to the following examples:

1. Total height of trees with broken top lying on the ground (fig. 01):

a. Measure height of the stub (A).

b. Measure length of the piece on the ground (B).

c. Add the two measurements to obtain total height (A + B).



14.25 - Figure 01
Height of Trees With Broken Top

2. Total height of trees with broken top attached (fig. 02). If distance to the break is short, measure tree height using procedures in paragraph 1. If distance to the break is great, measure tree height using the following procedures:

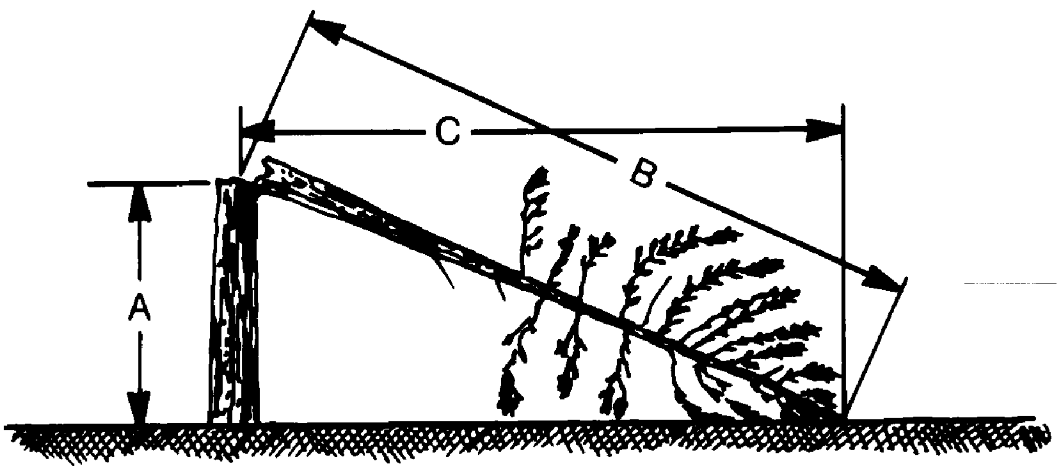
a. Measure height to break (A).

b. Measure ground distance from tip to stump (C).

c. Calculate length of the broken piece (B) using the pythagorean theorem for right triangles where:

$$Height\ B = \sqrt{A^2 + C^2}$$

d. Add the two height measurements to obtain total height (A + B).



14.25 - Figure 02
Height of Trees with Broken Top Attached

3. Total tree height when top is missing. Locate three trees of the same species, with similar DBH measurements and diameter measurements at a convenient point up the tree, such as 16 feet, 32 feet, or other height. Measure total height of the three comparison trees and use their average height as the total height measurement.

14.26 - When Measurement Point is Hidden. There are many instances where height to be measured such as merchantable height cannot be measured directly. Dense foliage or foliage from an adjacent tree may obscure the measurement point. In these instances, obtain an average height from three comparison trees.

Example of comparison tree method for merchantable height (reference height):

	Tree 1	Tree 2	Tree 3	Average	Tree being Measured
Total height	100 ft.	110 ft.	105 ft.	105	108
Merch. height	81 ft.	87 ft.	84 ft.	84	to be estimated
DBH	16	18	18	17.33	17

$$\text{Average height ratio} = \frac{84}{105} = .80$$

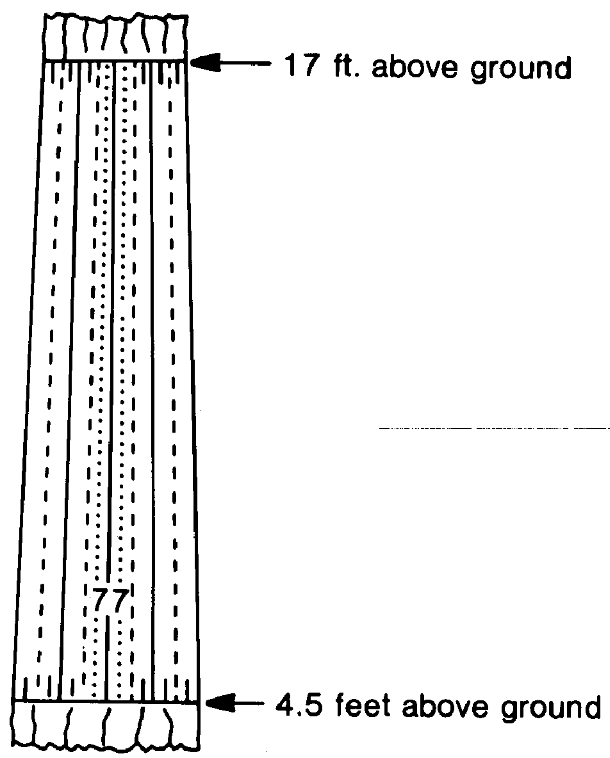
Reference height (tree being measured) = 108 feet x 0.80 = 86.4 = 86 feet.

14.3 - Tree Form Class. A measure commonly used as an independent variable along with DBH and height is Girard form class.

$$\textit{Girard form class} = \left(\frac{\textit{DIB at top of butt log}}{\textit{DBH}} \right) \times 100$$

Specify the length of the butt log used for this purpose since form class may be expressed for either a 16-foot or 32-foot butt log. (Normally the DIB of the butt log is recorded at 17 or 33 feet above the ground to allow for a 1-foot stump.)

An alternate method of determining Girard form class is to use the Wiant f-c wedge, available from forestry supply houses. Match the wedge to the form of the butt log.



14.3 - Figure 01
Wiant F-C Wedge (reduced size)

CHAPTER 20 - ESTIMATING TREE VOLUME AND WEIGHT

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23 WEIGHT DETERMINATION
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CHAPTER 20 - ESTIMATING TREE VOLUME AND WEIGHT

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.

21 - LOG RULES AND CUBIC FORMULAS.

21.1 - Log Rules. A log rule is a table of estimated volume of 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^2)
a = Small end cross section area (ft^2)
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. 05) 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. 05) is similar to the volume estimator except cubic feet may not be the unit of measure. Thus, sawtimber portions 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 and its use is preferable to other product estimators.

22.21 - Tree Stem Components. Measure the dimensions usually necessary for calculating volume. The most common measurements are 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 DOB (or 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 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. Four types of volume estimators are recognized based on the independent variables used. They are discussed in sections 22.22a-22.22e.

Before starting a cruise, know the specific product or volume estimator characteristics used to derive tract volumes. 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 height as independent variables and diameter inside bark (DIB) or diameter outside bark (DOB) to define diameter limit. The height variable is defined as: a) total height, from ground to tip or stump to tip; b) height to a specified diameter limit; or c) height to a point otherwise defined. In timber cruising, DOB is the preferred way to define the diameter limit since this is all the cruiser can accurately determine.

When using standard volume estimators:

1. Clearly understand the criteria that define the height for the applicable volume estimator. Heights other than total height are collectively called reference height and define the stem section for estimating volume if the section is less than the total stem length.

2. Measure heights to the specified diameter limit. Do not disregard the basic assumptions of the volume estimator regardless of utilization practiced by operators. 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, defect, 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. 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 downstem from the reference diameter. Do not measure a shorter height or record fewer logs for the tree to account for the defect.

<u>22.22b</u> - <u>Local Tree Volume Estimators</u>. 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 (sec. 04).

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.

<u>22.22c</u> - <u>Tarif Volume Estimators</u>. A tarif tree volume system is an indexed system of local tree volume estimators based on the relationship of tree volume to tree basal area. For many species of trees in even-aged stands, the relationship is expressed as a linear regression called a volume/basal area line. While the tarif concept is not limited to even-aged stands, the volume/basal area line is especially suited to stands having relatively uniform tree heights within DBH classes. Tarif estimators do not indicate volume of trees by log position and do not provide a direct means for determining defect and grade.

The basal area variable is converted to DBH equivalents for incorporation into a tarif volume reference. The tarif volume reference is defined by a specific volume/basal area line and identified by an indexed tarif number. Tarif number is defined as the cubic foot volume to the specified top of a tree of 1.0 square foot basal area.

To find the specific tarif number of an even-aged stand, measure the DBH and height of about 25 sample trees. Use the DBH and height of each tree to determine its tarif number. Average the tree tarif numbers to find the tarif number for the stand. The stand tarif number indicates the correct volume estimator.

To find the tarif number in an uneven-aged or mixed species stand, stratify the stand by species-DBH group and find an average tarif for each species-DBH group.

Use single tree tarif numbers when referencing tarif volume estimators to find volumes and volume/basal area ratios from a fixed point, point sample, or 3P cruise.

<u>22.22d</u> - <u>Aerial Volume Estimators</u>. Aerial volume estimators are specifically intended for estimating tree volume from aerial photographs. Aerial volume estimators are analogues of conventional tree volume estimators but use crown diameter as the independent variable instead of tree DBH. They may be based on crown diameter and total height or on crown diameter alone.

Use aerial volume estimators only when more generalized information with a larger sampling error will meet the cruise objective. Use of aerial volume estimators requires approval by the Regional Forester (sec. 04).

The use of aerial volume estimators is limited because aerial cruises require special photogrametric skills and a larger scale photography (1:5000 or 1:8000) than is generally required for the usual sale planning purposes. They also have a greater sampling error because the tree volume is more closely related to DBH than crown diameter.

<u>22.22e</u> - <u>Stem Profile Models</u>. 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.

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.

<u>22.23</u> - <u>Validation of Tree Volume Estimators</u>. 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 or goodness of fit measures for a tree volume estimator only apply 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.

Net is the residual volume after deducting wood loss (defect) from gross volume. Requirements for specifying measurement limits 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 2409.11a.

22.31 - Defect Deduction Methods. Estimate defect in standing trees in one of two ways:

1. Ocularly estimate the extent and position of defect 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. Make defect deductions in the raw data used for deriving the volume estimators to calculate the net volume of each sample tree. The result is a net volume estimate.

In using percentage deduction 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 ocular 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. Examples of such tables are shown in Exhibits 01 and 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

MERCH. HT.1/ (feet)	LOG HT.	Log number 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

MERCH. HT.1/ (feet)	LOG HT.	Log number 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 stem, 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 2409.11a, 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 representative of the tract being cruised and are, therefore, less prone to the bias inherent in indirect methods.

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 2409.11a; FSH 2409.11).

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 (sec. 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 identification.

   g. Data to be recorded.

23 - WEIGHT DETERMINATION. Use weight estimation for tree components, such as crownwood, 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.

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 tree portions left behind in logging and are outside the products specified in the timber sale contract.

2. Standing residues are standing trees not meeting 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 potential prediction equations have been developed for given utilization standards in several species and may be used when precise estimates are not needed.

Greater accuracy is obtained by some form of post-logging residue sampling. The line-intersect, planar-intercept method, or some other suitable method, may be used to get a tally of material lengths and critical diameters, by species. Estimates are expressed in tons per-acre.

Specific information about line-intersect sampling procedures can be found in a publication by C. E. Van Wagner (1968).

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.

CHAPTER 30 - CRUISING SYSTEMS

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During the design phase, choose the appropriate and most efficient cruise system from those described in this chapter. The numerical examples given are intended to illustrate the arithmetic procedures involved in each cruising system. The examples are necessarily brief, are not based on actual data, and in most cases would not meet error standards due to the small number of samples taken.

30.5 - Definitions.

Accuracy. Accuracy refers to how well the sample estimates the true value of a quantity. Either bias, lack of precision, or both, can impair accuracy of an estimate. An estimate may be very precise, but because of bias, may still be inaccurate.

Bias. Bias is a systematic error.

Coefficient of Variation. This is a measure of relative dispersion. It is the standard deviation expressed as a percentage of the mean.

Expansion Factor. In any sampling scheme, only selected trees are completely measured. The trees that are measured also represent those that were not measured and must be expanded to get a total stand value. A blow-up, or expansion factor can be calculated based on the sampling scheme that allows each sampled tree to be expanded to represent the entire stand. The factors (denoted by F) can be calculated to expand each sample tree to units such as trees per acre or volume per acre; the type of factor is denoted by subscripting the F.

Frequency Distribution. A frequency distribution divides the population into a relatively small number of classes, listing the number of observations belonging to each.

Mean. This is the average value obtained from dividing the sum of sample unit values by the number of sample units.

Normal Distribution. The normal distribution is a frequency distribution where the distribution of a random measuring error or random error for repeated measurements (for large n) of physical quantities exhibits a particular symmetric bell shape, with a typical maximum, the curve falling off on both sides, and large deviations from the measured value being rare. Assume a normal distribution governs the distribution of population values dealt with in timber cruises.

Parameter. Characteristics such as relative frequency, mean, or standard deviation which refer to the population, are called parameters. Mean tree volume for the entire population is called a parameter, and the sample-based mean tree volume is a statistic which estimates the parameter.

Population. The defined total set of all possible observations, about which information is desired is termed a population.

Precision. Precision describes the clustering of sample values about their mean.

Sampling Error. The sampling error expresses the precision of the inventory. It is the percent error of an estimated mean at a desired probability level. It is calculated as the standard error of the mean times a student t value, divided by the mean and multiplied by 100 to express a percent.

Standard Deviation. This commonly used measure of dispersion is calculated by taking the square root of the variance.

Standard Error. The standard error of the mean provides an estimate of the sampling error. It describes the variation of multiple sample means about the population mean. It can be estimated from a single sample as the square root of the sample variance divided by the sample size.

Tree Factor. A factor that expands each sampled tree to the number of trees that it represents.

Variance. Variance is a measure of how the sample unit values, such as tree volumes are dispersed (clustered, scattered) around the mean of the unit values.

Volume Factor. A factor that expands each sampled tree to the volume that it represents.

31 - STATISTICAL METHODS IN CRUISING.

To make valid estimates, use statistical methods together with the basic formulas to design a cruise. For detailed information about statistics, refer to Freese (1962 and 1967) or college text books on forest mensuration and statistics.

31.1 - Statistical Notation and Formulas.

There are several methods of writing many of the formulas. While an effort has been made to provide a consistent approach in this handbook, other references may use different notations and formulations for the same equations. Some mensuration and statistical texts use the notation as given in parenthesis. The following describes standard statistical notation used in this chapter:

x	*Individual measurement*
n	*Number of sampling units in a sample*
N	*Number of sampling units in the population*
$\sum$	*Summation sign, read as sum of*
$\bar{x}$	*Arithmetic mean of the sample*
V	*Variance* (s^2)
SD	*Standard deviation* (s)
SE	*Standard error of the mean* ($s_{\bar{x}}$)
E	*Sampling error in percent*
CV	*Coefficient of variation in percent*

31.2 - Statistical Concepts. Use the statistical concepts of population, population variance, and sampling error objective as a starting point in cruise design. The units to be sampled within each population exhibit a characteristic variation. Populations are never uniform, and the values of the units (trees, points, plots) comprising the population vary between certain limits, depending on how the population is defined. Therefore, the less variation there is in the measured variable from sampling unit to sampling unit, the fewer sampling units are needed to get a reliable estimate. Determine the reliability of estimates using the sampling error.

Use three basic elements in designing a cruise:

1. The population to be sampled.

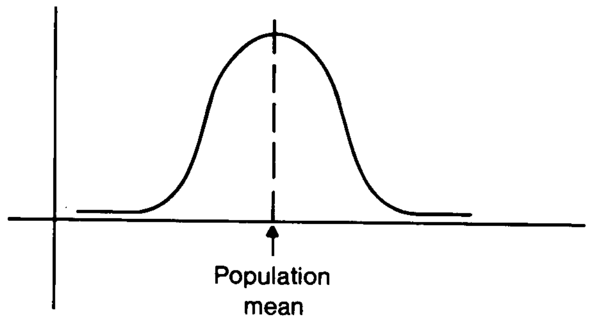
2. The degree of variation within the population.

3. The sampling error objective.

Once the cruise is completed, compute the estimate, the sampling error of the estimate (within 95 percent confidence limits), and the coefficient of variation.

31.21 - Frequency Distribution. The mathematical form of a frequency distribution is expressed as a distribution function. Each population has a distinctive distribution function and the form of the distribution function determines the suitable statistical treatment of sample data. The form of the distribution is seldom known and large samples tend to approximate a normal distribution; consider a large sample to be one consisting of 30 or more sampling units.

31.22 - The Normal Distribution. Assume that the normal distribution governs population values dealt with in timber cruises. The normal distribution is characterized by a bell-shaped curve (fig. 01).



31.22 - Figure 01
Normal Distribution

The total area under the curve above the x-axis is equal to 1. The detailed line erected at the mean divides the area under the curve into two halves.

See section 31.32 for a more detailed description of the characteristics of the normal curve.

31.23 - Sampling. From a population of the units to be measured, some are selected, such as trees in a stand or timber sale. Each unit in the sample becomes a sampling unit upon which an observation is made to determine the value for that unit. For example, out of a population of sawtimber trees, a selected number will be measured for the characteristics needed to determine a mean tree volume. Usually, these are diameter breast height (DBH) and height.

31.24 - Examples of Bias. The following are bias examples:

1. Measurement bias occurs when an instrument is out of adjustment, and mismeasures each sampling unit by a fixed amount.

2. Estimation bias occurs when a volume estimator consistently overestimates or consistently underestimates actual tree volume.

3. Selection bias occurs when plots over-represent a timber condition, such as taking a string of plots along a drainage instead of across a drainage.

31.3 - Sampling Statistics. Common statistics computed from samples obtained in cruising are the arithmetic mean, standard deviation, coefficient of variation, the standard error (of the mean), and the sampling error.

31.31 - Calculating a Mean. The mean is the average value obtained from dividing the sum of sample unit values by the number of sample units:

$$\bar{x} = \frac{\sum^{n} x}{n}$$

where:

$\bar{x}$ = the sample mean
x = the sample value for the i^{th} individual
n = the number of samples

The mean by itself is not an adequate measure of the 'goodness' of the sample estimate. It must be assessed in association with a measure of dispersion.

31.32 - Calculating Variance. Variance is calculated as:

$$V = \frac{\sum^{n} (x-\bar{x})^2}{n-1} = \frac{\sum^{n} x^2 - \frac{\left(\sum^{n} x\right)^2}{n}}{n-1}$$

where:

V = variance
x = the sample value
$\bar{x}$ = the average sample value
n = the number of samples

If all trees in a population and sample were exactly the same size they would have the same volume. In such a case, the sample mean volume is the same as the volume of each tree and there is no dispersion of sample units around the mean. That is, the variance is zero and only one sample is necessary to estimate the mean. In reality, there is variation and as individual tree volumes differ from the mean by ever larger dispersions, more samples are needed to obtain a reliable estimate of the mean.

31.33 - Calculating Standard Deviation. This commonly used measure of dispersion is calculated by taking the square root of the variance:

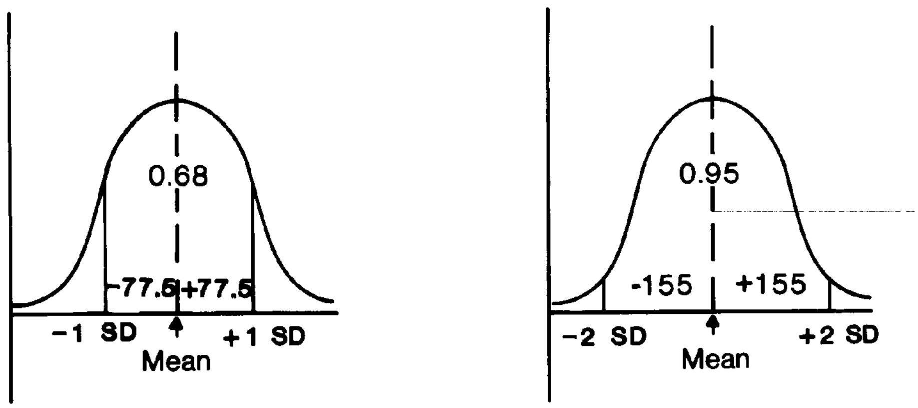
$$SD = \sqrt{V} = \sqrt{\frac{\sum^{n} x^2 - \frac{(\sum^{n} x)^2}{n}}{n-1}}$$

where:

SD = standard deviation
V = variance

x = sample value for i[th] individual
n = number of samples

The normal curve displays a relationship between the sample mean and standard deviation. For example, it is found that in one cruise, the standard deviation is ±77.5 BF. The probability is 0.68 (68 times out of 100) that an observed value will fall within ±77.5 BF of the sample mean, and 0.95 (95 times out of 100) that an observed value will fall within ±155 BF of the sample mean.



31.33 - Figure 01
Standard Deviation

The standard deviation measures the dispersion of individual observations about their mean. A similar relationship holds for the dispersion of sample means about their mean. The standard deviation of sample means is called the standard error of the mean.

31.34 - Calculating Coefficient of Variation. The coefficient of variation is calculated as:

$$CV = \frac{SD}{\bar{x}} \times 100$$

where:

CV = coefficient of variation
SD = standard deviation
$\bar{x}$ = mean value of all individuals sampled

Because the coefficient of variation is a measure of relative variability, it can be used to compare the degree of variation between different populations. For example, the following is known for two timber tracts:

Tract A

$\bar{x}$ = 8.5 cubic feet per tree
SD = ±4.7 cubic feet per tree
then:

$$CV = \frac{100(4.7)}{8.5} = 55.3\%$$

Tract B

$\bar{x}$ = 6.4 cubic feet per tree
SD = ±4.0 cubic feet per tree

$$CV = \frac{100(4.0)}{6.4} = 62.5\%$$

The calculations show tract B exhibits greater variation than tract A and requires a larger sample for a given sampling error.

31.35 - Standard Error and Confidence Limits. The standard error can be thought of as the standard deviation of sample means about their mean. The distribution of large numbers of sample means (30 or more) follows the normal curve and has the same relationship for sample means as for individual values about their mean.

For large samples of 30 or more observations, expect the true mean to fall within ±1 standard error of the sample mean with a probability of 0.68, or within ±2 standard errors of the sample mean with a probability of 0.95 (sec. 31.33, fig. 01). These are the confidence limits of a sample-based estimate of a population mean, since the true population mean is never known.

The standard error is calculated as:

$$SE = \frac{SD}{\sqrt{n}} = \sqrt{\frac{\sum^{n} X^2 - \frac{\left(\sum^{n} X\right)^2}{n}}{n(n-1)}}$$

where:

SE = standard error of the estimate
SD = standard deviation
x = sample value for i^{th} individual
n = number of samples

When simple random sampling is used and each sample unit appears only once in the sample, which is called sampling without replacement, a finite population correction can be applied to the standard error.

$$SE = \frac{SE}{\sqrt{n}}\sqrt{1-\frac{n}{N}}$$

$$= \sqrt{\frac{\sum^{n} x^2 - \frac{\left(\sum^{n} x\right)^2}{n}}{n(n-1)} \times \left(1-\frac{n}{N}\right)}$$

where:
SE = standard error of the estimate
SD = standard deviation
x = sample value for i^{th} individual
n = number of sampling units selected
N = number of units in the population.

The finite population correction is not needed if n/N is less than 0.05. That is, if the number of sample units is less than 5 percent of the total number of units in the population, the population correction factor is not needed. The purpose of the finite population correction is to prevent an inflated statement of standard error when the number of sampling units is a large proportion (0.05 or greater) of the total population.

In calculating the confidence limit, use the "Student t" distribution. For practical purposes, consider the value of t constant for a given degree of confidence.

These confidence limits are expressed as:

68 percent confidence limits (t = 1). Unless a 1-in-3 chance has occurred, the true mean will be within ±1 standard error of the sample mean.

95 percent confidence limits (t = 2). Unless a 1-in-20 chance has occurred, the true mean will be within ±2 standard errors of the sample mean.

99.7 percent confidence limits (t = 3). Unless a 1-in-300 chance has occurred, the true mean will be within ±3 standard errors of the sample mean.

Determine the confidence limit by:

1. Finding the mean and standard deviation,
2. Calculating the standard error,
3. Multiplying the standard error by the appropriate Student t value,
4. Subtracting this product from the mean to set the lower limit,
5. Adding the product to the mean to set the upper limit.

These limits set the range of values expected to include the true population mean. This is called the confidence interval. The probability that the population will fall within these limits is set by the t value chosen. For example, select a sample of trees from a stand and measure the cubic volume of each sample tree. Then calculate the confidence limits as follows:

Example:

$$\textit{Given}: \; SD = 8.318 \; ft^3$$

$$\bar{x} = 31.53 \; ft^3$$

$$n = 211$$

$$\textit{then}: \; SE = \frac{8.318}{\sqrt{211}} = 0.573 \; ft^3$$

The Student t value for the 95 percent confidence limits is approximately 2; therefore:

$$\begin{aligned} \text{Confidence limit} &= \bar{x} \pm (t \times SE) \\ &= 31.53 \pm (2 \times 0.573) \\ &= 31.53 \pm 1.146 \; ft^3 \end{aligned}$$

This can be interpreted as follows:

$$(\bar{x} - t \times SE) \; \textit{and} \; (\bar{x} + t \times SE)$$
$$(31.53 - 1.146) \; \textit{and} \; (31.53 + 1.146)$$
$$30.384 \; \textit{and} \; 32.676$$

Unless a 1-in-20 chance has occurred, the true population mean falls between these confidence limits.

31.36 - Calculating Sampling Error. Calculate sampling error by dividing the standard error by the mean, then multiplying by 100, and finally multiplying by the student t value appropriate to the confidence level:

$$E = \frac{SE}{\bar{X}} \times 100 \times t$$

In the above example with a mean of 31.53 and a SE of 0.573, the sampling error at the 95 percent confidence level is:

$$E = \frac{0.573}{31.53} \times 100 \times 2$$

$$= 3.63\%$$

We can expect, with 95 percent probability, the true population mean to lie within 3.63 percent of our sample mean.

31.4 - Determining Sample Size. Knowing the coefficient of variation (sec. 31.34) for a population, the number of sampling units (observations) needed for a specified sampling error objective can be calculated. Recognize two sampling conditions:

1. Sampling finite populations. (For example, the total number of sampling units in the population is approximately known).

$$n = \frac{1}{\frac{E^2}{t^2CV^2} + \frac{1}{N}} = \frac{(tCV)^2}{E^2 + \frac{(tCV)^2}{N}}$$

2. Sampling infinite populations (total number of sampling units in population not known) or if number of sampling units is a small proportion (less than 0.05) of the total population.

$$n = \frac{t^2CV^2}{E^2} = \frac{(t\ CV)^2}{E^2}$$

31.5 - Stratification. The statistical calculations discussed up to this point assumed simple random sampling conditions. In certain cases, it is advantageous to use stratified random sampling. The chief purpose in stratification is to divide the population into subpopulations (strata or sample groups) based on certain similar characteristics.

The aim of stratification is to create strata or sample groups such that the variation within each is less than it would be for the (unstratified) population as a whole. This enables taking fewer sampling units for a specified sampling error objective, or, conversely, a given number of sample units provides a more precise (stratified) estimate than if taken for the unstratified population.

Where sampling units are single trees, a population of sawtimber trees for example, might be stratified on the basis of 2-inch or 4-inch groups. Either option may reduce the sample size needed for a stated objective over the number needed for the unstratified population.

Similarly, sample plots might be stratified by timber types or by other groupings that are likely to increase homogeneity within groups.

Optimum allocation requires some precruise estimates of the number of sample units in each stratum, as well as the variation in each stratum. Based on this information, calculate a separate sampling intensity for each stratum and the total number of sample units prorated (allocated) by strata.

An example of optimum allocation is given in section 35.3.

32 - 100 PERCENT CRUISE. Every member of the population is visited and measured. The variable of interest, generally expressed as volume or value, is an exact measure of the strata. Apply this method to finite populations of trees where each tree in the population is measured, but restrict its use to special cases where sampling is not practical. For example, the trees to be cut from an access road right-of-way which lies outside the boundaries of the cutting units may be an appropriate use. Consider 100 percent measurement for sales of species or products with exceptionally high values.

33 - SAMPLE-TREE WITH COMPLETE TALLY.

33.1 - Sample-Tree With Complete Tally Method. In this method, single trees are sampled with equal probability of selection. Define the population(s) and components to be sampled. Some form of stratification may be used, either based on species, species groups, diameter breast height (DBH) classes, or a combination of these. In some cases, define a non-sampled (100-percent measured) component. Such a component might consist of trees above a certain DBH class, or trees of certain species estimated to have too few trees to yield the required minimum number of samples at the prescribed sampling frequency. To use this cruise method, make a complete tally of the population being sampled.

33.11 - Operational Features. Select trees without bias. Select trees randomly to meet the requirement for unbiased sample unit selection. Ensure randomness by using dice, poker chips, marbles, or random numbers in the selection process.

Systematic sampling (sampling every nth tree) may be used in certain controlled situations, where the cruiser does not keep track of their own samples. In such applications, someone other than the cruiser records the cruise data. This is to control personal bias on the part of the cruiser.

Sample-tree cruising is best done with a crew of three or four marker-cruisers and a tallier. This system loses its advantage in scattered timber. Crew members function as both marker and cruiser. The main advantage is that the tallier keeps the tree count and calls the sample trees to be measured as they come up, thereby removing a possible source of bias in sample selection.

The cruiser receiving the sample-tree call measures the sample-tree and either records the data or calls it in to the tallier. Identify cruise trees for later check cruising with the cruiser's identification and the tree number.

Conduct an accurate tree count and avoid missing trees or double-counting to ensure accurate results from this method. The best way to do this is to mark the tree, then report it to the tallier.

33.12 - Statistical Features. This cruising method may be used with simple random sampling or with stratified random sampling.

Use simple random sampling for single-product situations, such as pulpwood, where the need for sampling precision is less critical, or where the population is not large enough to make stratification worthwhile.

Prescribe stratified sampling where it is possible to subdivide the population into fairly homogeneous groups (sec. 31.5).

Generally, for sample-tree with complete tally, the variable of interest subject to sampling error, is volume per tree.

33.2 - Calculating Sample Size. Calculate optimum sample size using precruise data and the series of steps illustrated. In the example, the population is stratified (divided into sample groups) by species or combinations of species. Calculate the sample statistics by species group (ex. 02-03) from the precruise data (ex. 01).

33.2 - Exhibit 01
Precruise Data

Tree ID	Species	Sample Group	DBH	Height	Net ft^3 Volume/Tree Sample Group 1	Net ft^3 Volume/Tree Sample Group 2
1	A	1	10.0	48	10.7	
2	A	1	11.0	74	24.2	
3	A	1	13.0	67	29.0	
4	B	2	13.0	73		26.9
5	B	2	8.0	45		4.9
6	B	2	13.0	61		23.0
7	B	2	15.0	88		43.8
8	A	1	12.0	59	21.0	
9	B	2	10.0	56		11.5
10	B	2	9.0	61		10.1
11	B	2	16.0	66		29.4
12	B	2	12.0	43		6.7
13	A	1	13.0	67	41.4	
14	A	1	17.0	61	21.0	
15	A	1	12.0	74	30.9	
16	A	1	9.0	92	66.3	
17	B	2	11.0	63		19.3
18	B	2	13.0	54		8.8
19	C	2	11.0	54		14.0
20	A	1	14.0	77	31.8	
21	C	2	11.0	52		13.0
22	A	1	14.0	70	33.4	
23	C	2	11.0	63		16.8
24	A	1	14.0	69	32.4	
25	A	1	16.0	72	45.6	
26	A	1	12.0	74	27.8	
27	B	2	10.0	55		11.0
28	B	2	9.0	63		10.7
29	B	2	11.0	56		14.2
30	B	2	13.0	63		24.2
31	B	2	12.0	70		21.6
32	A	1	15.0	69	38.4	
33	C	2	12.0	57		17.7
34	A	1	11.0	63	19.7	
35	A	1	10.0	65	17.3	
36	B	2	13.0	73		26.9
37	B	2	8.0	45		4.9
38	B	2	13.0	61		23.0
39	B	2	15.0	88		43.8

33.2 - Exhibit 02
Standard Deviation and Coefficient of Variation of Sample Group 1

Tree ID	Net ft^3 Volume (x)	Net ft^3 Volume Squared (x^2)
1	10.7	114.49
2	24.2	585.64
3	29.0	841.00
8	21.0	441.00
13	41.4	1713.96
14	21.0	441.00
15	30.9	954.81
16	66.3	4395.69
20	31.8	1011.24
22	33.4	1115.56
24	32.4	1049.76
25	45.6	2079.36
26	27.8	772.84
32	38.4	1474.56
34	19.7	388.09
35	17.3	299.29
n = 16	490.9	17678.29

$$Mean = \bar{x} = \frac{\sum^{n} x}{n} = \frac{490.9}{16} = 30.68$$

$$Standard\ Deviation = SD = \sqrt{\frac{\sum^{n} x^2 - \frac{\left(\sum^{n} x\right)^2}{n}}{n-1}}$$

$$= \sqrt{\frac{17678.29 - \frac{490.9^2}{16}}{15}} = 13.21$$

$$Coefficient\ of\ Variation = CV = \frac{SD}{\bar{x}} \times 100$$

$$= \left(\frac{13.20}{30.68}\right)(100)$$

$$= 43.02 = 43\%$$

33.2 - Exhibit 03
Standard Deviation and Coefficient of Variation of Sample Group 2

Tree ID	Net ft³ Volume (x)	Net ft³ Volume Squared (x^2)
4	26.9	723.61
5	4.9	24.01
6	23.0	529.00
7	43.8	1918.44
9	11.5	132.25
10	10.1	102.01
11	29.1	846.81
12	6.7	44.89
17	19.3	372.49
18	8.8	77.44
19	14.0	196.00
21	13.0	169.00
23	16.8	282.24
27	11.0	121.00
28	10.7	114.49
29	14.2	201.64
30	24.2	585.64
31	21.6	466.56
33	17.7	313.29
36	26.9	723.61
37	4.9	24.01
38	23.0	529.00
39	43.8	1918.44
n = 23	425.9	10415.87

$$Mean = \bar{x} = \frac{\sum^{n} x}{n} = \frac{425.9}{23} = 18.52$$

$$Standard\ Deviation = SD = \sqrt{\frac{\sum^{n} x^2 - \frac{\left(\sum^{n} x\right)^2}{n}}{n-1}}$$

$$= \sqrt{\frac{10415.87 - \frac{425.9^2}{23}}{22}} = 10.72$$

$$Coefficient\ of\ Variation = CV = \frac{SD}{\bar{x}} \times 100$$

$$= \frac{10.72}{18.52}(100)$$

$$= 57.88 = 58\%$$

Develop volume per tree estimates by processing the precruise data as a cruise or from previous sale volume summaries of comparable sales.

Given the sale sampling error objective: E = 10% with 95% confidence (t = 2), then subdivide (stratify) the sale population into sample groups. For example, suppose that a sale of the following trees is being prepared:

Sample Group	Species Component	Estimated No. of Trees in Sale
1	A	152
2	B,C	276
Total		428

Calculate the coefficient of variation by sample group and a weighted CV over all sample groups.

