Dendrometry Field Manual

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1. INTRODUCTION

The years at the change of the millennia mark without doubt the most dynamic period in the long history of the forestry profession. While from the end of the Middle Age to the beginning of the XX century almost no significant advancements were present, especially in the natural resource assessment area, the end of the millennia came with the explosion of the IT industry. The spectacular developments within information technology field reached the environmental area when remote sensing techniques gain momentum, especially Landsat and MODIS. However, the most dramatic alteration of the forest measurements sector is associated with the advent of the material sciences, especially sensors development. To this end an area that was almost inexistent three decades ago, namely LIDAR, is now the most popular method used by large forest management companies in estimating their resources. Furthermore, the IT advances allowed the development of more elaborate sampling techniques, such as sampling with variable probability, or nonparametric sampling.

The present field manual was elaborated as a companion of a Forest Measurement course, in the sense that all the techniques learned in the classroom will be applied in the field. The manual provides reduced theoretical background of the procedures, which can be found in almost all classical forest measurements textbooks, such as Avery and Burkhard (2001), Husch et al (2002), van Laar and Akca (1997), or Lemay and Marshall (1990). As it was conceptualized, the manual is aligned with other field manual that are currently in use by different universities, such as Mississippi State University, Stephen F Austin, or University of British Columbia. The present manual is the first unified version of Louisiana Tech University of a Field Manual to be used in conjunction with the Forest Measurements course.

The manual covers both forest inventory techniques that are traditionally used in cruising, such as preset intensity inventory, as well as modern techniques, such as distance sampling. The manual is dedicated to layout in great details all the steps required for successful completion of a forest inventory. To each technique a special section is dedicated to the possible usage of the respective technique, such as distance sampling can be used in forest inventory, fuel load or forest planning.

A series of visual aids were used to enhance the presentation. The images, drawings, or chart presented are either produced by the author or courtesy of the US Forest Service, which states that "Photographs and images on this website (i.e., http://www.fs.fed.us/) are publicly owned, produced by Forest Service employees or other government agencies and institutions; or, have been obtained from non-governmental organizations and private photographers with their permission to use them on this website. Photographs included on this website that are publicly owned are available for free for non-commercial scientific and educational uses." In text the graphical aids obtained from the US Forest Service website were identified in the caption.

2. REPORT FORMAT

Contrary to popular belief that foresters, as well as experts working in environmental area in general, are focused mainly on outdoor or ecosystem related activities, many tasks performed by a forester involve writing. Writing became an integral part of forestry, when simple or complicated ideas needs to be conveyed to various audiences, from specialists to laymen. The ability to write technical reports clearly and concise marks a good forester. A forester should translate mathematical symbols, formula, and other forest related abstractions into an understandable, easy to comprehend, form. There are various formats for a report, depending on the entity overseeing reporting, each group or institution having its own "standard" format. Nevertheless, there are specific elements that are common in most forestry writings, which are present in a typical report. In essence, a technical report informs readers of the reasons (why?), means (how?), results (what?), and conclusions of the subject being reported. Even that the writing format a report differs from entity to entity the content is always similar. The following series describe the main sections (or chapters) that are commonly encountered in a technical report.

2.1 Title Page

The title page contains the title of the report, author(s) of the report, date of preparation, and report number. Each piece of title data should be centered horizontally.

2.2 Table of Contents

The table of contents should contain the section and items titles and their page numbers, ordered according to their page numbers. Each page in the report except for the title page should be numbered.

2.3 Introduction

The introduction briefly describes the objective of the report as well as the need for the work. The introduction should be less than one page.

2.4 Methods

The methods section of the report should include information about:

- the area were the report was carried out,
- the procedure used for data collection (sampling or cruising methods),
- the procedure used to compute the results.

The area were for which the report was performed (or for which the report collected data) should present information on the tract and ownership, number of stands in the tract (NOTE: remember what a stand is), stand locations, number of acres per stand, ages of stands, number of acres in the tract, boundary information, description of land, stand descriptions, landform etc. In this section you should include the location map, tract map, stand maps. Complete maps usually contain borders, titles, North arrows, scale, etc. All figures should be numbered in sequential order and have appropriate and descriptive titles. The description of the area should be between two and four pages (maps included).

The data collection section should contain information on how data was collected to address the objectives of the report. This section should present the type of sampling used (systematic or random), plot size or BAF, the values that were used in sampling computations (such as sampling error or significance level) and their source (such as US Forest Service Timber Cruising Handbook). This part of the methods should include information on tools and software used for cruising (such as clinometers, logger tape or GPS unit) or to prepare the cruise (such as Excel or ArcGIS). If some values require a pre-cruise, state this and how the pre-cruise was carried out (such as 4 plots spaced 5 x 5 chains were used to compute the coefficient of variation). Here it should also be stated how the actual cruise was performed (GPS units or compass and pacing). In this section it should also be clearly stated what attributes were measured (such as DBH, height, species etc) and how this information was recorded or coded (such as the US Forest Service or the Forest Inventory an Analysis National Program codes).

The last part of the methods should present information on how the collected data was processed to answer the report's objectives. This part should contain details on how the stand and stock tables were developed (such as the source of the volume equations), what software was used to process the data (such as Excel or Cruise Processing) or what type of information the stand and stock table would contain (such as # trees/ species or #trees/tract, and the confidence interval). You should specifically state the confidence level, if the confidence intervals are included in the stand and stock table.

The Methods section should present basically, how and what type of data was collected and how and what kind of information was developed from the collected data.

2.5 Results and Discussion

It is not uncommon as technical reports would group the results and the discussion section to increase the readability and discourse. However, most of the time they are separated.

The results should present the number of plots, how they were obtained (present the pre-cruise's details, if one was performed) and the spacing between the plots. If cruising was done using GPS units shows the plot location overlaid with the tract map. The results section must contain the main findings used to address the report's objectives (such as stand and stock table with confidence intervals). The stand and stock tables should be referenced by stand, species, product class all with confidence intervals.

The discussion section would interpret the results. You should include a narrative description of stand volumes by species and product class from silvicultural, economic or operation perspective. This section could also incorporate some recommendations related with the stand or tract management (such as thinning, pruning etc). All tables should be properly formatted and numbered in sequential order and have appropriate, descriptive, titles.

2.6 Conclusions

The conclusions section should be at most two page narrative (but no less than half page) summarizing the work that was executed. The focus of the conclusion section is to succinctly present the main finding of the report and how those findings were obtained. The conclusions should NOT include new information, only what was mentioned in the previous chapters. One can include stand information such as diameter distributions, known hazards, or any other information a landowner might want to know about their land (but already mentioned in the report).

2.7 References

All the sources used in the report should be acknowledged in text and completely identified in the Reference section. There are many formats available for referencing. The forester within the USA can use two formats, one recommended by the Forest Science journal and one by the US Forest Service technical reports. The details on referencing can be found at http://www.safnet.org/publications/forscience/ for the journal, or at http://www.fs.fed.us/rm/publications/authors_corner/index.shtml for the Forest Service

Inside text, the sources are commonly identified using the last name of the author(s) followed by the publication year (e.g., Garman 2004). In case that two authors are present then the last name of both authors are mentioned followed by the year of publication (e.g., Innes and Hickey 2006). For three or more authors only the last name of the first author is written, followed by "et al." and the year of publication (e.g., Dorren et al. 2004).

The cited literature should be presented immediately after the narrative, and could mirror the following templates, depending on the type of referred work (from the website of the journal ***Forest Science***):

Book:

Houghton, J.T., G.J. Jenkins, and J.J. Ephraums. 1990. *Climate change: The IPCC scientific assessment*. Cambridge University Press, Cambridge, United Kingdom. 365 p.

Chapter in book:

Brokaw, N.V.L. 1982. Treefalls: Frequency timing and consequences. P. 101-108 in *The ecology of a tropical forest: Seasonal rhythms and long term changes*, Leigh, E.G., Jr., A.S. Rand, and D.M. Windsor (eds.). Smithsonian Institution Press, Washington, DC.

Article in journal:

Jurgensen, M.F., J. Johnson, M.A. Wise, C.S. Williams, and R. Wilson. 1997. Impacts of timber harvesting on soil organic matter, nitrogen, productivity, and health of Inland Northwest forests. *For. Sci*. 43(2):234-251.

Proceedings:

Blake, J.I., G.L. Somers, and G.A. Ruark. 1990. Perspectives on process modeling of forest growth responses to environmental stress. P. 9-20 in *Proc. of conf. on Process modeling of forest growth responses to environmental stress*, Dixon, R.K. (ed.). Timber Press, Portland, OR.

Technical report:

Mason, R.R., and H.G. Paul. 1994. *Monitoring larval populations of the Douglas-fir tussock moth and western spruce budworm on permanent plots: Sampling methods and statistical properties of data*. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-333. 22 p.

Thesis/dissertation:

Korol, R.L. 1985. *The soil and water regime of uneven-age interior Douglas-fir* (Pseudotsuga menziesii var. glauca). M.Sc. thesis, Univ. of British Columbia, Vancouver, B.C., Canada. 164 p.

Web publications:

USDA Forest Service. 2002. *The process predicament: How statutory, regulatory, and administrative factors affect national forest management*. Available online at www.fs.fed.us/publications.html; last accessed Apr. 15, 2005.

2.8 Appendices

Commonly the appendix hosts the information that was used to produce the report but its inclusion in the body of the report would clutter the report discourse. Commonly the appendix includes the tally sheets or an Excel table (based on the plot number) with raw data as well as the detailed calculation sheets.

3. TREE MEASUREMENTS

Most forest measurements directed to the tree are focused on either assessment of the current status of the tree or for predicting its change thru time. The most popular tree measurements have as objective the volume or growth of either an individual tree or of a stand. These measurements are commonly used to determine the value of wood or fiber stored in a tree.

3.1 Diameter measurement

For diameter a ***diameter tape*** or a ***caliper*** are commonly used. Diameter tape is wrapped around the tree at 4½ feet above the ground (Fig 1), which is the standard point of measurement when volume is of interest. Because of its location close to the breast of an adult human, this diameter is called the **Diameter at Breast Height, and is abbreviated DBH** (in many instances **dbh**). Even that the tape is actually measuring the circumference of the tree, a D-tape, as diameter tape is commonly called, is calibrated to measure the diameter. Most D-tapes have one side measuring length (the units are inches and feet) and one side measuring diameter (the units are π×inches). The relationship between the two sides is given by the equation: Tree diameter = standard tape measure/π.

Fig 1. Diameter at breast height

Beside volume, diameter measurements are often used to determine the type and amount of products that can be produced from a tree. Minimum diameters vary according to the product and mill, but some general rules guides some products (Table 1).

Table 1.Common diameters defining a product

Class	Pulpwood	Chip-and-Saw[1]	Saw timber*	Poles**	Veneer Logs
Use	Paper, wood by-products	Small lumber	Large lumber	Utility poles	Plywood
DBH	>4”	>8”	>11”	Varies	>14”
Top diameter	2 – 4”	5 – 6”	8”	6”	8”

* Saw timber refers to log that are straight, at least 16 feet long, and with no large branches or diseases.
* A pole is a long, straight, nearly perfect stem.

In most cases dbh is easy to measure, as the 4 ½ feet above ground is a position clearly identified. However, there are situations when care should be paid in measuring the dbh, as presented in Figure 2.

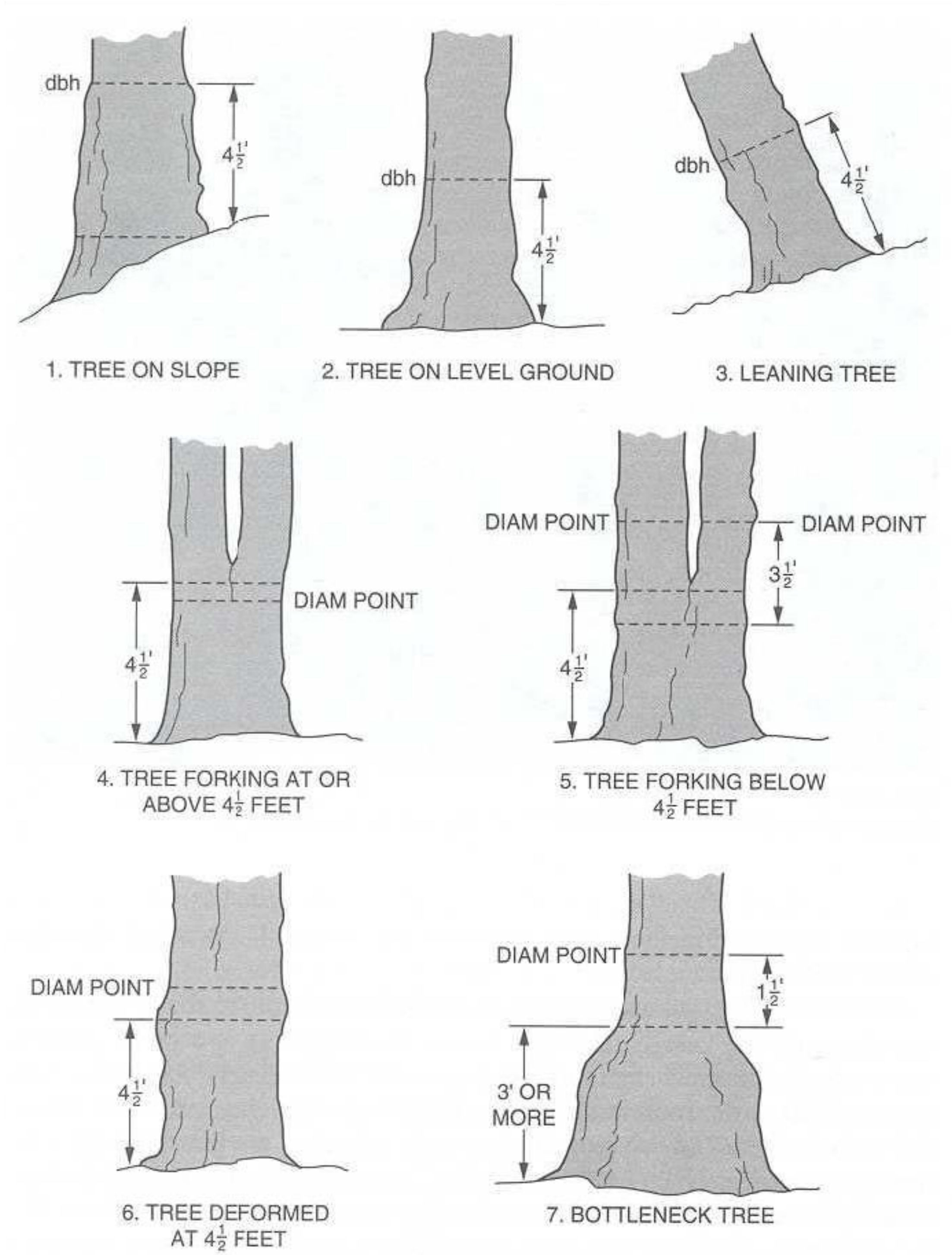


Figure 2. Measuring dbh in different situations that can be encountered during field measurements phase (courtesy of US Forest Service)

3.2 Height measurement

Foresters use a variety of instruments to measure the height of a tree. Older tools, such as Biltmore stick, are still in use, but clinometer, and now laser hypsometers, are prevalent.

The ***clinometer (***Figure 3***)*** is a popular among foresters, and measure heights using *trigonometry*. Many clinometers require a predefined distance from the tree, such as one chain, when the tree height is measured.

Figure 3. Haglof Clinometer

To measure heights using a clinometer three values are needed: the distance to the tree and two clinometer readings. The distance to the tree is usually measured using a D-tape, and is commonly a multiplier of a chain (i.e., 1 or 2 chains). When understory vegetation makes reading from clinometer difficult some people use 1.5 chains. The readings are supplied by the clinometer, one for the top part of the tree and one for the bottom part of the tree (**Error! Reference source not found.**). The height is the top reading minus the bottom reading, which is multiplied with the distance to the tree, measured in chains (i.e., if the clinometer was located at 2 chains from the tree the difference is multiplied with 2). It should be noticed that when eye level is above the base of the tree, the reading for the base will be negative. Therefore when the eye is above the base of the tree, the total height will be greater than the top reading.

Example

Assuming the distance to the tree of 1 chain.