Sample Group	Estimated Volume	(a) Percent Volume	(b) Est. CV%	CV Fraction (a) x (b)
1	4663	48	43	20.6
2	5111	52	58	30.2
	9774			50.8 Weighted CV

For the desired sale sampling error objective (E_T) of 10% and a weighted coefficient of variation of 50.8, determine the number of sample trees needed for sale as a whole, n_T:

$$n_T = \frac{t^2(\text{Weighted CV})^2}{(E_T)^2}, \text{ where } t = 2 \text{ standard errors}$$

$$n_T = \frac{2^2(50.8)^2}{10^2} = 103.2 = 104 \text{ sample trees}$$

Allocate number of trees for each j^{th} sample group, (there are s sample groups, and in this example, s = 2):

$$n_j = \frac{(\text{CV Fraction})n_T}{\text{Weighted CV}} = \text{Sample trees for } j^{th} \text{ group}$$

Allocate the trees to the sample groups; calculate the number of sample trees needed for sample group 1.

$$n_1 = \frac{(20.6)(104)}{50.8} = 42.2 = 43 \textit{ sample trees}$$

Calculate the number of sample trees needed for sample group 2.

$$n_2 = \frac{(30.2)(104)}{50.8} = 61.8 = 62 \textit{ sample trees}$$

33.3 - Calculating Sampling Statistics.

33.31 - Sample Expansion. Calculate the expansion factors for each species (total number of trees in the group divided by the number sampled):

		Sample Group 1	Sample Group 2
Total number of trees marked (N)	=	152	276
Total number of trees in sample (n)	=	16	23
Expansion factor (F_t) = N/n	=	9.5	12.0

Expand the volumes for each sample group as in exhibits 01 - 02.

33.31 - Exhibit 01
Sample Group 1 Volume

Tree ID	Net ft^3 Volume in tree (x)	Tree Factor (F_t)	Expanded net ft^3 Vol.	Squared net ft^3 (x^2)
1	10.7	9.5	101.65	114.49
2	24.2	9.5	229.90	585.64
3	29.0	9.5	275.50	841.00
8	21.0	9.5	199.50	441.00
13	41.4	9.5	393.30	1713.96
14	21.0	9.5	199.50	441.00
15	30.9	9.5	293.55	954.81
16	66.3	9.5	629.85	4395.69
20	31.8	9.5	302.10	1011.24
22	33.4	9.5	317.30	1115.56
24	32.4	9.5	307.80	1049.76
25	45.6	9.5	433.20	2079.36
26	27.8	9.5	264.10	772.84
32	38.4	9.5	364.80	1474.56
34	19.7	9.5	187.15	388.09
35	17.3	9.5	164.35	299.29
	490.9	152.0	4663.55	17678.29

n = 16

Total volume for sample group 1 = 4664

Alternately:

Estimated Volume = Estimated Average Tree Volume x Total Number of Trees Marked

Average tree volume = 490.9/16 = 30.681

Total volume for sample group 1 = 30.681 x 152 = 4664 ft^3

33.31 - Exhibit 02
Sample Group 2 Volume

Tree ID	Net ft^3 Volume (x)	Tree Factor (F_t)	Expanded net ft^3 Volume	Squared net ft^3 (x^2)
4	26.9	12.0	322.80	723.61
5	4.9	12.0	58.80	24.01
6	23.0	12.0	276.00	529.00
7	43.8	12.0	525.60	1918.44
9	11.5	12.0	138.00	132.25
10	10.1	12.0	121.20	102.01
11	29.1	12.0	349.20	846.81
12	6.7	12.0	80.40	44.89
17	19.3	12.0	231.60	375.49
18	8.8	12.0	105.60	77.44
19	14.0	12.0	168.00	196.00
21	13.0	12.0	156.00	169.00
23	16.8	12.0	201.60	282.24
27	11.0	12.0	132.00	121.00
28	10.7	12.0	128.40	114.49
29	14.2	12.0	170.40	201.64
30	24.2	12.0	290.20	585.64
31	21.6	12.0	259.20	466.56
33	17.7	12.0	212.40	313.29
36	26.9	12.0	322.80	723.61
37	4.9	12.0	58.80	24.10
38	23.0	12.0	276.00	529.00
39	43.8	12.0	525.60	1918.44
n = 23	425.9	276.0	5110.80	10415.87

Total volume for sample group 2 = 5111

Alternately:

Estimated Volume = Estimated Average Tree Volume x Total Number of Trees Marked

Average tree volume = 425.9/23 = 18.517

Total volume for sample group 2 = 18.517 x 276
= 5111 ft^3

Add the volumes for the two sample groups together for the sale volume.

Volume for sample group 1 = 4664 ft^3
Volume for sample group 2 = 5111 ft^3

Total volume for the sale = 9775 ft^3

<u>33.32</u> - <u>Sampling Error</u>. Compute the sampling error for each sampling group first, and then compute a combined sampling error for the sale as a whole. Given the sample tree data from section 33.31, and given the following information for sample group 1:

$$n = 16$$

$$Sum\ Tree\ Volume = \sum^{n} x = 490.9$$

$$Sum\ Tree\ Volume^2 = \sum^{n} x^2 = 17678.29$$

$$\bar{x} = \frac{490.9}{16} = 30.68$$

Total Number of Trees Marked = N = 152

Calculate the standard error for sample group 1:

$$SE = \sqrt{\frac{\sum^{n} x^2 - \frac{\left(\sum^{n} x\right)^2}{n}}{n(n-1)}\left(1 - \frac{n}{N}\right)}$$

$$= \sqrt{\frac{17678.29 - \frac{490.9^2}{16}}{16(15)}\left(1 - \frac{16}{152}\right)}$$

$$= \sqrt{\frac{2616.86}{240}(.89)}$$

$$= 3.12\ ft^3$$

Calculate sampling error for the sample group 1:

$$E_1 = \frac{SE}{\bar{x}} \times 100 \times t$$

$$= \frac{3.12}{30.68} \times 100 \times 2$$

$$= 20.34$$

$$= 20.3\%$$

Given the following information for sample group 2:

$$n = 23$$

$$\text{Sum Tree Volume} = \sum^{n} x = 425.9$$

$$\text{Sum Tree Volume}^2 = \sum^{n} x^2 = 10415.87$$

$$\bar{x} = \frac{425.9}{23} = 18.52$$

Total Number of Trees Marked = N = 276

Calculate the standard error for sample group 2:

$$SE = \sqrt{\frac{\sum^{n} x^2 - \frac{\left(\sum^{n} x\right)^2}{n}}{n(n-1)}\left(1-\frac{n}{N}\right)}$$

$$= \sqrt{\frac{10415.87 - \frac{425.9^2}{23}}{23(22)}\left(1-\frac{23}{276}\right)}$$

$$= \sqrt{\frac{2529.31}{506}(.917)}$$

$$= 2.14\ ft^3$$

Calculate sampling error for sample group 2:

$$E_2 = \frac{SE}{\bar{x}} \times 100 \times t$$

$$= 100\ \frac{2.14}{18.52} \times 100 \times 2$$

$$= 23.11$$

$$= 23.1\%$$

Combine the strata errors to get the total sale error (ex. 01).

33.32 - Exhibit 01
Sampling Error for the Strata

Sample Group	Volume ft^3 (V)	Sampling Error (%) (E)	Volume x % Error/100 (VxE)	$(VxE)^2$
1	4663	20.4	951.252	904880.37
2	5111	23.1	1180.641	1393913.17
	9774			2298793.54

Compute combined sampling error for sale:

$$E_T = \sqrt{\frac{(V_1E_1)^2 + (V_2E_2)^2}{V_T}}$$

$$= \sqrt{\frac{904880.37 + 1393913.17}{4663 + 5111}}$$

$$= 15.33\%$$

33.4 - Additional Population Characteristics. In addition to estimating the product volumes, it may be necessary to make estimates of other population characteristics. Determine the average diameter, the quadratic mean diameter, and the average height using the sample-tree data set (ex. 01).

33.4 - Exhibit 01
Cruise Data Necessary to Estimate Additional Population Characteristics

Sample Group	Tree ID	DBH	DBH^2	HT	Tree Fact (F_t)	Expanded DBH ($DBH x F_t$)	Expanded DBH^2 ($DBH^2 x F_t$)	Expanded HT ($HT x F_t$)
1	1	10	100	48	9.5	95.0	950.0	456.0
1	2	11	121	74	9.5	104.5	1149.5	703.0
1	3	13	169	67	9.5	123.5	1605.5	636.5
1	8	12	144	59	9.5	114.0	1368.0	560.5
1	13	16	256	67	9.5	152.0	2432.0	636.5
1	14	12	144	61	9.5	114.0	1368.0	579.5
1	15	13	169	74	9.5	123.5	1605.5	703.0
1	16	17	289	92	9.5	161.5	2745.5	874.0
1	20	13	169	77	9.5	123.5	1605.5	731.5
1	22	14	196	70	9.5	133.0	1862.0	665.0
1	24	14	196	69	9.5	133.0	1862.0	655.5
1	25	16	256	72	9.5	152.0	2432.0	684.0
1	26	12	144	74	9.5	114.0	1368.0	703.0
1	32	15	225	69	9.5	142.5	2137.5	655.5
1	34	11	121	63	9.5	104.5	1149.5	598.5
1	35	10	100	65	9.5	95.0	950.0	617.5
2	4	13	169	73	12.0	156.0	2028.0	876.0
2	5	8	64	45	12.0	96.0	768.0	540.0
2	6	13	169	61	12.0	156.0	2028.0	732.0
2	7	15	225	88	12.0	180.0	2700.0	1056.0
2	9	10	100	56	12.0	120.0	1200.0	672.0
2	10	9	81	61	12.0	108.0	972.0	732.0
2	11	14	196	66	12.0	168.0	2352.0	792.0
2	12	9	81	43	12.0	108.0	972.0	516.0
2	17	12	144	63	12.0	144.0	1728.0	756.0
2	18	9	81	54	12.0	108.0	972.0	648.0
2	19	11	121	54	12.0	132.0	1452.0	648.0
2	21	11	121	52	12.0	132.0	1452.0	624.0
2	23	11	121	63	12.0	132.0	1452.0	756.0
2	27	10	100	55	12.0	120.0	1200.0	660.0
2	28	9	81	63	12.0	108.0	972.0	756.0
2	29	11	121	56	12.0	132.0	1452.0	672.0
2	30	13	169	63	12.0	156.0	2028.0	756.0
2	31	12	144	70	12.0	144.0	1728.0	840.0
2	33	12	144	57	12.0	144.0	1728.0	684.0
2	36	13	169	73	12.0	156.0	2028.0	876.0
2	37	8	64	45	12.0	96.0	768.0	540.0
2	38	13	169	61	12.0	156.0	2028.0	732.0
2	39	15	225	88	12.0	180.0	2700.0	1056.0
Sum					428.0	5117.5	63298.5	27379.5
Count	39							

Calculate the additional population characteristics:

$$Mean\ DBH = \frac{\sum^{n}(DBH \times F_t)}{\sum^{n} F_t} = \frac{5117.5}{428} = 12.0\ inches$$

$$Quadratic\ Mean\ Diameter = \sqrt{\frac{\sum^{n}(DBH^2 \times F_t)}{\sum^{n} F_t}}$$

$$= \sqrt{\frac{63298.5}{428}}$$

$$= 12.2\ inches$$

$$Mean\ Height = \frac{\sum^{n}(HT \times F_t)}{\sum^{n} F_t} = \frac{27379.5}{429} = 64\ feet$$

33.5 - Application. Apply this method in the following cases:

1. Stands requiring partial cutting, in which the trees to be left are marked, or stands requiring overstory removal where trees to be cut are marked.

2. Small clearcut areas, usually less than 25 acres with a high coefficient of variation (plots or points), for which the number of sample points or plots needed for prescribed accuracy standards would be excessive (more than 1 point per acre).

3. Sales having numerous species, for which stratification can reduce variation, resulting in a light sample intensity relative to other cruising systems.

34 - FIXED PLOTS.

34.1 - Fixed Plot Method. This is an area sampling method using plots of a specified area so trees in the population are selected with equal probability. The plots may be either circular or rectangular. The population is the total number of plots of specified area contained in the proposed area to be cruised. For example, the population of fifth-acre plots on a 48-acre tract is 240. Cruises using fixed area plots are customarily described in terms of the percentage of tract area covered. On this same tract, a 10-percent cruise would sample 4.8 acres, the equivalent of 24 fifth-acre plots.

34.11 - Operational Features. Establish a specified number of sample plots of equal area in an unbiased manner over the tract of timber to be cruised. Measure each tree located within each sample plot boundary as a sample tree.

The cruise results in an estimate of average volume per acre. Determine the area of the tract by survey (ch. 50). Determine total estimated tract volume by multiplying estimated average volume per acre by the number of acres in the tract.

34.12 - Statistical Features. In this cruising method, each tree has an equal probability of being selected.

Stratification can be an advantage in plot sampling to reduce sampling variation and to reduce the number of plots needed. Ordinarily, stratify by similarity (homogeneity) of timber conditions. Subdivide the tract to be cruised into areas having similar conditions of density, product components, or other characteristics. Sample each stratum separately, and compute the sample statistics as for a stratified sample.

The use of sample groups (stratification of individual trees on a point) is not recommended due to of the difficulty in determining a sampling error.

The variable of interest, subject to sampling error, is average volume or value per acre.

34.2 - Field Procedures. Use the following field procedures appropriate to the situation. Evaluate the plot shape using the following criteria:

1. Circular plots. The center of each plot is definitively marked so it can be determined accurately whether borderline trees are in or out of the plot. Because there is less perimeter in a circular plot than a rectangular plot of the same area, there are fewer borderline trees.

2. Rectangular plots. With the steel tape on the centerline of the plot, the cruiser is able to rapidly and systematically progress through the plot. The rectangular plot allows cruiser to work continuously forward.

34.21 - Sample Plot Location and Monumentation of Plots and Trees. Plot size may vary between sampling strata. However, use only one plot size in each stratum. Gear plot size to tree density and select a plot size that will ensure an average of about 4 to 8 trees per plot. Consider stand variation and species composition in determining plot size.

Plot placement may follow various patterns, but locate plots in an unbiased manner. Select the location of the starting plot randomly if the sample plots are located on a grid.

Monument plot locations. Identify cruise starting points and plot locations in a way that make the locations highly visible in the field to enable a check cruiser to find them. File a written description with the cruise information to facilitate plot relocation.

Identify plot centers with either a wooden stake or wire pin. Number the tallied trees clockwise from north on the face of the tree toward the plot center.

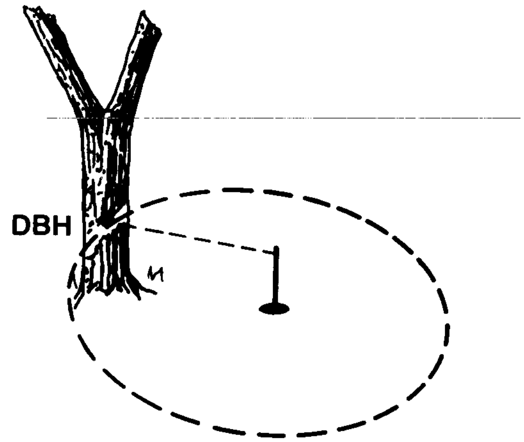
34.22 - Establishing Plot Boundaries. Establish plot boundaries by measurement, not by pacing. Determine circular plot boundaries by measuring the radius from the marked plot center. Determine rectangular plot boundaries from the centerline defined by the chain stretched between the marked end-line centers. Exhibit 01 lists radii for a variety of circular plot sizes.

34.22 - Exhibit 01
Plot Radius Table

Acre	Feet Radius
1	117.8
1/2	83.3
1/3	68.0
1/4	58.9
1/5	52.7
1/10	37.2
1/20	26.3
1/25	23.5
1/40	18.6
1/50	16.7
1/100	11.8
1/300	6.8
1/500	5.3
1/1000	3.7

Determine if problem trees, such as forked, leaning, or down trees, are in or out, depending on the location of tree DBH in relation to the plot boundary. Use tree DBH as the point of reference rather than the base of the tree because the tree base is considered to be an ambiguous reference point, particularly in the case of uprooted trees. Consider the following examples:

1. Forked trees. If the plot boundary passes through the center of the tree at DBH, count the tree in (fig. 01).

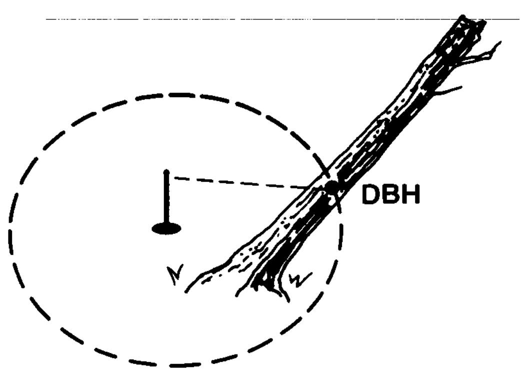


34.22 - Figure 01
Forked Trees

Determine the plot radius to the face of the tree, corrected for slope, as follows:

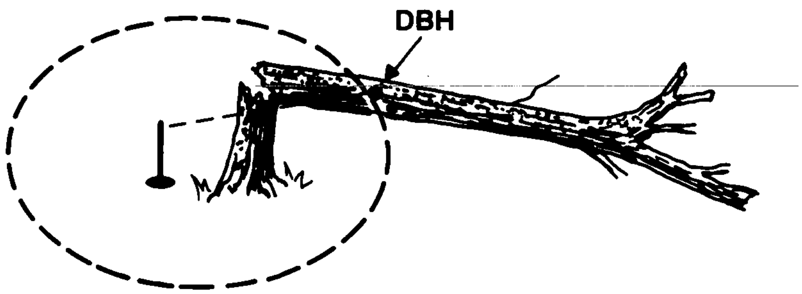
Plot radius to tree face = [Plot radius (ft.) - 0.5 × DBH (ft.)] x correction for slope from DBH to top of center stake.

2. Leaning trees. If the plot boundary passes through the center of the tree at DBH, count the tree in (fig. 02).



34.22 - Figure 02
Leaning Trees

3. Downed trees. Locate breast height at 4-1/2 feet above the root collar, as tree lies on the ground. If this point lies on or inside the plot boundary, count the tree in (fig. 03).



34.22 - Figure 03
Downed Trees

34.3 - Calculating Sample Size. Use the following method to calculate the number of fixed plots needed in the sample. To calculate sample size:

1. Specify the sampling error objective for the sale as a whole.

2. Subdivide (stratify) the sale population into sampling components. The purpose is to reduce the coefficient of variation within the sampling strata.

3. Calculate coefficient of variation by stratum and a weighted CV over all strata.

4. Calculate number of plots for the sale as a whole, then allocate by stratum.

For example, from a precruise, suppose the estimated values are as in exhibit 01.

34.3 - Exhibit 01
Data from Pre-cruise Analysis

Stratum	Timber Condition	Est. MBF/acre	Acres	Est. MBF	(a) Pct Volume	(b) Est. CV%	CV Fraction (a) x (b)
1	Mixed sizes	10	30	300	22	80	17.6
2	Even-aged	15	10	150	11	70	7.7
3	Scattered	5	20	100	8	90	7.2
4	Even-aged	20	40	800	59	60	35.4
			100	1350	100		67.9 Weighted CV

Given:
Sale sampling error objective (E_T) = 10%
Plot size: 1/5 acre
Weighted coefficient of variation: 67.9

Calculate the number of plots needed for sale as a whole (n_T):

$$n_T = \frac{t^2\ (weighted\ CV)^2}{E_T^2}, where\ t = 2\ standard\ errors$$

$$n_T = \frac{2^2\ (67.9)^2}{10^2} = 184.4\ or\ 185\ plots$$

Allocate the number of plots by strata (n_j):

$$n_j = \frac{(CV\ Fraction_j)\ (n_T)}{weighted\ CV}$$

	# Plots
n_1 = 17.6 x 185/67.9 =	48
n_2 = 7.7 x 185/67.9 =	21
n_3 = 7.2 x 185/67.9 =	20
n_4 = 35.4 x 185/67.9 =	96
Total Sale =	185

34.4 - Calculating Sampling Statistics.

34.41 - Sample Expansion. Exhibit 01 shows the basic procedure for expanding sample plot data. Data for only one strata is used; however, the procedure for combining strata calculating information about the sale as a whole is described in section 38.

The following information is given for the strata in this example:

Fixed Plot Size = 1/5 Acre
Strata Area = 18 Acres
Number of plots taken = 10

Compute the individual tree expansion factor or weight as:

$$F_t = \frac{1}{Sz \times p}$$

Where:
- F_t = Tree factor for i^{th} sample tree (trees per acre)
- Sz = Fixed area plot size (acres)
- p = Number of fixed area plots sampled

and for this example,

$$F_t = \frac{1}{0.2 \times 10} = 0.5$$

Since each sample tree represents F_t trees per acre, calculate the per acre volume by multiplying the trees per acre for a sample tree (F_t) by the volume for that sample tree (MV). That is, the volume factor is:

$$F_v = F_t \times MV$$

Where:
- F_v = Volume factor for i^{th} tree (Volume per acre)
- F_t = Tree factor for i^{th} tree (a constant for fixed area; trees per acre)
- MV = Measured volume for i^{th} tree

34.41 - Exhibit 01
Expanded Volume

Plot	Sp	DBH	HT	Net Vol (MV)	Plot Vol	Tree Fact (F_t)	Exp Vol ($MV \times F_t$)	Exp Plot Vol	Exp Plot Vol^2
1	A	10	48	10.7		0.5	5.4		
	A	11	74	24.2		0.5	12.1		
	A	13	68	29.0		0.5	14.5		
	B	13	73	26.9		0.5	13.5		
	B	8	45	4.9		0.5	2.5		
	B	13	61	23.0		0.5	11.5		
	B	15	88	43.8	162.5	0.5	21.9	81.4	6626.0
2	A	12	59	21.0		0.5	10.5		
	B	10	56	11.5		0.5	5.8		
	B	9	61	10.1		0.5	5.1		
	B	14	66	29.1		0.5	14.6		
	B	9	43	6.7		0.5	3.4		
	A	16	67	41.4	119.8	0.5	20.7	60.1	3612.0
3					0.0			0.0	0.0
4	A	12	61	21.0		0.5	10.5		
	A	13	74	30.9		0.5	15.5		
	A	17	92	66.3		0.5	33.2		
	B	12	63	19.3		0.5	9.7		
	B	9	54	8.8		0.5	4.4		
	C	11	54	14.0	160.3	0.5	7.0	80.3	6448.1
5	A	13	77	31.8		0.5	15.9		
	C	11	52	13.0		0.5	6.5		
	A	14	70	33.4		0.5	16.7		
	C	11	63	16.8	95.0	0.5	8.4	47.5	2256.3
6	A	14	69	32.4		0.5	16.2		
	A	16	72	45.6	78.0	0.5	22.8	39.0	1521.0
7					0.0			0.0	0.0
8	A	12	74	27.8		0.5	13.9		
	B	10	55	11.0		0.5	5.5		
	B	9	63	10.7		0.5	5.4		
	B	11	56	14.2		0.5	7.1		
	B	13	63	24.2		0.5	12.1		
	B	12	70	21.6	109.5	0.5	10.8	54.8	3003.0
9	A	15	69	38.4		0.5	19.2		
	C	12	57	17.7		0.5	8.9		
	A	11	63	19.7		0.5	9.9		
	A	10	65	17.3	93.1	0.5	8.7	46.7	2180.9
10	B	13	73	26.9		0.5	13.5		
	B	8	45	4.9		0.5	2.5		
	B	13	61	23.0		0.5	11.5		
	B	15	88	43.8	98.6	0.5	21.9	49.4	2440.4
Sum				916.8	916.8	19.5	459.2	459.2	28087.7
Count		39							

Strata Volume = Strata Acres x (Sum of Expanded ft^3 Volume)
= 18 × 459.2
= 8,265.6 ft^3

Calculate the stratum volume alternately as:

$$Strata\,Vol. = Strata\,ac. \times \left(\sum^{n} MV\right) \times F_t$$

$$= 18 \times 916.8 \times \frac{1}{0.2 \times 10}$$

$$= 18 \times 916.8 \times .5$$

$$= 8251.2\ ft^3$$

34.42 - Sampling Error. Calculate the sampling error for the strata using the data from section 34.41 - exhibit 01. The example calculations use the expanded volume per plot (x) to provide a consistent approach with other examples for point and two stage sampling presented in sections 35 and 37. For simple fixed plot sampling, where each tree has the same tree factor, the results are identical if the unexpanded volume per plot is used.
Compute the sample statistics for this example:

$$n = 10 \qquad \sum^{n} x = 459.2 \qquad \sum^{n} x^2 = 28087.7$$

$$Mean = \bar{x} = \frac{\sum^{n} x}{n}$$

$$= \frac{459.2}{10} = 45.9$$

$$Standard\,Deviation = SD = \sqrt{\frac{\sum^{n} x^2 - \frac{\left(\sum^{n} x\right)^2}{n}}{n-1}}$$

$$= \sqrt{\frac{28087.7 - \frac{(459.2)^2}{10}}{10-1}}$$

$$= 27.9$$

$$Coefficient\,of\,Variation = CV = \frac{SD}{\bar{x}} \times 100$$

$$= \frac{27.9}{45.9} \times 100$$

$$= 60.8\%$$

Compute the standard error of the mean for the sample strata. The value of N used in the following equation is 90. Plots 1/5 acre in size were used in this example. Thus the total number of plots for the strata would be 5 plots per acre x 18 Acres = 90 potential plots. Compute the standard error:

N = 90

$$SE = \sqrt{\frac{\sum^{n} x^2 - \frac{\left(\sum^{n} x\right)^2}{n}}{n(n-1)}\left(1-\frac{n}{N}\right)}$$

$$= \sqrt{\frac{28087.7-\frac{459.2^2}{10}}{10(10-1)}\left(1-\frac{10}{90}\right)}$$

$$= 8.3\ ft^3$$

Compute the sample error:

$$E = \frac{SE}{\bar{x}} \times 100 \times t$$

$$= \frac{8.3}{45.9} \times 100 \times 2$$

$$= 36.2\%$$

<u>34.5</u> - <u>Additional Population Characteristics</u>. In addition to estimating the product volume, it may be necessary to make estimates of other population characteristics. In this example, determine the average diameter, the quadratic mean diameter, and the average height using the expanded plot information in exhibit 01.

As with the calculation for sampling error, the example calculations in this section use the expanded volumes to maintain consistency with the other examples. For fixed plot samples, the results are identical using the unexpanded plot volumes.

34.5 - Exhibit 01
Expanded DBH, Quadratic DBH, and Height

Plot	Sp	DBH	DBH^2	HT	Tree Fact (F_t)	Exp DBH ($DBHxF_t$)	Exp DBH^2 (DBH^2xF_t)	Exp HT ($HTxF_t$)
1	A	10	100	48	0.5	5.0	50.0	24.0
	A	11	121	74	0.5	5.5	60.5	37.0
	A	13	169	68	0.5	6.5	84.5	34.0
	B	13	169	73	0.5	6.5	84.5	36.5
	B	8	64	45	0.5	4.0	32.0	22.5
	B	13	169	61	0.5	6.5	84.5	30.5
	B	15	225	88	0.5	7.5	112.5	44.0
2	A	12	144	59	0.5	6.0	72.0	29.5
	B	10	100	56	0.5	5.0	50.0	28.0
	B	9	81	61	0.5	4.5	40.5	30.5
	B	14	196	66	0.5	7.0	98.0	33.0
	B	9	81	43	0.5	4.5	40.5	21.5
	A	16	256	67	0.5	8.0	128.0	33.5
4	A	12	144	61	0.5	6.0	72.0	30.5
	A	13	169	74	0.5	6.5	84.5	37.0
	A	17	289	92	0.5	8.5	144.5	46.0
	B	12	144	63	0.5	6.0	72.0	31.5
	B	9	81	54	0.5	4.5	40.5	27.0
	C	11	121	54	0.5	5.5	60.5	27.0
5	A	13	169	77	0.5	6.5	84.5	38.5
	C	11	121	52	0.5	5.5	60.5	26.0
	A	14	196	70	0.5	7.0	98.0	35.0
	C	11	121	63	0.5	5.5	60.5	31.5
6	A	14	196	69	0.5	7.0	98.0	34.5
	A	16	256	72	0.5	8.0	128.0	36.0
8	A	12	144	74	0.5	6.0	72.0	37.0
	B	10	100	55	0.5	5.0	50.0	27.5
	B	9	81	63	0.5	4.5	40.5	31.5
	B	11	121	56	0.5	5.5	60.5	28.0
	B	13	169	63	0.5	6.5	84.5	31.5
	B	12	144	70	0.5	6.0	72.0	35.0
9	A	15	225	69	0.5	7.5	112.5	34.5
	C	12	144	57	0.5	6.0	72.0	28.5
	A	11	121	63	0.5	5.5	60.5	31.5
	A	10	100	65	0.5	5.0	50.0	32.5
10	B	13	169	73	0.5	6.5	84.5	36.5
	B	8	64	45	0.5	4.0	32.0	22.5
	B	13	169	61	0.5	6.5	84.5	30.5
	B	15	225	88	0.5	7.5	112.5	44.0
Sum					19.5	235.0	2929.0	1256.0
Count		39						

Calculate the additional population characteristics:

$$Mean\ DBH = \frac{\sum^{n}\left(DBH \times F_t\right)}{\sum^{n} F_t}$$

$$= \frac{235}{19.5}$$

$$= 12.0\ inches$$

$$Quadratic\ Mean\ Diameter = \sqrt{\frac{\sum^{n}\left(DBH^2 \times F_t\right)}{\sum^{n} F_t}}$$

$$= \sqrt{\frac{2929}{19.5}}$$

$$= 12.2\ inches$$

$$Mean\ Height = \frac{\sum^{n}\left(HT \times F_t\right)}{\sum^{n} F_t}$$

$$= \frac{1256.0}{19.5}$$

$$= 64\ feet$$

34.6 - Application. This method is applicable in timber of uniform distribution, especially where large areas are involved and clearcutting is the prescription.

35 - POINT SAMPLING.

35.1 - Point Sampling Method. Point sampling is an application of variable probability sampling.

35.11 - Operational Features. In this cruising method, establish a specified number of points in an unbiased manner over the tract of timber to be cruised. Visit each sample point and using an angle gauge, check each tree around the point, normally at breast height, as a possible sample tree. Select trees whose diameter is larger than the angle projected by the gauge, as sample trees.

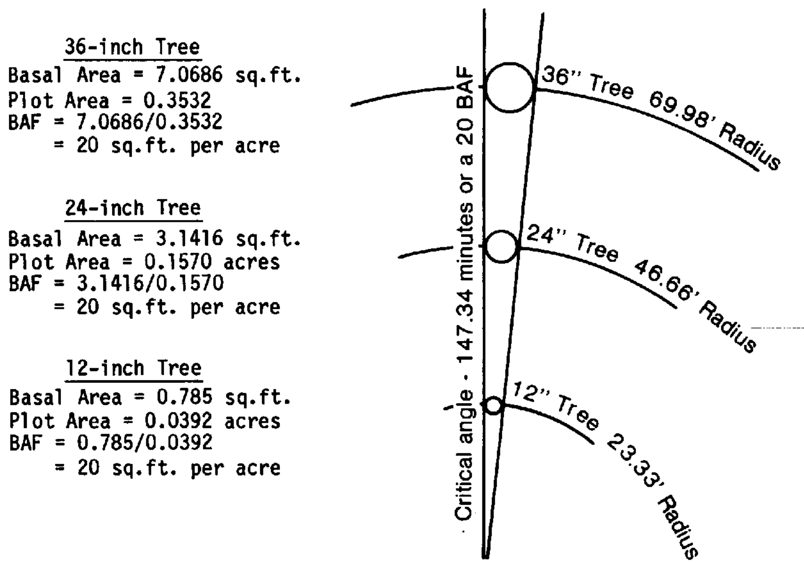
35.12 - Statistical Features. The probability of a tree being selected as a sample unit in point sampling is proportional to its basal area. For example, a tree of 2 square feet of basal area has twice the chance of being selected as a tree of 1 square foot of basal area. To account for this variable probability in calculating number of trees per acre and other estimates, weight each sample tree inversely to its selection probability. Therefore, in sample expansion, a tree of 2 square feet basal area would count half as much as a tree of 1 square foot basal area. This type of variable probability sampling is referred to as sampling with probability proportional to size (PPS).

Timber cruising using point sampling may be done by either simple point sampling or ratio double sampling. In either method,take a sample and systematically or randomly establish points over the area to be cruised. In simple point sampling, measure all point-sampled trees on all points. In ratio double sampling, count sample trees at all points but only measure on some of the points. The extension of simple point sampling to ratio double sampling is addressed in section 37.5.

The variable of interest for point sampling, subject to error, is volume or value per acre.

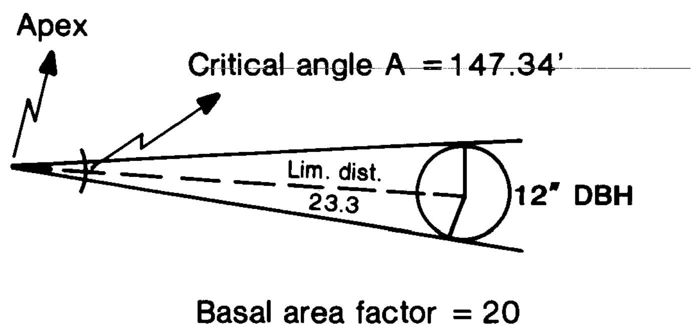
35.13 - Basal Area Factor. In point sampling, each sample tree, regardless of its diameter breast height (DBH), represents the same basal area per acre for a given critical angle. This constant is called the basal area factor (BAF) of the angle gauge (fig. 01). The rationale for this basic point sampling concept follows.

In fixed area sampling, when using circular plots, the plot radius is fixed for a plot of a given size. The plot radius for a fifth-acre plot is 52.7 feet, for example. Each tree on a fifth-acre plot, regardless of size is associated with a plot radius of 52.7 feet.



35.13 - Figure 01
Basal Area Factor Concept

In point sampling, each different tree diameter has a different plot radius associated with it and, therefore, a different plot size (fig. 01). The plot radius is the distance from the apex of the critical angle to the center of the tree subtending the critical angle (fig.02).



35.13 - Figure 02
Basal Factor 20

The circular plot area described by the plot radius is directly proportional to the basal area of the tree. For example, a tree of 2 square feet of basal area has a plot area twice the size of a tree of 1 square foot of basal area.

For a given critical angle, the basal area in square feet of a tree of any size, divided by the area of the trees plot in acres, is always equal to the same amount of basal area per acre. This angle gauge constant is called the basal area factor or BAF for short. Angle gauges are classified and referenced according to BAF.

35.2 - Field Procedures for Point Sampling.

35.21 - Sample Point Location and Monumentation of Points and Trees. Select the location of the starting point at random if the sample points are to be located on a grid. A systematic sample with a random start can be considered one random sample out of an infinite number of random samples.

Clearly monument the starting point and sample point locations to afford relocation for check cruising. File documentation in the cruise record describing how the starting points and sample point locations can be found.