If the eye is between the bottom and the top of the tree, and top reading = 60 ft, bottom reading = -5 ft, then height = 60 – (-5) = 65 ft

If your eye level is below the base of the tree, the total height for the tree will be less than the reading for the top: top reading = 60 ft, bottom reading = +5 ft → Height = 60 – 5 = 55 ft

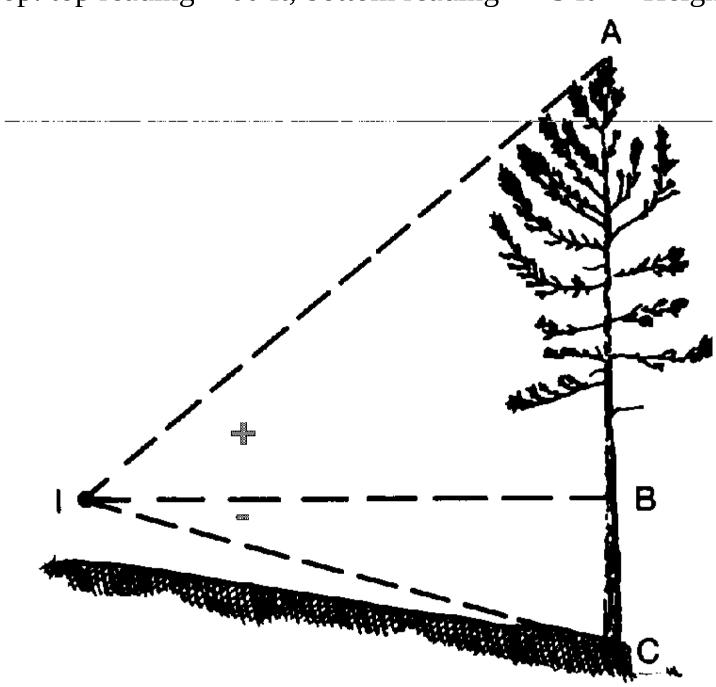


Figure 4. Measuring tree height using a clinometer (courtesy of US Forest Service)

There are two types of heights that are measured by a forester: ***total tree height, important for biomass and total volume estimation,*** and ***merchantable tree height, important for specific products, mainly saw timber***. The total tree height is the height from the ground to the terminal bud, while the ***merchantable tree height*** is the height from the ground to the upper limit of useable wood for a given product (Figure 5). Products are defined by taper, which is the decrease of diameter with height. Pulpwood height is commonly measured up to a 4 inch minimum diameter, while for sawtimber larger diameters are considered, usually an 8 inch top. Merchantable heights is often measured in units larger than the standard foot; pulpwood in 5 ½ foot sticks (16 feet minimum), and sawtimber in 16 foot logs. After the first full log, these products can be measured to the half-log. Height is always round down when measured in logs.

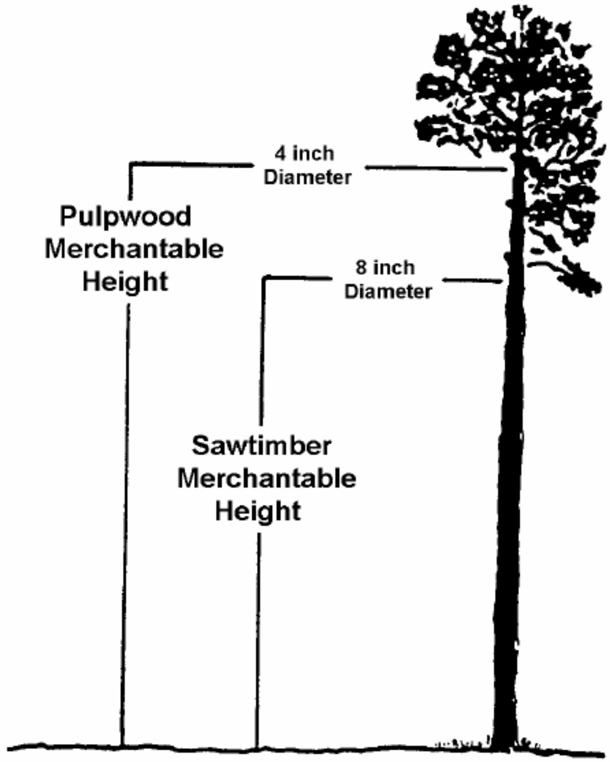


Figure 5. Different merchantable heights

When using a clinometer to measure heights several visibility or measurement errors can be encountered:

- The point to which one wishes to measure (e.g., 10" top, 8" top, 4" top, top of crown) n not seen
- The bottom of the tree is not seen
- Not taking into account the slope when measuring distance from the tree. Topo and percent scales requires a HORIZONTAL distance of 66 feet and 100 feet, respectively, which means longer/shorter distance on steep slopes.
- Wrong estimation of the upper merchantability (i.e., diameter of 4" top, 8" top, 10" top, etc…).
- Measuring the horizontal distance to the face of the tree not to the CENTER or the tree.
- A very common mistake is reading only the values for the top, and forgetting to sight the ground.

3.3 Form class measurement

Girard Form Class is a form quotient used to estimate taper. It is calculated as the ratio of diameter inside bark at the top of the first log (i.e., 16 ') to the diameter outside bark at breast height. With a stump assumed to be 1ft and a log trimming allowance of 0.3 ft, the upper-stem diameter corresponding to the Girard Form Class is measured at 17.3 ft above ground. Consequently, the formula used to compute the Girard form class is:

$$f_G = \frac{Diameter\ \ inside\ bark\ @17.3'\ above\ ground}{dbh}$$

3.4 Age and Growth measurement

Scientists and practioners are sometimes interested in determining whether or not a tree or a stand grows according to its potential. To estimate growth a drill-like tool called ***increment borer is used***. This tool can be bored into a tree and extract a tube that shows the annual rings of *earlywood* and *latewood* that the tree has accumulated throughout its life (Figure 7). Counting each dark ring should tell the age of the tree. If the rings are close together, the tree grew slowly that season, if they are far apart, it grew quickly. A change from widely spaced rings to narrow rings indicates slowed growth, which might be from competition, drought, or some other stresses.

Figure 6. Incremental borer used to determine age and growth of a tree

3.5 Basal area

Basal area is defined as the cross sectional area of the stem of a tree at breast height (i.e., 4.5 ft). It is commonly abbreviated as BA and is reported in ft^2. Assuming a circular cross section of the tree the basal area is computed with the formula:

$$BA = \pi dbh^2 / 4 \times 1/144 = 0.005454 \times dbh^2 \, [ft^2]$$

A natural extension of the basal area of the tree is the basal area of a stand, which is defined as the basal area of all the trees in the respective stands. Basal area of the stand can be reported in ft^2/stand, but this measure is of little use, as BA is not a product to be sold, but useful instruments in various silvicultural practices. Therefore, the common unit for the BA of a stand is ft^2/ac.

$$BA/ac = \sum_{i=1}^{n} \frac{BA_i}{n}$$

where BA_i is the basal area of the tree i, and n is the number of acres in the stand.

4. DIRECTION, DISTANCE, AREA MEASUREMENT AND TOPOGRAPHIC MAPS

Knowledge of the elements of land surveying is essential for forest inventory. A forester often retraces old lines, locates property boundaries, and measures land areas. To adequately perform these tasks, a forester could use pacing, chaining, running compass traverses, and various methods of area estimation. In addition, a forester should be familiar with the various systems of land subdivision.

Foresters must be able to navigate through vegetation and rough terrain to find specific locations or to traverse boundaries using the hand compass and pacing technique. This exercise is designed to provide students with practical experience in the use of quadrant and azimuth hand held compasses and distance pacing. At the end of the instruction period the student are expected to be able to:

- determine the average length of one pace and the average number of paces per chain in even terrain,
- correct bearings and azimuths for magnetic declination,
- calculate back bearings and azimuths, and
- locate a point on the ground given a course of bearings and distances using the compass and pacing method.

4.1 Distance measurements: Pacing

Introduction: The fundamental unit of horizontal measurement employed by foresters in the USA is the chain, also known as the surveyors' or Gunter's chain. A chain has 66 ft, and is divided into 100 equal parts that are known as links; each link is therefore 0.66 ft. in length. An acre is defined as a rectangle with the short side 1 chain and the long side 10 chains, therefore an acre is 10 square chains. It is this simple conversion from chained dimensions to acres and the history of the units that ensured continuous popularity of this standard. It follows immediately that a section (i.e., a tract of 1 square mile or a square with 80 chains side) contains 6,400 square chains or 640 acres.

Pacing is perhaps the most rudimentary of all techniques for determining distances in the field. With practice and frequently measured checks, an experienced pacer can expect to attain an accuracy of 1 part in 80 when traversing fairly level terrain or 1 in 50 over average terrain.

The pace is commonly defined as the average length of two natural steps, i.e. a count is made each time the same foot touches the ground. A natural walking gait is recommended, because this pace can be maintained under difficult terrain conditions. One should never attempt to use an artificial pace based on a fixed step length such as exactly 3 ft.; experienced pacers demonstrated that the natural step is much more reliable. Most foresters of average height and stride have a natural pace of 12 to 13 paces (double steps) per chain. It is also helpful to compute the exact number of feet per pace, for pacing is often relied upon to determine distances that are measured in feet.

Uniform pacing is difficult in mountainous terrain, as measurement of horizontal distance rather than slope distance is the main objective. Steps are necessarily shortened in walking up and down steep hillsides, and special problems are created when obstructions such as deep stream channels are encountered. Thus, some individual technique must be devised to compensate for such difficulties, or better not use pacing altogether.

Paced distances should always be field-recorded as horizontal distances in chains or feet-NOT as actual paces. When accurate mental counts become tedious, a reliable pacing record can be kept by a written tally or by using a hand-tally meter.

Note: One pace = the average length of two natural steps (i.e. a count is made each time the same foot hits the ground) (note, many people think a pace is a single step but foresters and ecologists use two steps as a pace)

Flat terrain: When measuring distances over the ground one would like to measure the horizontal distance as viewed from above. This means that when traversing uneven terrain one must compensate for the slope. If good accuracy is not required (i.e. you are just going to some location, not measuring a distance for property lines, transects, etc…) you will need to either add or subtract paces from your normal paces/chain or paces/tally over flat ground. If accuracy is required, one should use a tape.

Procedure: During the exercise, the student will pace a known, relatively flat course of 1 chain and 5 chains using a natural stride. The student will pace the course four times to determine a consistent average pace per chain for yourself.

Record the values below for your own future reference. An accurate pace can be a valuable tool.
Paces per chain for **flat ground** ___________________

Estimate distance from pacing
The following relationship can be used to estimate the distances measured in paces:

Conversions:
1 chain (1 ch) = 66 ft
20 chains = ¼ mile
80 chains = 1 mile
1 acre = 43560 square feet
640 acres = 1 section
36 sections = 1 township
40 acres = 20 chains x 20 chains
1 section = 80 chains x 80 chains

4.2 Angle measurements: Compass

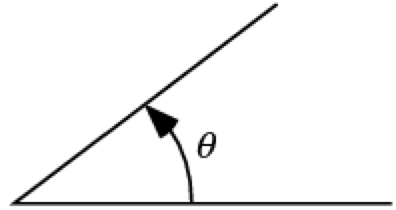


Figure 7. Definition of an angle

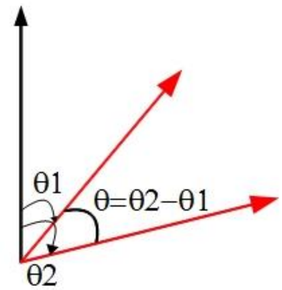


Figure 8. Measurement of a angle as a difference between two angles that have one common side.

Introduction: A direction is in many instances described by an angle. Given two intersecting lines or line segments, the amount of rotation around the point of intersection required to overlay the two lines (segments) is called the angle, θ, between them (Figure 8). An angle is measured in degrees. The abbreviation for 'degree' is °. There are 360° in a circle (or 'full turn'), a useful value, since 360° can be divided in many ways. One degree is a small amount, but can be further divided in 60 minutes, each minute having 60 seconds. So there are 1,296,000 seconds to a circle!
NOTE: The fascination with the number '60' came from the Babylonians, who had a base 60 number system, which is computed as 5 (the number of your fingers) x 12 (the number of months within a year).

An angle can be computed directly (from the definition) or by subtracting two other angles (Figure 9). In forestry the direction is measured using a compass, therefore the angle between two directions (or lines) is the difference between the directions of the two lines, expressed as azimuth.

Nomenclature of the Compass: The simplest compass consists of a magnetized needle on a pivot point, enclosed in a circular housing that has been graduated in degrees. Considering that Earth acts as a huge magnet, compass needle in the Northern Hemisphere points to the north magnetic pole. If a sighting base is attached to the compass housing, it is possible to measure the angle between the line of sight and the position of the needle. Such angles are referred to as **azimuths**. Azimuths are angles measured clockwise from due north, thus reading from 0° to 360. **Bearings** are horizontal angles that are referenced to one of the quadrants of the compass, namely NE, SE, SW, or NW. Azimuths and bearings are related, for example a bearing of N60°E corresponds to an azimuth of 60°, while a bearing of S60°W is the same as an azimuth of 240°. The compass needle points to the magnetic north pole rather than toward the geographical North Pole (true north). The angle formed between magnetic north and true north is called **declination**, and allowance must be made for this factor in converting magnetic bearings and azimuths to true angular readings.

Magnetic Declination: In North America, corrections may be required for east or west declination, the former when the north magnetic pole is east of true north and the latter when it is west of true north. Isogonic charts illustrating magnetic declination are issued periodically by various agencies.

On maps, points having equal declination are connected by lines known as isogons. The line of zero declination (no corrections required) is called the agonic line. It will be noted that areas east of the agonic line have west declination, while areas west of the agonic line have east declination. Because the position of the magnetic north pole is constantly shifting, it is important that current declination values be used in correcting magnetic bearings.

Allowance for declination: In establishing or retracing property lines, angles should preferably be recorded as azimuths. The simplest and most reliable technique for handling declination is to set the allowance directly on the compass itself. Therefore, the graduated degree circle must be rotated until the north end of the compass needle reads true north when the line of sight points in that direction. For most compasses, this requires that the graduated degree circle be turned counterclockwise for east declination and clockwise for west declination. When there is no provision for setting the declination directly on the compass, the proper allowance can be made mentally in the field, or recorded unchanged and corrected later at the office. For changing azimuths to true readings, east declinations are added, and west declinations are subtracted.

Use of the compass: measuring azimuth

To measure the azimuth of a specific direction select an obvious object situated on the direction of interest. Sight the object by holding the compass level, with the mirror at an angle between 50 and 70º, allowing you to see the compass dial while sighting your target. The target should be aligned with the sighting notch and/or sighting slit. In the mirror image, the sighting line (that is the direction of interest) should pass through the center of the compass (this is crucial, as it indicates correct alignment of your eye, the target and the compass). Rotate the compass dial until the N end of the magnetic needle (red end) is aligned with the red end of the orienting arrow (Figure 10). You may now read the azimuth of your direction.

Note that the sighting line passes through the center of the compass and that the compass dial has been rotated so that the N end of the magnetic needle is aligned with the red end of the orienting arrow.

Figure 9. An appropriate way of holding compass while taking azimuth or navigating to a given Point

Navigation

In the field in many instances you have to walk a preset azimuth. To do so, you should first identify an object (i.e., a significant feature from the surrounding environment) that has the desired azimuth, and then walk toward the respective feature (sometimes the distance that you have to walk following the azimuth is also preset- the case of forest inventories). Therefore, in this lab you should determine what object you would have to walk toward to follow an azimuth of x°, where x the first three digits from your birthday month and day (for example if you were born on December 23 then x° = 122° (the first three digits of 1223. If x is larger than 360 than subtract 360 or a multiple of 360 until a positive value smaller than 360 is obtained.) To do this, rotate the compass dial until the value x is aligned with the index pointer (at the top of the compass). Then, hold the compass and rotate yourself until the N end of the magnetic needle and red end of the orienting arrow are aligned (make sure the sighting line passes through the center of the compass image in the mirror). Now look through the sighting slit or notch, and choose an object that is in the direction of interest (x°) in this case. If you wanted to follow the x °azimuth, you would walk toward that object.

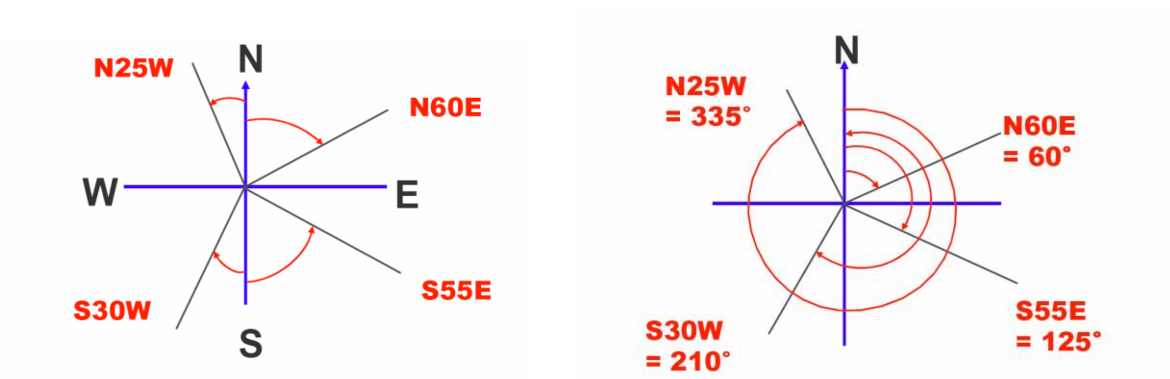


Figure 10. Bearings **are angles measured from N or S towards E or W**. Azimuths **are angles measured clockwise from North**.