Mark sample point locations with a wooden stake or a wire pin. Label the mark so that a checker can be certain which point it is. If a wooden stake is used, mark the point on the stake with a nail or other mark, such as an "X", to provide a specific point from which to measure limiting distance.

To facilitate check cruising, number tally trees clockwise from north or from the direction of travel on the side of the tree facing the point.

35.21a - Angle Gauge Use. Use the appropriate size angle gauge, depending on the size and/or dispersion of the timber to be cruised. The angle gauge used should have a basal area factor (BAF) that will select an average of 4 to 8 trees per point. Do not use a smaller BAF that results in more sample trees per point. This may not reduce the coefficient of variation but may result in missed trees. A larger BAF, on the other hand, will result in fewer sample trees per point but usually the coefficient of variation is increased. Use only one BAF for a particular stratum.

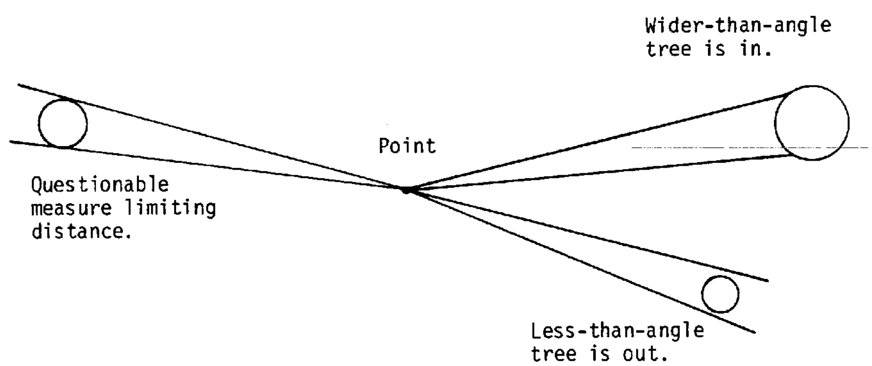
Angle gauges are made of various materials, such as metal, plastic, or glass, and differ in the way the critical angle is established.

Angle gauges made from metal or other lightweight material are cut at a specified width with a length of cord attached. The cord is marked so that the gauge is held a constant distance in front of the eye, usually about 18 to 20 inches. The width of the gauge and the length of the cord in combination establish the critical angle.

To use this type of angle gauge, the cruiser should stand with the eye over the point, viewing the width of the angle gauge in relation to tree DBH. A fixed angle is projected from the eye past the angle gauge to the tree at DBH. If the tree appears wider than the angle gauge, the tree is in. If it appears narrower, the tree is out. The angle gauge is made for use on a horizontal plane and does not work well on slopes.

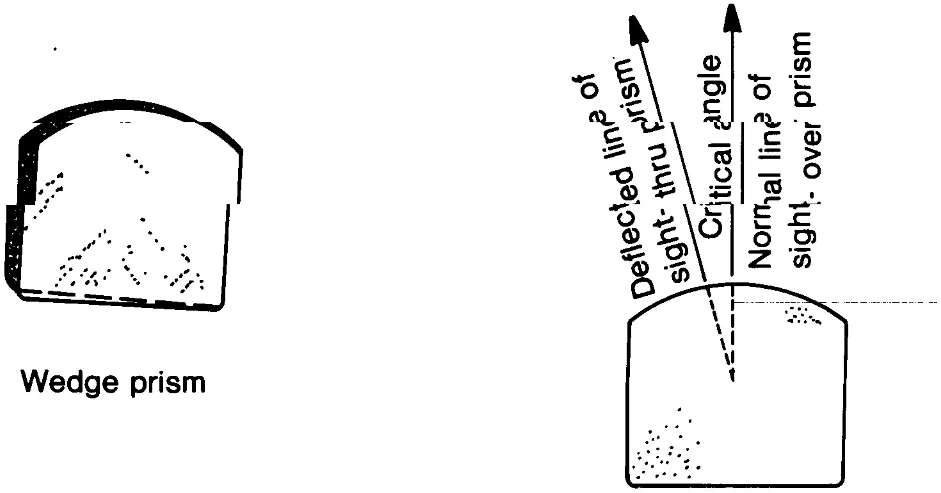
The relaskop, which is widely used for point sampling, and laser devices correct for slope and include a wide range of basal area factors.

A questionable tree (fig. 01) must be measured to determine if it is in or out (sec. 35.22a). These principles also apply to the relaskop.



35.21a - Figure 01
Use of a Simple Angle Gauge

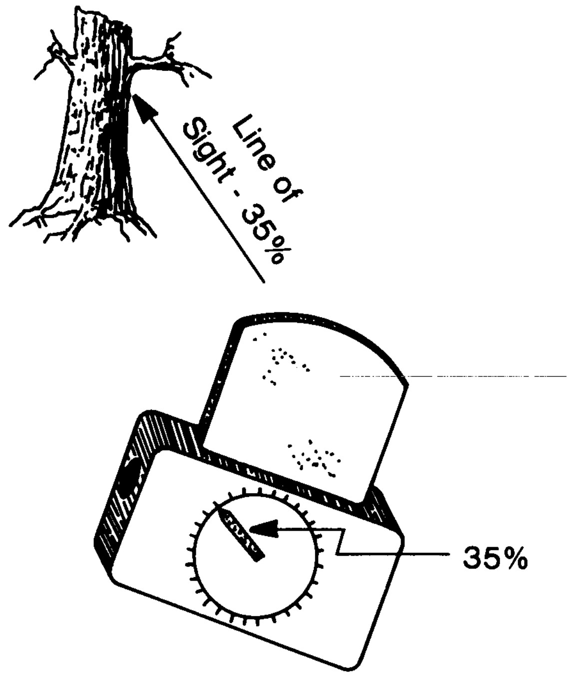
The wedge prism is an accurate angle gauge. The wedge prism is an optical instrument that bends light rays to establish the critical angle. The amount of critical angle is determined by the angle to which the prism is ground. Prisms are ground to specified units of refractive displacement called diopters, to produce exact basal area factors. A diopter is a right-angled deflection of 1 centimeter per 100 centimeters of distance from the object being viewed through the prism (fig. 02).



35.21a - Figure 02
Wedge Prism

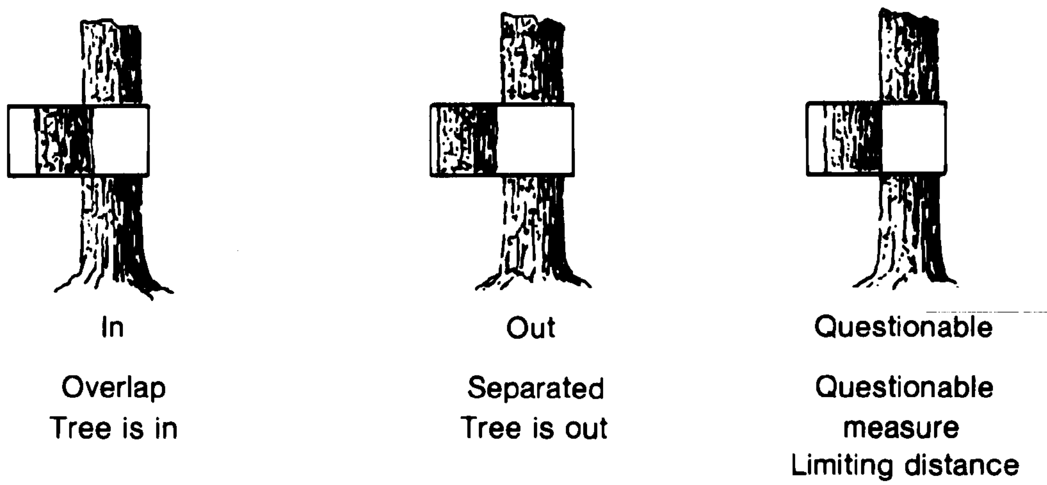
In use, keep the prism exactly over the point. Position it so that its face is perpendicular to the line of sight and the base is perpendicular to the stem of the tree being measured.

Where more than 10 percent slope is involved between the prism and the tree, rotate the prism around the line of sight by exactly the angle of slope between the prism and the trees's DBH (fig. 03).



35.21a - Figure 03
Using A Clinometer to Correct for Slope

To determine in and out trees, view each tree through the prism. The portion of the tree viewed through the prism is deflected, creating a displaced image. If the displacement overlaps the tree, the tree is in. If the displacement is separated from the tree, the tree is out. If the displacement is questionable or appears borderline, take measurements to determine whether or not the tree is included in the sample (fig. 04). See section 35.22a for more details on borderline and questionable trees.



35.21a - Figure 04
Use of a Prism in Point Sampling

35.22 - Sample Tree Determination. Select sample trees with the aid of an angle gauge with a fixed critical angle (sec. 35.1). Ordinarily, when using an angle gauge, trees are clearly either "in" or "out". However, it is not always possible to determine tree status with certainty. These are trees borderline to the plot radius, that is, too close to call when observed with the angle gauge. Another problem may exist when the tree DBH is masked by brush or other trees. Measure plot radius (limiting distance) for these trees to determine the in/out status.

35.22a - Assessing Borderline and Other Questionable Trees. Measure limiting distance to borderline or other questionable trees to conclusively determine if the tree in question is a sample tree.

Limiting distance is another term for plot radius, which is the maximum distance a tree can be from the point and still be in (a sample tree). Limiting distance is a function of tree DBH and an angle gauge constant called the plot radius factor (PRF). The plot radius factor varies with the size of the angle gauge. For a BAF of 20, the PRF is 1.944.

Calculate limiting distance using the following formula:

$$Limiting\ Distance\ (ft.) = DBH \times Plot\ Radius\ Factor$$

$$For\ example:\ DBH = 12\ inches$$

$$PRF = 1.944$$

$$Limiting\ Distance = (12)\ (1.944)$$

$$= 23.33\ feet$$

The PRF may be determined for an angle gauge of any size from either of the two formulas below:

$$PRF = \frac{0.0833}{\sin A} \qquad PRF = \frac{8.696}{\sqrt{BAF}}$$

Where:
- PRF = Plot radius factor
- A = Critical angle (in minutes) of the angle gauge.
- BAF = Basal area factor of the angle gauge.

For example, consider an angle gauge with a critical angle of 147.34 minutes which is equal to a BAF of 20 square feet per acre (sec. 35.13 fig. 02).

$$PRF = \frac{0.0833}{\sin A} = \frac{0.0833}{0.04285} = 1.944 \qquad PRF = \frac{8.696}{\sqrt{BAF}} = \frac{8.696}{\sqrt{20}} = 1.944$$

Tree DBH (in inches) multiplied by 1.944 gives limiting distance (in feet) from the point to the center of the tree for BAF 20.

It is, however, more efficient and more accurate to measure limiting distance to the point from the face of the tree. Determine a corrected PRF to calculate limiting distance from the face of the tree instead of from the center of the tree.

Calculate a corrected PRF for a given size angle gauge as follows:

1. Calculate the limiting distance to the center of tree.

   For a 12" tree and BAF 20:
   - Limiting Distance = PRF x DBH
   - Limiting Distance = 1.944 x 12 = 23.33 feet.

2. Calculate the corrected PRF to the face of the tree by using the following formula:

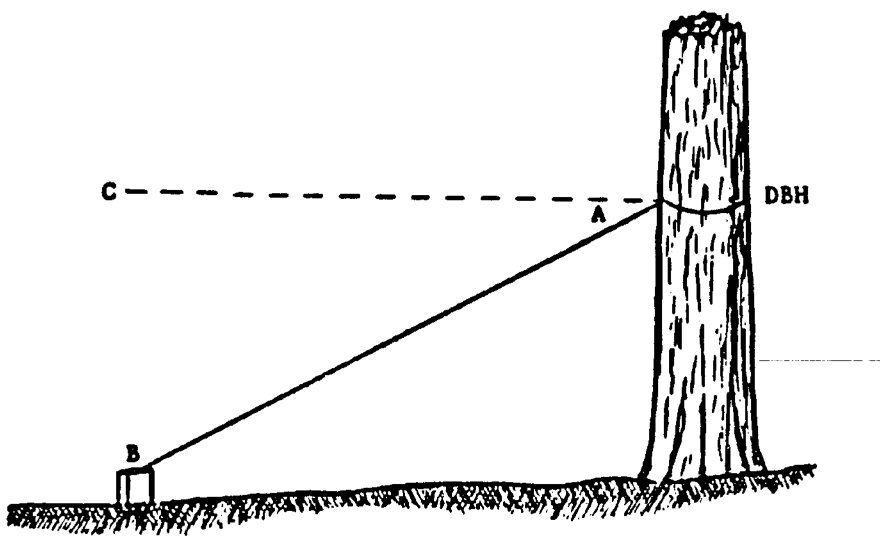
$$\text{Corrected PRF} = \frac{\text{Limiting Distance - Half DBH in Feet}}{\text{DBH in inches}}$$

For a 12" tree and BAF 20:

$$\text{Corrected PRF} = \frac{23.33' - 0.5'}{12"} = 1.902$$

Each tree DBH multiplied by 1.902 gives a set of limiting distances to the point from the face of the tree for an angle gauge of BAF 20. Limiting distance tables have been developed for various BAF's on this basis.

Use the following procedure to determine if a questionable tree is a sample tree:



35.22a - Figure 01
Determining if a Sample Tree is "IN"

1. Measure the diameter to the tenth of an inch.

2. Determine the horizontal limiting distance from the face of the tree. Horizontal Limiting Distance = Corrected PRF x Diameter (DBH) (AC, fig. 01).

3. Determine the percent of slope from the face of the tree at DBH to the point center (AB, fig. 01).

4. If the slope is ten percent or more, correct the horizontal limiting distance to slope limiting distance. Multiply the horizontal limiting distance by the appropriate slope correction factor (sec. 14.21, exhibit 01).

5. Use a steel tape graduated in tenths of feet to measure the distance from the face of the tree at DBH to the point center (AB, fig. 01). These are two exact points that can be measured "from" and "to". If the tree is abnormal at DBH measure from the face where the diameter is taken. Refer to sections 14.12-14.12m for details.

6. If the measured distance is equal to or less than the slope limiting distance the tree is "IN" and is sampled. If no slope correction is needed the horizontal limiting distance is compared to the measured distance.

35.3 - Calculating Sample Size. The following is a method for calculating the number of point sample plots needed using the optimum allocation method. Calculate sample size as follows:

1. Specify the sampling error objective for the sale as a whole.

2. Subdivide (stratify) the sale population into sampling components. The purpose is to reduce the coefficient of variation within the sampling strata.

3. Calculate the coefficient of variation by stratum and a weighted CV over all strata.

4. Calculate the number of plots by stratum as follows:

35.3 - Exhibit 01
Data from Pre-cruise Analysis

Stratum	Timber Condition	Est MBF/Acre	Acres	Est. MBF	(a) Pct. Volume	(b) Est CV%	CV_j Fraction
1	Scattered	2.8	18	50	4	90	3.6
2	Mixed sizes	10.0	35	350	26	80	20.8
3	Even-aged	15.0	10	150	11	70	7.7
4	Even-aged	20.0	40	800	59	60	35.4
Total			103	1350	100		67.5

Where:

$$\text{Stratum Percent Volume} = \frac{\text{Stratum Estimated MBF}}{\text{Sum of Estimated MBF}} \times 100$$

$$CV_j \text{ Fraction} = \frac{\text{Percent Volume} \times \text{Estimated CV\%}}{100}$$

Given:

Sale sampling error objective: $E_T = 10\%$
BAF: 20
Weighted CV: Sum of CV_j Fractions, or 67.5

Calculate the number of plots needed for sale as a whole, n_T:

$$n_T = \frac{t^2(weighted\ CV)^2}{E_T^2},\ where\ t = 2\ standard\ errors$$

$$n_T = \frac{2^2(67.5)^2}{10^2} = 182.3\ or\ 183\ Plots$$

Allocate the number of plots by strata:

$$n_j = \frac{(CV_j\ fraction)(n_T)}{Weighted\ CV}$$

n_1 = 3.6 x 183/67.5 = 10 PLOTS

n_2 = 20.8 x 183/67.5 = 56 PLOTS

n_3 = 7.7 x 183/67.5 = 21 PLOTS

n_4 = 35.4 x 183/67.5 = 96 PLOTS

Sale Total = 183 PLOTS

35.4 - Calculating Sampling Statistic.

35.41 - Sample Expansion. Two methods are commonly used in expanding point sample data: (1) the factor method, Beers and Miller (1964), and (2) the V-BAR method, Beers and Miller (1964), Dilworth and Bell (1981). Both methods give identical results except for trivial rounding differences. The tree factor method has the advantage of being able to expand all tree characteristics like DBH, height, grade, or logs/MBF because it represents trees/acre and not just volume. Section 37.54a gives the details for the V-BAR method.

The factor method involves calculating a tree factor also called the sample tree weight or frequency based on the sampling method. For point sampling, calculate the factor using the basal area of the tree.

Two factors of interest are the tree factor (F_t) and the volume factor (F_v). The tree factor is the number of trees per acre represented by each sample tree and the volume factor is the volume per acre represented by each sample tree. Compute the factors as follows:

$$F_v = F_t \times MV$$

where:

F_v = *Volume factor for i^{th} tree (volume/acre)*

F_t = *Tree factor for i^{th} tree (trees/acre)* $= \dfrac{BAF}{.005454 \times DBH^2 \times p}$

MV = *Measured volume in i^{th} tree*

BAF = *Basal area factor*

DBH = *Diameter of i^{th} tree*

p = *Number of prism points taken*

Compute the estimated total strata or tract volume contributed by each individual tree as follows:

$$SV = F_v \text{ x Acres}$$

where:
SV = Total volume for the i^{th} tree
Acres = Number of acres in the strata

In this method, measure all sample trees on all points. Exhibits 01 and 02 show the basic procedure for expanding point sample data and the plot by species cross-tabulation. The sample tree count, volume factors, and tree factors, and any other measured variables can be cross-tabulated by any other observed variable. The following information is given for the strata in the example:

Basal Area Factor (BAF) = 20
Strata Acres = 18
Number of plots taken = 10

Data for one strata (stratum 1) is shown. The procedure for combining strata and calculating information about the sale as a whole is described in section 38.

35.41 - Exhibit 01
Simple Point Sample Data

Plot No.	Sp	DBH	Meas Vol (MV)	HT	Tree Fact (F_t)	Vol Fact (F_v)	Plot Vol	Plot Vol^2
1	A	10	10.7	48	3.67	39.27		
1	A	11	24.2	74	3.03	73.33		
1	A	13	29.0	68	2.17	62.93		
1	B	13	26.9	73	2.17	58.37		
1	B	8	4.9	45	5.73	28.08		
1	B	13	23.0	61	2.17	49.91		
1	B	15	43.8	88	1.63	71.39	383.28	146903.56
2	A	12	21.0	59	2.55	53.55		
2	B	10	11.5	56	3.67	42.21		
2	B	9	10.1	61	4.53	45.75		
2	B	14	29.1	66	1.87	54.42		
2	B	9	6.7	43	4.53	30.35		
2	A	16	41.4	67	1.43	59.20	285.48	81498.83
3							0.00	0.00
4	A	12	21.0	61	2.55	53.55		
4	A	13	30.9	74	2.17	67.05		
4	A	17	66.3	92	1.27	84.20		
4	B	12	19.3	63	2.55	49.22		
4	B	9	8.8	54	4.53	39.86		
4	C	11	14.0	54	3.03	42.42	336.30	113097.69
5	A	13	31.8	77	2.17	69.01		
5	C	11	13.0	52	3.03	39.39		
5	A	14	33.4	70	1.87	62.46		
5	C	11	16.8	63	3.03	50.90	221.76	49177.50
6	A	14	32.4	69	1.87	60.59		
6	A	16	45.6	72	1.43	65.21	125.80	15825.64
7							0.00	0.00
8	A	12	27.8	74	2.55	70.89		
8	B	10	11.0	55	3.67	40.37		
8	B	9	10.7	63	4.53	48.47		
8	B	11	14.2	56	3.03	43.03		
8	B	13	24.2	63	2.17	52.51		
8	B	12	21.6	70	2.55	55.08	310.35	96317.12
9	A	15	38.4	69	1.63	62.59		
9	C	12	17.7	57	2.55	45.14		
9	A	11	19.7	63	3.03	59.69		
9	A	10	17.3	65	3.67	63.49	230.91	53319.43
10	B	13	26.9	73	2.17	58.37		
10	B	8	4.9	45	5.73	28.08		
10	B	13	23.0	61	2.17	49.91		
10	B	15	43.8	88	1.63	71.39	207.75	43160.06
Sum					109.73	2101.63	2101.63	599299.83
Count		39						

The sample tree count, volume factors, tree factors, and any other measured variables can be cross tabulated by any other observed variable. Exhibit 02 shows the plot by species cross tabulation.

35.41 - Exhibit 02
Sample Tree Count and Volume Factor Tabulations

	Count for Species				Volume for Species			
Plot	A	B	C	Sum	A	B	C	Sum
1	3	4	0	7	175.53	207.75	0.00	383.28
2	2	4	0	6	112.75	172.73	0.00	285.48
3	0	0	0	0	0.00	0.00	0.00	0.00
4	3	2	1	6	204.80	89.08	42.42	336.30
5	2	0	2	4	131.47	0.00	90.29	221.76
6	2	0	0	2	125.80	0.00	0.00	125.80
7	0	0	0	0	0.00	0.00	0.00	0.00
8	1	5	0	6	70.89	239.46	0.00	310.35
9	3	0	1	4	185.77	0.00	45.14	230.91
10	0	4	0	4	0.00	207.75	0.00	207.75
Sum	16	19	4	39	1007.01	916.77	177.85	2101.63

The resulting estimated values are:

$$\textit{Estimated trees per acre} = 109.73$$

$$\textit{Estimated volume per acre} = 2101.63\ ft^3$$

$$\textit{Estimated Total Strata Volume } (SV) = \left(\sum^{n} F_v\right) \times acres$$

$$= 2101.63 \times 18 = 37{,}829.3$$

35.42 - Sampling Error. In simple point sampling where all sample trees are measured on all points, sampling error is computed from:

$$E = \frac{SE}{\bar{x}} \times 100 \times t$$

where:

$$t = 2 \text{ standard errors } (95\% \text{ confidence limit})$$

$$SE = \sqrt{\frac{\sum^{n} x^2 - \frac{\left(\sum^{n} x\right)^2}{n}}{n(n-1)}}$$

$\bar{x}$ = Average volume per point.
x = Volume for i^{th} point.
x^2 = Volume squared for i^{th} point.
n = Number of points.

To calculate the sampling error, use the tabulated plot sub totals and squares of plot sub totals from section 35.41 exhibit 01.

$$\bar{x} = \frac{2101.63}{10} = 210.16 \ ft^3 \text{ per acre}$$

$$\text{Standard Error} = SE = \sqrt{\frac{599{,}299.83 - \frac{(2101.63)^2}{10}}{10(9)}}$$

$$= \sqrt{\frac{157{,}614.96}{90}}$$

$$= 41.85$$

$$E = \frac{41.83}{210.16} \times 100 \times 2 = 39.8\%$$

Identical results are obtained using point sums of V-BARS instead of volume factors.

35.5 - Additional Population Characteristics. Use the following formulas and see exhibits 01 and 02 for examples of additional population characteristics.

$$Arithmetic\ Mean\ Diameter = \frac{Sum\ (DBH \times Tree\ Factor)}{Sum\ Tree\ Factors}$$

$$= \frac{\sum^{n} (DBH \times F_t)}{\sum^{n} F_t}$$

$$Quadratic\ Mean\ DBH = \sqrt{\frac{Sum\ (DBH^2 \times Tree\ Factor)}{Sum\ Tree\ Factors}}$$

$$= \sqrt{\frac{\sum^{n} (DBH^2 \times F_t)}{\sum^{n} F_t}}$$

$$Mean\ Height = \frac{Sum\ of\ (HT \times Tree\ Factor)}{Sum\ of\ Tree\ Factors}$$

$$= \frac{\sum^{n} (HT \times F_t)}{\sum^{n} F_t}$$

Where:

DBH = Diameter of i^{th} tree
F_t = Tree factor of i^{th} tree (Trees per acre)
HT = height of i^{th} tree
n = number of sample trees from all points

35.5 - Exhibit 01

Cruise Data Necessary to Estimate Additional Population Characteristics.

Plot	Sp	DBH	DBH^2	HT	Tree Fact (F_t)	Exp DBH ($DBH x F_t$)	Exp DBH^2 ($DBH^2 x F_t$)	Exp HT ($HT x F_t$)
1	A	10	100	48	3.67	36.7	367.0	176.2
1	A	11	121	74	3.03	33.3	366.6	224.2
1	A	13	169	68	2.17	28.2	366.7	147.6
1	B	13	169	73	2.17	28.2	366.7	158.4
1	B	8	64	45	5.73	45.8	366.7	257.9
1	B	13	169	61	2.17	28.2	366.7	132.4
1	B	15	225	88	1.63	24.5	366.8	143.4
2	A	12	144	59	2.55	30.6	367.2	150.5
2	B	10	100	56	3.67	36.7	367.0	205.5
2	B	9	81	61	4.53	40.8	366.9	276.3
2	B	14	196	66	1.87	26.2	366.5	123.4
2	B	9	81	43	4.53	40.8	366.9	194.8
2	A	16	256	67	1.43	22.9	366.1	95.8
3								
4	A	12	144	61	2.55	30.6	367.2	155.6
4	A	13	169	74	2.17	28.2	366.7	160.6
4	A	17	289	92	1.27	21.6	367.0	116.8
4	B	12	144	63	2.55	30.6	367.2	160.7
4	B	9	81	54	4.53	40.8	366.9	244.6
4	C	11	121	54	3.03	33.3	366.6	163.6
5	A	13	169	77	2.17	28.2	366.7	167.1
5	C	11	121	52	3.03	33.3	366.6	157.6
5	A	14	196	70	1.87	26.2	366.5	130.9
5	C	11	121	63	3.03	33.3	366.6	190.9
6	A	14	196	69	1.87	26.2	366.5	129.0
6	A	16	256	72	1.43	22.9	366.1	103.0
7								
8	A	12	144	74	2.55	30.6	367.2	188.7
8	B	10	100	55	3.67	36.7	367.0	201.9
8	B	9	81	63	4.53	40.8	366.9	285.4
8	B	11	121	56	3.03	33.3	366.6	169.7
8	B	13	169	63	2.17	28.2	366.7	136.7
8	B	12	144	70	2.55	30.6	367.2	178.5
9	A	15	225	69	1.63	24.5	366.8	112.5
9	C	12	144	57	2.55	30.6	367.2	145.4
9	A	11	121	63	3.03	33.3	366.6	190.9
9	A	10	100	65	3.67	36.7	367.0	238.6
10	B	13	169	73	2.17	28.2	366.7	158.4
10	B	8	64	45	5.73	45.8	366.7	257.9
10	B	13	169	61	2.17	28.2	366.7	132.4
10	B	15	225	88	1.63	24.5	366.8	143.4
Sum					109.73	1230.1	14304.5	6707.2
Count		39						

The estimated cubic feet per acre and total cubic feet for the 18 acre tract for the factor calculation method is shown in exhibit 02. Also shown are the estimated number of trees per acre and the estimated quadratic mean DBH. Intermediate totals are taken from the tables in section 35.41 exhibit 02 and section 35.5 exhibit 01.

These tabulated values may be calculated by species or for all species combined. The procedures are identical; however, only use the sums for the appropriate species.

The volume per acre is the sum of the volume factors for all the sample trees, or $\sum^{n} F_v$. For example, the volume per acre in species A can be calculated from section 35.41 exhibit 01, or 1007.01 ft^3/acre.

The total tract volume is the per acre volumes multiplied by the total acreage, or $\left(\sum^{n} F_v\right) \times$ Acres. As an example, the tract volume in species B would be 916.77 x 18 = 16,501.86 ft^3. The number of trees per acre is the sum of the tree factors, or $\sum^{n} F_t$. For species C, the sum of tree factors from exhibit 01 is 11.6 trees per acre.

The arithmetic mean diameter is the sum of the diameter times the tree factor divided by the sum of the tree factors:

$$Mean\ Diameter = \frac{\sum^{n}\left(DBH \times F_t\right)}{\sum^{n} F_t}$$

For species A, this is 460.7/37.1 = 12.4. The intermediate totals for calculating this and the remaining parameters can be derived from exhibit 01.

The quadratic mean diameter is the diameter of the tree of average basal area. Divide the basal area (or sum of diameters squared) by the number of trees and convert the average basal area back to a diameter. To calculate the quadratic diameter for the entire stand:

$$Quadratic\ Mean\ Diameter = \sqrt{\frac{\sum^{n} DBH^2 \times F_t}{\sum^{n} F_t}} = \sqrt{\frac{6707.2}{109.7}} = 11.4$$

The height can likewise be calculated by summing the weighted heights and dividing by the sum of the weights. The average height for species B is:

$$Mean\ HT = \frac{\sum^{n}(HT \times F_t)}{\sum^{n} F_t} = \frac{657.5}{11.6} = 61.1$$

35.5 - Exhibit 02
Cruise Summary for Simple Point Sample

	Species			
	A	B	C	All Species
ft^3/acre	1007.01	916.77	177.85	2101.63
Total ft^3	18126.18	16501.86	3201.30	37829.34
Trees/acre	37.1	61.0	11.6	109.7
Arithmetic Mean Diameter	12.4	10.5	11.2	11.2
Quadratic Mean Diameter	12.6	10.7	11.2	11.4
Mean Height	67.1	58.4	56.7	61.1

35.6 - Application. Point sampling is an effective system to use in clear-cutting situations where large areas are to be cruised and where there is a range of tree sizes.

36 - 3P SAMPLING.

36.1 - 3P Sampling Method. 3P sampling is a form of variable probability sampling.

36.11 - Operational Features. 3P cruising involves visiting each tree to be sold on a timber sale. Tree volume or value (KPI) is estimated and the estimate is compared with a random number. If the estimated volume or value (KPI) is equal to or greater than the random number, measure the tree as a sample tree. Other tree variables that are closely correlated with tree volume such as DBH^2, (DBH^2 x HT), or $(.5 \times DBH)^2$ may also be used as KPI.

The larger the predicted volume or value (KPI), the greater chance a tree has of being selected as a sample unit. This chance or probability is proportional to KPI, hence, probability proportional to prediction or 3P. A tree of KPI 10, for example, has twice the chance of being selected as a tree of KPI 5. Therefore, the larger or more valuable trees are favored for sample tree selection.

36.12 - Statistical Features. The variable of interest in 3P sampling is the Measured/Predicted (M/P) ratio. This ratio is determined for each sample tree by dividing the measured volume or value for the tree by the predicted volume or value. The coefficient of variation of the M/P ratio is low, usually 35 percent or less. Therefore, few sample trees are needed to achieve standard errors of 5 percent or less. The M/P ratio, being sample based, is subject to sampling error.

36.2 - Field Procedures. A crew consisting of a tallier and two to four markers may provide the most efficient field setup.

As each tree is marked, the cruiser estimates and calls out the predicted volume or value (KPI). The tallier records the KPI and compares it to a random number. If the KPI equals or exceeds the random number, the tree qualifies as a 3P sample tree.

KPI must never exceed the largest number in the random number list, which is termed "K". Any KPI larger than K must be reduced to K or the tree and all others like it must be 100 percent cruised. Trees 100 percent cruised are termed "sure measures".

Sometimes minor or very high value species are 100 percent cruised. Such a situation might occur in a 3P cruise when it is known that only a few trees of a certain species will be marked during the sale and sampling will be inappropriate.

Once a cruiser has called the KPI and the subject tree qualifies as a sample, do not change the KPI. Sometimes a cruiser makes a poor estimate and upon measuring the sample tree, may be tempted to alter the estimate. Do not alter the estimate; to do so would bias the cruise.

Good bookkeeping technique is important in 3P cruising. Tally KPI's by stratum during the cruise so that later summarization involves no guess work.

Collect all cruise data at a day's end, particularly the KPI tally. A good KPI recording technique is to cut the random number lists into two-, three-, or four-column strips depending on the number of species in the sale. Label all strips as to sampling stratum before or immediately after cutting to insure no future mixups. Number strips within stratum consecutively for accountability purposes. As each KPI is called, record it beside a random number.

A solitary cruiser doing the complete cruising job (including sample selection and tallying) must keep the random numbers masked to avoid any chance of influencing the KPI. One number should be revealed at a time and then only after the KPI has been determined. A cheap masking device is a 35mm film cassette. Cut the random number lists into strips, by columns, splice with see-through tape, and spool onto the cassette arbor. Numbers can be revealed one at a time through the felt-tipped cassette opening.

36.3 - Calculating Sample Size and Preparing 3P Random Number Lists. Use the following optimum allocation method to calculate the number of 3P sample trees:

1. Specify the 3P sampling objective for the sale as a whole.

2. Subdivide the sale population into sampling components. The purpose of this is to reduce the coefficient of variation (CV) within the sampling strata.

3. Calculate the coefficient of variation (CV) by sample group and a weighted CV for the sale.

4. Calculate the number of 3P sample trees needed by sample group.

For example, CV for the measured/predicted (M/P) ratio is estimated to be 35 percent for sample group 1 and 25 percent for sample group 2. These estimates are based on past experience. Desired total cruise error is E_T = 10%. Calculate the CV fraction as follows:

Sample Group	Species	Estimated Volume	(a) Percent of Vol.	(b) Estimated CV %	CV Fraction (a) × (b)	
1	A	50000	.526	35	18.41	
2	B and C	45000	.474	25	11.85	
		95000	1.000		31.00	Weighted CV

Calculate the number of 3P sample trees for the sale as a whole from the formula:

$$n_{3p} = \frac{t^2\ CV^2}{E_T^2}$$

Where:
- n_{3p} = Number of 3P sample trees
- t = Student t. (t = 2 for 95% confidence level)
- CV = Coefficient of variation of the M/P ratio in percent.
- E_T = Sampling error.

Calculate the total number of trees needed for the sale as a whole:

$$n_{3p} = \frac{2^2\ 31^2}{10^2} = 39$$

Allocate the 39 sample trees to sample groups or stratum as follows:

$$n_j = \frac{(CV\ Fraction)\ (n_{3p})}{Weighted\ CV}$$

$$n_1 = \frac{(18.4)\ (39)}{31} = 24\ Sample\ Trees\ (3P)$$

$$n_2 = \frac{(11.9)\ (39)}{31} = 15\ Sample\ Trees\ (3P)$$

Where:
- n_j = the number of 3P sample trees in j^{th} sample group.

In any kind of sampling procedure, sample size is set to meet some statistical accuracy standards. In 3P cruising, because of low variance associated with the M/P ratio, small sampling errors are achieved with small sample sizes. If the coefficient of variation of the M/P ratio were 20 percent (not uncommon in 3P cruising), the sampling error at two standard errors for a sample size of 100 trees would be only 4 percent.

Ordinarily, for a one-stratum sale, sample size need not exceed 75 to 100 trees. This will ensure a maximum 8 percent sampling error at the 95 percent confidence level, even if the CV is as high as 35 percent.