4.3 Topographic maps and scales

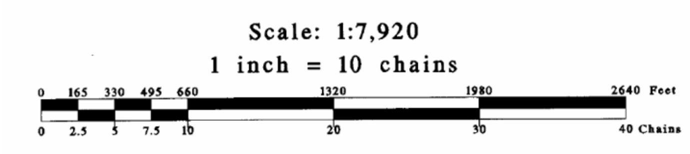
4.3.1 Map and scale

Scale: equals the ratio of a distance on a map/image to the corresponding distance in reality.

Representation of Scale: $RF = \frac{\textit{distance on the map}}{\textit{distance on the ground}}$

- **Representative Fraction (RF):** 1 unit of map/photo measure equals to x units of same measure on ground. RF can be a fraction or a ratio: 1/15,840 or 1:15,840
- **Equivalent Scale:** 1 unit of map/photo scale equals to x units of ground measure.

Example:1 inch = 20 chains 1 inch = 2,000 ft.



- **Graphic (Bar) Scale:** a graphic bar represents graphically a lineal scale.

Lineal Scale Expressions:

- **<u>Constants</u>:** 12 in/ft.; 1 chain = 66 ft.; 1 mile = 80 chains; 1 inch = 2.54 cm = 25.4 mm; 1 meter = 100 cm = 39.37 inches = 3.28 ft.
- **<u>Feet per Inch</u>:** 1 inch on map/photo equals F feet on ground
  Examples: 1"= 1,320' 1"= 660' 1"= 2,000'
- **<u>Chains per Inch</u>:** 1 inch on map equals C chains on ground.
  Examples: 1"= 20 chains 1"= 10 chains 1" = 30.30 chains
- **<u>Inches per Mile</u>**: 1 inch on map equals M miles on ground.
  Examples: 4 inches/mile 8 inches/mile 2.64 inches/mile
- **Meters per Inch:** 1 inch on map equals m meters on ground.
  Examples: 1"=402.336m 1"=201.168m 1"=609.6m
- **<u>Meters per Millimeter</u>:** 1 mm on map equal m meters on ground.
  Examples: 1mm=158.4m 1mm=79.2m 1mm = 240m

Area Scale Expressions:

- **Constants:** 1 acre= 43,560 sq.ft.; 1 acre= 10 sq. chains 1 hectare = 1002 meters = 10,000 sq. meters = 2.47 acres
- **Acres per Square Inch:** 1 square inch on map/photo equals A acres on the ground.
  Examples: 40 ac/sq.in. 100 ac/sq.in. 91.81 ac/sq.in.
- **Hectares per Square Inch:** 1 sq. in. on map/photo equals H hectares on the ground.
  Examples: 16.2 h/sq.in. 40.49 h/sq.in. 37.17 h/sq.in.
- **Hectares per square mm:** 1 sq.mm on map/photo equals h hectares on the ground.
  Examples: 0.0251 h/sq.mm 0.0628 h/sq.mm 0.0576h/sq.mm

Large vs. Small Scale:
Is 1:12,000 larger or smaller than 1:24,000?
Compare on basis of actual number (i.e. fraction)
Example: 1/12,000 is a larger number than 1/24,000.

4.3.2 Topographic /quad maps

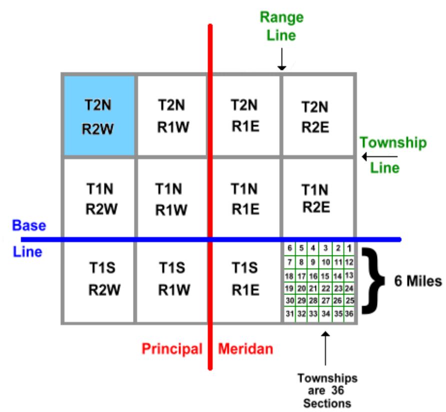
U.S. Geological Survey Map Series:
A quad sheet is a 7.5 minute Topographic Quadrangles. The 7.5 refers to minutes of latitude / longitude coverage where the scale is read as Scale: 1:24,000, and Contour interval: 5 to 20 feet of elevation change.

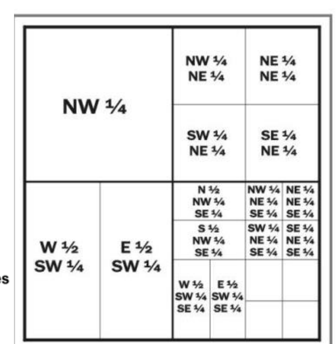
Measuring Distances on a 7.5 min Quad Sheet:

- Scale = 1:24,000 or 1 inch = 2,000 ft.

4.3.3 Public land survey system (PLSS)

- Township and Range Lines
- Township
- Section
- Partial Section - nearest 0.625 acres





Typical Section Subdivisions

4.3.4 Differences between Lat/Long, UTM and PLSS

- Lat/Longs = geographic location coordinates for all projection systems = represent known geographic locations of points on the earth spheroid.

- UTM = artificial grid system for specific projection system.
- PLSS = systematic land partitioning system; not a point location system.

Latitude-Longitude (Lat/Long)

Lat/Longs are the geographic location coordinates expressed in angles, and represent known locations on the earth representation as spheroid (Figure 11). There are parallels of latitude (lines parallel to equator) and meridians/lines of longitude (perpendicular to equator and converging at the poles). Longitude is measured from the prime meridian, while latitude is measured from Ecuator.

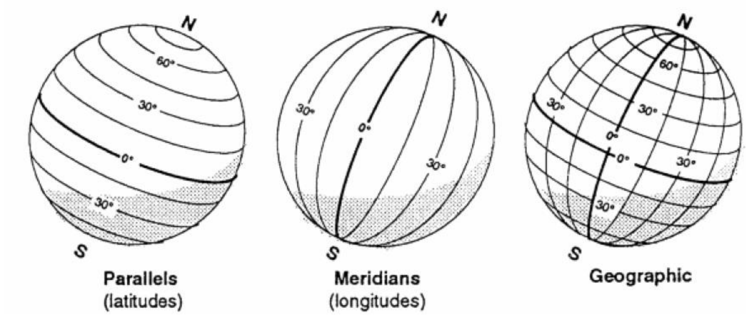


Figure 11Description of Earth using geographic coordinates

Universal Transverse Mercator Grid (UTM grid)

Geographic coordinates does not represents a location in Cartesian coordinates, which makes surficial computations difficult. Therefore, a new set of systems were developed, projected coordinates, which allows a simple determination of land attributes, such as distance or area. One of the most popular projected systems, a system that projects a 3D object on a 2D surface, is the Universal Transverse Mercator system (Figure 12). The UTM system divides the surface of Earth latitude into 60 zones, each 6° of longitude in width. The system start at longitude 180° with zone 1, which is from 180° to 174° West, and increases eastward to zone 60, which covers longitude 174 to 180 East. Each zone is defined by an east and west meridian of longitude and has a central meridian passing through the center of the grid zone; i.e. 3° each side of central meridian. Each zone has its own origin, located at the intersection of the equator and its own central meridian. A false origin for the north half of the zone lies 500,000 m west of the origin. This false origin impede crossing of zone lines.

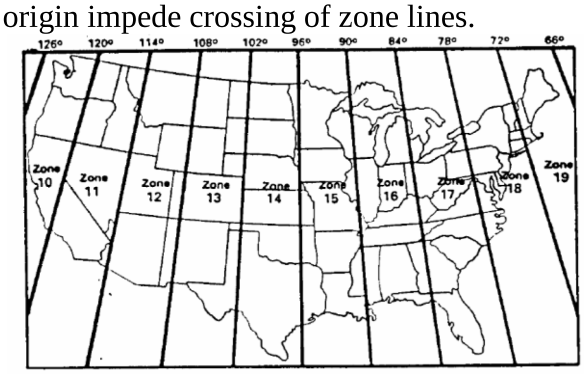


Figure 12Universal Transverse Mercator system that covers the USA

4.3.5 Datums and altitude references

In surveying and geodesy, a datum is a set of reference points located on the surface of the planet used for positional measurements. A datum is commonly associated with a model of the shape of the Earth, also called reference ellipsoid (as the planet is represented by an ellipsoid-Figure 13); model that defines a geographic coordinate system (Figure 14).

A geodetic datum is a mathematical model designed to fit the geoid, defined by the relationship between an ellipsoid and a point on the topographic surface (Figure 14). Horizontal datums are used to describe the location of a point on the surface of the planet either as latitude – longitude or as other coordinate system. Vertical datums measure elevations or depths.

Common Datums:
Current GPS version of the EC Cartesian coordinate system is World Geodetic System (WGS) 84. NAD 83 is very similar to WGS 84, but NAD 27 is very different from both.

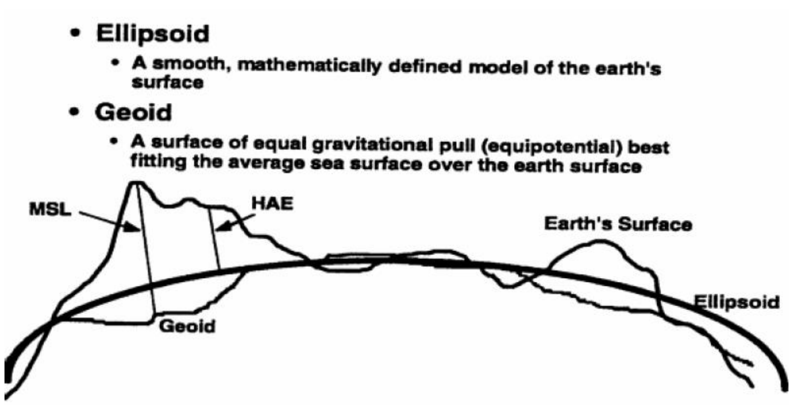


Figure 13. Ellipsoid representing the planet shape

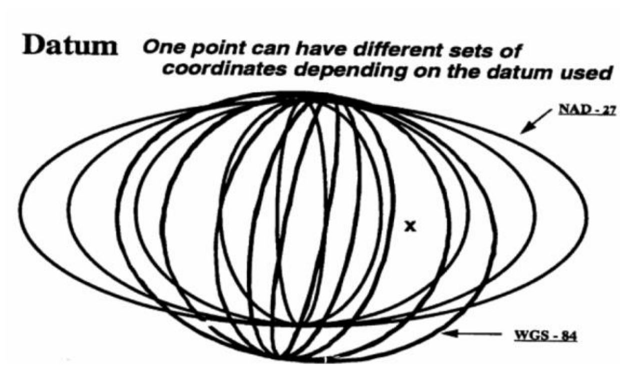


Figure 14. Datum and coordinate of a point

5. FIXED AREA PLOT CRUISE (sampling with probability proportional to frequency)

The main objective of a timber inventory is to provide a detailed assessment of the forest resources existing in an area. The most popular method of executing a forest inventory is by using sampling units that have the same size, more specifically plots with the same area. This method falls under the broad categories of sampling techniques called "Selection with Probability Proportion to Frequency". The selection of the plot size depends on the objective of the forest inventory, and commonly has one of the following preset values: 1/10 ac, 1/5 ac or ¼ ac. An excellent discussion on the selection of plot size can be found in van Laar and Akca (1997) and Husch et al (2002). The details of a forest inventory executed using fixed area plots (such as number of plots, layout, confidence level) can be determined using either a historical approach, which is based on sampling intensity, or a modern approach, which is based on sampling error. The approach using sampling error, which is the current standard in most of the jurisdictions, determine the sample size using preset levels of errors (i.e., sampling error and confidence level), while the approach based on tradition uses preset intensity levels (i.e., a preset percentage from the stand have to be inventoried). As intensity based forest inventory leads to violation of either the required guidelines (i.e., too few plots), or of the needed field effort (i.e., to many plots), most of the current inventories are based on sampling error.

Irrespective the approach used, to complete a forest inventory a series of three steps have to be carried out. The three steps ensuring the successful completion of the inventory are serial (i.e., follow one after other) and cumulative (i.e., each step is based or uses information from the previous step):

1. Cruise design
2. Measurement
3. Cruise computations and reporting

The **Cruise Design** is focused on determining 1) the number of plots required to obtain valid estimates of the attributes for which the forest inventory is carried out, and 2) the location of each plot in the field. Among the three steps Cruise layout is the only one that depends on the approach that will be employed to produce the forest inventory. While for the traditional approach to forest inventory, which is based on preset intensity, the first step is simple, and can be performed without field estimates, the modern approach, requires knowledge of the stand variability, knowledge that commonly is acquired in a pre-cruise, or a reconnaissance cruise.

The **Measurements** step of a forest inventory is focused on the actual determination of the attributes (e.g., dbh, height, or form class) that will be used to estimates the attributes of interest (such as volume or biomass). This step is based almost entirely on the usage of technology, and can be executed by personnel with minimal forestry knowledge.

The **Cruise computations** is the step on which the estimates and their corresponding confidence intervals are determined. This step combines the forest inventory knowledge with statistics and technical writing, as is the step where the values for which the forest inventory was executed are obtained and presented to the beneficiary.

1.1.Traditional method (Intensity based sampling)

You wish to conduct a 5% intensity cruise on a 60-acre tract of pine sawtimber.

5.1.1 Cruise design

Using the remote sensing information supplied by Google Earth you inferred that the stand contain valuable sawtimber trees. Therefore, you decided to use 1/5 acre circular plots.

First you need to determine the number of plots to be measured knowing that 5% of the surface of the stand have to be measured.

Step 1) Determine the number of acres to be sampled:
(cruise intensity %) x (stand's acres) = number of acres to sample

0.05 x 60 = 3 acres to sample

Step 2) Calculate number of plots needed, knowing that
(# of plots in an acre) x (# of acres to sample) = # plots to sample

5 x 3 = 15 plots to sample

To perform the measurements, finally you have to determine the radius of the plot.

To determine the plot radius for a plot with the size *plotsize* you use the formula:

$$r = \sqrt{\frac{plotsize}{\pi}}$$

In this example the *plotsize* = 1/5 acre, therefore $r = \sqrt{\frac{\frac{1}{5} ac \times 43560\ ft^2 / ac}{3.1415926}}$

$$r = 52.660381 \approx 52.7 \text{ feet}$$

Next it should be decided the lay out of the plots in the field, which is executed in two steps:

Step 1) Acres represented by each plot = Representative acres:

(Total acres) / (Number of plots) = Acres represented by each plot
(60 acres) / (15 plots) = 4 acres represented by each plot

Step 2) Spacing between plots:

You would like to place the plots within a grid. To reduce the field measurement errors you would like to have a grid with the cells as close as possible to a square and the sides multiple of one chain (sometimes you would agree with sides that are a multiple of half chain). Therefore, the sides of the grid's cell would be computed using the formula:

$$\text{size of grid's cell} = \text{representative acres} = (\text{int}\sqrt{representative\ acres \times 10})^2$$

Consequently, the side of the grid's cell would be $x = \sqrt{(RA) \times 10}$

where: RA= representative acres,
x = side of the grid's cell = spacing in chains, and
10 = # of ch^2 per acre

So $x = \sqrt{4 \times 10} = 6.32$ ch

Since it would be difficult to place plots on a 6.63 by 6.32 chain grid (hence a possible source of measurements errors), you will chose two numbers that are multipliers of half a chain that would represent the sides of a rectangle resembling the square for which the computations were done. The area covered by the rectangle should cover an area close to the representative area; therefore, in your case a 6 by 6.5 ch grid (6 x 6.5 = 39 ch^2) would ensure the fulfillment of the two conditions mentioned above (quadratic grid and the sides of the grid's cell are multiples of a chain). Consequently, you will have 6.5 chains between lines and 6 chains between plots. You should note that the representative acres under the final spacing (6 x 6.5 chains) decreases from 4 ac to 3.9 acres per plot, which means that each plot represents less area, meaning that the cruise intensity will increase.

Because you are using a grid to perform the measurements, you will be using a systematic sampling design. The systematic sampling design has only one degree of freedom, namely the starting point, which in your case is the location of the first plot. The first plot still has to represent one cell of the grid; therefore, it could be located anywhere inside the cell. However, considering that usually the first plot is close to the stand's edges you would like to avoid the influence of the neighboring stands or opening. Consequently, the plot center is recommended to be placed randomly inside the stand at least one height of the average dominant trees.

A large number of companies do not randomize the location of the first plot but use a deterministic positioning. This is violating the randomness assumption required by the systematic random sampling, but it is popular because allows an easy audit of the cruise. The most common positioning of the first line of the grid places the start at half the line interval inside the stand and the first plot will be placed at half the plot interval inside the stand (Figure 15).

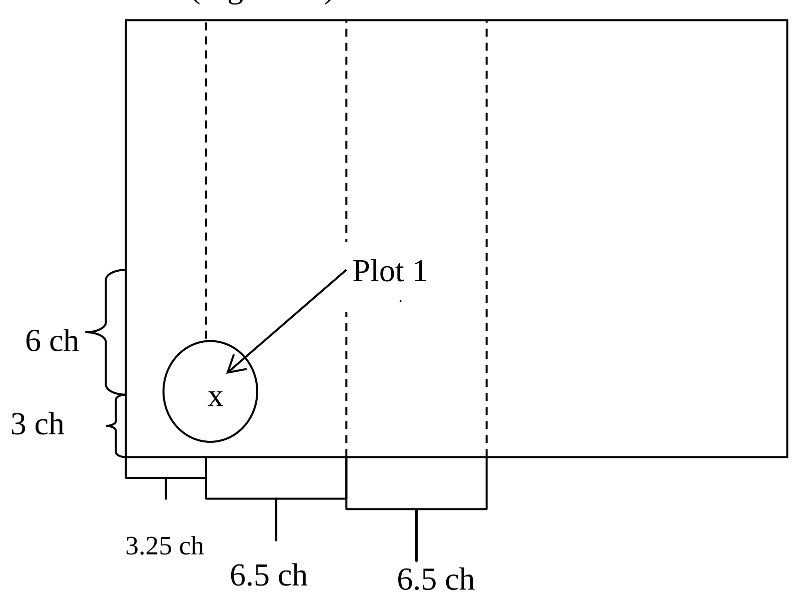


Figure 15. Layout of a cruise

During cruising process, you noticed that at the end of one line the plot is very close to the edge of the tract, and there is the possibility of boundary overlap between the plot and tract. In this case you should use the mirage method developed by Schmid (1969) and described by Beers (1977). The method is presented extensively in the notes, and in the Husch et al (2002) at pages 269-271 and 282.

5.1.2 Measurements

You cruised the stand and the data recorded during the measurements phase is presented in the following tally sheets. For simplification only four tally sheets are presented.

	Plot 1			Plot 2			Plot 3			Plot 4		
	Logs			Logs			Logs			Logs		
DBH	1	2	3	1	2	3	1	2	3	1	2	3
12		•			•	•		•				
14		•				•		•	•		• •	•
16			•		•				•			•

5.1.3 Cruise computations

Using the International 1/4 inch volume table for Girard form class $fc_G = 80$, the tally sheets can be filled with the volumes as:

	Plot 1			Plot 2			Plot 3			Plot 4		
	Logs			Logs			Logs			Logs		
DBH	1	2	3	1	2	3	1	2	3	1	2	3
12		• 98			• 98	• 127		• 98				
14		• 141				• 186		• 141	• 186		• • 141	• 186
16			• 256		• 190				• 256			• 256

Since the plot size is 1/5 acre the tree factor is 5. One should remember that the tree factor acts as an expansion factor from plot level to per unit area level (in this case 1 acre). Considering that inventory based on fixed area plots is based on a sampling scheme which assign each sampling unit the same probability, the tree factor is the ratio between the unit area and plot area, namely TF = 1ac/ (1/5 ac)=5.

Trees Per Acre

You can now do the necessary calculations to fill out the trees per acre column on tally sheets by multiplying the tallied trees in each diameter class by the tree factor as shown:

Plot 1

	Logs			BA per			
DBH	1	2	3	Tree	T/A	BA/A	Vol/A
12		• 98		0.79	5.0		
14		• 141		1.07	5.0		
16			• 256	1.40	5.0		
				Total	15.0		

Plot 2

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98	• 127	0.79	10.0		
14			• 186	1.07	5.0		
16		• 190		1.40	5.0		
				Total	20.0		

Plot 3

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98		0.79	5.0		
14		• 141	• 186	1.07	10.0		
16			• 256	1.40	5.0		
				Total	20.0		

Plot 4

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12				0.79	0.0		
14		• • 141	• 186	1.07	15.0		
16			• 256	1.40	5.0		
				Total	20.0		

Once the TPA for each dbh class and plot are computed you can use the Central Limit Theorem to estimate the actual TPA for the entire stand. The TPA according to CLT is

$$TPA / dbh = \left(\sum_{i=1}^{4} TPA / dbh_{plot\,i} \right) / 4$$

Therefore, for dbh=12” TPA=(5+10+5+0) / 4 plots = 5.0 TPA,

for dbh=14”, TPA=(5+5+10+15)/4 plots= 35 / 4 plots = 8.75 TPA, and

for dbh 16”, TPA= (5+5+5+5)/4 plots = 20 / 4 plots = 5.0 TPA

Basal Area/Acre:

To determine the BA/ac you should multiply the trees per acre for a specific dbh by the basal area of the respective dbh, as shown:

Plot 1

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98		0.79	5.0	3.95	
14		• 141		1.07	5.0	5.35	
16			• 256	1.40	5.0	7.00	
				Total	15.0	16.30	

Plot 2

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98	• 127	0.79	10.0	7.90	
14			• 186	1.07	5.0	5.35	
16		• 190		1.40	5.0	7.00	
				Total	20.0	20.25	

Plot 3

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98		0.79	5.0	3.95	
14		• 141	• 186	1.07	10.0	10.70	
16			• 256	1.40	5.0	7.00	
				Total	20.0	21.65	

Plot 4

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12				0.79	0.0	0.0	
14		• • 141	• 186	1.07	15.0	16.05	
16			• 256	1.40	5.0	7.00	
				Total	20.0	23.05	

Similarly to TPA, BA/ac for the entire stand can be computed using Central Limit Theorem. Therefore, BA/ac for each dbh class is $BA/ac = \left(\sum_{i=1}^{n} BA/ac_{plot\,i} \right) / n$, which in this case is

$$BA/ac = \left(\sum_{i=1}^{4} BA/ac_{plot\,i} \right) / 4 .$$

For dbh=12”, BA/ac = (3.95+7.9+3.95+0)/ 4 plots= 19.8 / 4 plots = 3.95 ft^2/acre,
for dbh=14” trees BA/ac = (5.35+5.35+10.7+16.05) / 4 plots = 37.46 / 4 plots = 9.36 ft^2/acre, and
for dbh=16” BA/ac = (7+7+7+7)/4 plots= 28 / 4 plots = 7.00 ft^2/acre.

Volume/Acre:

Volume per acre for each dbh class is calculated by multiplying the number of trees tallied in the first height for the respective dbh by the tree factor and the tree volume corresponding to the combination dbh class – height, plus the trees tallied in the next height for the same dbh multiplied by the tree factor and the corresponding tree volume and so forth, until all heights for the respective dbh are exhausted.

Plot 1

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98		0.79	5.0	3.95	490
14		• 141		1.07	5.0	5.35	705
16			• 256	1.40	5.0	7.00	1280
				Total	15.0	16.30	2475

Plot 2

DBH	Logs 1	2	3	BA per Tree	T/A	BA/A	Vol/A
12		• 98	• 127	0.79	10.0	7.90	1125
14			• 186	1.07	5.0	5.35	930
16		• 190		1.40	5.0	7.00	950
				Total	20.0	20.25	3005

Plot 3

DBH	Logs 1	2	3	BA per Tree	T/A	BA/A	Vol/A
12		• 98		0.79	5.0	3.95	490
14		• 141	• 186	1.07	10.0	10.70	1635
16			• 256	1.40	5.0	7.00	1280
				Total	20.0	21.65	3405

Plot 4

DBH	Logs 1	2	3	BA per Tree	T/A	BA/A	Vol/A
12				0.79	0.0	0.0	0
14		• • 141	• 186	1.07	15.0	16.05	2340
16			• 256	1.40	5.0	7.00	1280
				Total	20.0	23.05	3620

Similarly to TPA and BA/ac, the volume / ac can be computed appealing to Central Limit Theorem. The volume /ac for each dbh class is computed as the average vol/ac supplied by each plot for the respective dbh class, namely $Vol/ac = \left(\sum_{i=1}^{n} Vol/ac_{plot\,i}\right)/n$, which for this case is $Vol/ac = \left(\sum_{i=1}^{4} Vol/ac_{plot\,i}\right)/4$.

Therefore, for dbh =12”, Vol/ac = (490+1125+490+0) / 4 plots = 2105 / 4 plots = 526.25 bf/acre,
for dbh=14”vol/ac =(705+930+1635+2340) / 4 plots= 5610 / 4 plots = 1402.5 bf/acre , and
for dbh=16” Vol/ac =(1280+950+1280+1280) / 4 plots = 4790 / 4 plots = 1197.5 bf/acre.

The Stand and Stock table can be completed using the calculated figures from above:

DBH	Trees per Acre	Basal Area per Acre (sq ft)	Volume per Acre (bd ft)	Trees per Tract	Volume per Tract (bd ft)
12	5.00	3.93	526.3	300.0	31,572
14	8.75	9.35	1,402.5	525.0	84,150
16	5.00	6.98	1,197.5	300.0	71,850
Totals	18.75	20.26	3,126.3	1125.0	187,578

The figures for trees per tract and volume per tract were obtained by multiplying the values per acre with the size of the tract in acres.

Any stand and stock table should contain the confidence intervals (CI), for the expected means TPA, BA/ac, Vol/ac, Trees per tract and volume / tract. According to the US Forest Service Guidelines the estimates should have a 95% confidence level.

To calculate out CIs you will need to use the tally sheets.

	Plot 1			Plot 2			Plot 3			Plot 4		
	Logs			Logs			Logs			Logs		
DBH	1	2	3	1	2	3	1	2	3	1	2	3
12		1			1	1		1				
14		1				1		1	1		2	1
16			1		1				1			1
	3 trees			4 trees			4 trees			4 trees		

To compute the CI you will need the mean and variance for the attribute of interest, in this case TPA. To determine the variance one could use the simplified formula: $s^2 = \left(\Sigma x^2 - \frac{(\Sigma x)^2}{n} \right) / (n-1)$. Therefore, first determine how many trees were sampled in each plot and the squares of those numbers. Notice that the "x" is the value of plot totals from the tally sheets.

				x	x^2
Plot 1	=	3 tallied trees × 5	=	15	225
Plot 2	=	4 tallied trees × 5	=	20	400
Plot 3	=	4 tallied trees × 5	=	20	400
Plot 4	=	4 tallied trees × 5	=	20	400
				$\Sigma x = 75$	$\Sigma x^2 = 1425$

$\bar{x} = 18.75$ (Note: you can check this number against the stand and stock table)

$$\text{Variance} = s^2 = \frac{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}{n-1} = \frac{1425 - \frac{(75)^2}{4}}{3} = 6.25$$

$$\text{Std Error of the mean} = s_{\bar{x}} = \sqrt{\frac{s^2}{n} \times \frac{N-n}{N}} = \sqrt{\frac{6.25}{4} \times \frac{300-4}{300}} = 1.24$$

N = maximum number of plots that can be located in the tract: $N = A_{tract} / A_{plot} = 60/.2 = 300$
n = number of measured plots, in this case 4.

CI is $\bar{x} \pm (t_{(0.05,\, n-1)})(s_{\bar{x}})$ [t-value from Appendix Table 6, page 426 in Husch et al (2001)]
$t_{(0.05,\, n-1)} = t_{(0.05,\, 3)} = 3.182$

= 18.75 ± (3.182)(1.24)

= 18.75 ± 3.945

This means that you can state with 95% confidence that true mean number of trees per acre lies within ± 3.9775 of the mean estimated by our sample, or in other words, the true mean is somewhere between 14.8 and 22.7 trees per acre. For the *per tract* CIs, just multiply the CI per acre by the tract acres: 1125±237.

Similar computation would be computed for BA and volume per acre. For BA the variance is

$$s^2 = \frac{\sum_{i=1}^{4}(BA_i - \overline{BA})^2}{4-1} = \frac{(16.3-20.26)^2+..+(23.05-20.26)^2}{3} = 8.46$$

The standard error of the mean BA is: $s_{\overline{BA}} = \sqrt{\frac{s^2}{n} \times \frac{N-n}{N}} = \sqrt{\frac{8.46}{4} \times \frac{300-4}{300}} = 1.44$

Finally, the confidence interval for the BA is

$$\overline{BA} \pm t_{0.05,n-1} s_{\overline{BA}} = 20.26 \pm 3.182 \times 1.44 = 20.26 \pm 4.6$$

For volume the variance is

$$s^2 = \frac{\sum_{i=1}^{4}(V_i - \overline{V})^2}{4-1} = \frac{(2475-3126.3)^2+..+(3620-3126.3)^2}{3} = 253439$$

The standard error of the mean V is: $s_{\overline{V}} = \sqrt{\frac{s^2}{n} \times \frac{N-n}{N}} = \sqrt{\frac{8.46}{4} \times \frac{300-4}{300}} = 250$

Finally, the confidence interval for the V is

$$\bar{V} \pm t_{0.05,n-1} s_{\overline{V}} = 3126.3 \pm 3.182 \times 250 = 20.26 \pm 795.7$$

The complete Stand and Stock Table is:

DBH	Trees per Acre	Basal Area per Acre (sq ft)	Volume per Acre (bd ft)	Trees per Tract	Volume per Tract (bd ft)
12	5.00	3.93	526.3	300.0	31,572
14	8.75	9.35	1,402.5	525.0	84,150
16	5.00	6.98	1,197.5	300.0	71,850
Totals	18.75	20.26	3,126.3	1125.0	187,578
$CI_{95\%}$	±3.95	±4.6	±795.7	±237	±47,742

This form of the Stand and Stock table completes the computations associated with the traditional way of executing a timber inventory using fixed area plots.

5.2 Sampling error based method (guideline method)

You wish to determine the volume of a 60 ac tract of pine sawtimber. The results should meet the US Forest Service guidelines.

5.2.1 Cruise design

According to the US Forest Service guidelines the estimates should have a confidence level should be 95%. To determine the values of the two statistics needed in computations, namely the coefficient of variation and the sampling error, a preliminary cruise will be performed.

You have used Google Earth to identify the tract, and from the Louisiana Atlas website you have downloaded the DOQQ images were the tract is located. Based on Google Earth images you have concluded that the tract is relatively homogenous in term of size and species, and a simple random sampling procedure could be used to determine the sawtimber volume. With this information, you decided to use 1/5 acre circular plots, similar to the size of the plots used by the Continuous Forest Inventory system.

Based on the above information you travel to the tract to perform the preliminary cruise, also known as pre-cruise or reconnaissance cruise. The visual assessment of the stand in the field confirms the homogeneity of the stand inferred on the Goggle Earth images. Therefore, you decide to use five (5) plots laid out in a systematic pattern to determine the two statistics of interest: coefficient of variation and sampling error. The number of plots is in agreement with the USFS guideline FSM 2442.04, which recommends the measurement of a minimum of five plots (one being a mirage plot) and at least 50 trees. Considering all the above conditions, the layout of the preliminary cruise is determined as following:

- Determine the area represented by each plot:

$$A_{represented\ by a\ plot} = \frac{A_{tract}}{\#\ plots} = \frac{60}{5} = 12\ ac = 120\ square\ chains$$

- Determine the spacing between the plots:

$$Distance\ \ between\ \ plots = \text{int}(\sqrt{A_{represented\ by a\ plot}}) = \text{int}\sqrt{120} = 10\,chains$$

$$Distance\ between\ lines = \text{int}\frac{A_{represented\ by a\ plot}}{distance\ between\ plots} = \frac{120}{10} = 12\ chains$$

To ensure that you have a mirage plot you can place the center of the first plot on the boundary of the tract. The center of the plot on tract's boundary is determined by selecting one random number smaller than 12. This selection will ensure that the first plot is located within 12 chains from the next line of plots. Let assume that the random numbers are 3. Therefore, you will place the center of the first plot 3 chains from a randomly selected corner of the tract, on the boundary of the tract. The second plot will be placed 10 chains from the first plot in a direction easy to follow, let say north. The third plot will be placed on the same direction but 10 chains from the second plot and so forth. If the line will encounter the tract's boundary before you walked 10 chains, let say 8 chains, you will walk 12 chains on a perpendicular direction, let say east, and from the edge of the tract you will measure 2 chains on the south direction. You will repeat the above steps until you will measure all five plots.