When a sale is comprised of more than one stratum, or sample group, sample size for each stratum should be set high enough to adequately represent stratum grade characteristics. Thirty sample trees is the minimum that should be considered for any one stratum or sample group; however, even in multi-stratum sales, the sample size generally should not exceed 150 trees.

In this example, it was estimated that a total of 39 sample trees would be needed, distributed by species as shown, to represent adequately each stratum and to achieve the desired sampling error overall.

In sample group 2, 15 trees are estimated to be an adequate sample of both species although this should be increased to the minimum of 30 trees as described above. This gives the convenience of one random number list for both species. Tally the KPI's by species, if volume estimates are desired by species.

Produce random number lists to meet the needs of the individual sale. A random number list is needed for each stratum, or sample group, in the sale. A stratum, or sample group, is ordinarily comprised of one species, but can include two or more species. The lists are ordinarily produced by a computer (Grosenbaugh, 1965; Mesavage, 1971). However, 3P random number lists may be prepared from published lists of random digits or by any unbiased random number generator, such as in a handheld programmable calculator.

Random number lists are not needed when a programable data recorder, programed to generate random numbers, is used to collect the data.

Exhibit 01 illustrates the data needed to prepare a 3P random number list.

<u>36.3</u> - <u>Exhibit 01</u>
<u>Information Needed to Prepare Random Numbers</u>

Sample Group Number (j)	(1) Species	(2) Scaling Factor	(3) Largest Expected K_j	(4) Est. Vol. ft^3 (ΣKPI_j)	(5) 3P Sample Trees (n_j)	(6) KZ
1	A	10	90*	5000*	24	208*
2	B, C	1	100	45000	15	3000

*These values have been adjusted by the scaling factor of 10. For example, in sample group 1 the largest expected k_j is 900 and the total estimated volume is 50,000 ft^3.

The items listed in exhibit 01 are:

1. <u>Species</u>. List all species within the stratum. Use this information in labeling the random number list.

2. <u>Scaling Factor</u>. When cruising large timber it may be more efficient, without any loss in accuracy, to make predictions in tens of cubic feet. In these cases, use the scaling factor to express the units for the random numbers, KPI's, K, and KZ.

In this example, K for Species A is 90 with a scaling factor of 10. This means that the random numbers are produced in terms of tens of cubic feet and that no Species A tree larger than 900 cubic feet is expected on the sale. The Species B and C are not scaled and have a K of 100. More precision in the volume estimates is desired in this stratum because the trees are generally small. Random numbers for Species B and C are produced in terms of cubic feet, and the largest expected tree in the stratum is 100 cubic feet.

3. K. The term K is associated with the volume of the largest tree in the stratum; the scaling factor (item 2) is applied to this value. A prediction (KPI) cannot exceed this value. Thus, set K at least as high as the expected volume of the largest tree. When a tree is encountered that is larger than expected (that is, larger than K) do one of two things: 1) 100 percent cruise the tree (Sure-Measured and not a part of the 3P cruise), or 2) record KPI being equal to K. Avoid either alternative by setting K artificially high. Setting K high will not affect the sampling rate.

4. Est. Vol. Make a preliminary estimate of stratum net volume or an advance estimate of stratum sum KPI. In the example, it is shown in cubic feet; the scaling factor (item 2) is applied to this value. Use this information to estimate KZ. If KPI's are to be in terms of some other variable, such as DBH squared, make the advance estimate of stratum sum KPI in terms of DBH squared.

5. 3P Sample Trees. This is the sample size estimated to be needed to satisfy sampling error standards.

6. KZ. KZ is the sampling rate and is equal to Estimated Stratum Volume (Item 4) divided by number of 3P Sample Trees (Item 5); the scaling factor is applied to this value. It is not necessary that item 4, estimated net stratum volume, be very accurate (±30 percent perhaps).

If a preliminary estimate of stratum volume is low, the actual number of 3P sample trees will tend to exceed the presale estimate of Item (5), number of 3P sample trees. Conversely, if the preliminary estimate of the sum of KPI is high, the actual number of 3P sample trees will tend to be less than predicted. Sample error may also be lower or higher, respectively, than originally planned.

On the average, one sample tree can be expected for each group of tree estimates (KPI's) totaling KZ, the sampling rate (Item 6). The probability of any tree being selected as a sample unit is equal to KPI/KZ.

36.4 - Calculating Sampling Statistics.

36.41 - Sample Expansion. As with any sampling scheme, calculate the tree factor (also called 3P weight), or the number of trees represented by each sample tree. Calculate the tree factor as:

$$F_t = \frac{\sum^{n} KPI}{n_{3p} \times KPI}$$

Where:

F_t = Tree factor for i^{th} tree
KPI = Estimated volume for the i^{th} sample tree
n_{3p} = Number of selected 3P sample trees
n = Number of trees visited

Calculate the volume factor by multiplying the tree factor, or number of trees, by the measured volume, or:

$$F_V = F_t \times MV$$

where:

F_V = Volume factor for i^{th} tree
MV = Measured volume of i^{th} tree
F_t = Tree factor for i^{th} tree

Estimate the total volume by summing the volume factors for each strata, then summing the strata sums. That is:

$$SV_T = \sum^{s} \left(\sum^{n_{3p}} F_v \right)$$

where:

SV_T = Total estimated sale volume
F_v = Volume factor for i^{th} tree in j^{th} stratum
n_{3p} = Number of selected 3P sample trees in j^{th} stratum
s = Number of strata

When the sample includes only one stratum, ignore the sum over strata, reducing the formula to:

$$SV_T = \sum^{n_{3p}} F_v$$

where:

SV_T = Total estimated sale volume
F_v = Volume factor for i^{th} tree
n_{3p} = Number of selected 3P sample trees

Although the previous formulas are used to expand the sample, it is instructive to rearrange the formula. In this algebraically equivalent formula, the strata (or sale) volume can be calculated by multiplying the sum of the estimated volumes of all trees visited by the average measured to predicted (estimated) ratio (M/P ratio). That is:

$$SV_T = \sum^{s} \left(\left(\sum^{n} KPI \right) \times \bar{R} \right)$$

where:

$$\bar{R} = Mean\ M/P\ ratio\ of\ the\ j^{th}\ strata$$

$$= \frac{\sum^{n_{3p}} \left(\frac{MV}{KPI} \right)}{n_{3p}}$$

SV_T = Total estimated sale volume
KPI = Estimated tree volume of i^{th} tree in j^{th} stratum
MV = Measured tree volume of i^{th} tree in j^{th} stratum
n = Number of trees visited in j^{th} stratum
n_{3p} = Number of selected 3P sample trees in j^{th} stratum
MV/KPI = Ratio of the measured to estimated volume of the i^{th} 3P sample tree in j^{th} stratum
s = Number of strata.

Again, when a sample has only one strata, the summation over strata essentially disappears.

The M/P ratio, the variable of interest, is an adjustment factor to be applied to the predicted sale volume or sum of KPI's. The ratio is sample-based and is, therefore, subject to sampling error.

The tree factor, or 3P weight, can be multiplied by tree characteristics other than measured volume to develop other timber sale information. Average tree height and quadratic mean diameter are examples. Use the 3P weight to develop various cross tabulations such as distribution of sale volume by tree size, log grade, log size and so on.

The calculations for a one stratum timber sale are shown in exhibit 01.

36.41 - Exhibit 01
3P Volumes

Tree No.	KPI	MV	M/P Ratio (R)	M/P $Ratio^2$ (R^2)	DBH	HT	Tree Fact (F_t)	Vol Fact (F_v)	Exp DBH (DBHxF_t)	Exp DBH^2 (DBH2xF_t)	Exp HT (HTxF_t)
1	11										
*2	23	24.2	1.05	1.10	11	74	2.22	53.7	24.4	268.6	164.3
3	30										
*4	25	26.9	1.08	1.17	13	73	2.04	54.9	26.5	344.8	148.9
5	4										
6	25										
*7	40	43.8	1.10	1.21	15	88	1.28	56.1	19.2	288.0	112.6
8	22										
9	11										
*10	10	10.1	1.01	1.02	9	61	5.11	51.6	46.0	413.9	311.7
11	28										
12	7										
*13	42	41.4	0.99	0.98	16	67	1.22	50.5	19.5	312.3	81.7
14	22										
*15	34	30.9	0.91	0.83	13	74	1.50	46.4	19.5	253.5	111.0
*16	66	66.3	1.00	1.00	17	92	0.77	51.1	13.1	222.5	70.8
17	19										
18	9										
19	14										
*20	33	31.8	0.96	0.92	13	77	1.55	49.3	20.2	262.0	119.4
21	12										
22	34										
*23	17	16.8	0.99	0.98	11	63	3.01	50.6	33.1	364.2	189.6
*24	32	32.4	1.01	1.02	14	69	1.60	51.8	22.4	313.6	110.4
25	48										
*26	28	27.8	0.99	0.98	12	74	1.83	50.9	22.0	263.5	135.4
27	15										
*28	9	10.7	1.19	1.42	9	63	5.68	60.8	51.1	460.1	357.8
*29	14	14.2	1.01	1.02	11	56	3.65	51.8	40.2	441.7	204.4
30	24										
*31	23	21.6	0.94	0.88	12	70	2.22	48.0	26.6	319.7	155.4
32	40										
*33	18	17.7	0.98	0.96	12	57	2.84	50.3	34.1	409.0	161.9
34	20										
*35	17	17.3	1.02	1.04	10	65	3.01	52.1	30.1	301.0	195.7
*36	25	26.9	1.08	1.17	13	73	2.04	54.9	26.5	344.8	148.9
37	4										
38	25										
*39	40	43.8	1.10	1.21	15	88	1.28	56.1	19.2	288.0	112.6
Total	920		18.41	18.91			42.85	940.9	493.7	5871	2893
Count	39	18									

Note: There are three species (A, B, C); * = 3P measured sample tree.
Estimated Total Number of Trees = 43, although there were only 39 trees in actual sample.
Expanded Total Volume SV_T = 940.9 Cubic Feet

Calculate the total volume alternately as:

Est. Total Vol. = Sum KPI x Average Ratio
= 920 x (18.41/18)
= 941 Ft^3

36.42 - Sampling Error. The standard error of a 3P cruise is the standard error of the M/P ratio. Calculate the sampling error of a 3P cruise using the following formula:

$$E = \frac{SE}{\bar{R}} \times 100 \times t$$

Where:

E = Sampling error in percent

$$SE = \sqrt{\frac{\sum^{n_{3P}} R^2 - \frac{\left(\sum^{n_{3P}} R\right)^2}{n_{3P}}}{(n_{3P}-1)n_{3P}}}$$

$$\bar{R} = \frac{\sum^{n_{3P}} R}{n_{3P}}$$

R = M/P ratio for the i^{th} 3P sample tree.
n_{3p} = Number of 3P sample trees.
t = 2 (95% confidence interval).

The sampling error calculation in this example is for the one stratum timber sale shown in section 36.41, exhibit 01.

$$SE = \sqrt{\frac{\sum^{n_{3P}} R^2 - \frac{\left(\sum^{n_{3P}} R\right)^2}{n_{3P}}}{(n_{3P}-1)n_{3P}}}$$

$$= \sqrt{\frac{18.91 - \frac{(18.41)^2}{18}}{(18-1) \times 18}}$$

$$= \sqrt{\frac{.0807}{307}}$$

$$= 0.0162$$

$$\bar{R} = \frac{18.41}{18} = 1.02$$

$$E = \frac{0.0162}{1.02} \times 100 \times 2 = 3.2$$

<u>36.5</u> - <u>Additional Population Characteristics</u>. Calculate the additional population characteristics using the tabulated data from section 36.41 exhibit 01.

$$Mean\ Diameter = \frac{\sum^{n_{3p}} \left(DBH \times F_t\right)}{\sum^{n_{3p}} F_t}$$

$$= \frac{493.7}{42.85} = 11.5\ inches$$

$$Quadratic\ Mean\ Diameter = \frac{\sqrt{\sum^{n_{3p}} \left(DBH^2 \times F_t\right)}}{\sum^{n_{3p}} F_t}$$

$$= \sqrt{\frac{5871}{42.85}} = 11.7\ inches$$

$$Mean\ Height = \frac{\sum^{n_{3p}}(HT \times F_t)}{\sum^{n_{3p}} F_t}$$

$$= \frac{2893}{42.85} = 67.5\ feet$$

36.6 - Application. 3P cruising is probably most efficient in partial cut situations where the coefficient of variation of individual marked tree volumes or dollar value is large. 3P cruising fits well with many road right-of-way cruising jobs.

37 - TWO-STAGE SAMPLING. There are several methods of two-stage sampling. Common variants are discussed in this section.

37.1 - Sample-Tree With 3P Subsampling Method. Sample tree with 3P is a two-stage sampling method. The first stage is an equal probability sample where the probability of a tree being selected as a sampling unit is proportional to the tree frequency in the population. Trees are selected randomly or systematically and KPI is estimated for each first stage sample tree.

The second stage is a 3P sample of the trees selected with equal probability in the first stage. Select 3P sample trees by comparing the volume prediction (KPI) for a sample tree with a random number. If the KPI is equal to or greater than the random number, measure as a 3P sample tree.

37.12 - Operational Features. The operational features of sample-tree cruising are described in section 33 and the operational features for 3P sampling are described in section 36. The 3P procedure for sample-tree 3P is the same, except that KPI is estimated and recorded only for the sample trees selected in the first stage.

37.13 - Statistical Features. Sample-tree 3P sampling includes equal probability sampling at the first stage and variable probability (3P) sampling at the second stage. The variable of interest at the first stage is generally volume per tree, while the variable of interest at the second stage is the measured to predicted (M/P) ratio.

There are two sources of statistical error in a sample-tree 3P sample: the estimate of the stratum sum KPI and the estimate of the stratum mean M/P ratio. The population parameter for which sampling error is estimated in the first stage is mean tree KPI. In the second or 3P stage, sampling error is estimated for the mean M/P ratio which is ordinarily measured tree volume divided by estimated tree volume in sample-tree 3P cruising.

37.14 - Calculating Sample Size. Calculate combined sampling error in order to determine sample size for sample-tree 3P cruising. Determine sample size (number of trees) for the sample-tree sample and for the 3P sample to satisfy the desired sampling error for the stratum.

The combined sampling error includes the sample tree (first stage) error and the 3P (second stage) error.

If both the sample tree and 3P portions of the combined error are known, the formula for calculating the sampling error of a sample-tree 3P cruise is:

$$E_T = \sqrt{E_{st}^2 + E_{3p}^2}$$

Where:

E_T = *Combined percent sampling error* (*Total error*)

E_{st} = *Percent sampling error for the sample–tree sample*.

E_{3p} = *Percent sampling error for the* 3*P sample*.

More commonly, the cruise is being designed to meet a specific combined error. In this case, the desired combined error is known. One of the errors (sample-Tree or 3P) needs to be estimated, with the remaining error being determined using the following example where sample tree error is being estimated.

$$E_{st} = \sqrt{E_T^2 - E_{3p}^2}$$

Generally, 3P error is the more easily estimated of the two errors and can be determined through the use of past local cruises and experience.

Given:
Target combined sampling error of 20% (95% Confidence level)
Estimated 3P sampling error of 12% (95% Confidence level)

Determine sample tree sampling error:

$$E_{st} = \sqrt{E_T^2 - E_{3p}^2}$$

$$= \sqrt{20^2 - 12^2}$$

$$= \sqrt{256}$$

$$= 16.0\%$$

Note: Desired combined sampling error must be higher than the estimated 3P error.

To determine the number of samples needed to attain the errors identified for each stage of the sample tree with 3P cruise, estimate the coefficient of variation between sample trees in the first stage, and between predicted and actual measurements in the second stage. This estimate can be based on preliminary sample data, past cruises in the area in similar types, or inventory data.

First Stage	Second Stage
Assumed Coefficient of Variation = 80% t = 2 Sampling error = 16%	Assumed Coefficient of Variation = 25% t = 2 Sampling error = 12%

$$n_{st} = \frac{(t^2)\ (CV_{st})^2}{E_{st}^2} = \frac{(2^2)\ (80^2)}{16^2} = 100 \text{ trees}$$

$$n_{3p} = \frac{(t^2)\ (CV_{3p})^2}{E_{3p}^2} = \frac{(2^2)\ (25^2)}{12^2} = 18 \text{ trees}$$

37.15 - Producing Random Number List. Random numbers for sample-tree with 3P cruises are ordinarily in terms of per tree volume.

Use the following information to prepare a random number list:

1. Estimate of the sum of the KPI's (estimated tree volumes) for all the first stage sample trees (trees for which a KPI will be made).

2. Estimate of the largest tree volume in the population (K).

3. Estimate of the total number of first stage sample trees.

4. Number of 3P sample trees desired.

5. Sampling rate (KZ) (see below).

6. Number of first stage sample trees $n_{st} = 100$

7. Number of 3P sample trees $n_{3p} = 18$

In addition, estimates of largest volume (K = 80 ft^3 in example) and average KPI (22 ft^3 in the example) are used. This information can come from precruise data, inventory data, prior cruises, and personal knowledge of the area. For example:

Estimated Sum KPI = 22 x 100 = 2,200 Ft^3.

$$\text{Sampling rate (KZ)} = \frac{\text{Sum KPI}}{\text{No. of 3P sample trees}}$$

$$= \frac{2{,}200}{18}$$

= 122.2 (rounded to next whole number)

= 123

For this example, the set of random numbers would have the following characteristics:

K = 80 ft^3.

KZ = 123 or one 3P sample tree per 123 Ft^3.

<u>37.16</u> - <u>Calculating Sampling Statistics</u>.

<u>37.16a</u> - <u>Sample Expansion</u>. The expansion of the sample-tree 3P sample trees to the stratum level involves calculating the combined sample tree weight or frequency considering both the sample-tree sample and the 3P sample.

Compute the tree factor, or estimated frequency (F), for a sample-tree 3P sample from the following formula:

$$F_t = F_{t(st)} \times F_{t(3p)}$$

Where:

F_t = Tree factor; frequency or number of trees at the j^{th} stratum level for the i^{th} sample-tree 3P sample tree.

$$F_{t(st)} = \frac{\text{Number of trees tallied}}{\text{Number of first stage sample trees}}$$

$$F_{t(3p)} = 3P\ \text{frequency} = \frac{\sum^{n} KPI}{n_{3p} \times KPI}$$

$\sum^{n} KPI$ = Sum of estimated volumes of all first-stage sample trees.

n_{3p} = Number of 3P sampled trees

KPI = Estimated volume (KPI) of the i^{th} 3P sample tree

n = Number of first-stage sample trees.

The estimated expanded volume at the stratum level of an individual sample-tree 3P sample tree is computed from the following formula:

$$F_v = F_t \times MV$$

Where: F_v = Estimated stratum volume for the i^{th} 3P sample tree in the j^{th} stratum.

MV = Measured volume of the i^{th} 3P sample tree in the j^{th} stratum.

F_t = Tree factor for i^{th} tree

Calculate estimated total stratum volume by summing all sample-tree 3P sample tree volumes.

Calculations for a one-stratum example are shown in exhibit 01, given:

428 trees tallied
39 trees in sample-tree sample
10 acres in stratum.

The sample tree expansion factor for all trees is:

$$F_{st} = \frac{428}{39} = 10.97$$

The 3P expansion for each 3P tree is:

$$F_{t(3p)} = \frac{\sum^{n} KPI}{n_{3p} \ x \ KPI}$$

The resulting tree factor is:

$$F_t = F_{t(st)} \times F_{t(3p)}$$

37.16a - Exhibit 01
Calculation of Volume, Sample Tree with 3P Subsample

Tree No.	KPI	KPI^2	MV	M/P Ratio (R)	M/P Ratio² (R^2)	DBH	HT	3P Wt ($F_{t(3p)}$)	Tree Fact (F_t)	Exp Vol ($MVxF_t$)	Exp DBH ($DBHxF_t$)	Exp DBH^2 (DBH^2xF_t)	Exp HT ($HTxF_t$)
1	11	121											
*2	23	529	24.2	1.05	1.10	11	74	2.22	24.35	589.4	267.9	2946.8	1802.2
3	30	900											
*4	25	625	26.9	1.08	1.17	13	73	2.04	22.38	602.0	290.9	3782.0	1633.7
5	4	16											
6	25	625											
*7	40	1600	43.8	1.10	1.21	15	88	1.28	14.04	615.0	210.6	3159.4	1235.7
8	22	484											
9	11	121											
*10	10	100	10.1	1.01	1.02	9	61	5.11	56.06	566.2	504.5	4540.6	3419.5
11	28	784											
12	7	49											
*13	42	1764	41.4	0.99	0.98	16	67	1.22	13.38	554.1	214.1	3426.2	896.7
14	22	484											
*15	34	1156	30.9	0.91	0.83	13	74	1.50	16.46	508.5	213.9	2780.9	1217.7
*16	66	4356	66.3	1.00	1.00	17	92	0.77	8.45	560.0	143.6	2441.2	777.1
17	19	361											
18	9	81											
19	14	196											
*20	33	1089	31.8	0.96	0.92	13	77	1.55	17.00	540.7	221.0	2873.6	1309.3
21	12	144											
22	34	1156											
*23	17	289	16.8	0.99	0.98	11	63	3.01	33.02	554.7	363.2	3995.4	2080.2
*24	32	1024	32.4	1.01	1.02	14	69	1.60	17.55	568.7	245.7	3440.2	1211.1
25	48	2304											
*26	28	784	27.8	0.99	0.98	12	74	1.83	20.08	558.1	240.9	2890.8	1485.6
27	15	225											
*28	9	81	10.7	1.19	1.42	9	63	5.68	62.31	666.7	560.8	5047.1	3925.5
*29	14	196	14.2	1.01	1.02	11	56	3.65	40.04	568.6	440.4	4844.9	2242.3
30	24	576											
*31	23	529	21.6	0.94	0.88	12	70	2.22	24.35	526.0	292.2	3506.9	1704.7
32	40	1600											
*33	18	324	17.7	0.98	0.96	12	57	2.84	31.15	551.4	373.9	4486.3	1775.8
34	20	400											
*35	17	289	17.3	1.02	1.04	10	65	3.01	33.02	571.2	330.2	3302.0	2146.3
*36	25	625	26.9	1.08	1.17	13	73	2.04	22.38	602.0	290.9	3782.0	1633.7
37	4	16											
38	25	625											
*39	40	1600	43.8	1.10	1.21	15	88	1.28	14.04	615.0	210.6	3159.4	1235.7
Sum	920	28228		18.41	18.91			42.85	470.06	10318.3	5415.3	64406	31733
Count	39		18										

* = 3P sample tree
Estimated Number of Trees = 470
Estimated Total Volume = 10,318.3 ft^3
Estimated Volume per Acre = 10,318.3/10 = 1031.8 ft^3/ac

37.16b - Sampling Error. Calculate sampling error of a sample-tree 3P cruise from the following formula:

$$E_T = \sqrt{\left(\frac{SE_{st}}{\overline{KPI}} \times 100 \times t\right)^2 + \left(\frac{SE_{3p}}{\overline{R}} \times 100 \times t\right)^2}$$

$Where: \; E_T = Stratum\ sampling\ error.$

$$SE_{st} = \sqrt{\frac{\sum^{n_{st}} KPI^2 - \frac{\left(\sum^{n_{st}} KPI\right)^2}{n_{st}}}{(n_{st} - 1) \times n_{st}}}$$

$KPI = Estimated\ volumes\ (KPI)\ of\ all\ first\ stage\ sample\ trees.$

$n_{st} = Number\ of\ first\ stage\ sample\ trees.$

$\overline{KPI} = Mean\ KPI\ of\ first\ stage\ sample\ trees.$

$$SE_{3p} = \sqrt{\frac{\sum^{n_{3p}} R^2 - \frac{\left(\sum^{n_{3p}} R\right)^2}{n_{3p}}}{(n_{3p} - 1) \times n_{3p}}}$$

$R = M/P\ ratios\ for\ i^{th}\ 3P\ sample\ tree.$

$n_{3p} = Number\ of\ sample\ tree\text{–}3P\ sample\ trees.$

$\overline{R} = Mean\ M/P\ ratio.$

$t = 2\ (95\ percent\ confidence)$

The calculations use the values from section 37.16a, exhibit 01. The mean M/P ratio is 18.41/18 = 1.02. The standard error components are:

$$SE_{st} = \sqrt{\frac{\sum^{n_{st}} KPI^2 - \frac{\left(\sum^{n_{st}} KPI\right)^2}{n_{st}}}{(n_{st} - 1)(n_{st})}}$$

$$= \sqrt{\frac{28,228 - \frac{920^2}{39}}{(39-1)(39)}}$$

$$= 2.098$$

$$SE_{3p} = \sqrt{\frac{\sum^{n_{3p}} R^2 - \frac{\left(\sum^{n_{3p}} R\right)^2}{n_{3p}}}{(n_{3p} - 1)(n_{3p})}}$$

$$= \sqrt{\frac{18.91 - \frac{(18.41)^2}{18}}{(18-1)(18)}}$$

$$= 0.0162$$

The sampling errors are:

$$E_{st} = \frac{SE_{st}}{\overline{KPI}} \times 100 \times t$$

$$= \frac{2.098}{23.59} \times 100 \times 2$$

$$= 17.8\%$$

$$E_{sp} = \frac{SE_{3p}}{\overline{R}} \times 100 \times t$$

$$= \frac{0.0162}{1.023} \times 100 \times t$$

$$= 3.2\%$$

The total error is:

$$E_T = \sqrt{E_{st}^2 + E_{3p}^2}$$

$$= \sqrt{17.8^2 + 3.2^2}$$

$$= \sqrt{327.1} = 18.1\% \ (95\% \ confidence\ level)$$

37.17 - Additional Population Characteristics. Calculate the additional population characteristics using the tabulated data from section 37.16a, exhibit 01.

$$Mean\ Diameter = \frac{\sum^{n_{3p}} (DBH \times F_t)}{\sum^{n_{3p}} F_t}$$

$$= \frac{5415.3}{470.06}$$

$$= 11.5\ inches$$

$$Quadratic\ Mean\ Diameter = \sqrt{\frac{\sum^{n_{3p}} (DBH^2 \times F_t)}{\sum^{n_{3p}} F_t}}$$

$$= \sqrt{\frac{64406}{470.06}}$$

$$= 11.7\ inches$$

$$Mean\ Height = \frac{\sum^{n_{3p}} (HT \times F_t)}{\sum^{n_{3p}} F_t}$$

$$= \frac{31733}{470.06}$$

$$= 67.5\ feet$$

37.18 - Application. Sample tree with 3P subsampling is most efficient in partial cut situations where the coefficient of variation of individual marked tree volumes or values is large. This form of 3P cruising fits well with many road right-of-way cruising jobs.

37.2 - Fixed Area Plot With 3P Subsampling.

37.21 - Fixed Area Plot With 3P Subsampling Method. Plot-3P is a two-stage sampling system. The first stage is a fixed area sample where the probability of a tree being selected as a sample unit is proportional to the tree frequency in the population. The second stage is a 3P sample of the sample trees on the fixed area plots.

In the second or 3P stage, estimate and record volume (KPI) of each sample tree on the fixed area plot. Select 3P sample trees by comparing the volume estimate (KPI) for a sample tree with a random number. If the KPI is equal to or greater than the random number, measure the tree as a sample tree.

37.22 - Operational Features. The operational features of the first stage fixed area plot cruising are described in section 34. The purpose of the plot sample in plot-3P cruising is to estimate the stratum sum of KPI's. KPI is in terms of tree volume.

Operational features for the second stage 3P sampling are described in section 36. The 3P procedure for plot-3P cruising is the same except that KPI is estimated and recorded only for the trees on the plot.

37.23 - Statistical Features. Plot-3P sampling includes equal probability sampling at the first stage and variable probability (3P) sampling at the second stage. The variable of interest at the first stage is generally volume per acre while the variable of interest at the second stage is the measured to predicted (M/P) ratio.

There are two sources of statistical error in plot-3P sampling: the estimate of the stratum sum KPI (estimated volume) and the estimate of the stratum mean M/P ratio. In the first stage, the population parameter for which sampling error is estimated is mean sum estimated volume (KPI) for each plot.

In the second or 3P stage, sampling error is estimated for the mean M/P ratio which is measured tree volume divided by estimated tree volume in plot-3P cruising. The sampling error for each stratum includes both sources of error.

37.24 - Calculating Sample Size. Combined sampling error must be calculated in order to determine sample size for fixed plot-3P cruising. Sample size is determined for both the sample fixed plot (number of plots) and for the 3P sample (number of trees) to satisfy the desired sampling error for the stratum.

The combined sampling error includes the fixed plot (first stage) error and the 3P (second stage) error.

If both the fixed plot and 3P portions of the combined error are known, use the following formula for calculating the sampling error of a fixed plot-3P cruise:

$$E_T = \sqrt{E_{fp}^2 + E_{3p}^2}$$

where:
- E_T = Combined sampling in percent (Total error)
- E_{fp} = Sampling error (in percent) of the fixed plot sample.
- E_{3p} = Sampling error (in percent) of the 3P sample.

More commonly, the cruise is designed to meet a specific combined error. In this case the desired combined error is known. Estimate one of the errors (fixed plot or 3P) and determine the remaining error using the following example where the fixed plot error is determined:

$$E_{fp} = \sqrt{E_T^2 - E_{3p}^2}$$

Note that the desired combined sampling error must be higher than either the fixed plot or 3P sampling error. 3P error is generally the more easily estimated of the two errors and can be determined through past local cruises and experience. Given the target combined sampling error of 20 percent at 95 percent confidence level, and a 3P estimated sampling error of 12 percent at a 95 percent confidence level, the fixed plot error is:

$$E_{fp} = \sqrt{E_T^2 - E_{3p}^2}$$

$$= \sqrt{20^2 - 12^2}$$

$$= \sqrt{256}$$

$$= 16.0\%$$

To determine the number of samples needed to attain the errors identified for each stage of the fixed plot-3P cruise, estimate the coefficient of variation between sample plots in the first stage, and between predicted and actual measurements in the second stage. This estimate may be based on reconnaissance data, past cruises in the area in similar types, or inventory data.

First Stage (Plots)	Second Stage (Trees)
Assumed Coefficient of Variation = 50%	Assumed Coefficient of Variation = 25%
Confidence Level = 95% (t=2)	Confidence Level = 95% (t=2)

$$n_{fp} = \frac{(CV_{fp}^2)\,(t^2)}{E_{fp}^2}$$

$$= \frac{(50^2)\,(2^2)}{16^2}$$

$$= 39\ \textit{points}$$

$$n_{3p} = \frac{(CV_{3p}^2)\,(t^2)}{E_{3p}^2}$$

$$= \frac{(25^2)(2^2)}{12^2}$$

$$= 18\ \textit{trees}$$

37.25 - Producing Random Number List. Random numbers for plot-3P cruises are in terms per tree of volume.

Use the following example to prepare a random number list:

1. Estimate of the sum of KPI's (estimated tree volumes) on all the sample plots.

2. Estimate of the largest tree volume in the population (K).

3. Estimate of the total number sample trees on all the plots.

4. Number of 3P sample trees desired.

5. Sampling rate (KZ).

6. Number of plots = 39

7. Number of 3P sample trees = 18

In addition, it is estimated:

Largest volume (K) = 80 ft^3.
Average KPI = 23.1 ft^3.
Average number of sample trees per plot = 4.3

Therefore:

Estimated Sum KPI (Sum of estimated tree volumes on 39 plots)	= 39 plots x 4.3 trees per plot x 23.1 ft^3 per tree.
	= 3,874 ft^3
Sampling rate (KZ)	$= \frac{\text{Estimated Sum KPI}}{\text{number of 3P sample trees}}$
	$= \frac{3,874}{18}$
	= 215
Estimated total number of trees on all plots	= 39 plots x 4.3 trees/plot
	= 168

K and KZ are based on a combination of pre-cruise information, inventory data, and personal knowledge of the area. For this example, the set of random numbers would have the following characteristics:

K = 80 ft^3
KZ = 215 or one 3P sample tree per 215 ft^3

37.26 - Calculating Sampling Statistics.

37.26a - Sample Expansion. The expansion of the plot-3P sample trees to the per acre and stratum level involves calculating the sample tree weight or frequency considering both the plot sample and the 3P sample.

For demonstration purposes in this section, 10 fixed plots with 18 3P sample trees are being expanded to derive an estimated volume of the area.

The tree factor, or estimated frequency per acre for an individual plot-3P sample tree is derived as the product of two component expansion factors. These components are identical to the tree factors developed previously for simple fixed area and simple 3P sampling. It is computed from the following formula:

$$F_t = F_{t(fp)} \times F_{t(3p)}$$

where: F_t = Tree factor for the i^{th} 3P sample tree (trees per acre)

$F_{t(fp)}$ = Tree factor for i^{th} tree to expand fixed plot component

$$= \frac{1}{Sz \times p}$$

$F_{t(3p)}$ = Tree factor for i^{th} tree to expand 3P sampling component

$$= \frac{\sum^{n} KPI}{n_{3p}\, KPI}$$

Sz = Plot size of fixed area plot

p = Number of fixed area plots

KPI = Estimated volume of i^{th} tree visited

n = Number of trees visited on all fixed plots

n_{3p} = Number of selected 3P sample trees

The volume factor, or estimated volume per acre for an individual plot-3P sample tree is computed from the following formula:

$$F_v = F_t \times MV$$

where:

F_v = volume factor, or estimated volume for i^{th} 3P sample (Vol. per acre)

MV = measured volume of the i^{th} 3P sample tree

Compute the estimated total tract stratum volume contribution by an individual 3P sample tree as the product of the volume per acre factor and the total acres:

$$SV = F_v \text{ x Acres}$$

where:

SV = Estimated sale volume for i^{th} 3P sample tree
Acres = Acres in the Tract

Calculate estimated total stratum volume per acre and total stratum volume by summing all plot-sample tree values. Exhibit 01 shows a two-stratum example given:

1. 10 one fifth acre plots, therefore $F_{t(fp)} = (1/(.2 \times 10)) = 0.5$

2. 18 acres in stratum

3. Volume measured in ft^3

4. Species group 1 = A

5. Species group 2 = B, C

37.26a - Exhibit 01
Calculations for a Two-Stratum Sale.