The layout of the preliminary cruise could be like in the following drawing (Figure 16):

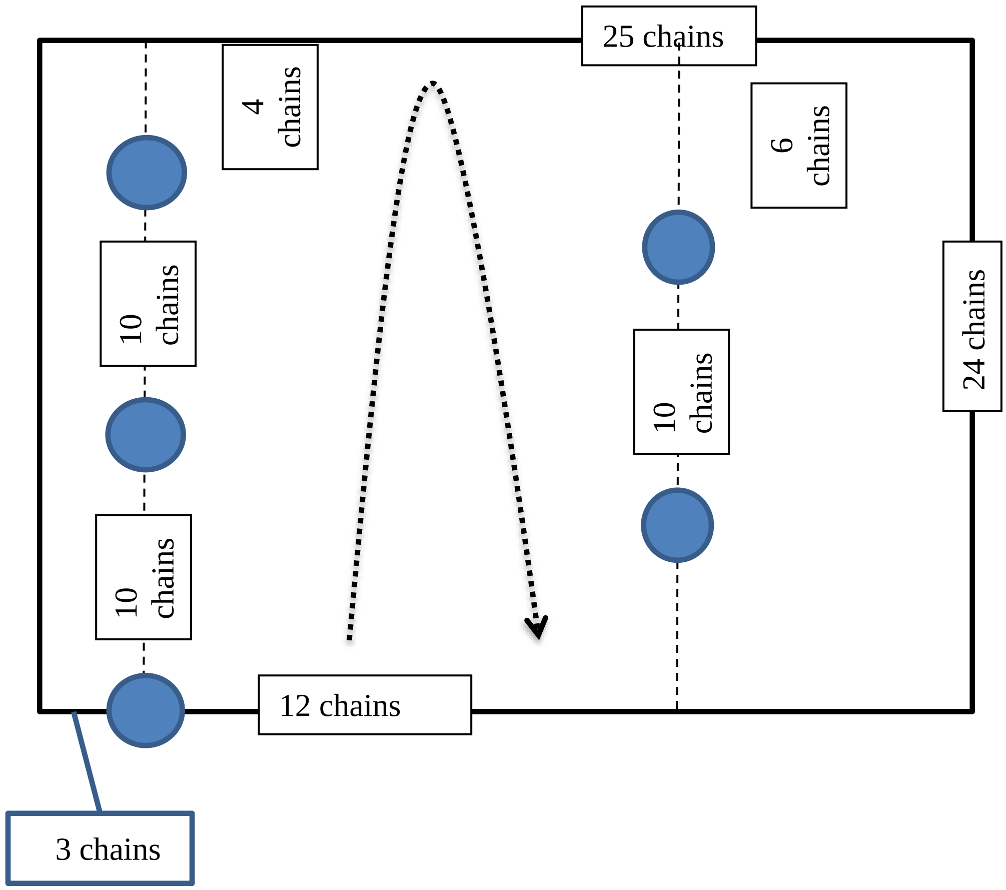


Figure 16. Layout of a preliminary cruise with 5 plots, one a border plot, on a tract of 60 ac.

The radius of a circular plot with area 1/5 ac = 0.2 ac =0.2 x 43560 ft^2 = 8712 ft^2 is

$$r = \sqrt{\frac{A_{plot}}{\pi}} = \sqrt{\frac{8712}{3.141}} = 52.7\,ft$$

5.2.2 Measurements

The procedures used to measures different tree attributes (such as dbh, height or form class) are presented in Chapter 2.

With the above information you start the preliminary cruise, and obtained the following tally sheets:

	Plot 1 Logs			Plot 2 Logs			Plot 3 Logs			Plot 4 Logs			Plot 5 Logs		
DBH	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
12		•			•			•	•		•				
14			•		•				•		•	•		• •	•
16			•			•		•				•			•

5.2.4 Cruise computations

Using the International 1/4 inch volume table for Girard form class $fc_G = 80$, you can fill in the cell volumes as:

	Plot 1 Logs			Plot 2 Logs			Plot 3 Logs			Plot 4 Logs			Plot 5 Logs		
DBH	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
12		•98			•98			•98	•127		•98				
14			•186		•141				•186		•141	•186		•141 •	•186
16			•256			•256		•190				•256			•256

Since our plot size is 1/5 acre the tree factor is 5.

Considering that this is a preliminary cruise you are not interested in all the details of the stand and stock table, only the volume. Therefore, you will not compute the TPA and basal area at this stage.

The volume per acre for each dbh is calculated by multiplying the volumes of the trees with same dbh (i.e., product of the tallied trees with same height with the volume of a tree with the specified dbh and height) with the expansion factor. The volume per acre given by a plot is simply the sum of the volumes corresponding to all dbhs.

Plot 1

	Logs				
DBH	1	2	3	TF	Vol/ac
12		• 98		5.0	490
14			• 186	5.0	930
16			• 256	5.0	1280
					2700

Plot 2

	Logs				
DBH	1	2	3	TF	Vol/ac
12		• 98		5.0	490
14		• 141		5.0	705
16			• 256	5.0	1280
					2475

Plot 3

	Logs				
DBH	1	2	3	TF	Vol/ac
12		• 98	• 127	10.0	1125
14			• 186	5.0	930
16		• 190		5.0	950
					3005

Plot 4

DBH	Logs 1	Logs 2	Logs 3	TF	Vol/ac
12		• 98		5.0	490
14		• 141	• 186	10.0	1635
16			• 256	5.0	1280
					3405

Plot 5

DBH	Logs 1	Logs 2	Logs 3	TF	Vol/ac
12				0.0	0
14		• • 141	• 186	15.0	2340
16			• 256	5.0	1280
					3620

With the above information the mean and the standard deviation of the volume/acre is determined.

The mean volume per acre is: $\bar{V} = \frac{\sum_{i=1}^{5} V_{plot\,i}}{5} = \frac{2700+2475+3005+3405+3620}{5} = 3041\ bd.ft.$

The standard deviation is consequently:

$$s = \sqrt{\frac{\sum_{i=1}^{5}(V_i - \bar{V})^2}{5-1}} = \sqrt{\frac{(2700-3041)^2 + (2475-3041)^2 + (3005-3041)^2 + (3405-3041)^2 + (3620-3041)^2}{4}}$$

$$s = 475.83$$

Finally, the coefficient of variation is:

$$CV = \frac{s}{\bar{V}} = \frac{475.83}{3041} = 15.6\%$$

The estimated tract volume is: $V_{tract} = \bar{V} / ac \times A_{tract} = 3041 \times 60 = 182460\ bd.ft.$

The estimated timber sale, according to the Louisiana Quarterly Report of Forest Products, volume 57 report 1, the stumpage price is \$261.3 / 1000 bd. ft., which makes the value of the tract 182,460 bd. ft. x \$261.3 / 1000 bd. ft.=\$47,676. According to the US Forest service guidelines, a tract with this value should be inventoried using a sampling error of 16%.

You have now all the information needed to determine the number of plots to perform the cruise that will provide estimates within the USFS guidelines:

- CV = 15.6 %
- SE = 16 %
- CL = 0.95 →α=0.05

The formula used to determine the number of plots layout in a systematic sampling design, therefore the sampling will be without replacement:

$$n = \frac{1}{\left(\frac{SE}{t \times CV}\right)^2 + \frac{1}{N}}$$

where N is the maximum number of plots that can be sampled, assuming census.

Therefore, $N = \frac{A_{tract}}{A_{plot}} = \frac{60}{0.2} = 300$

Consequently, the number of plots to be measures, if n>30, is:

$$n = \frac{1}{\left(\frac{16}{1.96 \times 15.6}\right)^2 + \frac{1}{300}} = \frac{1}{0.27383 + 0.003333} = 3.6 \approx 4$$

In the computations of n we assumed that the degrees of freedom for the t-value is large (e.g., n>30), which was contradicted by the final results. Therefore, we have to iterate in respect with n until we will have agreement between the degrees of freedom and the number of plots. The iteration process repeats the computations of the number of plots to be measured, assuming that the last estimate is correct. The convergence property of the hyperbolic function ensures that after a certain number of iteration (i.e., repetitions) the degrees of freedoms used to select t will not conflict with the number of plots.

Therefore, assume now that n=4 is correct $\rightarrow t_{4-1,0.05} = 3.182$

With the new t you re-compute the number of plots:

$$n = \frac{1}{\left(\frac{16}{3.182 \times 15.6}\right)^2 + \frac{1}{300}} = \frac{1}{0.1039 + 0.003333} = 9.3 \approx 10$$

As the starting n was 4 and the computed n was 10, you should continue to iterate assuming that n=10 is now the correct n. The t-value for DF=10-1=9 is 2.262

$$n = \frac{1}{\left(\frac{16}{2.262 \times 15.6}\right)^2 + \frac{1}{300}} = \frac{1}{0.20559 + 0.003333} = 4.8 \approx 5$$

As staring n=10 is different than final n=5, you should continue to iterate, assuming that n=5 is the correct n. The t-value for the new DF=5-1=4 is 2.776

$$n = \frac{1}{\left(\frac{16}{2.776 \times 15.6}\right)^2 + \frac{1}{300}} = \frac{1}{0.13651 + 0.003333} = 7.1 \approx 8$$

Again, starting and final n are different, which force you to continue iterating, now assuming n=8. The t-value for the new DF=8-1=7 is 2.364

$$n = \frac{1}{\left(\frac{16}{2.364 \times 15.6}\right)^2 + \frac{1}{300}} = \frac{1}{0.17568 + 0.003333} = 5.2 \approx 6$$

As 8 and 6 are different more than 1 unit, you should continue iterations. The t-value for the new DF=6-1=5 is 2.57

$$n = \frac{1}{\left(\frac{16}{2.57 \times 15.6}\right)^2 + \frac{1}{300}} = \frac{1}{0.15926 + 0.003333} = 6.1 \approx 7$$

You reached a point when the difference between the assumed degrees of freedom and determined the degrees of freedom is 1, and the computations are varying around 7, meaning from DF=6 to DF=7. Therefore, the number of plots that would ensure the required confidence level (i.e., 95%) is n=7.

With this information you will layout the cruise:

- Determine the area represented by each plot:
  $$A_{represented\ by\ a\ plot} = \frac{A_{tract}}{\#\ plots} = \frac{60}{7} = 8.5\ ac = 85.72\ square\ chains$$
- Determine the spacing between the plots:
  $$Distance\ between\ plots = \text{int}(\sqrt{A_{represented\ by\ a\ plot}}) = \text{int}\sqrt{85.72} = 9\ chains$$

$$Distance\ between\ lines = \text{int}\frac{A_{represented\ by\ a\ plot}}{distance\ between\ plots} = \frac{85.72}{9} = 9.5\ chains$$

Because you are using a grid to perform the measurements, you will be using a systematic sampling design. The systematic sampling design has only one degree of freedom, namely the starting point, which in your case is the location of the first plot. The first plot still has to represent one cell of the grid; therefore, it could be located anywhere inside the cell. However, considering that usually the first plot is close to the stand's edges you would like to avoid the influence of the neighboring stands or opening. Consequently, the plot center is recommended to be placed randomly inside the stand at least one height of the average dominant trees.

A large number of companies do not randomize the location of the first plot but use a deterministic positioning. This is violating the randomness assumption required by the systematic random sampling but allows an easy audit of the cruise. The most common positioning of the first line of the grid places the start at half the line interval inside the stand and the first plot will be placed at half the plot interval inside the stand (Figure 17):

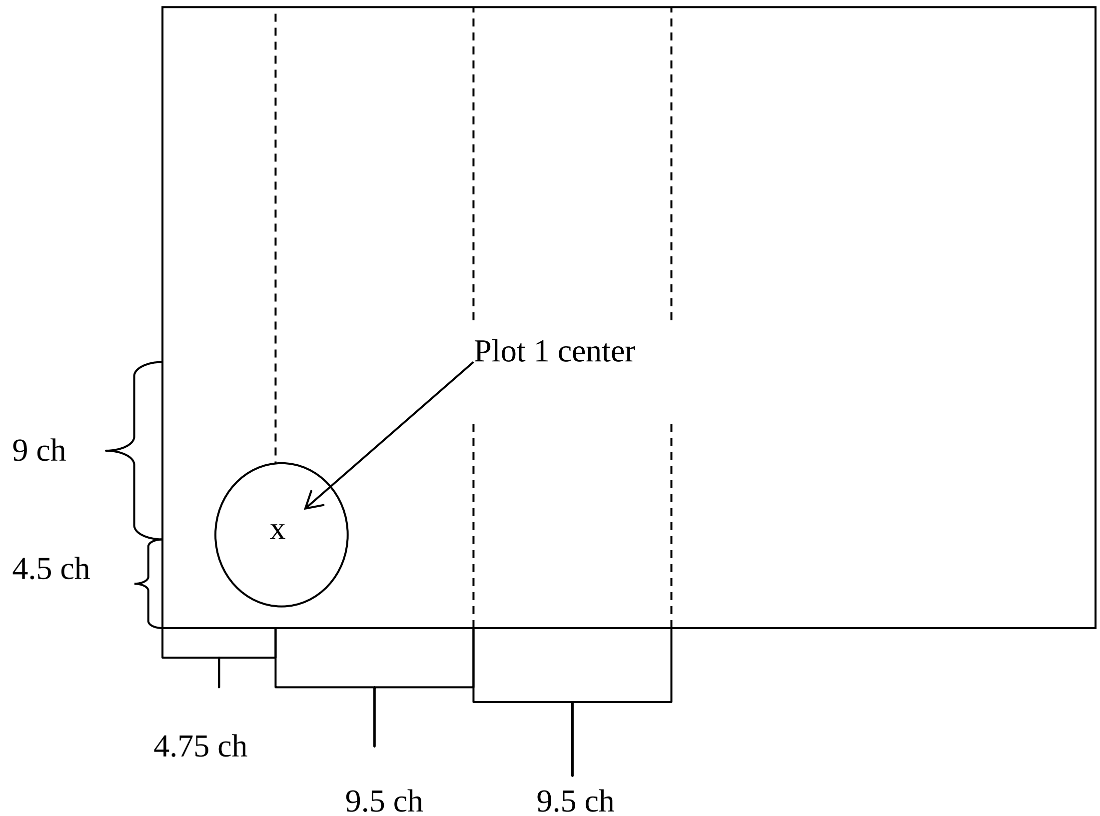


Figure 17. Layout of a cruise with 7 plots on a tract of 60 ac.

During cruising process, you noticed that at the end of one line the plot is very close to the edge of the tract, and there is the possibility of boundary overlap between the plot and tract. In this case you should use the mirage method developed by Schmid (1969) and described by Beers (1997). The method is presented extensively in the notes, and in the Husch et al. 2001at pages 269-271 and 282.

For simplicity, the following computations are presented assuming that only 4 plots were measured (not 7), as required for the actual cruise. For a different number of plots, the computations are similar with the one presented subsequently, the only change being the number of plots.

After the stand was cruised, the volume of each tree was filled in the corresponding cell from the tally sheet. Consequently, the estimation of trees/ac, basal area /ac and volume/ac can be completed.

Trees Per Acre

You can now do the necessary calculations to fill out the trees per acre column on the tally sheets by multiplying the tallied trees in each diameter class by the tree factor as shown:

Plot 1

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98		0.79	5.0		
14		• 141		1.07	5.0		
16			• 256	1.40	5.0		
				Total	15.0		

Plot 2

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98	• 127	0.79	10.0		
14			• 186	1.07	5.0		
16		• 190		1.40	5.0		
				Total	20.0		

Plot 3

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98		0.79	5.0		
14		• 141	• 186	1.07	10.0		
16			• 256	1.40	5.0		
				Total	20.0		

Plot 4

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12				0.79	0.0		
14		• • 141	• 186	1.07	15.0		
16			• 256	1.40	5.0		
				Total	20.0		

Once the TPA for each dbh class and plot are computed you can use the Central Limit Theorem to estimate the actual TPA for the entire stand. The TPA according to CLT is

$$TPA/dbh = \left(\sum_{i=1}^{4} TPA/dbh_{plot\,i} \right) / 4$$

Therefore, for dbh = 12”, TPA = (5+10+5+0)/ 4 plots = 20 / 4 plots = 5.0 TPA
for dbh = 14”, TPA =(5+5+10+15)/4 plots = 35 / 4 plots = 8.75 TPA

for dbh = 16”, TPA = (5+5+5+5)/4 plots = 20 / 4 plots = 5.0 TPA.

Basal Area/Acre:

To determine the BA/ac for each plot and dbh class, you should multiply the trees per acre for the respective dbh class with the basal area of the dbh class under consideration, as shown:

Plot 1

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98		0.79	5.0	3.95	
14		• 141		1.07	5.0	5.35	
16			• 256	1.40	5.0	7.00	
				Total	15.0	16.30	

Plot 2

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98	• 127	0.79	10.0	7.90	
14			• 186	1.07	5.0	5.35	
16		• 190		1.40	5.0	7.00	
				Total	20.0	20.25	

Plot 3

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98		0.79	5.0	3.95	
14		• 141	• 186	1.07	10.0	10.70	
16			• 256	1.40	5.0	7.00	
				Total	20.0	21.65	

Plot 4

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12				0.79	0.0	0.0	
14		• • 141	• 186	1.07	15.0	16.05	
16			• 256	1.40	5.0	7.00	
				Total	20.0	23.05	

Similarly to TPA, BA/ac for the entire stand can be computed using Central Limit Theorem. Therefore, BA/ac for each dbh class is $BA/ac = \left(\sum_{i=1}^{n} BA/ac_{plot\,i} \right) / n$, which in this case is

$$BA/ac = \left(\sum_{i=1}^{4} BA/ac_{plot\,i} \right) / 4 .$$

For dbh=12”, BA/ac = (3.95+7.9+3.95+0)/ 4 plots= 19.8 / 4 plots = 3.95 ft^2/acre,
for dbh=14” trees BA/ac = (5.35+5.35+10.7+16.05) / 4 plots = 37.46 / 4 plots = 9.36 ft^2/acre, and
for dbh=16” BA/ac = (7+7+7+7)/4 plots= 28 / 4 plots = 7.00 ft^2/acre.

Volume/Acre:
For any given dbh class, the volume per acre is calculated by multiplying the number of trees tallied in the first height by the tree factor and the tree volume that correspond to respective combination dbh class – height plus the trees tallied in the next height multiplied by the tree factor and the corresponding tree volume and so forth, until all heights are exhausted.

Plot 1

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98		0.79	5.0	3.95	490
14		• 141		1.07	5.0	5.35	705
16			• 256	1.40	5.0	7.00	1280
				Total	15.0	16.30	2475

Plot 2

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98	• 127	0.79	10.0	7.90	1125
14			• 186	1.07	5.0	5.35	930
16		• 190		1.40	5.0	7.00	950
				Total	20.0	20.25	3005

Plot 3

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12		• 98		0.79	5.0	3.95	490
14		• 141	• 186	1.07	10.0	10.70	1635
16			• 256	1.40	5.0	7.00	1280
				Total	20.0	21.65	3405

Plot 4

DBH	Logs 1	Logs 2	Logs 3	BA per Tree	T/A	BA/A	Vol/A
12				0.79	0.0	0.0	0
14		• • 141	• 186	1.07	15.0	16.05	2340
16			• 256	1.40	5.0	7.00	1280
				Total	20.0	23.05	3620

Similarly to TPA and BA/ac, the volume / ac can be computed appealing to Central Limit Theorem. The volume /ac for each dbh class is computed as the average vol/ac supplied by each plot for the respective dbh class, namely $Vol/ac = \left(\sum_{i=1}^{n} Vol/ac_{plot\,i}\right)/n$, which for this case is $Vol/ac = \left(\sum_{i=1}^{4} Vol/ac_{plot\,i}\right)/4$.

Therefore, for dbh =12", Vol/ac = (490+1125+490+0) / 4 plots = 2105 / 4 plots = 526.25 bf/acre,
for dbh=14"vol/ac =(705+930+1635+2340) / 4 plots= 5610 / 4 plots = 1402.5 bf/acre , and

for dbh=16" Vol/ac =(1280+950+1280+1280) / 4 plots = 4790 / 4 plots = 1197.5 bf/acre.

The Stand and Stock table can be completed using the calculated figures from above:

DBH	Trees per Acre	Basal Area per Acre (sq ft)	Volume per Acre (bd ft)	Trees per Tract	Volume per Tract (bd ft)
12	5.00	3.93	526.3	300.0	31,572
14	8.75	9.35	1,402.5	525.0	84,150
16	5.00	6.98	1,197.5	300.0	71,850
Totals	18.75	20.26	3,126.3	1125.0	187,578

Any stand and Stock Table should contain the confidence intervals (CI), for the means TPA, BA/ac, Vol/Ac. Trees/tract and volume / tract. According to the US Forest Service Guidelines the estimates should have a 95% confidence level.

To calculate the CIs the tally sheets will be used.

	Plot 1			Plot 2			Plot 3			Plot 4		
	Logs			Logs			Logs			Logs		
DBH	1	2	3	1	2	3	1	2	3	1	2	3
12		1			1	1		1				
14		1				1		1	1		2	1
16			1		1				1			1
	3 trees			4 trees			4 trees			4 trees		

To compute the CI you will need the mean and variance for the attribute of interest, in this case TPA. To determine the variance one could use the simplified formula: $s^2 = \left(\Sigma x^2 - \frac{(\Sigma x)^2}{n} \right) / (n-1)$. Therefore, first determine how many trees were sampled in each plot and the squares of those numbers. Notice that the "x" is the value of plot totals from the tally sheets.

				x	x^2
Plot 1	=	3 tallied trees × 5	=	15	225
Plot 2	=	4 tallied trees × 5	=	20	400
Plot 3	=	4 tallied trees × 5	=	20	400
Plot 4	=	4 tallied trees × 5	=	20	400
				$\Sigma x = 75$	$\Sigma x^2 = 1425$

$$\overline{TPA} = \sum x / 4 = 18.75$$

Note: The average TPA can be checked against the value from the Stand and Stock table.

$$\text{Variance} = s^2 = \frac{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}{n-1} = \frac{1425 - \frac{(75)^2}{4}}{3} = 6.25$$

$$\text{Std Error of the mean} = s_{\bar{x}} = \sqrt{\frac{s^2}{n} \times \frac{N-n}{N}} = \sqrt{\frac{6.25}{4} \times \frac{300-4}{300}} = 1.24$$

N = maximum number of plots that can be located in the tract: $N=A_{tract} / A_{plot}$ = 60/.2 =300
n = number of measured plots, in this case 4.

CI is $\bar{x} \pm (t_{(0.05,\, n-1)})\,(s_{\bar{x}})$ [t-value from Appendix Table 6, page 426 in Husch et al (2001)]

= 18.75 ± (3.182)(1.24) = 18.75 ± 3.945

This means that you can state with 95% confidence that true mean number of trees per acre lies within ±3.9775 of the mean estimated by our sample, or in other words, the true mean is somewhere between 14.8 and 22.7 trees per acre. For the *per tract* CIs, just multiply the CI per acre by the tract acres: 1125±237.

Similar computation would be computed for BA and volume per acre. For BA the variance is

$$s^2 = \frac{\sum_{i=1}^{4}(BA_i - \overline{BA})^2}{4-1} = \frac{(16.3-20.26)^2 + .. + (23.05-20.26)^2}{3} = 8.46$$

The standard error of the mean BA is: $s_{\overline{BA}} = \sqrt{\frac{s^2}{n} \times \frac{N-n}{N}} = \sqrt{\frac{8.46}{4} \times \frac{300-4}{300}} = 1.44$
Finally, the confidence interval for the BA is

$$\overline{BA} \pm t_{0.05,n-1} s_{\overline{BA}} = 20.26 \pm 3.182 \times 1.44 = 20.26 \pm 4.6$$

For volume the variance is

$$s^2 = \frac{\sum_{i=1}^{4}(V_i - \overline{V})^2}{4-1} = \frac{(2475-3126.3)^2 + .. + (3620-3126.3)^2}{3} = 253439$$

The standard error of the mean V is: $s_{\overline{V}} = \sqrt{\frac{s^2}{n} \times \frac{N-n}{N}} = \sqrt{\frac{8.46}{4} \times \frac{300-4}{300}} = 250$

Finally, the confidence interval for the V is

$$\bar{V} \pm t_{0.05,n-1} s_{\overline{V}} = 3126.3 \pm 3.182 \times 250 = 20.26 \pm 795.7$$

The complete Stand and Stock Table is:

DBH	Trees per Acre	Basal Area per Acre (sq ft)	Volume per Acre (bd ft)	Trees per Tract	Volume per Tract (bd ft)
12	5.00	3.93	526.3	300.0	31,572
14	8.75	9.35	1,402.5	525.0	84,150
16	5.00	6.98	1,197.5	300.0	71,850
Totals	18.75	20.26	3,126.3	1125.0	187,578
$CI_{95\%}$	±3.95	±4.6	±795.7	±237	±47,742

This form of the Stand and Stock table completes the computations associated with the sampling error based estimates of a timber inventory using fixed area plots.

6. VARIABLE RADIUS PLOT CRUISING (sampling with probability proportional to size)

The main objective of a timber inventory is to provide a detailed assessment of the forest resources existing in an area. The most popular method of executing a forest inventory is by using sampling units that have the same size, more specifically plots with the same area. The section of the plot size depends on the objective of the forest inventory, and commonly has one of the following preset values of 1/10 ac, 1/5 ac or ¼ ac. An excellent discussion on the selection of plot size can be found in van Laar and Akca (1997) and Husch et al (2002). The details of a forest inventory executed using fixed area plots (such as number of plots, layout, confidence level) can be determine using either a historical approach, which is based on sampling intensity, or a modern approach, which is based on sampling error. The approach using sampling error, which is the current standard in most of the jurisdictions, determine the sample size using preset levels of errors (i.e., sampling error and confidence level), while the approach based on tradition uses preset intensity levels (i.e., a preset percentage from the stand have to be inventoried). As intensity based forest inventory leads to violation of either the required guidelines (i.e., too few plots), or of the needed field effort (i.e., to many plots), most of the current inventories are based on sampling error.

Irrespective the approach used, to complete a forest inventory a series of three steps have to be carried out. The steps ensuring the successful completion of the inventory are serial (i.e., follow one after other) and cumulative (i.e., each step is based or uses information from the previous step):

1. Cruise layout
2. Measurement
3. Cruise computations and reporting

The **<u>Cruise design</u>** is focused on determining 1) the number of plots required to obtain valid estimates of the attributes for which the forest inventory is carried out, and 2) the location of each plot in the field. Among the three steps Cruise layout is the only one that depends on the approach that will be employed to produce the forest inventory. While for the traditional approach to forest inventory, which is based on preset intensity, the first step is simple, and can be performed without field estimates, the modern approach, which requires knowledge of the stand variability, knowledge that commonly are acquired in a pre-cruise, or a reconnaissance cruise.

The **<u>Measurements</u>** step of a forest inventory is focused on the actual determination of the attributes (e.g., dbh, height, or form class) that will be used to estimates that attributes of interest (such as volume or biomass). This step is based almost entirely on the usage of technology, and can be executed by personnel with minimal forestry knowledge.

The **<u>Cruise computations</u>** is the step on which the estimates and their corresponding confidence intervals are determined. This step combines the forest inventory knowledge with statistics and technical writing, as is the step where the values for which the forest inventory was executed are obtained and presented to the beneficiary.

6.1 Traditional method (rule of thumb)

You would like to conduct a point cruise on a client's 30-acre tract of pine sawtimber. Using information from the Forest Inventory and Analysis database you computed the average DBH of the stands in the area and decided to use a prism with the BAF 10.

6.1.1 Cruise design

The first step in cruising is to determine the number of plots that would be measured. You decide that rather than using a sample in the field and compute the sample size you would use the rule of thumb mentioned by Hush et al (2003) (page 344) to determine how many plots to sample:

If area in acres is:	Number of plots should be:
Less than 10	10
11-40	1 per acre
41-80	20 + 0.5 × (area in acres - 40)
81-200	40 + 0.25 × (area in acres - 80)
over 200	Use the formula (Chapter 6.2)

Considering that the tract is 30ac, you should measure 30 plots. However, in this example, for simplicity you only 4 plots will be used. To layout the plots the same procedure as for fixed area plot sampling will be followed:

Step 1) Acres represented by each plot = Representative acres:

(Total acres) / (Number of plots) = Acres represented by each plot

(30 acres) / (4 plots) = 7.5 acres represented by each plot

Step 2) Spacing between plots:

You would like place the plots within a grid. To reduce the field measurement errors you would like to have a grid with the cells as close as possible to a square and the sides multiple of one chain (sometimes you would agree with sides that are a multiple of half chain). Therefore, the sides of the grid's cell would be computed using the formula:

$$\text{size of grid's cell} = \text{representative acres} = \left(\operatorname{int}\sqrt{\textit{representative acres} \times 10}\right)^2$$

Therefore one side of the grid's cell would be $x = \operatorname{int}\sqrt{(RA) \times 10}$

where: RA= representative acres,
x = side of the grid's cell = spacing in chains, and
10 = # of ch^2 per acre

So x = $\sqrt{7.5 \times 10}$

x = 8.66 ch

Since it would be difficult to place plots on an 8.66 by 8.66 chain grid (hence a possible source of measurements errors), you will chose two integers that would represent the sides of a rectangle resembling the square for which the computations were done. The area covered by the rectangle should cover an area close to the representative area; therefore, in your case a 8 by 9 ch grid (8 x 9 = 72) would ensure the fulfillment of the two conditions mentioned above (quadratic grid and the sides of the grid's cell are multiples of a chain). Therefore we will have 9 chains between lines and 8 chains between plots. You should note that the representative acres under the final spacing (8 x 9 chains) decreases from 7.5 ac to 7.2 acres per plot, which means that each plot represents less area, hence the actual cruise intensity will increase.

The selection of the starting plot should be randomly located inside a rectangular area with the sides the computed spacing (i.e., any location starting from one corner of the stand that is within distance between lines and between plots). However, most inventories use a deterministic approach of identifying the starting plot of the cruise. The first line will start at half the line interval inside the stand and the first plot will be placed at half the plot interval inside the stand. This procedure violates the sampling requirements but allows for fast audit of the cruise, reason that it is preferred in industry (Figure 18).

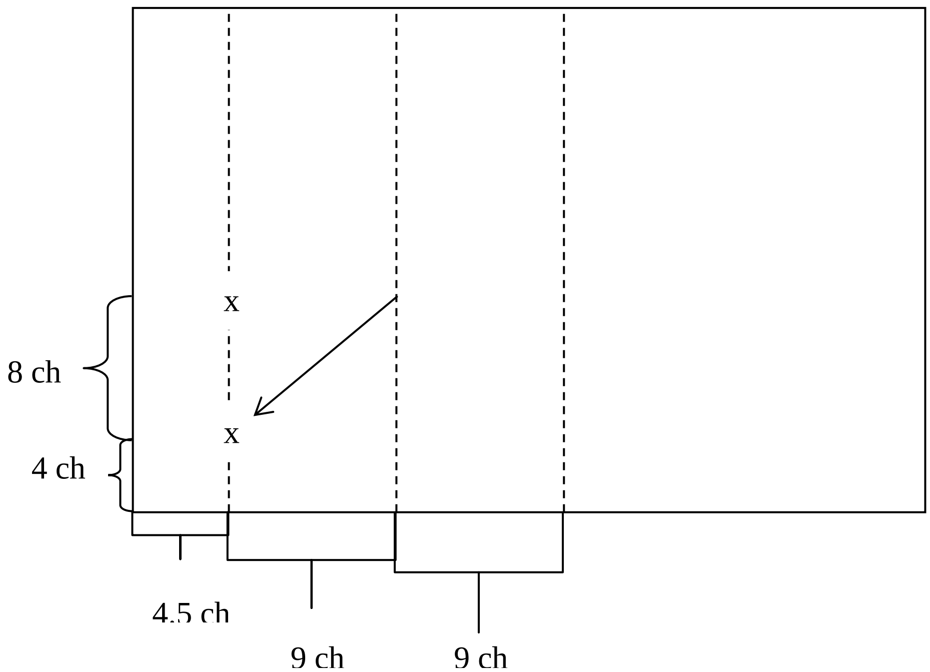


Figure 18. Layout of cruise with 7 plots on a 30 ac tract.

6.1.2 Measurements

The measurements carried at each location are performed using the procedures presented in Chapter 2. At the sampling unit level (i.e., plot) additionally will be recorded the number of the unit, and if necessary other sampling details such as the stratum (if stratified random sampling was used).

As you cruise through the stand, we encounter a tree that appears to be in a borderline condition, meaning that with the prism, we can't tell whether the tree is in or out. Since a basal area factor of 10 has a plot radius factor of 2.75 you know that any tree farther away than 2.75ft x DBH from plot center is outside the plot. You measure the DBH of the questionable tree and find it to be 15.8 inches. You also measure the distance from plot center to the **middle** of the tree (not the point facing side) and find it to be 43.2 feet away. Since 43.2 ft < (2.75x15.8 = 43.45ft) you conclude that the tree is "in", measure it, and record it.