Plot No.	Tree No.	Sp	KPI	DBH	HT	MV	3P Wt ($F_{t(3p)}$)	Tree Fact (F_t)	Vol Fact (F_v)	Tract Vol (SV)
1	1	A	11							
*1	2	A	23	11	74	24.2	2.73	1.37	33.2	597.6
1	3	A	30							
*1	4	B	25	13	73	26.9	1.67	0.84	22.6	406.8
1	5	B	4							
1	6	B	25							
*1	7	B	40	15	88	43.8	1.05	0.53	23.2	417.6
2	1	A	22							
2	2	B	11							
*2	3	B	10	9	61	10.1	4.18	2.09	21.1	379.8
2	4	B	28							
2	5	B	7							
*2	6	A	42	16	67	41.4	1.49	0.75	31.1	559.8
3										
4	1	A	22							
*4	2	A	34	13	74	30.9	1.85	0.93	28.7	516.6
*4	3	A	66	17	92	66.3	0.95	0.48	31.8	572.4
4	4	B	19							
4	5	B	9							
4	6	C	14							
*5	1	A	33	13	77	31.8	1.90	0.95	30.2	543.6
5	2	C	12							
5	3	A	34							
*5	4	C	17	11	63	16.8	2.46	1.23	20.7	372.6
*6	5	A	32	14	69	32.4	1.96	0.98	31.8	572.4
6	6	A	48							
7										
*8	1	A	28	12	74	27.8	2.24	1.12	31.1	559.8
8	2	B	15							
*8	3	B	9	9	63	10.7	4.64	2.32	24.8	446.4
*8	4	B	14	11	56	14.2	2.99	1.50	21.3	383.4
8	5	B	24							
*8	6	B	23	12	70	21.6	1.82	0.91	19.7	354.6
9	1	A	40							
*9	2	C	18	12	57	17.7	2.32	1.16	20.5	369.0
9	3	A	20							
*9	4	A	17	10	65	17.3	3.69	1.85	32.0	576.0
*10	1	B	25	13	73	26.9	1.67	0.84	22.6	406.8
10	2	B	4							
10	3	B	25							
*10	4	B	40	15	88	43.8	1.05	0.53	23.2	417.6
	Total		920				40.66	20.38	469.6	8452.8
	Count		39			18				

* = 3P Sample Tree.

Item	Group 1	Group 2	All
KPI	502	418	920
n_{3p}	8	10	18
F_t	8.4	12.0	20.4

F_v	249.9	219.7	469.6
SV	4498	3955	8453

Calculate the stratum values:

$$Estimated\ Number\ Trees/Acre = \left(\sum^{n_{3p}} F_t\right) = 20.38$$

$$Estimated\ Total\ Number\ of\ Trees = 366$$

$$Estimated\ Volume/Acre = \left(\sum^{n_{3p}} F_v\right) = 469.6\ ft^3$$

$$Estimated\ Total\ Volume = \left(\sum^{n_{3p}} SV\right) = 8{,}453.0\ ft^3$$

37.26b - Sampling Error. Use the following formulas to compute sampling error. Two sampling error components must be accounted for; the sampling error of the fixed plot and the sampling error of the 3P subsample. The formula for calculating the sampling error over all strata is:

$$E_T = \sqrt{\left(\frac{SE_{fp}}{\overline{PV}} \times 100 \times t\right)^2 + \left(\frac{SE_{3p}}{\overline{R}} \times 100 \times t\right)^2}$$

Where:

E_T = *The stratum sampling error*

SE_{fp} = *Standard error of estimated plot volumes on fixed plots*

$$= \sqrt{\frac{\sum^{p} PV^2 - \frac{\left(\sum^{p} PV\right)^2}{p}}{(p-1)(p)}}$$

PV = *Sum of estimated volumes for* j^{th} *fixed plot*

p = *The number of fixed plots*

$\overline{PV}$ = *Mean estimated volume for all p plots*

SE_{3p} = *Standard error of 3P sample trees*

$$= \sqrt{\frac{\sum^{n_{3p}} R^2 - \frac{\left(\sum^{n_{3p}} R\right)^2}{n_{3p}}}{(n_{3p}-1)(n_{3p})}}$$

R = *M/P (measured/predicted) ratio for* i^{th} *3P sample tree*

n_{3p} = *Number of 3P sample trees*

$\overline{R}$ = *Mean M/P ratio*

t = 2 (95 *percent confidence*)

Sampling error tabulations in exhibit 01 use the data from section 37.26a, exhibit 01, and consider all the sampling was from one stratum.

37.26b - Exhibit 01
Sampling Error

Plot No.	Tree No.	KPI	Plot KPI	Plot KPI^2	Meas Vol (MV)	M/P Ratio (R)	M/P $Ratio^2$ (R^2)
1	1	11					
1	2	23			24.2	1.052	1.107
1	3	30					
1	4	25			26.9	1.076	1.158
1	5	4					
1	6	25					
1	7	40	158	24964	43.8	1.095	1.199
2	1	22					
2	2	11					
2	3	10			10.1	1.010	1.020
2	4	28					
2	5	7					
2	6	42	120	14400	41.4	0.986	0.972
3			0	0			
4	1	22					
4	2	34			30.9	0.909	0.826
4	3	66			66.3	1.005	1.010
4	4	19					
4	5	9					
4	6	14	164	26896			
5	1	33			31.8	0.964	0.929
5	2	12					
5	3	34					
5	4	17	96	9216	16.8	0.988	0.976
6	5	32			32.4	1.013	1.026
6	6	48	80	6400			
7			0	0			
8	1	28			27.8	0.993	0.986
8	2	15					
8	3	9			10.7	1.189	1.414
8	4	14			14.2	1.014	1.028
8	5	24					
8	6	23	113	12769	21.6	0.939	0.882
9	1	40					
9	2	18			17.7	0.983	0.966
9	3	20					
9	4	17	95	9025	17.3	1.018	1.036
10	1	25			26.9	1.076	1.158
10	2	4					
10	3	25					
10	4	40	94	8836	43.8	1.095	1.199
	Sum	920	920	112506		18.405	18.892
	Count	39	10		18		

The sampling error calculations using the above formulas, and the tabulations in exhibit 01 are:

$$SE_{fp} = \sqrt{\frac{112506 - \frac{(920)^2}{10}}{(10-1)(10)}}$$

$$= \sqrt{\frac{27,866}{90}}$$

$$= \sqrt{309.62}$$

$$= 17.596$$

$$SE_{3p} = \sqrt{\frac{18.892 - \frac{(18.405)^2}{18}}{(18-1)(18)}}$$

$$= \sqrt{\frac{0.0729}{306}}$$

$$= \sqrt{0.00024}$$

$$= 0.0154$$

Therefore, the sampling error for the total is:

$$E_T = \sqrt{\left(\frac{17.596}{920/10} \times 100 \times 2\right)^2 + \left(\frac{0.0154}{18.405/18} \times 100 \times 2\right)^2}$$

$$= \sqrt{(38.25)^2 + (3.01)^2}$$

$$= 38.4\%\ (95\%\ \textit{confidence level})$$

37.27 - Additional Population Characteristics.

As with other sampling schemes, additional population characteristics can be estimated. Exhibit 01 shows the tabulations used to calculate the estimated mean diameter and height.

37.27 - Exhibit 01
Data for Calculating Additional Population Characteristics

Plot No.	Tree No.	SP	KPI	DBH	DBH^2	HT	Meas Vol (MV)	3P Wt ($F_{t(3p)}$)	Tree Fact F_t	Exp DBH ($DBH x F_t$)	Exp DBH^2 ($DBH^2 x F_t$)	Exp HT ($HT x F_t$)
1	1	A	11									
1	2	A	23	11	121	74	24.2	2.73	1.37	15.1	165.8	101.4
1	3	A	30									
1	4	B	25	13	169	73	26.9	1.67	0.84	10.9	142.0	61.3
1	5	B	4									
1	6	B	25									
1	7	B	40	15	225	88	43.8	1.05	0.53	8.0	119.3	46.6
2	1	A	22									
2	2	B	11									
2	3	B	10	9	81	61	10.1	4.18	2.09	18.8	169.3	127.5
2	4	B	28									
2	5	B	7									
2	6	A	42	16	256	67	41.4	1.49	0.75	12.0	192.0	50.3
3												
4	1	A	22									
4	2	A	34	13	169	74	30.9	1.85	0.93	12.1	157.2	68.8
4	3	A	66	17	289	92	66.3	0.95	0.48	8.2	138.7	44.2
4	4	B	19									
4	5	B	9									
4	6	C	14									
5	1	A	33	13	169	77	31.8	1.90	0.95	12.4	160.6	73.2
5	2	C	12									
5	3	A	34									
5	4	C	17	11	121	63	16.8	2.46	1.23	13.5	148.8	77.5
6	5	A	32	14	196	69	32.4	1.96	0.98	13.7	192.1	67.6
6	6	A	48									
7												
8	1	A	28	12	144	74	27.8	2.24	1.12	13.4	161.3	82.9
8	2	B	15									
8	3	B	9	9	81	63	10.7	4.64	2.32	20.9	187.9	146.2
8	4	B	14	11	121	56	14.2	2.99	1.50	16.5	181.5	84.0
8	5	B	24									
8	6	B	23	12	144	70	21.6	1.82	0.91	10.9	131.0	63.7
9	1	A	40									
9	2	C	18	12	144	57	17.7	2.32	1.16	13.9	167.0	66.1
9	3	A	20									
9	4	A	17	10	100	65	17.3	3.69	1.85	18.5	185.0	120.3
10	1	B	25	13	169	73	26.9	1.67	0.84	10.9	142.0	61.3
10	2	B	4									
10	3	B	25									
10	4	B	40	15	225	88	43.8	1.05	0.53	8.0	119.3	46.6
	Sum		920						20.38	237.7	2860.8	1389.5
	Count		39				18					

Calculate the additional population characteristics using the tabulated data in exhibit 01:

$$\text{Arithemetic Mean Diameter} = \frac{\sum^{n_{3p}} (DBH \times F_t)}{\sum^{n_{3p}} F_t}$$

$$= \frac{237.7}{20.38}$$

$$= 11.7 \; in.$$

$$\text{Quadradic Mean Diameter} = \sqrt{\frac{\sum^{n_{3p}} (DHB^2 \times F_t)}{\sum^{n_{3p}} F_t}}$$

$$= \sqrt{\frac{2860.8}{20.38}}$$

$$= 11.8 \; in.$$

$$\text{Mean Height} = \frac{\sum^{n_{3p}} (HT \times F_t)}{\sum^{n_{3p}} F_t}$$

$$= \frac{1389.5}{20.38}$$

$$= 68.2 \; ft.$$

37.28 - Application. The fixed plot-3P cruise system is applicable in uniformly distributed timber, especially where clearcutting is the prescription and large areas are involved.

37.3 - Point Sampling with 3P Subsampling. Point-3P is a two-stage sampling system. The first stage is a point sample where sample trees are selected in proportion to tree basal area. The second stage is a 3P sample of the point-sampled trees.

In the second or 3P stage, estimate and record height (KPI) of each point-sampled tree (in this example, height is estimated, rather than volume) by species. Select 3P sample trees by comparing the height prediction for a tree with a random number. If the height prediction is equal to or greater than the random number, measure the tree as a 3P sample tree.

37.31 - Operational Features. The operational features and field procedures of point sampling are described in section 35. The purpose of the point sample in point-3P cruising is to estimate the stratum sum of KPIs. KPI is in terms of units of tree height. Tree height can be estimated in terms of lineal feet of total height or merchantable height or in terms of logs or half logs to some top diameter. However, the height unit must be consistent within a stratum.

Operational features and field procedures for 3P sampling are described in section 36. The 3P procedure for point-3P cruising is the same, except that KPI is estimated and recorded for only the point sampled trees.

37.32 - Statistical Features. Point-3P sampling includes two forms of variable probability sampling; PPS (probability proportional to size) at the first stage,and 3P (probability proportional to prediction) at the second stage. The variable of interest at the first stage is generally volume per acre while the variable of interest at the second stage is the measured to predicted (M/P) ratio.

There are two sources of statistical error in point 3P sampling: the estimate of the sum of stratum KPI and the estimate of the M/P ratio. In the first stage, sampling error is estimated for mean sum units of tree height (KPI) for each point. In the second, or 3P stage, sampling error is estimated for the mean M/P ratio, which is measured tree volume divided by D^2H in point-3P cruising. The combined sampling error for the strata includes both sources of error.

37.33 - Calculating Sample Size. The formula for calculating the sampling error of a point-3P cruise is:

$$E_T = \sqrt{E_p^2 + E_{3P}^2}$$

Where:

E_T = Combined sampling error in percent.
E_p = Sampling error (in percent) of the point sample.
E_{3p} = Sampling error (in percent) of the 3P sample.

Determine sample size for the point sample (number of points) and for the 3P sample (number of trees) to satisfy the target combined sampling error specified for the stratum.

Given the desired combined sampling error, an estimate must also be made for either the point sampling error or the 3P sampling error in order to determine the remaining unknown sampling error. For example, given a desired combined sampling error of 15 percent and an estimated point sampling error of 12 percent, both at the 95 percent level of confidence, the 3P sampling error can be determined as follows:

$$E_{3p} = \sqrt{E_T^2 - E_p^2}$$

$$= \sqrt{15^2 - 12^2}$$

$$= \sqrt{81}$$

$$= 9\%$$

The number of sample units for each stage of the point-3P cruise is determined as follows:

First Stage (Points)

Assumed Coefficient
of Variation = 14%
Confidence Level = 95% (t=2)
Sampling error = 12%

$$n = \frac{(CV_p^2)\ (t^2)}{E_p^2}$$

$$= \frac{(14^2)\ (2^2)}{12^2}$$

$$= 5.4 = 6 \textit{ points}$$

Second Stage (Trees)

Assumed Coefficient
of Variation = 19%
Confidence Level = 95% (t=2)
Sampling error = 9%

$$n = \frac{(CV_{3p}^2)\ (t^2)}{E_{3p}^2}$$

$$= \frac{(19^2)\ (2^2)}{9^2}$$

$$= 17.8 = 18 \textit{ trees}$$

37.34 - Random Number List. Random numbers for point-3P cruises are in terms of units of tree height. For the example, lineal feet to a 6-inch top, outside bark is assumed. Other possibilities include lineal feet of total height, or number of logs or half logs to some top diameter.

The example information needed to prepare a random number list is:

1. Estimate of the sum of estimated tree heights on the sample points (sum KPI).

2. Estimate of the tallest tree in the population (K).

3. Estimate of the number of point sampled trees.

4. Number of 3P sample trees desired.

5. Sampling rate (KZ).

6. Number of points = 6

7. Number of 3P sample trees = 18

In addition, the estimates include:

Tallest tree (K) = 100 feet
Average tree height = 70.0 feet
Average number of sample trees per point = 3.9

Therefore:

Estimate of sum KPI = 6 points x 3.9 trees per point x 70.0 feet per tree

= 1,638 linear feet

Sampling Rate (KZ) = $\frac{1,638}{18 \text{ 3P samples}}$ = 91

Estimated Number of point sampled trees = 6 x 3.9 = 24

For this example, the set of random numbers would have the following characteristics:

K = 100 feet (to a 6-inch top, DOB).
KZ = 91 or one 3P sample tree per 91 lineal feet of estimated tree height.

37.35 - Calculating Sampling Statistics.

37.35a - Sample Expansion. The expansion of point-3P sample trees to the per acre and stratum level involves calculating the sample tree weight or frequency considering both the point sample and the 3P sample.

Compute the estimated frequency per acre for an individual point-3P sample tree from the following formula:

$$F_t = F_{t(p)} \times F_{t(3p)}$$

Where:

F_t = Tree factor or frequency or number of trees per acre for the i^{th} point-3P sample tree.

$$F_{t(p)} = \textit{Point sample frequency of } i^{th} \textit{ tree}$$

$$= \frac{\textit{Basal Area Factor}}{0.005454 \times DBH^2 \times p}$$

DBH = diameter of the i^{th} point-3P sample tree

$$F_{t(3p)} = 3P \textit{ Frequency} = \frac{\sum^{n} KPI}{n_{3p} \times KPI}$$

$$\textit{KPI in numerator} = \textit{Height estimate of } i^{th} \textit{ point-sampled tree.}$$

$$n = \textit{Number of point-sampled trees.}$$

$$n_{3p} = \textit{Number of point-3P sampled trees.}$$

$$\textit{KPI in denominator} = \textit{KPI of the } i^{th} \textit{ point-3P sampled tree.}$$

$$p = \textit{Number of points.}$$

Compute the estimated volume per acre for an individual point 3P sample tree from the following formula:

$$F_v = F_t \times MV$$

Where:

F_v = Estimated volume per acre for the i^{th} point 3P sample tree.

MV = Measured volume of the i^{th} point-3P sample tree.

Compute estimated stratum volume for an individual point 3P sample tree as follows:

$$SV = F_v \times Acres$$

Where:

SV = Stratum volume for the i^{th} point-3P sample tree.

Acres = Acres in the stratum.

Calculate estimated stratum volume per acre and total stratum volume by summing all point-sample tree values.

The calculations for a timber sale of eighteen acres and ten sample points are shown in exhibit 01, given:

1. BAF = 20

2. Acres = 18

3. Volumes are in ft^3

4. Species group 1 = A

5. Species group 2 = B and C

37.35a - Exhibit 01
Volume Calculation: Point Sample 3P

Plot No.	Tree No.	SP	KPI	DBH	HT	Meas Vol (MV)	Point Wt ($F_{t(p)}$)	3P Wt ($F_{t(3p)}$)	Tree Fact (F_t)	Vol Fact (F_v)	Tract Vol (SV)
1	1	A	50								
1	2	A	75	11	74	24.2	3.03	1.83	5.54	134.1	2413.8
1	3	A	65						0.00		
1	4	B	75	13	73	26.9	2.17	1.90	4.12	110.8	1994.4
1	5	B	45						0.00		
1	6	B	60						0.00		
1	7	B	90	15	88	43.8	1.63	1.58	2.58	113.0	2034.0
2	1	A	60						0.00		
2	2	B	55						0.00		
2	3	B	60	9	61	10.1	4.53	2.38	10.78	108.9	1960.2
2	4	B	65						0.00		
2	5	B	45						0.00		
2	6	A	65	16	67	41.4	1.43	2.12	3.03	125.4	2257.2
3									0.00		
4	1	A	60						0.00		
4	2	A	75	13	74	30.9	2.17	1.83	3.97	122.7	2208.6
4	3	A	90	17	92	66.3	1.27	1.53	1.94	128.6	2314.8
4	4	B	65						0.00		
4	5	B	55						0.00		
4	6	C	55						0.00		
5	1	A	75	13	77	31.8	2.17	1.83	3.97	126.2	2271.6
5	2	C	50						0.00		
5	3	A	70						0.00		
5	4	C	65	11	63	16.8	3.03	2.19	6.64	111.6	2008.8
6	5	A	70	14	69	32.4	1.87	1.96	3.67	118.9	2140.2
6	6	A	70						0.00		
7									0.00		
8	1	A	75	12	74	27.8	2.55	1.83	4.67	129.8	2336.4
8	2	B	55						0.00		
8	3	B	65	9	63	10.7	4.53	2.19	9.92	106.1	1909.8
8	4	B	55	11	56	14.2	3.03	2.59	7.85	111.5	2007.0
8	5	B	65						0.00		
8	6	B	70	12	70	21.6	2.55	2.04	5.20	112.3	2021.4
9	1	A	70						0.00		
9	2	C	60	12	57	17.7	2.55	2.38	6.07	107.4	1933.2
9	3	A	65						0.00		
9	4	A	65	10	65	17.3	3.67	2.12	7.78	134.6	2422.8
10	1	B	75	13	73	26.9	2.17	1.90	4.12	110.8	1994.4
10	2	B	45						0.00		
10	3	B	60						0.00		
10	4	B	90	15	88	43.8	1.63	1.58	2.58	113.0	2034.0
	Total		2525						94.43	2125.7	38263
	Count		39			18					

Item	Group 1	Group 2	All
KPI	1100	1425	2525
n_{3p}	8	10	18
$F_{t(3p)}$	15.1	20.7	35.8
F_t	34.6	59.9	94.4

F_v	1020	1105	2126

<u>37.35b</u> - <u>Sampling Error</u>. Sampling error of a point 3P cruise can be calculated from the following formula:

$$E_T = \sqrt{E_p + E_{3p}}$$

$$= \sqrt{\left(\frac{SE_p}{\overline{PH}} \times 100 \times t\right)^2 + \left(\frac{SE_{3p}}{\overline{R}} \times 100 \times t\right)^2}$$

Where:

E_T = *Stratum sampling error in percent.*

$$SE_p = \sqrt{\frac{\sum^{p} PH^2 - \frac{\left(\sum^{p} PH\right)^2}{p}}{(p-1)\,(p)}}$$

PH = *Sum of estimated tree heights of point sample trees on jth plot.*

p = *Number of points.*

$\overline{PH}$ = *Mean of the sum of tree height over all points.*

$$SE_{3p} = \sqrt{\frac{\sum^{n_{3p}} R^2 - \frac{\left(\sum^{n_{3p}} R\right)^2}{n_{3p}}}{(n_{3p}-1)\,(n_{3p})}}$$

R = *M/P ratio for ith point-3P sample tree* $= \dfrac{\text{measured volume}}{(D^2H)}$

n_{3p} = *Number of point-3P sample trees.*

$\overline{R}$ = *Mean M/P ratio.*

Sampling error calculations use the data shown in exhibit 01 which was derived from the data shown in 35.35a exhibit 01.

37.35b - Exhibit 01
Sampling Error, One Stratum Sale

Plot No.	Tree No.	KPI	Plot KPI	Plot KPI^2	DBH	HT	Meas Vol (MV)	D^2H [1/] (DBH^2xH)	M/P [2/] Ratio (R)	M/P [3/] $Ratio^2$ (R^2)
1	1	50								
1	2	75			11	74	24.2	9075	0.0027	0.0000073
1	3	65								
1	4	75			13	73	26.9	12675	0.0021	0.0000044
1	5	45								
1	6	60								
1	7	90	460	211600	15	88	43.8	20250	0.0022	0.0000048
2	1	60								
2	2	55								
2	3	60			9	61	10.1	4860	0.0021	0.0000044
2	4	65								
2	5	45								
2	6	65	350	122500	16	67	41.4	16640	0.0025	0.0000063
3			0	0						
4	1	60								
4	2	75			13	74	30.9	12675	0.0024	0.0000058
4	3	90			17	92	66.3	26010	0.0025	0.0000063
4	4	65								
4	5	55								
4	6	55	400	160000						
5	1	75			13	77	31.8	12675	0.0025	0.0000063
5	2	50								
5	3	70								
5	4	65	260	67600	11	63	16.8	7865	0.0021	0.0000044
6	5	70			14	69	32.4	13720	0.0024	0.0000058
6	6	70	140	19600						
7			0	0						
8	1	75			12	74	27.8	10800	0.0026	0.0000068
8	2	55								
8	3	65			9	63	10.7	5265	0.0020	0.0000040
8	4	55			11	56	14.2	6655	0.0021	0.0000044
8	5	65								
8	6	70	385	148225	12	70	21.6	10080	0.0021	0.0000044
9	1	70								
9	2	60			12	57	17.7	8640	0.0020	0.0000040
9	3	65								
9	4	65	260	67600	10	65	17.3	6500	0.0027	0.0000073
10	1	75			13	73	26.9	12675	0.0021	0.0000044
10	2	45								
10	3	60								
10	4	90	270	72900	15	88	43.8	20250	0.0022	0.0000048
	Sum	2525	2525	870025					0.0413	0.0000959
	Count	39	10				18			

1/ D^2H = (Measured DBH)^2 x Estimated Height (KPI).
2/ M/P Ratio = Measured Tree Volume / D^2H = R.
3/ The covariance term is excluded because its effect on E is trivial.

Calculate the standard errors and sampling error:

$$SE_{3p} = \sqrt{\frac{\sum^{n_{3p}} R^2 - \frac{\left(\sum^{n_{3p}} R\right)^2}{n_{3p}}}{(n_{3p} - 1)\ (n_{3p})}}$$

$$= \sqrt{\frac{0.0000959 - \frac{0.0413}{18}}{(18 - 1)\ (18)}}$$

$$= 0.000061$$

$$E_{3p} = \frac{SE_{3p}}{\bar{R}} \times 100 \times t$$

$$= \frac{(0.000061)}{\left(\frac{0.0413}{18}\right)} \times 100 \times 2$$

$$= 5.3\%$$

$$SE_p = \sqrt{\frac{\sum^{p} PH^2 - \frac{\left(\sum^{p} PH\right)^2}{p}}{(p - 1)\ (p)}}$$

$$= \sqrt{\frac{870{,}025 - \frac{6{,}375{,}625}{10}}{(10 - 1)\ (10)}}$$

$$= 50.82$$

$$E_p = \frac{SE_p}{\overline{KPI}} \times 100 \times t$$

$$= \frac{50.82}{\left(\frac{2525}{10}\right)} \times 100 \times 2$$

$$= 40.3\%$$

$$E_T = \sqrt{E_p^2 + E_{3p}^2}$$

$$= \sqrt{40.3^2 + 5.3^2}$$

$$= 40.6\%\ (95\%\ \textit{confidence level})$$

<u>37.36</u> - <u>Additional Population Characteristics</u>. Use the data from exhibit 01 to calculate the average stratum diameter and height.

<u>37.36</u> - <u>Exhibit 01</u>
<u>Plot Data for Calculating Population Characteristics for Point 3P</u>

Plot No.	Tree No.	SP	KPI	DBH	DBH^2	HT	Point Wt ($F_{t(p)}$)	3P Wt ($F_{t(3p)}$)	Tree Fact (F_t)	Exp DBH ($DBH x F_t$)	Exp DBH^2 ($DBH^2 x F_t$)	Exp HT ($HT x F_t$)
1	1	A	50									
1	2	A	75	11	121	74	3.03	1.83	5.54	60.9	670.3	410.0
1	3	A	65									
1	4	B	75	13	169	73	2.17	1.90	4.12	53.6	696.3	300.8
1	5	B	45									
1	6	B	60									
1	7	B	90	15	225	88	1.63	1.58	2.58	38.7	580.5	227.0
2	1	A	60									
2	2	B	55									
2	3	B	60	9	81	61	4.53	2.38	10.78	97.0	873.2	657.6
2	4	B	65									
2	5	B	45									
2	6	A	65	16	256	67	1.43	2.12	3.03	48.5	775.7	203.0
3												
4	1	A	60									
4	2	A	75	13	169	74	2.17	1.83	3.97	51.6	670.9	293.8
4	3	A	90	17	289	92	1.27	1.53	1.94	33.0	560.7	178.5
4	4	B	65									
4	5	B	55									
4	6	C	55									
5	1	A	75	13	169	77	2.17	1.83	3.97	51.6	670.9	305.7
5	2	C	50									
5	3	A	70									
5	4	C	65	11	121	63	3.03	2.19	6.64	73.0	803.4	418.3
6	5	A	70	14	196	69	1.87	1.96	3.67	51.4	719.3	253.2
6	6	A	70									
7												
8	1	A	75	12	144	74	2.55	1.83	4.67	56.0	672.5	345.6
8	2	B	55									
8	3	B	65	9	81	63	4.53	2.19	9.92	89.3	803.5	625.0
8	4	B	55	11	121	56	3.03	2.59	7.85	86.4	949.9	439.6
8	5	B	65									
8	6	B	70	12	144	70	2.55	2.04	5.20	62.4	748.8	364.0
9	1	A	70									
9	2	C	60	12	144	57	2.55	2.38	6.07	72.8	874.1	346.0
9	3	A	65									
9	4	A	65	10	100	65	3.67	2.12	7.78	77.8	778.0	505.7
10	1	B	75	13	169	73	2.17	1.90	4.12	53.6	696.3	300.8
10	2	B	45									
10	3	B	60									
10	4	B	90	15	225	88	1.63	1.58	2.58	38.7	580.5	227.0
	Sum		2525						94.43	1096.3	13124.8	6401.6
	Count		39	18								

Calculate the additional population characteristics from the tabulated data in exhibit 01:

$$Arithemetic\ Mean\ Diameter = \frac{\sum^{n_{3p}}(DBH \times F_t)}{\sum^{n_{3p}} F_t}$$

$$= \frac{1096.3}{94.43}$$

$$= 11.6\ inches$$

$$Quadratic\ Mean\ Diameter = \sqrt{\frac{\sum^{n_{3p}}(DBH^2 \times F_t)}{\sum^{n_{3p}} F_t}}$$

$$= \sqrt{\frac{13124.8}{94.43}}$$

$$= 11.8\ inches$$

$$Mean\ Height = \frac{\sum^{n_{3p}}(HT \times F_t)}{\sum^{n_{3p}} F_t}$$

$$= \frac{6401.6}{94.43}$$

$$= 67.8\ feet$$

37.37 - Application. Point sampling with a 3P subsample is an effective method to use in clearcutting situations where large areas are to be cruised and where there is a small range of tree sizes.

37.4 - Point Count/Measure-Plot Method. In ratio double sampling, count sample trees at all points but measure volume only on some proportion of the points. Use the data from the points on which sample trees are measured to estimate a ratio of volume to basal area. Apply this ratio, called V-BAR, to the estimated basal area for the tract to arrive at an estimate of tract volume. There are two sources of statistical error in double sampling: estimated average basal area per acre and estimated average V-BAR.

37.41 - Operational Features. The operational and field procedures of point sampling are described in section 35. The purpose of the first stage point sample is to estimate strata basal area. The purpose of the second stage sample is to collect measured tree information for the development of volume to basal area ratios.

37.42 - Statistical Features. Ratio double sampling can be done with either a completely random or a systematic design. Determine the initial number of plots (or count plots), then select a subsample of these plots for measurement plots based on some proportion of the initial plots.

The advantage of ratio double sampling results from the time saved in counting the trees on some of the plots instead of measuring all the trees on all the plots. This advantage is reduced if the time saved is not appreciable or if the relationship between the volume per basal area ratio and the number of count trees is weakly correlated.

37.43 - Calculating Sample Size. Calculate the sample size as in Johnson (1965). An example for determining the sample size in ratio double sampling for the west side forests in Washington is:

$$n = k(1.732)\sqrt{r}$$

Where: n = Total number of count points plus measure points.

$$k = \text{Number of measured points} = \left(\frac{CV^2}{E^2}\right)\left(\frac{0.433}{\sqrt{r}} + 0.25\right)$$

r = Cost of measuring all trees on a point divided by cost of counting all trees on a point.

CV = Coefficient of variation for volume/basal area ratio (V-BAR).

E = Sampling error percent.

See the chapter 90 for tables giving the number of points needed to meet a specified sampling error, given the coefficient of variation and relative cost of measuring versus counting sample trees on a point. These tables are presented as examples and should be modified for local conditions.

37.44 - Calculating Sampling Statistics.

37.44a - Sample Expansion. Two methods are commonly used in expanding point sample data: the factor method, (Beers and Miller,

1964) and the V-BAR method, (Beers and Miller, 1964; Dilworth and Bell, 1981). Both methods give identical results except for trivial rounding differences. Computations are given in this section for each method.

1. Factor Method. The factor expansion method involves calculating the sample tree weight or frequency using the proportion of the measured trees as a weighting factor. Compute the expansion factor for each tree from the following formula:

$$F_t = F_{t(p)} \times F_{t(c)}$$

Where:

F_t = Number of trees per acre for the i^{th} measured tree.

$F_{t(p)}$ = Tree expansion factor due to point sampling $= \dfrac{\text{Basal Area Factor}}{0.005454 \times DBH^2 \times p}$

$F_{t(c)}$ = Frequency of count trees = n/k

n = Number of measured trees plus number of count trees.

k = Number of measured trees.

p = Number of plots established.

Compute the estimated volume per acre for the i^{th} individual measured tree from the following formula:

$$F_v = F_t \times MV$$

Where:

F_v = Estimated volume per acre for the i^{th} sample tree.
F_t = Number of trees for i^{th} measured tree.
MV = Measured volume for the i^{th} measured tree.

2. V-BAR Method. The V-BAR method calculates the volume per acre by calculating the average volume to basal area ratio and multiplying it by average basal area per acre. Using the V-BAR method, calculate the volume per acre for each tree using the following formula:

$$F_v = VBAR \times \overline{BAPA}$$

Where:

F_v = Estimated volume per acre for i^{th} measured tree.
VBAR = Volume to BA ratio of i^{th} tree
$= \dfrac{MV}{(0.005454 \times DBH^2)}$

MV = Volume of the i^{th} measured tree.

$\overline{BAPA}$ = Average BA per acre = (BAF x n/p) / k

BAF = Basal Area Factor

n = Number of count trees + number of measured trees.

p = Number of sample points.

k = Number of measured trees

Compute the estimated total volume for the individual measured trees for both methods as follows:

$$SV = F_v \times Acres.$$

Where:

SV = Total volume for the i^{th} measured tree.
F_v = Volume factor for i^{th} measured tree.
Acres = Number of acres in the stand.

In exhibits 01 - 02, sample trees are counted at all points and measured for volume at some fraction of the points, separated by species type.

Given:

1. number of count points = 5;
2. number of measure points = 5;
3. BAF = 20;
4. tract acres = 18.

37.44a - Exhibit 01
Measure/Count Data and Summary

Plot No.	Sp	Type	Count	DBH	HT	Net Vol (MV)
1	A	C	3.0			
	B	C	4.0			
2	A	M		12	59	21.0
	B	M		10	56	11.5
	B	M		9	61	10.1
	B	M		14	66	29.1
	B	M		9	43	6.7
	A	M		16	67	41.4
3		C	0.0			
4	A	M		12	61	21.0
	A	M		13	74	30.9
	A	M		17	92	66.3
	B	M		12	63	19.3
	B	M		9	54	8.8
	C	M		11	54	14.0
5	A	C	2.0			
	C	C	2.0			
6	A	M		14	69	32.4
	A	M		16	72	45.6
7		C	0.0			
8	A	M		12	74	27.8
	B	M		10	55	11.0
	B	M		9	63	10.7
	B	M		11	56	14.2
	B	M		13	63	24.2
	B	M		12	70	21.6
9	A	C	3.0			
	C	C	1.0			
10	B	M		13	73	26.9
	B	M		8	45	4.9
	B	M		13	61	23.0
	B	M		15	88	43.8

Item	Species A	Species B	Species C	All
n	16	19	4	39
k	8	15	1	24
$F_{t(c)}$	2.000	1.267	4.000	1.625
BAPA	4.000	2.533	8.000	3.250

Because this example is separated by species, n and k are the number of counted and measured trees by species. Calculate the expansion factors for each tree.