At the end of one line you noticed that the plot is very close to the edge of the tract, and there is the possibility that of boundary overlap between the plot and tract. In this case you should use the mirage method developed by Schmid-Haas (1969, 1982) and described by Beers (Beers 1977). The method was the subject of an extensive research by Ducey et al (2004) and is presented extensively in the notes that can be found online (http://www2.latech.edu/~strimbu/Teaching/FOR315/Point.pdf) and in Husch et al, 2001 at pages 269-271 and 282.

As you continue cruising we encounter a tree on a slope that looks "out" when viewed through the prism. To determine if the tree is "in" or "out", you measure the slope and find it to be 27°. You also measure the DBH of the tree and find it to be 10.6 inches. Therefore, the horizontal limiting distance for that tree is 29.15 feet (2.75 x 10.6 = 29.15). You measure the slope distance from the plot center to the middle of the tree you find it to be 32.9 ft, which reduced to the horizontal is 32.9 ft ×cos (27°) = 29.31 ft. Since the real horizontal distance is larger than the limiting horizontal distance (i.e., 29.31 feet > 29.15 feet), you conclude that the tree is, in fact, "out".

A simpler method of determining whether or not a tree is inside or outside a plot is the prism rotation method, on which the prism is rotated an amount equal to slope, perpendicular to slope, as described by Avery and Burkhart (2001), at page 240.

The stand was cruised with 10 Basal Area Factor prism, and the following tally sheets were obtained:

	Plot 1			Plot 2			Plot 3			Plot 4		
	Logs			Logs			Logs			Logs		
DBH	1	2	3	1	2	3	1	2	3	1	2	3
12		•			•	•		•				
14		•				•		•	•		• •	•
16			•		•				•			•

6.1.3 Cruise Computations

Using the International 1/4 inch volume table for Girard form class 80, you can fill the tree volumes for each combination of dbh class – height (in logs), as:

Plot 1

DBH	Logs 1	2	3
12		• 98	
14		• 141	
16			• 256

Plot 2

DBH	Logs 1	2	3
12		• 98	• 127
14			• 186
16		• 190	

Plot 3

DBH	Logs 1	2	3
12		• 98	
14		• 141	• 186
16			• 256

Plot 4

DBH	Logs 1	2	3
12			
14		• • 141	• 186
16			• 256

The next step is to compute the tree factor (TF) for each of the diameter classes (remember that the tree factor is similar to the expansion factor from fixed area plot sampling, such that is expanding the information from the **TREE** level to per – unit area level, in this case to **PER – ACRE**). Since we used a 10 BAF prism we can use the shortcut TF formula of:

$$TF = \frac{BAF}{BA/_{Tree}} \quad \text{where } BA/_{Tree} \text{ is the basal area of the tree, so:}$$

DBH Class	Basal Area per DBH Class	BAF	TF
12	0.7854	10	12.73 = 10/0.7854
14	1.0690	10	9.35 = 10/1.0690
16	1.3963	10	7.16 = 10/1.3963

Trees Per Acre

You can now execute the calculations to estimate the trees per acre. The TPA are computed for each plot by multiplying the tallied trees in each diameter class with the TF corresponding to the respective dbh class, as shown:

Plot 1

DBH	Logs 1	2	3	TF	TPA	BA/ac	Vol/ac
12		• 98		12.73	12.73		
14		• 141		9.35	9.35		
16			• 256	7.16	7.16		
				Total	29.24		

Plot 2

DBH	Logs 1	2	3	TF	TPA	BA/ac	Vol/ac
12		• 98	• 127	12.73	25.46		
14			• 186	9.35	9.35		
16		•		7.16	7.16		

		190					
				Total	41.97		

Plot 3

DBH	Logs 1	2	3	TF	TPA	BA/ac	Vol/ac
12		• 98		12.73	12.73		
14		• 141	• 186	9.35	18.70		
16			• 256	7.16	7.16		
				Total	38.59		

Plot 4

DBH	Logs 1	2	3	TF	TPA	BA/ac	Vol/ac
12				12.73	0		
14		• • 141	• 186	9.35	28.05		
16			• 256	7.16	7.16		
				Total	35.21		

Basal Area per Acre

In variable radius plot sampling each sampled, or "in", tree corresponds to a basal area per acre equal to the Basal Area Factor (in this case the BAF=10). This simple expansion from plot to acre is ensured by the procedure itself which considers not the number of trees (as the fixed area plot procedure) but basal area. Therefore, you can fill out the BA/ac column on the tally sheets by multiplying the number of trees tallied in a diameter class by the BAF (10 ft^2 per acre), as shown:

Plot 1

DBH	Logs 1	2	3	TF	TPA	BA/ac	Vol/ac
12		• 98		12.73	12.73	10	
14		• 141		9.35	9.35	10	
16			• 256	7.16	7.16	10	
				Total	29.24	30	

Plot 2

DBH	Logs 1	2	3	TF	TPA	BA/ac	Vol/ac
12		• 98	• 127	12.73	25.46	20	
14			• 186	9.35	9.35	10	
16		• 190		7.16	7.16	10	
				Total	41.97	40	

Plot 3

DBH	Logs 1	2	3	TF	TPA	BA/ac	Vol/ac
12		• 98		12.73	12.73	10	
14		• 141	• 186	9.35	18.70	20	

DBH	1	2	3	TF	TPA	BA/ac	Vol/ac
16			• 256	7.16	7.16	10	
				Total	38.59	40	

Plot 4

DBH	1	Logs 2	3	TF	TPA	BA/ac	Vol/ac
12				12.73	0	0	
14		• • 141	• 186	9.35	28.05	30	
16			• 256	7.16	7.16	10	
				Total	35.21	40	

Volume Per Acre

Volume per acre for each plot and each dbh class is calculated by multiplying the number of tallied trees having the same height and dbh by the TF and the tree volume that correspond to the respective combination dbh class – height, plus the trees tallied in the next combination dbh class -height multiplied by the TF and the corresponding tree volume, and so forth until all heights are exhausted. This method of computing the volume using variable-radius plot sampling is known under the name **Volume Factor** method.

For example: on plot 4 you tallied two 14 inch trees with 2 logs and on 14 inch trees with 3 logs. Therefore, the volume represents by plot 4 in the 14-inch class is equal to:

$$(2 \times 141 \times 9.35) + (1 \times 186 \times 9.35) = (2636.7) + (1739.1) = 4375.8$$

The end result is:

Plot 1

DBH	1	Logs 2	3	TF	TPA	BA/ac	Vol/ac
12		• 98		12.73	12.73	10	1247.54
14		• 141		9.35	9.35	10	1318.35
16			• 256	7.16	7.16	10	1832.96
				Total	29.24	30	4398.85

Plot 2

DBH	1	Logs 2	3	TF	TPA	BA/ac	Vol/ac
12		• 98	• 127	12.73	25.46	20	2864.25
14			• 186	9.35	9.35	10	1739.10
16		• 190		7.16	7.16	10	1360.40
				Total	41.97	40	5963.75

Plot 3

DBH	1	Logs 2	3	TF	TPA	BA/ac	Vol/ac
12		• 98		12.73	12.73	10	1247.54
14		• 141	• 186	9.35	18.70	20	3057.45
16			•	7.16	7.16	10	1832.96

DBH	Logs 1	2	3	TF	TPA	BA/ac	Vol/ac
			256				
				Total	38.59	40	6137.95

Plot 4

DBH	Logs 1	2	3	TF	TPA	BA/ac	Vol/ac
12				12.73	0	0	0
14		• • 141	• 186	9.35	28.05	30	4375.80
16			• 256	7.16	7.16	10	1832.96
				Total	35.21	40	6208.76

STAND AND STOCK TABLES

After plot level computations you can execute the necessary calculations to complete the stand and stock table:

Trees/Acre:
Average trees per acre can be estimated using the Central Limit Theorem. Therefore,

(The Sum of TPA in the i^{th} DBH class)/ (# of plots) = Trees per acre in the i^{th} DBH class

so:

Plot	Dbh = 12"	Dbh = 14"	Dbh = 16"
1	12.73	9.35	7.16
2	25.46	9.35	7.16
3	12.73	18.7	7.16
4	0	28.05	7.16
Average TPA	12.73 (50.94/4 plots)	16.5 (65.45/4 plots)	7.16 (28.64/4 plots)

Basal Area/Acre:
Average basal area per acre can be calculated using the Central Limit Theorem, similarly to TPA.

Plot	Dbh = 12"	Dbh = 14"	Dbh = 16"
1	10	10	10
2	20	10	10
3	10	20	10
4	0	30	10
Average BA/ac	10 ft^2 (40 / 4 plots)	17.5 ft^2 (70 / 4 plots)	10 ft^2 (40 / 4 plots)

Volume/Acre:
Average volume per acre can be also calculated using the Central Limit Theorem, as was done for TPA and BA/ac.

Plot	Dbh = 12”	Dbh = 14”	Dbh = 16”
1	1247.54	1318.35	1832.96
2	2864.25	1739.10	1360.40
3	1247.54	3057.45	1832.96
4	0	4375.80	1832.96
Average volume/ac	1339.83 bf (5359.33 / 4 plots)	2622.68 bf (10490 / 4 plots)	1714.82 bf (6859.3 / 4 plots)

The Stand and Stock table can be completed at this stage using the previous computed values:

DBH	Trees per Acre	Basal Area per Acre (sq ft)	Volume per Acre (bd ft)	Trees per Tract	Volume per Tract (bd ft)
12	12.7	10.0	1,339.8	381.0	40,194
14	16.4	17.5	2,622.7	492.0	78,681
16	7.2	10.0	1,714.8	216.0	51,444
Totals	36.3	37.5	5,677.3	1089.0	170,319

CONFIDENCE INTERVALS

Any Stand and Stock Table should contain the confidence intervals (CI) for the estimated values. To fulfill the US Forest Service guidelines, you have to determine a confidence intervals around the mean sample estimates that has a significance level of 5%.

The CIs are not computed for individual dbh classes, as this information is of little use in decision making. However, the CIs for total TPA, BA/ac, Vol/ac, Trees per tract, and Volume per tract are important in assessing the quality of the estimates.

Trees per acre

To determine the CI for the number of trees you could start with the number of trees per acre, which will be subsequently expanded to the entire tract by multiplying TPA with tract size expressed in acres.

Plot 1

DBH	Logs 1	Logs 2	Logs 3	TF	T/A
12		1		12.73	12.73
14		1		9.35	9.35
16			1	7.16	7.16
				Total	29.24

Plot 2

DBH	Logs 1	Logs 2	Logs 3	TF	T/A
12		1	1	12.73	25.46
14			1	9.35	9.35
16		1		7.16	7.16
				Total	41.97

Plot 3

DBH	Logs 1	Logs 2	Logs 3	TF	T/A

Plot 4

DBH	Logs 1	Logs 2	Logs 3	TF	T/A

12		1		12.73	12.73
14		1	1	9.35	18.70
16			1	7.16	7.16
				Total	38.59

			12.73	0
	2	1	9.35	28.05
		1	7.16	7.16
			Total	35.21

$$\overline{TPA} = 36.25$$

The CI requires the computation of the variance.

Variance = s^2 $= \dfrac{\sum_{i=1}^{4}(TPA_i - \overline{TPA})^2}{n-1} = \dfrac{(29.24-36.25)^2 + \ldots + (35.21-36.25)^2}{4-1} = 29.47$

Std. error of the mean $= s_{\bar{x}} = \sqrt{\dfrac{s^2}{n}} = \sqrt{\dfrac{29.47}{4}} = 2.71$

CI is $\overline{TPA} \pm (t_{(0.05,\, n-1)})\, (s_{\overline{T/A}})$ (where $t_{(0.05,\, 4-1)} = t_{(0.05,\, 3)} = 3.182$)

$= 36.25 \pm (3.182 \times 2.71) = 36.25 \pm 8.62$

What do obtained values mean?
The results shows that you are 95% confident that the actual mean number of trees per acre lies within $\pm$8.62 of the estimated sample mean (i.e., 95% of other sample based results will provide an estimate within the CI) , or simpler stated: the true mean is somewhere between 27.63 and 44.87 trees per acre. The *per tract* CIs, are just multiplication of the CIs for TPA by the size of the tract in acres: 1089 ± 258.7 trees.

Basal area per acre

Similarly to the CI for trees per acre the CI for BA/ac is determined. From the tally sheets the BA/ac for each plot is summed, which leads to the following table:

Plot	BA/ac
1	30
2	40
3	40
4	40
Average	37.5

The variance for basal area is computed similarly to variance for TPA, therefore,

Variance = s^2 $= \dfrac{\sum_{i=1}^{4}(BA_i - \overline{BA})^2}{n-1} = \dfrac{(30-37.5)^2 + \ldots + (40-37.5)^2}{4-1} = 25$

Std. error of the mean $= s_{\overline{BA}} = \sqrt{\dfrac{s^2}{n}} = \sqrt{\dfrac{25}{4}} = 2.5$

CI is $\overline{BA} \pm (t_{(0.05,\, n-1)})\, (s_{\overline{BA}})$ (where $t_{(0.05,\, 4-1)} = t_{(0.05,\, 3)} = 3.182$)

$= 37.5 \pm (3.182 \times 2.5) = 37.5 \pm 7.95$

For basal area only the values for per acre bases are determined, as basal area for the entire tract is useless.

Volume per acre

The determination of the CI for volume mirrors the computations executed for TPA and BA/ac. Therefore, from the tally sheets, the total volume per acre for each plots are:

Plot	Volume/ac
1	4398.8
2	5963.7
3	6137.9
4	6208.7
Average	5677.28

The variance for volume is computed similarly to variance for TPA or BA, therefore,

Variance = s^2 $= \dfrac{\sum_{i=1}^{4}(V_i - \overline{V})^2}{n-1} =$

$$= \frac{(4398.8 - 5677.3)^2 + \ldots + (6208.7 - 5677.3)^2}{4-1} = 737039.4$$

Std. error of the mean = $s_{\overline{V}} = \sqrt{\dfrac{s^2}{n}} = \sqrt{\dfrac{737039.4}{4}} = 429.3$

CI is $\overline{V} \pm t_{0.05,\, n-1} \times s_{\overline{V}}$ (where $t_{0.05,\, 4-1} = t_{0.05,\, 3} = 3.182$)

= 5677.3 ± (3.182×429.3) = 5677.3 ± 1365.9

For the *per tract* CI, the value is 1365.9 × 30 = 40977 bd.ft.

The final Stand and Stock Table is:

DBH	Trees per Acre	Basal Area per Acre (sq ft)	Volume per Acre (bd ft)	Trees per Tract	Volume per Tract (bd ft)
12	12.7	10.0	1,339.8	381.0	40,194
14	16.4	17.5	2,622.7	492.0	78,681
16	7.2	10.0	1,714.8	216.0	51,444
Totals	36.3	37.5	5,677.3	1,089.0	170,319
$CI_{95\%}$	±8.64	±7.95	±1365.9	±258.7	±40,977

6.2 Sampling error based method (guideline method)

You wish to determine the volume of a 60 ac tract of pine sawtimber. The results should meet the US Forest Service guidelines. Therefore, the confidence level should be 95%.

6.2.1 Cruise design

To determine the values of the two statistics needed in computations, namely the coefficient of variation and the sampling error, a preliminary cruise will be performed.

You have used Google Earth to identify the tract, and from the Louisiana Atlas website you have downloaded the DOQQ images were the tract is located. Based on Google Earth images you have concluded that the tract is relatively homogenous in term of size and species, therefore a simple random sampling procedure will be used to determine the sawtimber volume. With this information, you decided to use variable radius plot sampling procedure, using a prism with basal area factor 10, the most common value for a prism in the southern region of the US.

Based on the above information you travel to the tract to perform the preliminary cruise, also known as pre-cruise or reconnaissance cruise. The visual assessment of the stand in the field confirms the homogeneity of the stand inferred on the Goggle Earth images. Therefore, you decide to use five (5) plots laid out in a systematic pattern to determine the two statistics of interest: coefficient of variation and sampling error. The number of plots is in agreement with the USFS guideline FSM 2442.04 which recommends the measurement of a minimum of five plots, one being a mirage plot, and at least 50 trees. Considering all the above conditions, the layout of the preliminary cruise is determined as following:

- Determine the area represented by each plot:

$$A_{represented\ by\ a\ plot} = \frac{A_{tract}}{\#\ plots} = \frac{60}{5} = 12\ ac = 120\ square\ chains$$

- Determine the spacing between the plots:

$$Distance\ between\ plots = \text{int}(\sqrt{A_{represented\ by\ a\ plot}}) = \text{int}\sqrt{120} = 10\ chains$$

$$Distance\ between\ lines = \text{int}\frac{A_{represented\ by\ a\ plot}}{distance\ between\ plots} = \frac{120}{10} = 12\ chains$$

To ensure that you have a mirage plot you will place the center of the first plot on the boundary of the tract. The center of the plot on tract's boundary is determined by selecting one random number smaller than 12. This selection will ensure that the first plot is located within 12 chains from the next line of plots. Let assume that the random numbers are 3. Therefore, you will place the center of the first plot 3 chains from a randomly selected corner of the tract, on the boundary of the tract. The second plot will be placed 10 chains from the first plot in a direction easy to follow, let say north. The third plot will be placed on the same direction but 10 chains from the second plot and so forth. If the line will encounter the tract's boundary before you walked 10 chains, let say 8 chains, you will walk 12 chains on a perpendicular direction, let say east, and from the edge of the tract you will measure 2 chains on the south direction. You will repeat the above steps until you will measure all five plots.