37.44a - Exhibit 02
Factor and V-BAR Calculation Example and Summary

Plot No.	Sp	---- Factor Point Fact ($F_{t(p)}$)	Count Fact ($F_{t(c)}$)	--------------- Tree Fact (F_t)	Vol Fact (F_v)	---- VBAR	VBAR BAPA	---- Vol Fact (F_v)
2	A	2.547	2.000	5.093	107.0	26.739	4.000	107.0
	B	3.667	1.267	4.650	53.5	21.085	2.533	53.4
	B	4.527	1.267	5.740	58.0	22.862	2.533	57.9
	B	1.871	1.267	2.370	69.0	27.222	2.533	69.0
	B	4.527	1.267	5.740	38.5	15.166	2.533	38.4
	A	1.432	2.000	2.860	118.4	29.651	4.000	118.6
4	A	2.547	2.000	5.090	106.9	26.739	4.000	107.0
	A	2.170	2.000	4.340	134.1	33.524	4.000	134.1
	A	1.269	2.000	2.540	168.4	42.063	4.000	168.3
	B	2.547	1.267	3.230	62.3	24.574	2.533	62.2
	B	4.527	1.267	5.740	50.5	19.920	2.533	50.5
	C	3.031	4.000	12.120	169.7	21.214	8.000	169.7
6	A	1.871	2.000	3.740	121.2	30.309	4.000	121.2
	A	1.432	2.000	2.860	130.4	32.660	4.000	130.6
8	A	2.547	2.000	5.090	141.5	35.397	4.000	141.6
	B	3.667	1.267	4.650	51.2	20.169	2.533	51.1
	B	4.527	1.267	5.740	61.4	24.221	2.533	61.4
	B	3.031	1.267	3.840	54.5	21.517	2.533	54.5
	B	2.170	1.267	2.750	66.6	26.255	2.533	66.5
	B	2.547	1.267	3.230	69.8	27.503	2.533	69.7
10	B	2.170	1.267	2.750	74.0	29.184	2.533	73.9
	B	5.730	1.267	7.260	35.6	14.038	2.533	35.6
	B	2.170	1.267	2.750	63.3	24.953	2.533	63.2
	B	1.630	1.267	2.060	90.2	35.692	2.533	90.4
Total				106.233	2096.0	632.7		2095.6

Item	[--- Species A	B	C ---]	All Species
FACTOR				
Estimated Vol/acre (Sum F_v)	1027.9	898.4	169.7	2096.0
Estimated Trees/acre (Sum F_t)	31.6	62.5	12.1	106.2
Estimated total Vol (Sum SV)	18502.2	16171.2	3054.6	37728.0
V-BAR				
Estimated Vol/acre (Sum F_v)	1028.3	897.6	169.7	2095.6
Estimated BA/acre	32.0	38.0	8.0	78.0
Estimated total Vol (Sum SV)	18509.9	16156.7	3054.8	37721.5
No. Measured Trees (k)	8	15	1	24
No. Counted Trees (n-k)	8	4	3	15
No. Measured + Counted Trees (n)	16	19	4	39

When dealing with multiple species in double sampling do the following:

1. Collect data by species or species groups (tree counts and measured tree data) if definitive species data is needed for appraisal purposes.

2. Group a species weakly represented in measured point data, with another species as similar in form and value as is possible.

3. Disregard trivial differences between the sum of the species per acre volumes and the calculated tract average volume per acre. The difference is due to the difference among species in the ratio of measure to count trees.

<u>37.44b</u> - <u>Sampling Error</u>. When double sampling, use the following formulas (Johnson 1965), for calculating the standard error and the sampling error:

$$SE = \sqrt{\frac{\sum^{m} X^2 - \frac{(\sum^{m} X)^2}{m}}{p(m-1)} + \frac{\sum^{m} X^2 + \bar{R}^2 \sum^{m} W^2 - 2\bar{R} \sum^{m} XW}{m\,(m-1)} \left(\frac{P-m}{p}\right)}$$

Where:

X = Volume factors for a measured point (F_v or V-BAR)

$\bar{R}$ = Mean volume factor for measured trees = $\frac{\sum^{k} F_v}{k}$.

W = Tree count for a measured point.
p = Number of measured points + count points.
m = Number of measured points.

If V-BARS are used in lieu of volume factors, multiply the square root of the formula by the basal area factor used. The data in exhibit 01 is used in the example calculation.

<u>37.44b</u> - <u>Exhibit 01</u>
<u>Data</u>

Point	F_v	F^2_v	W	W^2	$W \times F_v$
2	444.400	197491.36	6	36	2666.400
4	691.900	478725.61	6	36	4151.400
6	251.600	63302.56	2	4	503.200
8	445.000	198025.00	6	36	2670.000
10	263.100	69221.61	4	16	1052.400
Total	2096.000	1006766.14	24	128	11043.400

Given:

$p = 10$

$m = 5$

$\bar{R} = 2096.000/24 = 87.333$

$\bar{R}^2 = 7627.053$

$(p-m)/p = 0.5$

$\bar{x} = 2096.00/5 = 419.200$

Then, substituting component values in the formula:

$$SE = \sqrt{\frac{1006766.14 - \frac{2096.000^2}{5}}{10(4)} + \frac{1006766.14 + 7627.053(128) - 2(87.333)(11043.400)}{5(4)}\left(\frac{10-5}{10}\right)}$$

$$= \sqrt{3203.074 + 2706.121(0.5)}$$

$$= \sqrt{4556.135}$$

$$= 67.499$$

$$then: \; E = 100\left(\frac{t \times SE}{\bar{x}}\right) = 100\,(2)\left(\frac{67.499}{419.20}\right) = 32.204$$

<u>37.45</u> - <u>Additional Population Characteristics</u>.

$$Mean\ Diameter = \frac{\sum^{k}(DBH \times F_t)}{\sum^{k} F_t}$$

$$= \frac{1208.9}{106.2} = 11.4$$

$$Quadratic\ Mean\ Diameter = \sqrt{\frac{\sum^{k}(DBH^2 \times F_t)}{\sum^{k} F_t}}$$

$$= \sqrt{\frac{14302.3}{106.2}} = 11.6$$

$$Mean\ Height = \frac{\sum^{k}(HT \times F_t)}{\sum^{k} F_t}$$

$$= \frac{6594.3}{106.2} = 62.1$$

37.46 - Application. Point sampling is an effective system to use in clear-cutting situations where large areas are to be cruised and where there is a range of tree sizes. This is a very cost effective method where the individual tree VBAR variance is low and the basal area variance per acre is high. The cost of taking count plots is much less than measure plots, and this samples where most of the variance occurs.

37.5 - Point Count/Measure-Tree Method. Point count/measure-tree is a ratio double sampling technique. In ratio double sampling, all sample trees are counted but only a portion of the trees are measured at each plot. The data from the sample trees that are measured is used to estimate a ratio of volume to basal area. This ratio, called V-BAR, is applied to the estimated basal area for the tract to arrive at an estimate of tract volume. There are two sources of statistical error in double sampling: estimated average basal area per acre and estimated average V-BAR.

37.51 - Operational Features. The operational and field procedures of point sampling are described in section 35. The purpose of the first stage point sample is to estimate strata basal area. The purpose of the second stage sample is to collect measured tree information for the development of volume to basal area ratios.

37.52 - Statistical Features. Ratio double sampling can be done with either a completely random or a systematic design. Determine the initial number of plots, then select a subsample of the trees on these plots for measurement.

The advantage of ratio double sampling results from the time saved in measuring only a portion of trees on the plots. This advantage is reduced if the time saved is not appreciable or if the relationship between the volume per basal area ratio and the number of count trees is weakly correlated.

37.53 - Calculating Sample Size. Calculate combined sampling error to determine sample size for point count/measure-tree cruising. Determine sample size for the point sample and the count/measure-tree sample to satisfy the desired sampling error for the stratum.

The combined sampling error includes the point sample error and the count/measure tree error (Bruce, 1961).

If both the point sample and count/measure-tree errors are known, use the following formula for calculating the sampling error:

$$E_T = \sqrt{E_p^2 + E_{cm}^2}$$

Where:

E_T = Combined percent sampling error.

E_p = Percent sampling error for the point sample.

E_{cm} = Percent sampling error for the count/measure-tree sample.

This formula assumes the two errors are independent, which is not quite true. However, the formula may be used to approximate the error, and it is useful in estimating number and approximate ratio of count/measure plots or trees. The cruise may be designed to meet a specific combined error. In this case the desired combined error is known. Estimate one of the errors and determine the remaining error using the following example where count/measure error is estimated and the point error is being determined:

$$E_p = \sqrt{E_T^2 - E_{cm}^2}$$

For example, given:

1. Target combined sampling error of 20 percent (95 percent confidence level)

2. Count/measure error is estimated to be 12 percent (95 percent confidence level).

Calculate the point error:

$$E_p = \sqrt{E_T^2 - E_{cm}^2}$$

$$= \sqrt{20^2 - 12^2}$$

$$= \sqrt{256}$$

$$= 16.0\%$$

Note: Desired combined sampling error must be higher than either component sampling error.

Determine the number of samples needed to attain the errors identified for each stage of the point count/measure tree cruise. Estimate the coefficient of variation between point/basal area in the first stage, and between volume/basal area ratio (V-BAR) in the second stage. Base these estimates on preliminary sample data, past cruises in the area in similar types, or inventory data.

Calculate the number of plots for the first stage sample and the number of trees for the second stage:

First Stage	Second Stage
Assumed Coefficient of Variation = 25%	Assumed Coefficient of Variation = 25.5%
Confidence level = 95% (t=2)	Confidence level = 95% (t=2)
Sampling error = 16%	Sampling error = 12%

$$n_p = \frac{(t^2)(CV_p^2)}{E_p^2} = \frac{(2^2)(25^2)}{16^2} = 9.77 = 10 \textit{ plots}$$

$$n_{cm} = \frac{(t^2)(CV_{cm}^2)}{E_{cm}^2} = \frac{(2^2)(25.5)^2}{12^2} = 18.06 = 18.0 \textit{ trees}$$

37.54 - Calculating Sampling Statistics.

37.54a - Sample Expansion. Two methods are commonly used in expanding point sample data: the factor method, (Beers and Miller, 1964) and the V-BAR method, (Beers and Miller, 1964; Dilworth and Bell, 1981). Both methods give identical results except for trivial rounding differences. Computations are given in this section for each method.

1. Factor Method. The factor expansion method involves calculating the sample tree weight or frequency using the proportion of the measured trees as a weighting factor. Compute the expansion factor for each tree from the following formula:

$$F_t = F_{t(p)} \times F_{t(c)}$$

Where:

F_t = Tree factor; number of trees per acre for the i^{th} measured tree

$F_{t(p)}$ = Expansion of prism cruise = $\frac{\text{Basal Area Factor}}{0.005454 \times DBH^2 \times p}$

$F_{t(c)}$ = Expansion of count; frequency of measured trees = $\frac{n}{k}$

n = Number of measured trees plus number of count trees.

k = Number of measured trees.

p = Number of sample points.

The estimated volume per acre for an individual measured tree is computed from the following formula:

$$F_v = F_t \times MV$$

Where:

F_v = Volume factor; estimated volume per acre for i^{th} measured tree.

F_t = Tree factor; estimated trees per acre for i^{th} measured tree

MV = Measured volume for the i^{th} measured tree.

2. V-BAR Method. The V-BAR method calculates the volume per acre by calculating the average volume to basal area ratio and multiplying it by average basal area per acre. The volume per acre using the V-BAR method is calculated using the following formula:

$$F_v = VBAR \times \overline{BAPA}$$

Where:

F_v = Volume factor; estimated volume per acre for the i^{th} measured tree.

VBAR = Volume to basal area ratio of the i^{th} measured tree

$$= \frac{MV}{0.005454 \times DBH^2}$$

MV = Measured volume of the i^{th} measured tree

k = Number of measured trees

$$\overline{BAPA} = average\ BA\ per\ acre = \frac{BAF \times n}{pk}$$

BAF = *Basal Area Factor*.

n = *Number of count trees plus number of measured trees*.

p = *Number of sample points*.

k = *Number of measured trees*.

The estimated total volume for the individual measured trees is computed for both methods as follows:

$$SV = F_v \times Acres.$$

Where:

SV = Total volume for the i^{th} measured tree.
F_v = Volume factor.
Acres = Number of acres in the stand.

In the following example (ex. 01 - 02), all sample trees are counted at each point, but only a portion of the trees are measured for volume at each point.

Given:

1. Number of points = 10

2. BAF = 20

3. tract acres = 18.

37.54a - Exhibit 01
Stand Data for Point Count/Measure-Tree Sample

Plot No.	Sp	Type	Count	DBH	HT	Net Vol
1	A	M		10	48	10.7
	A	C	2.0			
	B	M		13	73	26.9
	B	C	3.0			
2	A	M		12	59	21.0
	B	M		10	56	11.5
	B	C	3.0			
	A	C	1.0			
3		M	0.0			
4	A	M		12	61	21.0
	A	C	2.0			
	B	M		12	63	19.3
	B	C	1.0			
	C	M		11	54	14.0
5	A	M		13	77	31.8
	C	M		11	52	13.0
	A	C	1.0			
	C	C	1.0			
6	A	M		14	69	32.4
	A	C	1.0			
7		M	0.0			
8	A	M		12	74	27.8
	B	M		10	55	11.0
	B	C	4.0			
9	A	M		15	69	38.4
	C	M		12	57	17.7
	A	C	2.0			
10	B	M		13	73	26.9
	B	C	3.0			

Item	Species A	Species B	Species C	All Species
n	16	19	4	39
k	7	5	3	15
$F_{t(c)}$	2.286	3.800	1.333	2.600
BAPA	4.571	7.600	2.667	5.200

37.54a - Exhibit 02
Factor and V-BAR Calculation and Summary for Point Count/Measure-Tree Example

Plot No.	Sp	Factor $F_{t(p)}$	$F_{t(c)}$	F_t	F_v	VBAR VBAR	BAPA	F_v
1	A	3.667	2.286	8.383	89.7	19.619	4.571	89.7
	B	2.170	3.800	8.245	221.8	29.184	7.600	221.8
2	A	2.547	2.286	5.821	122.2	26.739	4.571	122.2
	B	3.667	3.800	13.935	160.3	21.085	7.600	160.2
4	A	2.547	2.286	5.821	122.2	26.739	4.571	122.2
	B	2.547	3.800	9.677	186.8	24.574	7.600	186.8
	C	3.031	1.333	4.040	56.6	21.214	2.667	56.6
5	A	2.170	2.286	4.960	157.7	34.500	4.571	157.7
	C	3.031	1.333	4.040	52.5	19.699	2.667	52.5
6	A	1.871	2.286	4.277	138.6	30.309	4.571	138.5
8	A	2.547	2.286	5.821	161.8	35.397	4.571	161.8
	B	3.667	3.800	13.935	153.3	20.169	7.600	153.3
9	A	1.630	2.286	3.726	143.1	31.292	4.571	143.0
	C	2.547	1.333	3.395	60.1	22.537	2.667	60.1
10.0	B	2.170	3.800	8.245	221.8	29.184	7.600	221.8
Total				104.321	2048.5	392.241		2048.3

FACTOR	A	B	C	All Species
Estimated Vol/acre (Sum F_v)	935.3	944.0	169.2	2048.5
Estimated Trees/acre (Sum F_t)	38.8	54.0	11.5	104.3
Estimated total Vol (Sum SV)	16835.4	16992.0	3045.6	36873.0
V-BAR				
Estimated Vol/acre (Sum F_v)	935.2	943.9	169.2	2048.3
Estimated total Vol (Sum SV)	16833.7	16990.0	3046.0	36869.7
No. Measured Trees (k)	7	5	3	15
No. Counted Trees (n-k)	9	14	1	24
No. Measured+Counted Trees (n)	16	19	4	39

Do the following when dealing with multiple species in double sampling:

1. Collect data by species or species groups (tree counts and measure tree data) if definitive species data is needed for appraisal purposes.

2. When a species is weakly represented in measured point data, group with another species as similar in form and value as possible.

3. Disregard trivial differences between the sum of the species per acre volumes and the calculated tract average volume per acre. The difference is due to the difference among species in the ratio of measure to count trees.

<u>37.54b</u> - <u>Sampling Error</u>. When this form of double sampling is used, use the following formulas for calculating the standard error and the sampling error:

$$E_T = \sqrt{E_{cm}^2 + E_p^2}$$

$$= \sqrt{\left(\frac{SE_{cm}}{\overline{VBAR}} \times 100 \times t\right)^2 + \left(\frac{SE_p}{\bar{n}_p} \times 100 \times t\right)^2}$$

Where:

E_T = Stratum sampling error percent

E_{cm} = Stratum sampling error of tree VBAR

E_p = Stratum sampling error of point sampling

$$SE_p = \sqrt{\frac{\sum^p n_p^2 - \frac{\left(\sum^p n_p\right)^2}{p}}{(p - 1)\,(p)}}$$

n_p = *Number of prism trees on the* j^{th} *point*

$$SE_{cm} = \sqrt{\frac{\sum^k VBAR^2 - \frac{\left(\sum^k VBAR\right)^2}{k}}{(k - 1)\,(k)}}$$

$VBAR$ = *Volume to basal area ratio* (V–BAR) *for* i^{th} *measured tree*

k = *Number of measured trees*

p = *Number of points*

$$\overline{VBAR} = \text{Mean volume to basal area ratio} = \frac{\sum^k VBAR}{k}$$

$$\bar{n}_p = \text{Mean number of trees per plot} = \frac{\sum^p n_p}{p}$$

For example, given the data in exhibit 01, calculate the error as shown.

37.54b - Exhibit 01
Derivations

Point	VBAR	$VBAR^2$	n_p	n_p^2
1	19.619	384.905	7	49
	29.184	851.706		
2	26.739	714.974	6	36
	21.085	444.577		
4	26.739	714.974	6	36
	24.574	603.881		
	21.214	450.034		
5	34.500	1190.250	4	16
	19.699	388.051		
6	30.309	918.635	2	4
8	35.397	1252.948	6	36
	20.169	406.789		
9	31.292	979.189	4	16
	22.537	507.916		
10	29.184	851.706	4	16
Total	392.241	10660.535	39	209

Calculate the sampling statistics:

$$SE_p = \sqrt{\frac{209 - \left(\frac{39^2}{10}\right)}{(10-1)(10)}} = \sqrt{0.632} = 0.795$$

$$\bar{n}_p = \frac{39}{10} = 3.9$$

$$SE_{cm} = \sqrt{\frac{10660.535 - \left(\frac{392.241^2}{15}\right)}{(15-1)(15)}} = \sqrt{1.922} = 1.387$$

$$\overline{VBAR} = \frac{392.241}{15} = 26.149$$

Calculate the sampling error:

$$E = \sqrt{\left(\frac{0.795}{3.9} \times 100 \times 2\right)^2 + \left(\frac{1.387}{26.149} \times 100 \times 2\right)^2}$$

$$= \sqrt{40.769^2 + 10.608^2} = \sqrt{1,774.641}$$

$$= 42.1\%\ (95\%\ \textit{confidence level})$$

37.55 - Additional Population Characteristics.

$$Mean\ Diameter = \frac{\sum^{k}(DBH \times F_t)}{\sum^{k} F_t}$$

$$= \frac{1212.4}{104.321}$$

$$= 11.6\ inches$$

$$Quadratic\ Mean\ Diameter = \sqrt{\frac{\sum^{k}(DBH^2 \times F_t)}{\sum^{k} F_t}}$$

$$= \sqrt{\frac{14301.7}{104.321}} = 11.7\ inches$$

$$Mean\ Height = \frac{\sum^{k}(HT \times F_t)}{\sum^{k} F_t}$$

$$= \frac{6552.1}{104.321} = 62.8\ feet$$

37.56 - Application. Point sampling is an effective system to use in clear-cutting situations where large areas are to be cruised and where there is a range of tree sizes.

38 - COMBINING STRATA. Combining information from multiple strata is needed to calculate total statistics and quantities for the sale population.

38.1 - Combining Sampling Statistics. The purpose of combining sampling statistics is to combine the volumes and sampling errors of different stands or strata into a total volume and sampling error for the entire sale.

A timber sale is comprised of several strata, each having individual volume and variation. Sample each stratum separately, using the sampling technique that will best estimate those individual stratum characteristics. This is, in effect, stratifying the sale into strata of like characteristics, which can be combined to give an estimate of the total sale population.

Determine the total volume and the sampling error for each stratum using one of the sampling methods discussed earlier. Calculate the estimated total volume by summing the individual stratum volumes. Calculate the sampling error for the sale population using the following formula:

$$E_T = \frac{\sqrt{\sum^{n} (V \times E)^2}}{V_T}$$

Where:

E_T = Sampling error for the sale population in percent

V = Estimated total volume for the j^{th} stratum

E = Sampling error percent for the j^{th} stratum

n = Number of strata in sale

$$V_T = \textit{Estimated total volume for the sale} = \sum^{n} V$$

After expansion, the equation is:

$$E_T = \frac{\sqrt{(V_1E_1)^2 + (V_2E_2)^2 + \ldots\ldots\ldots + (V_nE_n)^2}}{V_1 + V_2 + \ldots\ldots\ldots + V_n}$$

Note: E_T will be smaller than the individual values of the sampling Errors (E) most of the time. The reason for this is, by combining the Individual samples, the overall sample size increases, which will decrease the overall sampling error. As the sample size, n, increases, the sample error, E, decreases, and as n approaches the population size (N), the sample error (E) approaches 0.

38.11 - Same Cruising Technique. Use the following example to calculate total error for two strata sampled using the same cruising technique (Sample tree, sec. 33).

1. Stratum 1:

   Total Volume (V_1) = 4663 ft^3

   % Sampling Error (E_1) = 20.4%

   V_1 x E_1 = 95125.2

2. Stratum 2:

   Total Volume (V_2) = 5111 ft^3

   % Sampling Error (E_2) = 23.1%

   V_2 x E_2 = 118064.1

Estimated Total Volume (V_T) = 4663 + 5111 = 9774

Substituting into the formula:

$$E_T = \frac{\sqrt{(95125.2)^2 + (118064.1)^2}}{9774}$$

$$= 15.5\%$$

Note: Only one error term can come from each stratum. If the stratum was substratified, then stratifications within each stratum must be combined to get a single estimate of total volume and error for that stratum before it can be combined with volumes and errors from other strata.

38.12 - Different Cruising Techniques, Two Strata. Use the following example to calculate total sampling error for two strata sampled using different tree cruising techniques. In the example, the first stratum was cruised using point sampling (sec. 35.4), and the second stratum was cruised using point-count/measure-plot sampling (sec. 37.5). For the two strata:

1. Stratum 1: (Point Sampling)

   V_1 = 37,820.9

   E_1 = 39.8%

   V_1 x E_1 = 1505271.82

2. Stratum 2: (Point-Count/Measure-Plot)

V_2 = 37,728.0

E_2 = 22.1%

V_2 x E_2 = 833788.8

Estimated Total Volume (V_T) = 37,820.9 + 37,728.0 = 75,548.9

Substituting into the formula:

$$E_T = \frac{\sqrt{(1505271.82)^2 + (833788.8)^2}}{75548.9} = 22.8\%$$

Note: When combining volumes (and sampling errors for these volumes), all volumes must be in the same units. Cubic foot volumes cannot be combined directly with board foot volumes. Likewise, the errors based on cubic foot volumes cannot be combined directly to errors based on board foot errors.

38.13 - Different Cruising Techniques, Three Strata. In the following example, three strata, using different cruising techniques, were sampled. The first stratum was sampled using sample tree; the second using point sampling; and the third using point count/measure plot. The following statistics illustrate the method of calculations.

1. Stratum 1. (Sample Tree)

   V_1 = 9774.0

   E_1 = 15.5%

   V_1 x E_1 = 151,497.0

2. Stratum 2. (Point)

   V_2 = 37,820.9

   E_2 = 39.8%

   V_2 x E_2 = 1,505,271.82

3. Stratum 3. (Point Count/Measure-Plot)

   V_3 = 37,728.0

   E_3 = 22.1%

   V_3 x E_3 = 833,788.8

Estimated Total Volume = 9744.0 + 37820.9 + 37728.0 = 85,292.9

$$E_T = \frac{\sqrt{(151,497.0)^2 + (1505271.2)^2 + (833,788.8)^2}}{85,292.9}$$

$$= 20.3\%$$

38.2 - Combining Additional Population Characteristics. Use the following formula for estimating mean diameters and height for the sale population:

$$Mean\ Diameter = \frac{\sum^{n} (DBH \times ET)}{\sum^{n} ET}$$

$$Quadratic\ Mean\ Diameter = \sqrt{\frac{\sum^{n} (DBH^2 \times ET)}{\sum^{n} ET}}$$

$$Mean\ Height = \frac{\sum^{n} (HT \times ET)}{\sum^{n} ET}$$

Where:

ET = Estimated total number of trees each sample tree represents for j^{th} stratum.

n = number of strata being combined

For plot based samples (Fixed Plot, Variable Plot)

$ET = F_t$ x number of acres

For tree based samples (Sample Tree, 3p)

$ET = F_t$

38.21 - Additional Characteristic, Two Strata. In the following example, two strata, using two different cruising techniques, were sampled. The first stratum was cruised using point sampling (sec. 35.4); the second stratum was cruised using point-count/measure-plot sampling (sec. 37.5). The following example illustrates calculation of the statistics:

1. Stratum 1. (Point)

$$Number\ of\ acres = 18$$

$$\sum^{n} F_t = 109.7$$

$$\sum^{n} (DBH \times ET) = \sum^{n} (DBH \times F_t \times acres) = 22{,}134.61$$

$$\sum^{n} (DBH^2 \times ET) = \sum^{n} (DBH^2 \times F_t \times acres) = 257{,}425.7$$

$$\sum^{n} (HT^2 \times ET) = \sum^{n} (HT \times F_t \times acres) = 120{,}644.8$$

$$\sum^{n} ET = \sum^{n} (F_t \times acres) = 1974.6$$

2. Stratum 2. (Sample Tree)

$$\sum^{n} F_t = 428.0$$

$$\sum^{n} (DBH \times ET) = \sum^{n} (DBH \times F_t) = 5117.5$$

$$\sum n(DBH \times ET) = \sum (DBH^2 \times F_t) = 63{,}298.5$$

$$\sum^{n} (HT \times ET) = \sum^{n} (HT \times F_t) = 27{,}379.5$$

$$\sum^{n} (ET) = \sum^{n} F_t = 428.0$$

$$Mean\ Diameter = \frac{(22134.61 + 5117.5)}{(1974.6) + (428.0)}$$

$$= 11.3\ inches$$

$$Quadratic\ Mean\ Diameters = \sqrt{\frac{(257425.7 + 63298.5)}{(1974.6) + (428.0)}}$$

$$= 11.6\ inches$$

$$Mean\ Height = \frac{(120644.8 + 27379.5)}{(1974.6) + (428.0)}$$

$$= 61.6\ feet$$

38.3 - Applications of Combined Statistics. Use combined statistics to determine the final sale characteristics after all strata in a sale have been cruised.

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FSH 2409.12 - TIMBER CRUISING HANDBOOK

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POSTING NOTICE. Amendments are numbered consecutively by Handbook number and calendar year. Post by document name. Place the Table of Contents in front of chapter 40. Retain this transmittal as the first page of this document. The last amendment to this Handbook was Amendment 2409.12-96-2 to FSH 2409.12,70.

Document Name	Superseded (Number of Pages)	New (Number of Pages)
2409.12,40 Contents	--	2

Digest:

2409.12,40 Contents - Revises codes and captions to agree with text changes in chapter 40 and creates the chapter table of contents as a separate document.

MIKE DOMBECK
Chief

FSH 2409.12 - TIMBER CRUISING HANDBOOK
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FOREST SERVICE HANDBOOK
Washington, D.C.

FSH 2409.12 - TIMBER CRUISING HANDBOOK

Amendment No. 2409.12-2000-2

Effective April 20, 2000

POSTING NOTICE. Amendments are numbered consecutively by Handbook number and calendar year. Post by document name. Remove entire document and replace with this amendment. Retain this transmittal as the first page of this document. The last amendment to this Handbook was Amendment 2409.12-2000-1 to FSH 2409.12,40 Contents.

This amendment supersedes Amendment 2409.12-93-1 to chapter 40.

Document Name	Superseded (Number of Pages)	New (Number of Pages)
40 thru 43.5	11	--
2409.12,40	--	14

Digest:

Makes minor editorial and grammatical corrections throughout chapter 40.

41.1 - Revises sampling error standards to provide for a sliding scale for sampling errors and to increase the estimated sale value for error standards.

42.6 - Clarifies direction on security data collection forms and data equipment.

43.5 - Revises the caption for section 43.5 from the former Check Cruise Information to the current Certifying Cruise information.

MIKE DOMBECK
Chief

FSH 2409.12 - TIMBER CRUISING HANDBOOK
WO AMENDMENT 2409.12-2000-2
EFFECTIVE 04/20/2000

CHAPTER 40 - CRUISE PLANNING, DATA RECORDING, AND CRUISE REPORTING

41 - CRUISE PLANNING. Prepare a cruise plan for each timber sale (FSM 2442.04 and 2442.2). At a minimum, the cruise plan must include:

1. A definition of the sample population(s).

2. The sampling method(s) and intensity for each population.

3. Product merchantability specifications for each population.

4. Sale area maps.

5. Silvicultural guides, when required.

41.1 - Sampling Error Standards.

1. Use sampling error standards when sales include the following products:

    a. Sawtimber;

    b. Pulp;

    c. Cedar products, such as shakes, posts, and rails split from trees; and

    d. Posts and poles, such as power and utility poles.

2. Do not apply sampling error standards when the products are:

    a. For administrative use;

    b. Non-convertible products;

    c. Cull decks;

    d. Non-commercial species;

    e. For personal use;

    f. Sold by the piece; and

    g. Biomass, such as hog fuel.

3. When sampling errors apply, advertise only those sales that meet the standards. The maximum sampling errors are at the 95 percent confidence level (two standard errors or t = 2 in the appropriate statistical formulas for relatively large sample sizes). Apply sampling errors at the sale level, the strata level, and value groups at the sale level.

4. For the purpose of design, estimate total sale value using the prices in effect when the field work for the cruise is initiated. Prior to initiation of field work for the cruise, establish value groups that reflect the appraisal groupings for each market area.

5. Use the following error standards for the indicated stand components:

a. Sale-as-a-Whole Volume Error Standard. The error standard for the sale-as-as-whole is dependent on the estimated value of the sale; the estimated value is the expected bid (ex. 01).

b. Stratum Volume Error Standard. The maximum sampling error for any one stratum is 50 percent for scaled sales, and 40 percent for tree measurement sales.

c. Value Group Error Standard. The sale level volume is estimated within plus or minus 40 percent for each value group (that is, the Transactional Evidence Appraisal group) comprising at least 10 percent of the total sale value.

The Regional Forester may establish other standards appropriate for specific salvage sale situations (sec. 04).

Check cruising is required for tree measurement sales in excess of 2,000 hundred cubic feet (CCF) or 1 million board feet (MMBF). Refer to section 61.3 for the check cruising process.

41.1 - Exhibit 01

Maximum Sampling Errors
(95 Percent Confidence Level)
for the Sale-as-a-Whole Volume Error Standard

Estimated Sale Value ($)	Scaled Sales (%)	Tree Measurement Sales (%)
> 5,000 ≤ 15,000	± 30	± 20
> 15,000 ≤ 35,000	± 30	± 19
> 35,000 ≤ 55,000	± 30	± 16
> 55,000 ≤ 75,000	± 30	± 14
> 75,000 ≤ 95,000	± 30	± 12
> 95,000	± 20	± 10

41.2 - Silvicultural Guides. Use the silvicultural prescription to determine the cutting methods. This prescription assists the cruise planner by identifying a stand treatment which can include information about the species to be removed, expected cutting methods, and leave basal area.

Consult with the responsible silviculturist to determine how to integrate the logging needs and conditions of the timber stand with the silvicultural prescription. Ensure that cruise instructions require all marking and cruising to be done within the prescription.

41.3 - Sampling Methods and Sampling Intensity. Use pre-cruise analysis (ch. 30) as the first step in determining cruise methods and sampling intensity. This analysis may use data obtained from one or more of the following sources:

1. Reconnaissance Cruise. Use a reconnaissance cruise of the proposed sale area to provide reliable data for designing a cruise. Randomly locate enough sample units over the proposed sale area to support reliable estimates of coefficients of variation for the possible cruising methods.

2. Compartment Examination. Use compartment data to determine approximate volume, coefficients of variation (CV), and species composition. Ensure that proper comparisons are made; for example, the CV derived from point sampling is not reflective of the CV of individual trees.

3. Comparison Cruises. Use data from an adjacent area to estimate statistics for a proposed sale if the stands are similar in form class, tree spacing, and size variation. Comparison of non-similar stands could result in under-sampling, or over-sampling. If under-sampled, a cruise would have to be redone.

41.31 - How To Use Pre-Cruise Data. To determine the most cost-effective cruise method(s), gather enough pre-cruise information to estimate the cost of each cruise method considered. Estimates may be based on the costs of the following:

1. Pre-cruise estimate of the CV for the variable of interest of the population to be sampled for each cruise system.

2. Pre-cruise volume and area estimates by stratum.

3. Desired sampling error percent.

4. Means of stratifying the sample.

5. Number of sampling units required (such as plots, points, and trees) by stratum.

6. Establishment (plots, points) and measurement of sampling unit (plots, points, and trees).

7. Acreage determination.

8. Tree marking (including paint) or other form of designation.

9. Data recording.

Use the calculations to compare the costs of different cruising methods to arrive at the method of least cost for the sale-as-a-whole and for each of the sampling strata within the sale.

41.32 - Supplemental Samples. In most sampling situations, design the cruise to sample all the species or identified populations for the sale.

1. In rare instances, a minor species or population for which no sample is selected may be recorded in the tally. Without a sample, an expanded volume for the species or population cannot be calculated.

To avoid such a situation, either combine the minor species or population with a larger species group or population or, if that approach is not feasible, make a sample tree of the first tree encountered of a minor species or population (this approach introduces a bias in the sampling but ensures the minor species or populations are included in the sale if no other valid samples are taken).

2. When the original cruise exceeds the desired sampling error and a small number of additional samples are needed to reduce the error to an acceptable level, calculate the total number of additional samples needed, locate and measure unbiased samples in the field, and add these data to the original cruise. Use this method one time only. If the error remains unacceptable, redesign and redo the entire cruise.

41.4 - Stratification of Cruises. Assess the potential benefits of stratification for reducing the overall sampling cost during the cruise design process. No single stratification method fits every situation. Stratified populations must have a valid number of samples to make the population estimates meaningful. Regional Foresters may supplement the direction in sections 41.4 through 41.46 with examples of stratification typical for the Region (sec. 04).

1. For area-based sampling, group the units by stands, timber types, site quality, or other characteristics that reflect a degree of similarity in the volume or value to be cut per acre.

2. For tree-based sampling, group the populations by tree species, size, or value.

3. Do not stratify homogeneous populations, very small jobs, or uniform cuts because this form of stratification does not improve precision and can have a small, negative effect on the confidence limit.

4. Stratify heterogeneous populations to provide more precise estimates of total sale volume or value for a given sample size. Maximize the differences between groupings; minimize the differences within groupings; and ensure that each group has an adequate number of samples. Properly stratified samples improve the estimate; provide a potentially smaller number of samples that meet accuracy standards; and provide a confidence estimate for the different components of a sale, such as for high- and low-value species.

5. Do not over-stratify. Too much stratification causes increased levels of sampling to meet the accuracy standard.

6. Do not post-stratify. Stratification after the field samples are taken does not permit optimum allocation of samples by strata and it introduces bias in the estimate.

41.41 - Timber Type. Consider use of timber type as the basic stratification identifier when both of the following criteria apply:

1. More than one timber type occurs in the cutting area, and

2. The largest differences in volume and value to be cut are accounted for by the difference between the types.

41.42 - Stand. Use stands as the basic stratification identifier when both of the following criteria apply:

1. More than one stand occurs in the area to be cut, and

2. Meaningful differences in volume and value occur between the stands.

41.43 - Payment or Cutting Unit. Use units or groups of units with similar treatments as the basic stratification identifier when all of the following criteria apply:

1. The timber sale is comprised of more than one cutting or payment unit,

2. Meaningful differences in volume, value, or variable of interest occur between the units or groups, and

3. Different marking intensities or sampling methods are used in the individual units or groups of units.

41.44 - Species. Use species as the basic stratification identifier when both of the following criteria apply:

1. More than one species is to be cut, and

2. Major differences in volume, value, defect characteristics, or other variables of interest occur between the species.

41.45 - Diameter. Consider diameter at breast height (DBH) class as a stratification identifier when all of the following criteria apply:

1. A large variation in diameters occurs,

2. Sample tree with complete tally (sec. 33) or 3P-sampling (sec. 36) will be used, and

3. Major differences in volume, value, and defect characteristics are accounted for by the diameter class.

When using diameter class to identify a population, do not change the estimated class of the tree if the DBH measurement is different from the estimate; the measurement of sample trees represents other trees in the class that are incorrectly estimated.

41.46 - Other Stratification Methods. Use any other method of stratification where efficiency and accuracy would be improved over the commonly used stratifications.

41.5 - Merchantability Specifications. In the cruise plan, specify:

1. Minimum tree size,

2. Product specification,

3. Tree diameter,

4. Number of product units,

5. Product length,

6. Diameter inside bark at the small end, and

7. Net scale as a percentage of gross.

Use specifications in effect for the area when completing the cruise plan.

Include utilization standards and timber designation requirements to complete the cruise plan (FSH 2409.15).

When pulpwood and substandard materials are to be cruised as part of the proposed sale, list instructions for measurement and recording of the material in the cruise plan. Use the Region’s merchantability requirements for cruising pulp logs and substandard material.

Include special instructions, such as counting or linear measurements for cruising special products, such as railroad ties, firewood, poles, posts, piling, shake bolts, and mine timbers. Length and strength are often more important for such material than the volume they contain. The cruise design must account for length, diameter limits, and allowable defect for the products specified in the cruise.

41.6 - Sale Work Maps. Include work maps and photographs necessary to execute the cruise. The plats of each cutting unit or other subdivisions must contain locations of lines, plots, or strips. Use cutting unit cards or similar documentation to summarize and record field information and instructions from the interdisciplinary team that completed the environmental analysis and the responsible official (line officer) who made the decision.

41.7 - Special Instructions. Include special instructions for cruising under hazardous conditions, volume estimators, painting requirements, and cruising stands with catastrophic damage.

1. Cruising Under Hazardous Conditions. When the pre-cruise survey shows that abnormal cruising conditions are present, the cruise plan should provide appropriate safety instructions, such as:

   a. Staying away from snag areas and broken, wind-damaged tree stands during windy or heavy snow-load periods.

   b. Wearing nonslip footwear while cruising heavy concentrations of blown-down timber.

   c. Maintaining radio contact when cruising in isolated and remote areas.

2. Volume Estimators. The cruise plan may specify the volume tables to be used on the cruise. Section 22 explains the functions of timber product volume estimators.

3. Painting Requirements. The cruise plan must include security requirements for the use of tracer paint or any special paint marker that may be used. See chapter 70 for tree marking details.

4. Cruising Stands With Catastrophic Damage. The Regional Forester shall provide instructions necessary to cruise stands that contain windthrown and broken trees from major windstorms, fire damage, insect epidemics, and flood damage.

41.8 - Quality and Value Determination. List in the cruise plan the tree and log grading guides to be used when cruising for quality and value on the proposed timber sale, especially in areas with higher-value softwood and hardwood sawtimber.

41.9 - Safety in Cruising. Hazards in cruising require all members of the crew to be safety minded at all times. Each crew leader shall have access to a copy of FSH 6709.11, Health and Safety Code Handbook, and shall provide training and information on safety practices for the cruising crew before and during cruising assignments.

Following are cross-references to subjects in the Health and Safety Code Handbook, FSH 6709.11, that pertain to individuals engaged in cruising projects:

Chapters	Subjects
Chapter 10 - Travel	• Travel safety for the cruising assignment
Chapter 20 - Work Projects and Activities	• Work in remote areas • Scaling while on training assignment • Scaling on mill decks • Scaling in mill yards • Timber sale administration, while training or working near logging operations • Tree felling and bucking
Chapter 40 - Equipment and Machinery	• Chopping tools and cutting tools

42 - DATA RECORDING.

42.1 - Standard Codes. Use codes in FSH 2409.14. The Regional Forester shall establish the codes for cruise items not listed in the referenced Handbook.

42.2 - Tree Tally Techniques. Select the tally method based on the method used for processing and summarizing the cruise data.

1. Use the "gate" notation () or lumber tally for tallying small numbers of trees. This method counts in units of five.

2. As the standard method for large tallies, use the dot-and-dash notation (), which counts in units of ten.

42.3 - Field Aids and Recording Equipment.

42.31 - Field Aids. Use the following field aids to promote accuracy and to make the work easier:

1. Species codes.

2. Tree codes.

3. Location codes.

4. Tree and log grading rules.

5. Percentage deduction tables.

6. Standard upper limit diameter outside bark (DOB) by species.

7. Limiting distance tables for point-sampling.

8. Stratification guides.

42.32 - Recording Equipment. Cruisers must be equipped with an electronic data recorder or a clipboard with a receptacle for storing cards.

Pencils with firm (F) grade lead are preferable, but hard black (HB) lead is also acceptable. Other grades are unacceptable: Grades 2H, 3H, or soft grades are difficult to erase cleanly; very hard leads produce especially poor results if the recording paper is damp.

Other equipment typically includes:

1. Compass.

2. Diameter tape.

3. 100-foot metal or cloth measuring tape.

4. Packsack or vest.

5. Ribbon and tree marking paint.

6. Angle gauge.

7. Height measuring instrument.

8. Pacing stick.

9. Marking pens.

10. Tally sheets.

11. Random sample selection device.

42.4 - Forms and Electronic Data Recorders.

42.41 - Forms. Use approved formats for recording in a consistent manner. Avoid recording on notebook sheets or other non-standard sheets for subsequent transcribing to standard tally forms. Subsequent transcribing is inefficient and may result in lost records or transcription errors.

Regions shall maintain consistent and approved formats for recording cruise data (FSM 2442.04). Avoid the use of local forms. Provide standard waterproof forms where cruising must be done under damp conditions. Forms should be printed in green ink on a white background for ease of reading.

42.42 - Electronic Data Recorders. Use electronic data recorders whenever possible. Regions must provide standard programs for data entry; local programs are not permitted.

42.5 - Other Recording Requirements. Cruisers must write numerals and letters legibly to avoid ambiguity when entering cruise data into a computer from source documents. Allow ample space for recording to enable instant, correct recognition by the data entry operator. Edit the data before leaving the plot or point and edit immediately after recording the data for a single tree in sample tree cruises.

42.6 - Data Security. Because timber sale valuation is based on the cruise, it is necessary that cruisers protect any collected data from inadvertent, or willful and fraudulent changes. Use any password or audit trail features available in the data collection software. Secure all completed data collection forms or data recorders in a locked environment to ensure access only by authorized personnel. Scan any paper forms and electronic data for indications of possible unauthorized changes.

43 - CRUISE REPORTING.

43.1 - Information to Report. Compute the information for the particular needs of the timber sale appropriate to the type of timber sale appraisal, prospectus, contract, and payment method. As needed, generate information such as estimates of live-cut volume and numbers of trees by species; cut volume sampling statistics; dead timber volume and trees; timber quality tabulations; unsound sapwood data; and various appraisal tables.

43.2 - Volume, Value, and Sampling Error Reporting. Cruisers may use either the National Cruise Program or the Regional computer programs established by the Regional Forester (FSM 2442.3) for calculating and reporting the results of timber cruises. Follow the procedures in chapter 30 to calculate timber cruise estimates.

Computer programs must accommodate data from all Regional cruising systems. Outputs must satisfy informational needs for preparing the appraisal, prospectus, and contract.

Provide the required volume and value estimates for developing the appraisal, prospectus, contract, and sum for the sale as a whole. Show the sampling error by timber sale component and for the sale as a whole.

Regions may supplement this section with descriptions of, and user instructions for, the selected timber cruise programs.

43.3 - Area Information. Acreage measurements, by total sale and any subdivision, should be as accurate as possible. The magnitude of the volume error is in direct proportion to the area error for area-based cruises. For example, if the error in area is 10 percent high, the volume estimate is also 10 percent high. Summarize point-sample and plot-sample data on a per acre basis, and expand by the number of acres in the tract.

Where a closed traverse is used, state the error of closure. See chapter 50 for detailed information on area determination. Include a statement of the method used to determine area in the timber sale file.

43.4 - Other Information. The cruise report may also include the following elements by payment or logging units:

1. Logging method.
2. Percent slope.
3. Method of cut.
4. Sawtimber weights by DBH (diameter at breast height) classes.
5. Chippable component weights (outside of sawlog portion of stem).
6. Sell-product volumes in terms of local log rules.
7. Sell-product volumes in cubic feet for each product.
8. Cut-basal area per acre.
9. Color of marking paint.
10. Environmentally important items not previously identified.

43.5 - Certifying Cruise Information. Include a copy of the cruise inspection summary (sec. 66) in the timber sale file, and provide a certification signed by the responsible official. The accompanying cruise inspection summary must show names of cruisers and other workers, date of certification, and date of last check. See exhibit 01 for an example of a cruise certification.

43.5 - Exhibit 01

Certification of Cruising Standards

CRUISE CERTIFICATION

I certify that the timber for the ___*Dry Creek*____ timber sale has been designated and cruised by the procedures and standards in FSH 2409.12, Timber Cruising Handbook. Records of checks are on file at the District Ranger office,

*Big Pine*_______ Ranger District	*Dry Lake, California*________ (name of headquarters town)
/s/ *John H. Smith* District Ranger	*1/20/2000* Date

43.6 - Disposition of Records. Dispose of records in accordance with direction in FSH 6209.11, Records Management Handbook.

FOREST SERVICE HANDBOOK
Washington, D.C.

FSH 2409.12 - TIMBER CRUISING HANDBOOK

Amendment No. 2409.12-2000-3

Effective April 20, 2000

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Document Name	Superseded (Number of Pages)	New (Number of Pages)
2409.12,50 Contents	--	2

Digest:

2409.12,50 Contents - Revises codes and captions to agree with text changes in chapter 50 and creates the chapter table of contents as a separate document.

MIKE DOMBECK
Chief

FSH 2409.12 - TIMBER CRUISING HANDBOOK
WO AMENDMENT 2409.12-2000-3
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CHAPTER 50 - AREA DETERMINATION

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Washington, D.C.

FSH 2409.12 - TIMBER CRUISING HANDBOOK

Amendment No. 2409.12-2000-4

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This amendment supersedes Amendment 2409.12-93-1 to chapter 50.

Document Name	Superseded (Number of Pages)	New (Number of Pages)
50 thru 54	7	--
2409.12,50	--	9

Digest:

Makes minor editorial and grammatical corrections throughout chapter 50.

52.2 - Revises standards for global positioning systems (GPS).

MIKE DOMBECK
Chief

FSH 2409.12 - TIMBER CRUISING HANDBOOK
WO AMENDMENT 2409.12-2000-4
EFFECTIVE 04/20/2000

CHAPTER 50 - AREA DETERMINATION

51 - REQUIREMENTS. An accurate determination of sale area is required to calculate sale volume in area-dependent sampling methods. Sale area-determination is also required for the timber sale appraisal, contract preparation, reporting and monitoring, and various post-sale activities. The following steps are required:

1. Determine the area by traverse when area is a factor in calculating the volume of timber to be sold.

Regional Foresters may approve exceptions, such as orthophotographic mapping, for sales or sale units involving large cut areas where volume may be accurately estimated using a different area-determination technique.

2. Document in the sale case file all acreage specifications and calculations used; also include a map of the area.

52 - TRAVERSE. Determine area by using traditional survey techniques for measuring distances and angles or use a global positioning system (GPS).

52.1 - Survey. Use instruments that meet accuracy standards to take bearings and distances of lines enclosing the areas of interest.

52.11 - Standards. Meet the following standards for each surveyed area:

1. Do not exceed a minimum error of closure ratio of:

   a. 1:50 for areas of 20 acres or less, or

   b. 1:100 for areas greater than 20 acres.

2. Adjust traverse acreages for any error of closure. Carry unit acreages to the nearest tenth of an acre before rounding so the project acreage is not biased.

3. Accept a traverse not meeting error of closure standards, only if it has one or more verification traverses where the difference in acreage between the original survey and the verification survey is ±10 percent. Use a different crew to run the verification traverse.

52.12 - Procedures. To begin a traverse, select a corner of the tract as a point of beginning and mark this point with a stake. Take backsights and foresights on each line and each compass station. Compute the interior angles. If bearings are properly read and recorded, the sum of all the interior angles is equal to $(n-2) \times 180°$, where n is the number of sides in the traverse.

Use computer programs and their data entry forms to close traverses and determine acreage from traverse survey data. Record foresights, backsights, and the allowable closure error necessary to produce a closed traverse. When computer programs are not available, use manual computation as a last resort. Exhibit 01 is an example of field notes.

52.12 - Exhibit 01

Example of Field Notes

FOREST Big	# 01	DISTRICT Small	# 01	BY N.O. Closure	DATE 4/1/92
AREA NAME AND/OR NUMBER Starvation Ridge, Unit 2					

Point Number	Units (leave blank for feet)	Slope Distance Enter "P" Horiz. Distance (leave blank)	Distance Ahead	Azmuth Ahead	Remarks and Field Notes
1			264	328	Start SW Corner
2			264	337	
3			132	346	
4			396	357	
5			132	9	
6			99	16	
7			330	89	
8			132	135	
9			264	102	
10			132	104	Big rock here
11			132	112	
12			132	178	
13			132	114	
14			132	180	Along the fence
15			132	211	
16			132	200	
17			132	195	
18			132	208	
19			132	215	
20			99	235	
21			445	265	Last shot this unit

52.2 - Global Positioning System. A global positioning system (GPS) utilizes signals transmitted from satellites to determine the coordinate location (x, y, z) of points on the ground. When these points are located on the perimeter of a closed traverse, they form a polygon whose area can be calculated.

52.21 - Global Positioning System Traverse Standards. The following standards apply to GPS traverses used for area-dependent timber sale cruises, appraisals, and contracts, and for various post-sale purposes:

1. Train all crew members using the GPS equipment for timber sale preparation to gain a basic understanding before actual use in collecting field data.

2. Differentially correct all position fixes to a reference/base station that is no farther than 500 kilometers (300 miles) away. Collect position fixes by the remote GPS receiver under the following conditions:

a. Position dilution of precision (PDOP) no greater than 6.

b. Minimum satellite elevation angle of 15°.

c. Minimum signal level of 6, or the manufacturer's recommended level for good signal quality.

d. 3-D manual mode.

3. Use the reference/base station of a third order (or better) NAD 83 datum position.

4. Collect position fixes while moving around the perimeter at a time interval that accurately defines the perimeter of the traverse. In general, use a 5-second interval for a walk file; however, if moving more rapidly, use a 1-second interval. Loss of position fixes (signal) is acceptable for a short duration while moving in a straight line; however, position fixes must be received while moving through all turning points in order to portray the true representation of the traverse.

5. Use only differentially corrected 3-D positions for area determination. Show position fixes lying one after another, in a relative sequential pattern, defining the perimeter of the traverse in a computer display or plot of the file. Allow only slight irregularities (jumping from side to side) of position fixes; if some of these are outliers and do not represent the traverse, delete them from the file. The employee who collects the data should review the computer display or large-scale plot of the data for the following:

a. Consistency of data collection; look for a smooth string of fixes.

b. Large spacing between points. Large spacing indicates loss of signal and the possibility of missing position fixes at critical turning points that define the traverse.

c. Polygon shape. The polygon should resemble the traverse walked in the field.

6. Calculate area using NAD 83 datum when the data collected meet the established standards outlined in the preceding paragraphs 1 to 5.

7. Re-collect the data if the established standards are not met. Data for a portion of a traverse, such as in the case of a large traverse, may be collected at different dates and times as long as collection occurs while moving in the same direction as the original traverse.

8. Keep the following information as part of the final record:

a. The corrected data file containing the differentially corrected position fixes in NAD 83 datum.

b. A plot of the traverse at 1:24,000 scale in the current NAD 27 datum (the agency's primary base series maps are displayed in the NAD 27 datum).

c. The date and name of the person who collected the data.

d. The name of the reference/base station used for the differential corrections.

e. The method (software) used for area calculation.

53 - AERIAL PHOTOGRAPHY AND MAPPING METHODS. Non-rectified aerial photographs (sec. 53.1), orthophotographs (sec. 53.2), and, in some cases, maps (sec. 53.3) may be used as a data source in determining the acreage of timber to be sold. Each of these methods has different characteristics that affect how and when each is used and the accuracy of results. Use these methods only with cruising systems (ch. 30) that are not dependent on area in determining the volume to be sold (for example, sample tree with complete tally (sec. 33), because they are less accurate than traversing.

53.1 - Non-Rectified Aerial Photographs. When using aerial photographs that have not been dimensionally corrected for flight anomalies (non-rectified), confine mapping for area estimate purposes to the affected area of the photograph to avoid distortion errors. Use terrain features and vegetational characteristics that are sufficiently recognizable on the photograph to permit accurate location of the area boundary. Follow up with ground measurements to verify photographic scale.

53.2 - Orthophotographic Maps. Orthophotographic maps combine the utility of aerial photographs and topographic maps on a single map sheet (although at a small scale), and can be rectified. They are free of the anomalies of scale caused by distortion and elevational differences. They also may have contour lines superimposed on the imagery, producing a three-dimensional visual effect on the flat surface, which lessens the need for stereoscopy and increases usefulness in field situations.

53.3 - Topographic and Planimetric Maps. Maps may be useful in determining acreage when the area to be harvested is large and the boundaries coincide with accurately mapped physical features, such as sharp ridges, roads, or surveyed lines. However, the use of maps for accurately determining boundaries of areas entails considerable guesswork. Maps lack the advantages of aerial photographs due to the absence of imagery. The map scale is usually too small to accurately locate boundaries. Maps have limited suitability for determining the acreage of timber to be sold.

53.4 - Determining Area. Use a dot grid (sec. 53.41), mechanical planimeter (sec. 43.42), or digital or computing planimeter (sec. 53.43), to determine area when non-rectified aerial photographs or maps are used as a base.

53.41 - Dot Grid. Normally, use a dot grid to approximate areas on vertical aerial photographs and maps.

Use this technique if the terrain is mostly level and photographic scales are accurate. In regions of rough topography, however, make area measurements on maps rather than directly on photographic prints. Do not use a dot grid when the volume determination depends on area.

Create a dot grid by placing a piece of clear tracing material over a sheet of graph paper and punching pin holes at all grid intersections. Dot grid and graphical methods of area determination are based on the same principle. Dots representing squares (or rectangular areas) are counted in lieu of the squares themselves. The principal advantage of dots over graphed squares is that the ambiguity of counting fractional squares along tract boundaries is eliminated; whether the dot is in or out determines if the square is tallied.

Estimate the area by counting the number of dots falling within the boundary and multiplying by the proper conversion factor to determine the total acreage.

To correctly use a dot grid:

1. Drop the grid on the area so that it assumes a random position.

2. Take a dot count of whatever the grid orientation happens to be.

3. Count only every other dot that occurs on a boundary line of the area.

4. Take three independent counts and use the average of the three counts.

53.42 - Mechanical Planimeter. Using the mechanical planimeter is simpler and more accurate than using the dot grid method. Use a planimeter for accurately measuring areas of any form. Read the area directly from the measuring wheel and dial by moving the tracer pin or lens around the periphery of the figure.

Mechanical planimeters come with fixed or adjustable arms.

1. Planimeters with fixed arms require no setting adjustment, are easy to operate, and measure areas with accuracy and speed. Although they measure areas only in square inches or square centimeters, they may be used on drawings or maps to any scale. They measure the area in the desired unit (square feet, acres, and so on) by multiplying the result by a factor.

2. Planimeters with adjustable arms offer direct readings of various parameters for a larger variety of ratios than the fixed arm instrument.

To operate the planimeter, move the pointer of the instrument in a clockwise direction around the boundaries of the figure being traced. Trace the perimeter two or three times and use an average reading. Convert the average to the desired units on the basis of the map scale.

53.43 - Digital and Computing Planimeters (Electronic Acreage Counters). This equipment determines acreage and has a digital display and paper printout of area and distance measurements.

1. Digital planimeters have the elements of mechanical planimeters but include electrical features with the following benefits:

a. Greater accuracy by reducing mistakes that are common with conventional equipment.

b. Time savings from the instant readout display and cumulative measuring feature.

2. Computing planimeters provide all the benefits of the digital planimeters and include features such as:

a. Instant digital readout and printouts of automatically computed results.

b. Label printouts for identification.

c. Full processing of results through the calculator without loss of the measuring constant.

d. Conversion of results into other length units.

e. Cumulated and stored results for later processing.

54 - ADDITIONAL EQUIPMENT. Utilize additional equipment as it becomes available and affordable, such as data recorders (sec. 54.1) and laser measuring devices (sec. 54.2).

54.1 - Data Recorders. Some data recorders may have software to record distance and bearings, and they can compute the area immediately in the field or later in the office.

54.2 - Laser Measuring Devices. Laser measuring devices with integral compasses are useful for traverse surveys because they are fast and accurate. Laser technology is best used in conjunction with a global positioning system (GPS) (sec. 52.2), by using GPS to locate one point and using the laser traverse to determine the area. To do this, locate the first survey point or other identifiable boundary point on the survey with GPS; then locate the traversed area on the base map using the GPS coordinates.

FOREST SERVICE HANDBOOK
Washington, D.C.

FSH 2409.12 - TIMBER CRUISING HANDBOOK

Amendment No. 2409.12-2000-5

Effective April 20, 2000

POSTING NOTICE. Amendments are numbered consecutively by Handbook number and calendar year. Post by document name. Place the Table of Contents in front of chapter 60. Retain this transmittal as the first page of this document. The last amendment to this Handbook was Amendment 2409.12-2000-4 to FSH 2409.12,50.

Document Name	Superseded (Number of Pages)	New (Number of Pages)
2409.12,60 Contents	--	2

Digest:

2409.12,60 Contents - Revises codes and captions to agree with text changes in chapter 60 and creates the chapter table of contents as a separate document.

MIKE DOMBECK
Chief

FSH 2409.12 - TIMBER CRUISING HANDBOOK
WO AMENDMENT 2409.12-2000-5
EFFECTIVE 04/20/2000

CHAPTER 60 - QUALITY CONTROL

Contents

60.2 Objective
60.4 Responsibility

61 CRUISER TRAINING AND CERTIFICATION STANDARDS
61.1 Qualified Cruiser
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61.3 Check Cruiser
61.4 Master Cruiser
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62 INSPECTING INDIVIDUAL CRUISER PERFORMANCE
62.1 Qualified Cruiser
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62.4 Cruiser Inspection Frequency

63 INSPECTING SALES
63.1 Inspection Elements
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63.2 Sale Inspection Frequency
63.3 Certification of Sale

FOREST SERVICE HANDBOOK
Washington, D.C.

FSH 2409.12 - TIMBER CRUISING HANDBOOK

Amendment No. 2409.12-2000-6

Effective April 20, 2000

POSTING NOTICE. Amendments are numbered consecutively by Handbook number and calendar year. Post by document name. Remove entire document and replace with this amendment. Retain this transmittal as the first page of this document. The last amendment to this Handbook was Amendment 2409.12-2000-5 to FSH 2409.12,60 Contents.

This amendment supersedes Amendment 2409.12-93-1 to chapter 60.

Document Name	Superseded (Number of Pages)	New (Number of Pages)
60 thru 66.1	10	--
2409.12,60	--	14

Digest:

This amendment extensively revises the entire chapter 60 to establish check cruising standards. This amendment also recodes and reorganizes direction and makes minor editorial and formatting changes throughout the chapter.

60.4 - Adds a responsibility section incorporating direction formerly in section 61.

61 - Sets up qualified cruiser and advanced cruiser as separate levels of cruiser competency, instead of production cruiser sublevels of certification.

61.3 - Adds requirements for check cruisers to maintain an active field check cruising program and retain sufficient records to verify cruiser certification levels and competency. Requires that check cruise results must be filed in the sale folder (FSH 6209.11).

61.4 - Eliminates the previous requirement for master cruisers to have all the skills required of check cruisers.

Digest--Continued:

61.5 - Provides for check cruiser and master cruiser certification as indefinite, provided there is evidence that the cruiser's performance continues at a satisfactory level. (1) For all levels of cruisers, sets minimum requirements for refresher training before a cruiser may resume cruising, if inactive for a period of more than one year, and (2) Continuing education requirements. Loss of check cruiser certification may occur based on unsatisfactory performance.

62 - Sets out evaluation and documentation requirements for inspections, as well as actions necessary in the event of unsatisfactory work.

62.1 - Requires the use of a field measurement evaluation for qualified cruisers and sets out a sample evaluation format in exhibit 01.

62.2 - Eliminates the previous requirement for inspections of an advanced cruiser to be performed by a certified check or master cruiser. Provides an exhibit of a checklist of elements to be used by an advanced cruiser in designing cruises, in addition to the scorecard required for qualified cruisers.

62.3 - Adds requirements for inspection of check cruisers.

62.4 - Sets the minimum frequency for cruiser inspections.

63 - Requires sale inspections to evaluate cruising procedures and sales volume determinations, and provides a sample check sheet and evaluation report format.

MIKE DOMBECK
Chief

FSH 2409.12 - TIMBER CRUISING HANDBOOK
WO AMENDMENT 2409.12-2000-6
EFFECTIVE 04/20/2000

CHAPTER 60 - QUALITY CONTROL

60.2 - Objective. To ensure accurate, objective, and uniform measurement and estimates of product volume and value of National Forest System timber through quality control that includes:

1. Cruiser training and certification.

2. Inspection of cruiser performance.

3. Inspection of timber sale cruises.

60.4 - Responsibility. (FSM 2442.04). Cruise assistants may be used to help in the collection of cruise data. Assistants must complete appropriate training and must be capable of operating necessary measurement equipment. They must be personally supervised on-site by a certified cruiser when collecting data. The certified cruiser in charge remains accountable for the accuracy of work done by assistants.

The Forest Supervisor certifies qualified, advanced, and check cruisers (FSM 2442.04b).

61 - CRUISER TRAINING AND CERTIFICATION STANDARDS. This section specifies the minimum levels of experience, technical knowledge, and field ability a cruiser must have to be certified. The Regional Forester has overall responsibility for the quality control program for cruising in the Region (FSM 2442.04a).

Minimum national standards provide for four levels of cruiser competency: qualified cruiser (sec. 61.1), advanced cruiser (sec. 61.2), check cruiser (sec. 61.3), and master cruiser (sec. 61.4).

Standards and requirements for each of the certification levels are specified in the following sections 61.1 to 61.4.

61.1 - Qualified Cruiser. A qualified cruiser is responsible for applying a variety of volume determination techniques. Working alone, as a crew member, or as a crew leader, a qualified cruiser must ensure all necessary field work is completed in compliance with cruise plan instructions. This includes, but is not limited to, preparation of data for computer compilation.

The knowledge and training requirements for qualified cruiser certification are:

1. Proficiency in timber cruising fundamentals, including as a minimum:

   a. Tree measurement (diameters and heights).

   b. Species identification.

   c. Defect recognition and determination.

   d. Quality determination.

   e. Use of timber cruising tools.

   f. Map reading and compass use.

   g. Traverses.

   h. Elementary use of aerial photography.

2. A working knowledge of the cruise systems (ch. 30) expected to be used.

3. Demonstrated ability to interpret and follow the timber cruise plan and cruise data recording instructions.

4. Passing scores on both a Regionally approved written test and a Regionally approved field test conducted on prepared certification test areas. Topics tested shall include species, measurements, defects, and grading information representative of what the cruiser normally encounters.

61.2 - Advanced Cruiser. An advanced cruiser is fully qualified to perform measurements, train prospective cruisers, conduct all types of timber cruises, and design and implement cruises. Experience, technical interest, training ability, and initiative characterize this classification.

The knowledge and training requirements for advanced cruiser certification are:

1. Documented experience as a qualified cruiser.

2. Training in cruise design, sampling theory, sale preparation, data collection, and cruise processing.

3. Passing score on a Regionally approved written examination. Topics tested shall include elementary statistics, sampling design, and impacts of biased and/or imprecise data on the measurements.

61.3 - Check Cruiser. A check cruiser is responsible for check cruising, cruiser training, and conducting evaluations to recommend certification of qualified and advanced cruisers. The check cruiser must maintain an active field check cruising program and retain records sufficient to verify cruiser certification levels and competency; check cruise results must be filed in the sale folder (FSH 6209.11). Check cruisers inspect timber sale cruises and recommend acceptance or identify necessary corrective actions. In addition, with the assistance of a master cruiser, the check cruiser establishes Forest certification test areas as needed.

The knowledge and training requirements for a check cruiser are:

1. Must be currently certified as an advanced cruiser and have at least two years of experience as an advanced cruiser.

2. Must be thoroughly familiar with all aspects of timber cruising, including cruise design, sampling theory and systems, statistical analysis, log and tree grading, defects, and use of cruising tools.

3. Must demonstrate training and leadership ability and be capable of setting up continuing training, certification testing, and check cruising programs.

61.4 - Master Cruiser. The level of master cruiser is certified by the Regional Forester. The master cruiser serves as the Regional representative for cruising and coordinates the Regional quality control program. This assigned responsibility is based on demonstrated ability in all aspects of cruising and varying timber sale situations common to the Region.

61.5 - Maintenance of Certification. Certification of all levels of cruisers is indefinite, provided there is evidence (sec. 62) that the cruiser's performance continues at a satisfactory level.

1. If the cruiser has been inactive for a period of more than one year, refresher training is required prior to resuming cruising. This should include, as a minimum, a session in fundamentals, together with field measurement of a sufficient number of plots and trees to update skills.

2. All levels of cruisers, whether inactive or active, must attend formal training or workshops intended to update their skills at least once every four years to maintain knowledge appropriate to the level of certification.

3. Check cruisers may recommend loss of a cruiser's certification to the certifying official based on unsatisfactory performance.

62 - INSPECTING INDIVIDUAL CRUISER PERFORMANCE. Inspection of the cruiser's performance includes all components of the timber cruise relevant to the level of certification. Cruiser performance is evaluated from office checks and field measurement checks of the sale. Evaluate and document physical measurements on a timely and continuing basis as each sale check is made; results shall also be reviewed on an annual basis. In the event of unsatisfactory work, take immediate corrective action such as retraining. Continued unsatisfactory performance shall result in loss of certification. Check cruisers shall maintain a historical record of office and field measurement checks identified by each cruiser.

62.1 - Qualified Cruiser. The performance check of a qualified cruiser's work must:

1. Assess compliance with the cruise plan instructions.

2. Validate the field work by conducting a check cruise that includes:

   a. Accuracy of tree measurements and species identification.

   b. Accuracy and lack of bias in sample selection.

   c. Defect estimates.

   b. Tree and log grading (quality or product identification).

   e. Area determination measurements.

   f. Tree counts for plots on area-based samples.

   g. Quality of timber designation.

   h. Sample (tree/plot/point) identification.

   i. Locally required items.

3. Assess data recording for legibility and accuracy, including timber measurement and area-determination data.

4. Review the care and use of cruising tools.

5. Verify use of appropriate volume and product estimators.

6. Assess knowledge and correct use of marking paint and paint security measures.

7. Use a scorecard for evaluating individual performance on field measurements. The Regional Foresters shall establish:

   a. The items to be checked;

   b. Tolerances;

   c. Error weights; and

   d. Acceptable scores with format similar to that shown in exhibit 01.

Assess the cruiser's measurements and judgments by comparative analysis of check cruise data versus original data.

62.1 - Exhibit 01

Sample Format for Field Measurement Evaluation

Check Cruise Elements	Tolerance	Total Possible Correct Answers	Number of Incorrect Answers	Error Weight	Total Error (bxc)	Percent Correct (1-(d/a))x100
		(a)	(b)	(c)	(d)	(e)
In/out trees	none	123	3	5	15	88
Species	none	123	1	5	5	96
DBH	± 0.2 in.	123	2	1	2	98
Height	± 4 ft.	123	3	1	3	97
Defect	± 10%	123	5	1	5	96
Region Item 1						
Region Item 2						
						Overall Percent Correct

Overall Percent Correct = Total of (e) ÷ number of items about which information is checked.

Note: To pass this check, each item checked must have at least 80 percent correct and the overall accuracy must be at least 85 percent.

The "Total Possible Correct Answers" (a) is the number of trees measured by the check cruiser. For plot or point cruises, the "Total Possible Correct Answers" of "in/out trees" is the number of trees identified by the check cruiser; for all other elements, it is the number of correctly identified in/out trees.

Recommendation:

____

Measurements ok at 95%, passed check__________________________________

____

____

____

____

____

____

Tom Short (Certified Check Cruiser) *Jan. 1, 2000*____________
Signature Date

62.2 - Advanced Cruiser. When an advanced cruiser is designing cruises, check the cruise design and other applicable elements from section 63.1, exhibit 01. For production cruising, check the field cruising procedures as listed under qualified cruiser (sec. 62.1).

62.3 - Check Cruiser. Each check cruiser shall be periodically reviewed by an authorized official at a higher administrative level. Evaluate the check cruiser on the basis of the following items:

1. Maintenance of training records for qualified and advanced cruisers.

2. Maintenance of cruiser roster and individual performance checks.

3. Comprehensive sale inspections.

4. All inspection items listed for the performance check of the advanced cruiser if the check cruiser is also designing sales or production cruising.

Check cruisers need not be checked on a fixed schedule unless they are working as qualified cruisers. If this is the case, check cruises should be performed by a check cruiser from another administrative unit.

62.4 - Cruiser Inspection Frequency. Review qualified or advanced cruiser records for the past year to ensure the following minimum of work checked: 5 plots for plot-based cruises, 25 trees for tree-based cruises, or an equivalent combination of trees and plots for a combination of cruising methods. These annual minimums should be used when checking measurement technique and sample application for an individual, and they constitute a qualified check cruise. The minimum number of plots or trees need not be from a single sale, but can be from several sales. When the minimum has not been checked, either schedule the individual for a check, or consider the cruiser as inactive. Inactive cruisers must demonstrate proficiency prior to resuming production cruising.

63 - INSPECTING SALES. Conduct sale inspections to evaluate cruising procedures and sale volume determination. Sale inspections also serve to monitor cruiser performance. Indicate when results of a sale inspection are unsatisfactory and recommend corrective action needed to make the cruise acceptable. Inspections shall not be used to adjust sale volumes, but to indicate potential problems that need further investigation. Problems identified in the check cruise must be addressed and the resolution documented in the sale folder.

Regional Foresters shall establish the methods and standards for what constitutes an acceptable or satisfactory evaluation.

63.1 - Inspection Elements. Cruises should be systematically reviewed for completeness. Exhibit 01 includes a list of office and field components that should be examined as appropriate; the list also includes cross-references to the sections or chapters in this Handbook and other Handbooks containing related direction. Use this list to develop a unit checklist similar to the sample shown in exhibit 02 that can be initialed, dated, and filed in the sale folder after the inspection has been completed.

63.1 - Exhibit 01

Timber Sale Preparation and Check-Cruise Elements

Element (Cross-References Are to FSH 2409.12 or Other Directives)

A. CRUISE DESIGN PLAN
   1. Harvest Guidelines
      a. Stand Marking Guide (sec. 41)
      b. Minimum Product Merchantability Specifications (sec. 41)

   2. Sample Method Analysis
      a. Population Stratification Identification (sec. 31.5, 41.4)
      b. Precruise Documentation (sec. 41.31)
      c. Sampling Intensity and Allocation Documentation (sec. 33.2, 34.3, 35.3, 36.3)
      d. Sample Error Standards (sec. 41.1)

   3. Sampling Controls
      a. Sample Tree/Plot Distribution and Location (sec. 33.11, 34.21, 35.21)
      b. Plot Monumentation (sec. 34.21, 35.21)
      c. Cruise Trees Numbered (sec. 33.11, 34.21, 35.21)
      d. Supplemental Samples (sec. 41.32)
      e. Limiting Distance/Mirage Method (Plot Edge Effect) (sec. 35.22)
      f. 3P KPI Estimates and Random Number List (sec. 36.2)

B. TREE VOLUME DETERMINATION
   1. Volume Estimators (sec. 22)
   2. Form Class (sec. 14.3)
   3. Visible Defect Deduction Instructions (sec. 22.3, 22.31a-d)
   4. Hidden Defect and Breakage Instructions (sec. 22.31e)
   5. Tree Height Instructions (sec. 14.2)
   6. Special Measurement Techniques (ch. 10)

C. TIMBER DESIGNATION AND PRODUCT ACCOUNTABILITY
   1. Unit Boundary Instructions/Applications (sec. 71.22, 71.4)
   2. Tree Designation Instructions/Applications (sec. 71.3, 72.2)
   3. Tracer Paint Testing and Security (sec. 72.11, 72.12, 72.6)

D. TREE VALUE DETERMINATION
   1. Approved Log/Tree Grade Instructions

E. AREA DETERMINATION
   1. Traverse Notes Security (sec. 50)
   2. Traverse Maps Available (sec. 50)
   3. Area Determination Standards (sec. 50)
   4. First Station Marked with Stake (sec. 52.12)

63.1 - Exhibit 01--Continued

F. FINAL CRUISE PRINTOUT AUDIT
1. Sample Error Standards Met (sec. 41.1)
2. Validation of Cruise Data and Reports (sec. 65, 66)

G. SALE AREA MAP
1. Unit and Road Locations (FSH 2409.18, sec. 53.24, 54.2)
2. Unit Designation (CC, ITM, LTM) (Timber Sale Contract Provision B&C Sale Area Map)

H. SAFETY CONSIDERATIONS
1. Tailgate Safety Meetings Prior to Cruising (FSH 6709.11, Health and Safety Code Handbook, sec. 04.2, 05, and 22.4)
2. Local Safety Issues (for example, paint safety films)

I. CRUISED BY CERTIFIED CRUISERS (FSM 2442.03)

J. TIMBER SALE MEASUREMENTS EVALUATION (sec. 41.1)

K. JUSTIFICATION DOCUMENTATION FOR NOT SELLING TREE MEASUREMENT TIMBER SALES (TMS)

L. CERTIFICATION OF CRUISE STANDARDS DOCUMENTED AND SIGNED (sec. 43.5)

M. DOCUMENTATION OF CRUISE PLAN CHANGES

63.1 - Exhibit 02

Timber Sale Evaluation Report

TIMBER SALE CRUISE EVALUATION REPORT - PAGE 1						
FOREST: *My Forest*	CHECK CRUISER: *Joe*					
DISTRICT: *My District*	DATE INSPECTED: *Jan. 1, 2000*					
SALE NAME: *My Sale*	CRUISE METHOD(S): *Sample Tree*					
TYPE OF SALE: SCALE		TMS |x|	DATE CRUISED: *Nov. 5, 1999*					
SALE PREPARATION ELEMENTS	OFFICE-FIELD	O	F	SATIS	UNSAT	NA
A. CRUISE DESIGN PLAN						
1. Harvest Guidelines						
a. Stand marking guide				X		
b. Minimum product merchantability specifications				X		
2. Sample Method Analysis						
a. Population stratification identification				X		
b. Precruise sample documentation				X		
b. Precruise sample documentation				X		
c. Sampling intensity and allocation documentation				X		
d. Cost analysis of cruise methods				X		
e. Sample error standards				X		
3. Sample Controls						
a. Sample tree/plot distribution and location				X		
b. Plot monumentation				X		
c. Cruise trees numbered				X		
d. Supplemental samples						X
e. Plot/point edge effect (Mirage Method)						X
f. Guide for KPI estimates						X
B. TREE VOLUME DETERMINATION						
1. Volume Estimators				X		
2. Form Class				X		
3. Visible Defect Deduction Instructions				X		
4. Hidden Defect and Breakage Instructions				X		
5. Tree Height Instructions				X		
6. Special Measurement Techniques						X
C. TIMBER DESIGNATION AND PRODUCT ACCOUNTABILITY						
1. Unit Boundary				X		
2. Quality of Tree Designation				X		
3. Tracer Paint Analysis				X		
4. Documentation for Sale Modifications				X		
D. TREE VALUE DETERMINATION						
1. Approved Log/Tree Grade Instructions				X		
E. AREA DETERMINATION						
1. Traverse Notes Available/Secure				X		
2. Traverse Maps Available				X		
3. Error of Closure (N/A for GPS)				X		
4. First Station Marked with Stake				X		
5. Traverse Boundary follows Posted Unit Boundary				X		
F. FINAL CRUISE PRINTOUT AUDIT						
1. Data Recorded Accurately				X		
2. Sample Error Standards met				X		
3. Validate Volume Reports				X		
4. Validate Species				X		

63.1 - Exhibit 02--Continued

TIMBER SALE CRUISE EVALUATION REPORT - PAGE 2

SALE PREPARATION ELEMENTS OFFICE-FIELD	O	F	SATIS	UNSAT	NA
G. SALE AREA MAP					
1. Unit Locations			X		
2. Road Locations			X		
3. Unit designation (CC, ITM, LTM)			X		
H. SAFETY CONSIDERATIONS					
1. Local Safety Issues (for example, Paint Safety Films)			X		
2. Tailgate Safety Meeting Prior to Cruising			X		
I. CRUISED BY CERTIFIED CRUISERS			X		
J. TIMBER SALE CHECK CRUISE					
1. Met Gross Volume Standards					X
2. Met Net Volume Standards			X		
3. Met Value Standards					X
4. Met Field Measurement Evaluation Standards			X		
K. CERTIFICATION OF CRUISE STANDARDS DOCUMENTED AND SIGNED			X		
L. DOCUMENTATION OF CRUISE PLAN CHANGES/ACCOMPLISHMENTS			X		

Following are: comments on the performance or unsatisfactory work under the above cruise plan elements. Make reference in Item No. below for the element listed above.

Item No.	Description

63.11 - Check Cruise Field Measurement Inspection. Measurement checks should be designed to obtain a representative sample of the original number of sample units and not to concentrate on individual cruisers. The sample should be dispersed throughout the cutting units in the sale area to determine if all significant variables, including measurement problems, species, larger trees, or defect, have been identified. Consider the amount of time required to conduct a check cruise, and vary requirements depending on the sampling system being used, the number of cruisers, and the complexity of the particular sale being checked.

On a sale check, 25 to 150 trees may need to be checked, depending on the number of cruise methods used and other factors. Take a reasonable, quantitative sample of all conditions.

Compare the measurements and results against the original cruise data to determine accuracy.

If fundamental errors are noted on an individual cruiser's measurements during a sale check, such as incorrect species identification or missing trees on plots, all of the individual's work on the sale may need to be examined.

63.12 - Other Elements. When data are being entered from handwritten cruise cards, make a 10 percent minimum spot comparison between the computer output and the information on the cards. If errors are found, perform a 100 percent audit.

Check the management of data recorded by the cruiser. The cruiser should follow a system designed to prevent loss of recorded data; for example, each day's data should be stored in the timber sale file. Electronic field data recorder files should be deleted only after the data manager has ensured that all data have been successfully transferred to the personal computer.

63.2 - Sale Inspection Frequency. As a minimum, conduct sale cruise inspections at the following target frequencies. Perform office checks on all sales. Office checks ensure that the cruise was performed according to direction in this Handbook. Perform field measurement checks with the following frequencies and use a random draw to determine each sale in the sample to be checked:

Sale Size	Scaled Sales	Tree Measurement Sales
> $10,000 and ≦ 2000 CCF	Not applicable	1:10 (10 %)
≧ 2000 CCF	1:4 (25 %)	1:1 (100 %)

63.3 - Certification of Sale. Each sale cruise must be certified by the District Ranger or Forest Supervisor (see the sample certification in sec. 43.5). Do not advertise a timber sale for bid if the cruise inspection indicates that the timber sale does not meet sampling error standards (sec. 41.1).

FOREST SERVICE HANDBOOK
WASHINGTON

FSH 2409.12 - TIMBER CRUISING HANDBOOK

Amendment No. 2409.12-96-1

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Document Name	Superseded (Number of Pages)	New
2409.12,70 Contents	-	2

Digest:

70 Contents - Revises codes and captions to agree with text changes in chapter 70.

JACK WARD THOMAS
Chief

FSH 2409.12 - TIMBER CRUISING HANDBOOK
WO AMENDMENT 2409.12-96-1
EFFECTIVE 9/18/96

CHAPTER 70 - DESIGNATING TIMBER FOR CUTTING

Contents

71 TIMBER MARKING
71.1 Marking Timber in Advance of Sale
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71.21 Marking With Paint
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71.3 Checking Timber Marking Quality
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72 TRESPASS PREVENTION
72.1 Tracers
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FOREST SERVICE HANDBOOK
WASHINGTON

FSH 2409.12 - TIMBER CRUISING HANDBOOK

Amendment No. 2409.12-96-2

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Document Name	Superseded (Number of Pages)	New
70 thru 72.2	4	-
2409.12,70	-	8

Digest:

72.12 - Changes caption. Revises standards for providing security of tracer paint. Establishes responsibility for District Ranger to designate a property custodian and accountable property officer for tracer paint. Establishes auditing and reporting requirements for inventory and use of tracer paint.

72.13 - Adds new caption and provides guidelines for purchase of tracer paint. Changes contact for assistance from Missoula to San Dimas Technology and Development Center.

72.14 - Adds new caption and provides guidelines for use of tracer paint.

JACK WARD THOMAS
Chief

FSH 2409.12 - TIMBER CRUISING HANDBOOK
WO AMENDMENT 2409.12-96-2
EFFECTIVE 9/18/96

CHAPTER 70 - DESIGNATING TIMBER FOR CUTTING

71 - TIMBER MARKING. Designate timber for cutting only within the sale area boundary unless the contract also includes timber outside the boundary to be cur in clearing for roads or other improvements.

Use only tree marking paint containing registered tracers(s) in designating any National Forest tree for removal, measurement, tallying, scaling, and so forth, and in designating the area where these activities will take place.

Regions shall provide guides to achieve quality standards for designating timber, including control methods and measures (FSM 2441).

71.1 - Marking Timber in Advance of Sale. Mark or designate all timber to be cut prior to sale. This permits the prospective bidder to determine the volume and quality of the offered timber. Long-term sales, salvage sales, or cutting to control active insect infestations may necessitate exceptions.

Complete the marking of unit planned for cutting within a rate redetermination period, before establishing rates.

71.2 - Marking Guides. Ensure that written guides have been prepared which will achieve the silvicultural objectives (FSM 2441.03). If established marking guides are not available, develop detailed guides for marking units. These guides shall include:

1. Desired residual stocking

2. Selection criteria for cut and leave trees.

3. Boundaries.

4. Special trees.

5. Paint colors to use for each purpose.

71.21 - Marking With Paint. The primary methods for designating timber to be cut include marking with paint containing registered tracer(s) the trees to be cut or to be left, and marking the boundaries around the area in which the cutting will take place.

Know the planned timber sale contract requirement and the marking plan. Mark or designate timber for cutting in accordance with the plan. Use a paint mark at or above eye level and another below stump height for each cut tree, leave tree, or boundary tree to be marked.

71.22 - Marking Boundaries. Use paper or plastic signs, as needed, to identify the cutting units. payment units, and sale area boundaries in addition to painted or other boundary identifications. Boundaries may be unmarked if natural or man-made features are so conspicuous that they can be identified from the sale area map alone and if doing so would not cause mistakes to be made when the trees are cut.

71.3 - Checking Timber Marking Quality. Individuals designated to ensure the quality of timber marking must inspect timber marking activities to ensure compliance with written marking guides. File written documentation that relates marking crew compliance with marking guides in each timber sale case folder.

Determine compliance with marking guides and plans by systematically checking crew performance on a sample basis.

71.4 - Designating Without Marking Individual Trees. Use designation by clearcut units, overstory or understory removal, or similar designations to reduce sale layout costs when such methods will accomplish the sale objectives.

Clearly mark the cutting unit boundaries (sec. 71.22) with tree marking paint containing registered tracer(s). Leave no question of which trees are designated for removal.

Ensure that the sale area map agrees with boundaries placed on the ground.

71.5 - Protecting Special Trees. Highly valuable trees often need to be retained on the site while trees around them are cut or removed. Mark such trees clearly and in a manner that will avoid the likelihood of these trees being cut through error.

71.51 - Witness Trees. Do not designate witness and corner trees for cutting. If, for some reason, destruction of such trees is inevitable, coordinate with the Forest cadastral surveyor or preservation or replacement of such monuments before destruction occurs.

71.52 - Wildlife and Other Trees. Mark trees needed for wildlife habitat, tree improvements, or other purposes as identified in the plan or as instructed. Use the appropriate color of marking paint and metal or plastic signs to identify the reason for protecting the tree and/or the penalty for cutting it.

72 - TRESPASS PREVENTION. Ensure that designation methods minimize the chance of trespass and maximize the probability of early detection and successful prosecution if trespass does occur.

72.1 - Tracers. Paint with tracer(s) helps reduce unauthorized cutting and may provide evidence when such cutting does occur.

72.11 - Paint Testing. Use the field test kit available from the paint manufacturer on a sample of the marked trees to verify that the special additives (tracer(s)) are present and that the intended paint was used. Document the results along with the date, name of the tester and other pertinent details. File any test results in the sale case folder. Ordinarily, few fields tests are needed if other records can verity the paint used for the timber marking.

When test of a more thorough depth are desired, they must be made in a laboratory analysis. The Federal Bureau of Investigation, State police, General Services Administration, or private testing labs make such analyses.

72.12 - Tracer Paint Security. Tracer marking paint is specially prepared for Forest Service use and must be safeguarded.

Each District Ranger shall designate a property custodian(s) to issue paint and maintain the paint inventory and an accountable property officer responsible for quantity audits. These positions must be separate individuals. There may be one primary and one backup property custodian. This should ensure a minimum number of personnel have access to the tracer paint storage area.

1. Property Custodian.

a. Paint Storage.

(1) Store all tracer paint in a locked area away from other paints. Do not use a Forest Service lock.

(2) Store tracer paint separately from any non-tracer marking paint. Non-tracer marking paint must be disposed of since it does not meet safety requirements.

(3) Organize paint in the storage area by color, brand, batch number, and container size for easy counting and accountability.

(4) Apply the same care and labeling procedures to solvent that has been used to wash cans of tracer paint as that used to protect and identify tracer paint.

(5) Store, on a separate shelf in the tracer paint storage area, solvent that is in tracer paint cans.

b. Paint Inventory.

(1) Record tracer paint by paint color, brand name, batch number, and container size, and for full, partially full, and empty containers. Record and maintain this inventory in a format similar to exhibit 01.

(2) Reconcile the inventory at least once monthly.

c. Disposal of Containers.

(1) Keep all empty containers in the storage area until proper disposal can occur.

(2) Dispose of all tracer paint containers at least monthly.

(3) Ensure that all paint has hardened prior to disposal.

2. Accountable Property Officer.

a. Audit tracer paint inventory, at least, once per quarter and report results to the Forest Supervisor through the District Ranger. This audit must also include compliance with the policy and procedures, as stated throughout sections 72.12 through 72.14.

b. Shortages must be reported after each quarterly audit on Form AD-112, Report of Unserviceable, Lost, or Damaged Property.

3. Forest Staff. The Forest staff officers must audit each District annually. This audit should be scheduled with the District Ranger, without the knowledge of the property custodian and accountable property officer

72.12 - Exhibit 01

Daily Records of Issues - Tree Marking Paint (Tracer)

SEE THE PAPER COPY OF THE MASTER SET
FOR THE SECTION 72.12 - EXHIBIT 01

72.13 - Paint Purchase.

1. Purchase only approved tracer paint through the normal procurement channels. Specifications for paint limit the tracer solely to Forest Service use. The tracer is registered with the Missoula Technology and Development Center.

2. Contact the Missoula Technology and Development Center for information and assistance with marking paint questions.

72.14 - Paint Use.

1. When paint orders are received, and prior to its use, check for presence of tracer. Document information on the inventory form.

2. Use tracer paint for all sale designations where paint is needed, including the following:

a. Cut tree marking.

b. Leave tree marking.

c. Posting sale or unit boundaries.

d. Reserve trees.

e. Special area protection zones.

f. Streamside zones.

g. Designating additional timber.

3. Follow all safety requirements as stated on the manufacturer's label.

4. Keep all tracer paint carried to the field in a locked tool box when not in use. Do not use a Forest Service lock.

5. When contract marking is used, require a daily accounting for all paint used. Consider including contract provisions to level fines for missing paint cans.

6. Sale administrators must check use of tracer paint on each active sale unit as a function of normal sale administration. Document findings on an inspection report (FSH 2409.15, 13.42).

72.2 - Stump Marks. Always use stump marks for any tree marked with the intention of designating for, or protecting from, cutting. Ensure that the mark is at or near the ground line, but on the tree and not the ground. Make it large enough to be conspicuous if scraped or chipped off. Avoid marking thick moss or loose bark that could easily be removed from the tree. When possible, mark on the low side or where it is less likely that the mark could be removed by cutting the tree.

CHAPTER 80 - MISCELLANEOUS TIMBER CRUISING SUBJECTS

Contents

81 TRESPASS CRUISES
81.1 Requirements for Trespass Cruises
81.2 Conducting the Trespass Cruise

81 - TRESPASS CRUISES. Trespass cruises must be conducted by certified cruisers (sec. 61) who can qualify as experts in a court of law. The measurement problems may be complicated; however, the methods used must be explainable so a lay person can understand the process. Contact the cruiser as soon as possible and provide all necessary information to accurately determine stumpage value for civil damages. Whether the trespass appears to be willful or unintentional does not influence the way the cruise is conducted.

81.1 - Requirements For Trespass Cruises. Each trespass requires special considerations depending on the circumstances involved. However, the following guidelines apply to all cruises:

1. Keep a diary for reference in court. The case may not go to trial for years and it is necessary to have accurate data rather than memory on which to rely.

2. Brand material measured as trespass volume with "U.S." When practical, identify material with a number using paint containing registered tracer(s). The U.S. brand certifies that the material was measured by an employee of the Government, and the number identifies the piece in the field cruise records.

3. Make photographs showing a step-by-step process of how the cruise was conducted.

4. Use the same cruise methods as those in common usage at the time of the incident.

81.2 - Conducting the Trespass Cruise. The National Forest Log Scaling Handbook, FSH 2409.11 (ch. 40), provides instructions for identifying trespass trees and for making the necessary measurements to determine their volume.

The process outlined in the National Forest Log Scaling Handbook does not produce all the data necessary to conduct a complete appraisal. In many trespasses the majority of the material has been removed. The remaining tops and logs are usually moved and scattered, making it difficult to identify which stump they originally belonged to. When appraisal data is needed or volume cannot be scaled, make a stump comparison cruise. This type of cruise allows each appraisal item to be related to stump size.

In stump cruising, every stump should be measured. Under certain circumstances, such as an extensive trespass, a sampling of stumps may be used. Measure stump diameters at a common height from the high ground side to provide a common index upon which to base correlations with standing trees. When stumps have been cut at all heights, it may be necessary to specify the measuring point at ground level on the high side. When all stumps have been cut at least 1 foot high, the measuring point shall be specified at 1 foot above ground on the high side.

Record species, diameter, and cruiser's identification for each stump measured. After measuring, brand the stump U.S. and number it with paint containing registered tracer(s). Group the stump data by species in 1-inch diameter classes. From the data obtained in the comparison cruise, determine relationships (diameter breast height, height, tree volume, and so on) for each stump size.

The comparison cruise may be done in the immediate stand if a sufficient sample can be obtained. Cruise adjacent stands, if necessary.

Use the comparison cruise data to develop regression equations for each appraisal item's relationship to stump diameter. Prepare a regression equation and use it to estimate each item's value as a function of stump diameter.

The comparison cruise provides data to develop a relationship to stump diameter. Samples must be selected in an unbiased manner. If the trespass involved only a certain size or species, it may be necessary to limit the cruise to individual trees. However, if a wide range of material is involved, a plot or point cruise should be used.

Record the following information on the cruise trees: species, stump diameter, diameter breast height, and height. Determine and record grade and defect assessments.

Refer to a mensuration textbook for examples of regression equations. Prepare an equation for calculating tree volume from a curve of tree volume over stump diameter. Obtain help or mensurational advice if uncertain how to proceed. Someone with mensuration expertise or experience should check the results.

Develop relationships to other dependent variables to stump diameter. Common variables are DBH, height, volume, value, log scale, and number of 16-foot logs.

Exhibit 01 shows an example of expanding the volume by the number of stumps in each diameter class for lodgepole pine.

The relationship of the independent variable to stump diameter must be explainable in a court of law. This procedure should be used in trespass cases whenever individual trees or logs cannot be measured.

81.2 - Exhibit 01

Sample Summary of a Trespass Cruise

AREA #4 LODGEPOLE BOARD FOOT VOLUME

Stump Diameter	No. Stumps	Tree Volume[1/]	Total Volume
10	2	30.51	61.02
11	6	41.65	249.90
12	19	54.25	1030.75
13	30	68.30	2049.00
14	35	83.30	2933.35
15	24	100.78	2418.72
16	27	119.20	3218.40
17	29	139.08	4033.32
18	13	160.41	2085.33
19	19	193.20	3480.80
20	7	207.44	1452.08
21	1	233.14	233.14
22	1	260.30	260.30
TOTAL	213		23506.11

[1/] Tree Volume = $-0.84021 - 4.14395(SD) + 0.7279(SD)^2$
Where: SD = Stump diameter in inches.

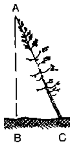
CHAPTER 90 - MISCELLANEOUS TABLES

Contents

91 EXHIBITS

91 - EXHIBITS. The following exhibits are miscellaneous tables which may be used for determining leaning tree heights, determining limiting distance, and determining the number of plots.

Exhibit 01 - Table I	Leaning Tree Heights
Exhibit 02 - Table II	Limiting distance to Face of Tree for Different Diameters for Various Basal Area Factors
Exhibit 03 - Table III(A)	Number of Measurement Points (k), by Coefficient of variation (CV) and Sampling Error (E), when a Measurement point costs three times more than a count-only point (r = 3.00)
Exhibit 04 - Table III(B)	Number of Measurement Points (k), by Coefficient of Variation (CV) and Sampling Error (E), When a Measurement Point Costs 5.33 Times More Than a Count-only Point (r = 5.33)
Exhibit 05 - Table III(C)	Number of Measurement Points (k), by Coefficient of Variation (CV) and Sampling Error (E), When a Measurement Point Costs 8.33 Times More Than a Count-only Point (r = 8.33)
Exhibit 06 - Table III(D)	Number of Measurement Points (k), by Coefficient of Variation (CV) and Sampling Error (E), When a Measurement Point Costs 12.00 Times More Than a Count-only Point (r = 12.00)



91 - Exhibit 01

Table I

Leaning Tree Heights

Vertical Height (AB) to Top of Lean

B	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	BC
8	31																								8
10	32	34	35	37																					10
12	32	34	36	38	40	42	44	46																	12
14	33	35	37	39	40	42	44	46	48	50	52														14
16	34	36	38	39	41	43	45	47	49	51	52	54	56	58	60										16
18	35	37	38	40	42	44	46	48	49	51	53	55	57	59	61	63	65	66							18
20	36	38	39	41	43	45	47	48	50	52	54	56	58	59	61	63	65	67	69	71	73				20
22	37	39	40	42	44	46	47	49	51	53	55	56	58	60	62	64	66	68	70	71	73	75	77	79	22
24	38	40	42	43	45	47	48	50	52	54	55	57	59	61	63	65	66	68	70	72	74	76	78	80	24
26	40	41	43	44	46	48	49	51	53	55	56	58	60	62	64	65	67	69	71	73	75	77	78	80	26
28	41	42	44	46	47	49	50	52	54	56	57	59	61	63	64	66	68	70	72	74	75	77	79	81	28
30	42	44	45	47	48	50	52	53	55	57	58	60	62	64	65	67	69	71	72	74	76	78	80	82	30
32	44	45	47	48	50	51	53	54	56	58	59	61	63	64	66	68	70	72	73	75	77	79	81	82	32
34	45	47	48	50	51	52	54	56	57	59	60	62	64	66	67	69	71	72	74	76	78	80	81	83	34
BC	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120			BC

Vertical Height (AB) to Top of Lean

B	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	BC
8	31																								8
22	81																								22
24	82	84	85	87																					24
26	82	84	86	88	90	92	94	96																	26
28	83	85	87	89	90	92	94	96	98	100	102														28
30	84	85	87	89	91	93	95	97	99	101	102	104	106	108	110										30
32	84	86	88	90	92	94	96	97	99	101	103	105	107	109	111	113	115	116							32
34	85	87	89	91	92	94	96	98	100	102	104	106	108	109	111	113	115	117	119	121	123	125			34

Measure height AB (nearest foot) to tip, or to any point on the leaning stem to which slant height is needed. Measure horizontal distance BC to base of leaning tree. Read slant height from table. Interpolate as needed.

91 - Exhibit 02
Table II

Limiting Distance to Face of Tree for Different Diameters for Various Basal Area Factors
(To Face of Tree)

	Basal Area Factor										
DBH	5	10	15	20	25	30	40	50	60	70	80
	Plot Radius Factor										
In.	3.847	2.708	2.203	1.902	1.697	1.546	1.333	1.188	1.081	.997	.930
	PLOT RADII TO FACE OF TREE IN FEET										
0.1	.38	.27	.22	.19	.17	.16	.13	.12	.11	.10	.09
0.2	.77	.54	.44	.38	.34	.31	.27	.24	.22	.20	.19
0.3	1.15	.81	.66	.57	.51	.46	.40	.36	.32	.30	.28
0.4	1.54	1.08	.88	.76	.68	.62	.53	.48	.43	.40	.37
0.5	1.92	1.35	1.11	.95	.85	.77	.67	.59	.54	.50	.47
0.6	2.31	1.63	1.32	1.14	1.02	.93	.80	.71	.65	.60	.56
0.7	2.69	1.90	1.54	1.33	1.19	1.08	.93	.83	.76	.70	.65
0.8	3.08	2.17	1.76	1.52	1.36	1.24	1.07	.95	.87	.80	.74
0.9	3.46	2.44	1.98	1.71	1.53	1.39	1.20	1.07	.97	.90	.84
1	3.85	2.71	2.20	1.90	1.70	1.55	1.33	1.19	1.08	1.00	.93
2	7.69	5.42	4.41	3.80	3.39	3.09	2.67	2.38	2.16	1.99	1.86
3	11.54	8.12	6.61	5.71	5.09	4.64	4.00	3.56	3.24	2.99	2.79
4	15.39	10.83	8.81	7.61	6.79	6.18	5.33	4.75	4.32	3.99	3.72
5	19.24	13.54	11.02	9.51	8.49	7.73	6.67	5.94	5.41	4.99	4.65
6	23.08	16.25	13.22	11.41	10.18	9.28	8.00	7.13	6.49	5.98	5.58
7	26.93	18.96	15.42	13.31	11.88	10.82	9.33	8.32	7.57	6.98	6.51
8	30.78	21.66	17.62	15.22	13.58	12.37	10.66	9.50	8.65	7.98	7.44
9	34.62	24.37	19.83	17.12	15.27	13.91	12.00	10.69	9.73	8.97	8.37
10	38.47	27.08	22.03	19.02	16.97	15.46	13.33	11.88	10.81	9.97	9.30
20	76.94	54.16	44.06	38.04	33.94	30.92	26.66	23.76	21.62	19.94	18.60
30	115.41	81.24	66.09	57.06	50.91	46.38	39.99	35.64	32.43	29.91	27.90
40	153.88	108.32	88.12	76.08	67.88	61.84	53.32	47.52	43.24	39.88	37.20
50	192.35	135.40	110.15	95.10	84.85	77.30	66.65	59.40	54.05	49.85	46.50
60	230.82	162.48	132.18	144.12	101.82	92.76	79.98	71.28	64.86	59.82	55.80
70	269.29	189.56	154.21	133.14	118.79	108.22	93.31	83.16	75.67	69.79	65.10

Example: Given a tree DBH of 22.8 inches and a BAF of 5, determine limiting distance to face of tree:

20-inch distance = 76.94

2-inch distance = 7.69
0.8-inch distance = 3.08

Limiting distance to face of 22.8-inch tree = 87.71 feet

91 - Exhibit 03
Table III(A)

Number of Measurement Points (k), by Coefficient of Variation (CV) and Sampling Srror (E), When a Measurement Point Costs Three Times More Than a Count-only Point (r = 3.00)

Coefficient of Variation	Sampling error (standard error of estimated total sale volume expressed as a proportion of estimated total sale volume)							
	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.10
	--- Number of Measurement Points ---							
0.20	200	50	22	12	8	6	-	-
0.25	312	78	35	20	12	9	5	-
0.30	450	112	50	28	18	12	7	-
0.35	612	153	68	38	24	17	10	6
0.40	800	200	89	50	32	22	12	8
0.45	1,012	253	112	63	40	28	16	10
0.50	1,250	312	139	78	50	35	20	12
0.55	1,512	378	168	95	60	42	24	15
0.60	1,800	450	200	112	72	50	28	18
0.65	2,112	528	235	132	84	59	33	21
0.70	2,450	612	272	153	98	68	38	24
0.75	2,812	703	312	176	112	78	44	28
0.80	3,200	800	356	200	128	89	50	32
0.85	3,612	903	401	226	144	100	56	36
0.90	4,050	1,012	450	253	162	112	63	40
0.95	4,512	1,128	501	282	180	125	71	45
1.00	5,000	1,250	556	312	200	139	78	50

NOTE: Multiply the indicated number of measurement points by 3 to find the total number of points.

Tables III(A), III(B), III(C), and III(D) are excerpts from Johnson (1965).

91 - Exhibit 04
Table III(B)

Number of Measurement Points (k), by Coefficient of Variation (CV) and Sampling Error (E), When a Measurement Point Costs 5.33 Times More Than a Count-only Point (r = 5.33)

Coefficient of Variation	Sampling error (standard error of estimated total sale volume expressed as a proportion of estimated total sale volume)							
	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.10
	--- Number of Measurement Points ---							
0.20	175	44	19	11	7	5	-	-
0.25	273	68	30	17	11	8	-	-
0.30	394	98	44	25	16	11	6	-
0.35	536	134	60	34	21	15	8	5
0.40	700	175	78	44	28	19	11	7
0.45	886	222	98	55	35	25	14	9
0.50	1,094	273	122	68	44	30	17	11
0.55	1,324	331	147	83	53	37	21	13
0.60	1,575	394	175	98	63	44	25	16
0.65	1,849	462	205	116	74	51	29	18
0.70	2,144	536	238	134	86	60	34	21
0.75	2,461	615	273	154	98	68	38	25
0.80	2,800	700	311	175	112	78	44	28
0.85	3,161	790	351	198	126	88	49	32
0.90	3,544	886	394	222	142	98	55	35
0.95	3,949	987	439	247	158	110	62	39
1.00	4,376	1,094	486	273	175	122	68	44

NOTE: Multiply the indicated number of measurement points by 4 to find the total number of points.

91 - Exhibit 05
Table III(C)

Number of Measurement Points (k), by Coefficient of Variation (CV) and Sampling Error (E), When a Measurement Point Costs 8.33 Times More Than a Count-only Point (r = 8.33)

Coefficient of Variation	Sampling error (standard error of estimated total sale volume expressed as a proportion of estimated total sale volume)							
	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.10
	--- Number of Measurement Points ---							
0.20	160	40	18	10	6	-	-	-
0.25	250	63	28	16	10	7	-	-
0.30	360	90	40	23	14	10	6	-
0.35	490	123	54	31	20	14	8	5
0.40	640	160	71	40	26	18	10	6
0.45	810	203	90	51	32	23	13	8
0.50	1,000	250	111	63	40	28	16	10
0.55	1,210	303	134	76	48	34	19	12
0.60	1,440	360	160	90	58	40	23	14
0.65	1,690	423	188	106	68	47	26	17
0.70	1,960	490	218	123	78	54	31	20
0.75	2,250	563	250	141	90	63	35	23
0.80	2,560	640	284	160	102	71	40	26
0.85	2,890	723	321	181	116	80	45	29
0.90	3,240	810	360	203	130	90	51	32
0.95	3,610	903	401	226	144	100	56	36
1.00	4,000	1,000	444	250	160	111	63	40

NOTE: Multiply the indicated number of measurement points by 5 to find the total number of points.

91 - Exhibit 06
Table III(D)

Number of Measurement Points (k), by Coefficient of Variation (CV) and Sampling Error (E), When a Measurement Point Costs 12.00 Times More Than a Count-only Point (r = 12.00)

Coefficient of Variation	Sampling error (standard error of estimated total sale volume expressed as a proportion of estimated total sale volume)							
	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.10
	--- Number of Measurement Points ---							
0.20	150	37	17	9	6	-	-	-
0.25	234	59	26	15	9	7	-	-
0.30	337	84	38	21	14	9	5	-
0.35	459	115	51	29	18	13	7	5
0.40	600	150	67	37	24	17	9	6
0.45	759	190	84	47	30	21	12	8
0.50	937	234	104	59	38	26	15	9
0.55	1,134	284	126	71	45	32	18	11
0.60	1,350	337	150	84	54	37	21	14
0.65	1,584	396	176	99	63	44	25	16
0.70	1,837	459	204	115	74	51	29	18
0.75	2,109	527	234	132	84	59	33	21
0.80	2,400	600	267	150	96	67	37	24
0.85	2,709	677	301	169	108	75	42	27
0.90	3,037	759	338	190	122	84	47	30
0.95	3,384	846	376	212	135	94	53	34
1.00	3,750	937	417	234	150	104	59	37

NOTE: Multiply the indicated number of measurement points by 6 to find the total number of points.