The layout of the preliminary cruise could be like in the following drawing (Figure 19):

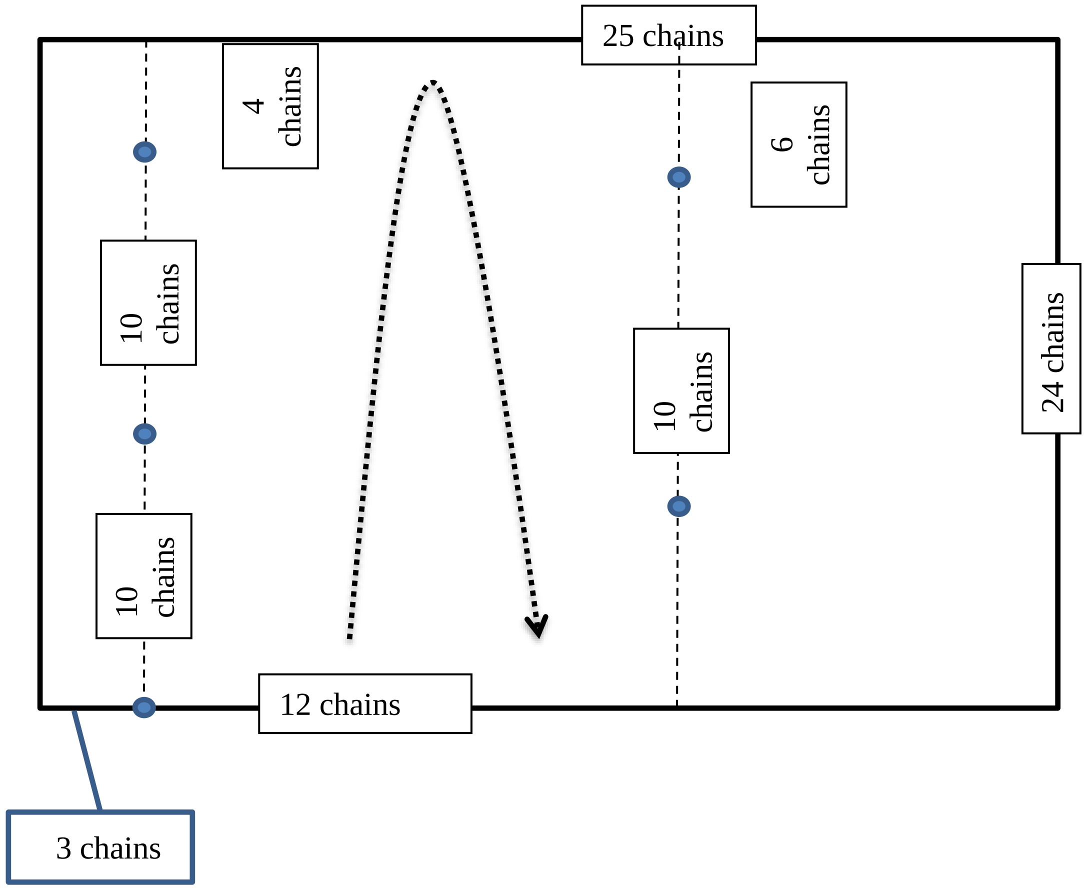


Figure 19. Layout of a preliminary cruise with 5 plots on a 60 ac stand.

6.2.2 Pre-cruise Measurements

With the above information you start the preliminary cruise, and obtained the following tally sheets, where height is the total height:

DBH	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5	
	Height	# trees	Height	# trees	Height	# trees	Height	# trees	Height	# trees
12	80	2	70	2	80	3	80	1	80	2
14	80	2	80	1	80	1	80	2	90	2
14	90	1	90	2	90	1	90	1	100	1
16	90	3	80	2	80	1	90	1	80	1
16	100	1	90	1	90	1	100	1	100	1

6.2.3 Preliminary cruise computations

To calculate the volume in cubic feet, up to 4-in diameter top, the values determined by Clark and Souter (1994) in the USFS Research Paper SE-290 *Stem cubic-foot volume tables for tree species in the South* (Table 22) could be used.

As this is a preliminary cruise you are not interested in all the details of the stand and stock table, only the volume. Therefore, you will not compute the trees per acre and basal area at this stage.

As in traditional cruising method, the volume per acre is calculated by summing across all DBH measured in a plot the product of the number of trees tallied for each DBH with the Tree Factor (which makes the expansion from the plot level to per acre level) and with the volume of the tree that has the respective DBH and height.

Plot	DBH	Height	# trees	Tree volume	Tree factor	Volume/ac	Vol./ac
1	12	80	2	28.8	12.73	733.248	
	14	80	2	38.5	9.35	719.95	
	14	90	1	43.0	9.35	402.05	3486
	16	90	3	55.5	7.16	1192.14	
	16	100	1	61.2	7.16	438.192	
2	12	70	2	25.4	12.73	646.684	
	14	80	1	38.5	9.35	359.975	
	14	90	2	43.0	9.35	804.1	2920
	16	80	2	49.7	7.16	711.704	
	16	90	1	55.5	7.16	397.38	
3	12	80	3	28.8	12.73	1099.87	
	14	80	1	38.5	9.35	359.975	
	14	90	1	43.0	9.35	402.05	2615
	16	80	1	49.7	7.16	355.852	
	16	90	1	55.5	7.16	397.38	
4	12	80	1	28.8	12.73	366.624	
	14	80	2	38.5	9.35	719.95	
	14	90	1	43.0	9.35	402.05	2324
	16	90	1	55.5	7.16	397.38	
	16	100	1	61.2	7.16	438.192	
5	12	80	2	28.8	12.73	733.248	
	14	90	2	38.5	9.35	719.95	
	14	100	1	43.0	9.35	402.05	2649
	16	80	1	49.7	7.16	355.852	
	16	100	1	61.2	7.16	438.192	

6.2.4 Cruise layout

With the above information you will be able to determine the statistics required to determine the sample size of the actual cruise, namely mean and the standard deviation of the volume/acre.

The mean volume per acre is: $\overline{V} = \frac{\sum_{i=1}^{5} V_i}{5} = \frac{3486 + 2920 + 2615 + 2324 + 2649}{5} = 2798.8\, ft^3$

The standard deviation is consequently:

$$s=\sqrt{\frac{\sum_{i=1}^{5}(V_i-\overline{V})^2}{5-1}}=\sqrt{\frac{(3486-2799)^2+(2920-2799)^2+(2615-2799)^2+(2324-2799)^2+(2649-2799)^2}{4}}$$

$$s=438.08$$

Finally, the coefficient of variation is:

$$CV=\frac{s}{\overline{V}}=\frac{438.08}{2798.8}=15.6\%$$

The estimated tract volume is: $V_{tract}=\overline{V}/ac\times A_{tract}=2798.8\times 60=167928\ ft^3$.

The estimated timber sale, according to the Louisiana Quarterly Report of Forest Products, volume 57 report 1, the stumpage price is $42.4 / ton, which makes the value of the tract at least $ 142,000 (167,928 ft^3 x $42.4 / ton x 0.02 ton/$ft^3$), assuming 0.02 ton/$ft^3$ (as found by Haynes (1990) An analysis of the timber situation in the United Sates: 1989-2040). According to the USF Forest Service guidelines a tract valued at $142,000 should be inventoried with a sampling error of 10%.

You have now all the information needed to determine the number of plots to perform the cruise that will provide estimates within the US Forest Service guidelines:

- CV = 15.6 %
- SE = 10 %
- CL = 0.95 → α = 0.05

Assuming that a large number of plots is need to cruise the tract, the exact number of plots is:

$$n=\left(\frac{t_{n-1,\alpha}\times CV}{SE}\right)^2=\left(\frac{1.96\times 15.6}{10}\right)^2=9.3\approx 10\ plots$$

Observing that the final number of plots is smaller than the “large” assumption (which is at least 30), you should iterate, according to *n*, until the starting *n* and the final *n* coincide. Consequently, you should continue by assuming that the last *n* is the correct *n*, therefore select t-values that corresponds to *n*=10, which is $t_{n-1,\alpha}=t_{10-1,0.05}=2.262$. With the new t-value the sample size is:

$$n=\left(\frac{t_{n-1,\alpha}\times CV}{SE}\right)^2=\left(\frac{2.262\times 15.6}{10}\right)^2=12.4\approx 13\ plots$$

As the final n=13 is not equals with the stating n (i.e., 10), you should continue to iterate assuming now that the correct n=13. The t-value for DF=13-1=12 is 2.179, which leads to

$$n = \left(\frac{t_{n-1,\alpha} \times CV}{SE} \right)^2 = \left(\frac{2.179 \times 15.6}{10} \right)^2 = 11.55 \approx 12 \ plots$$

As the final n=13 differs from the starting n, continue to iterate assuming that the last n is correct. Therefore, the t-value for 11 DF (i.e., 12-1) is 2.201, for which the computed n is:

$$n = \left(\frac{t_{n-1,\alpha} \times CV}{SE} \right)^2 = \left(\frac{2.201 \times 15.6}{10} \right)^2 = 11.8 \approx 12 \ plots$$

Finally you have reached the convergence of the two n, which indicate that the number of plots needed for the inventory is 12. With this information you will layout the cruise:

- Determine the area represented by each plot:
  $$A_{represented\ by\ a\ plot} = \text{int} \frac{A_{tract}}{\#\ plots} = \text{int} \frac{60}{12} = 5\,ac = 50 \ square \ chains$$
- Determine the spacing between the plots:
  $$Distance \ between \ plots = \text{int}\left(\sqrt{A_{represented\ by\ a\ plot}} \right) = \text{int}\sqrt{50} = 7\,chains$$

  $$Distance \ between \ lines = \text{int} \frac{A_{represented\ by\ a\ plot}}{distance \ between \ plots} = \text{int} \frac{50}{7} = 7 \ chains$$

Similarly to the traditional cruising method, the first line of the grid representing the systematic sampling is located at half the line interval inside the stand and the first plot will be placed at half the plot interval inside the stand on the first line (Figure 20):

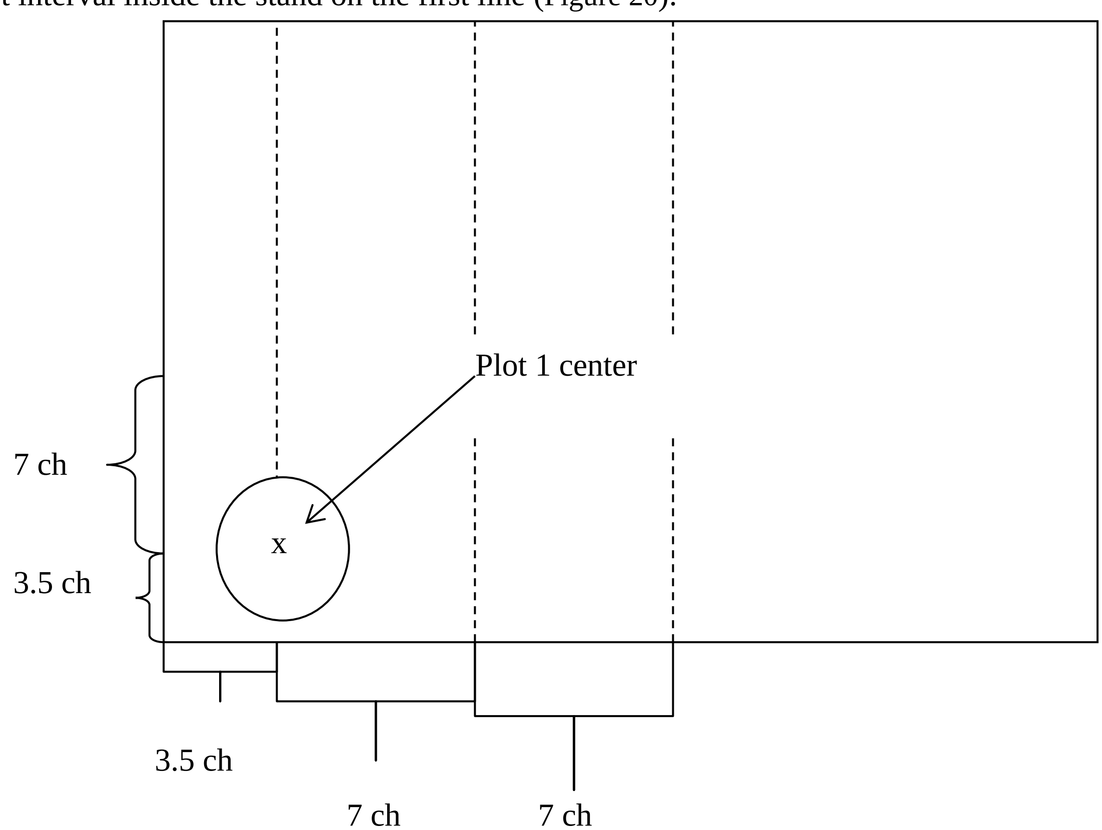


Figure 20. Layout of a cruise with 12 plots on a 60 ac stand.

The computations for the sampling error based inventories mimics the computations of the "rule of thumb" based inventories (i.e., traditional method), therefore they are not subsequently presented.

Important note

It should be noticed that, using the Husch et al (2001) recommendations, a number of 50 plots should be measured; while the computations performed using USFS guidelines indicates that only 12 plots are sufficient. This means that 12 plots would ensure that results have the required level of accuracy. Therefore, the values obtained using general rules, likely, would ensure the fulfillment of the contractual specifications, but with an unjustified effort, in this case almost three (3) times (i.e., 50 plots / (5 plots pre-cruise + 12 plots actual cruise)=2.91 times). It pays to be smart, three times in this case!

7. STRATIFIED RANDOM SAMPLING EXAMPLE

Often prior knowledge on the population from which a sample will be taken can be used to increase the accuracy of the sample. In stratified random sampling the units of the population (such as trees or turkeys) are grouped together on the basis of similarity of some characteristics. When sampling frame is partitioned into groups prior to selecting a sample and a sample is taken from within each group, the groups are called **Strata** and the sampling design is called **Stratified Sampling.** Operationally, a stratified random sample is taken the same way as a simple random sample, but the sampling is done separately and independently within each stratum. In forest inventories, the stratified random sampling can be used in conjunction with either fixed area plot or with variable radius plot.

Definition: A stratified random sample is a sampling plan in which a population is divided into L mutually exclusive and exhaustive strata, and a simple random sample of n_h elements is taken within each stratum h. The sampling is performed independently within each stratum.

One can wonder why stratified random sampling? Stratified random sampling has many advantages. It provides the simplicity of simple random sampling. In many cases there are gains in reliability over that of a simple random sample. It also provides a convenient technique to obtain separate estimates for population parameters for each sub domain in which the sample size is fixed and not a random variable. Finally it provides a method to ensure the sample is representative of the population.

The computations associated with stratified random sampling are currently performed using different software, such as T-Cruise or Cruise processing. However, as a professional you have to be familiar with the computations performed “behind the screen” by different packages. Depending on the forest region or jurisdiction, the details associated with the stand and stock table computation can differ. Nevertheless, the large variety of procedures can be grouped in two classes: one based on guidelines (aka accuracy based sampling or sampling error based sampling) and one based on tradition. The procedures using guidelines, which are the current standard in most of the jurisdictions, determine the sample size using preset levels of errors (i.e., sampling error and confidence level) while the procedure based on tradition uses preset intensity levels (i.e., a preset percentage from the stand have to be inventoried). Additionally, the volume can be computed using total volume (the volume is measured in cubic feet - commonly associated with the guideline based procedures) or volume of “square timber” (the volume is measured in board feet - commonly associated with the traditional method). The following material would present an example based on the guidelines, as the stratified random sampling estimates require a significant amount of statistical knowledge, way more than the one involved in sample size computations.

7.1 Stratified Random Sampling using Variable Radius Plot

You wish to determine the volume of a 60 ac tract of mixed species hardwood - pine sawtimber. The results should meet the US Forest Service guidelines. Therefore, the confidence level should be 95%.

You have used Google Earth to identify the tract, and from the Louisiana Atlas website you have downloaded the DOQQ images were the tract is located. Based on Google Earth images you have concluded that the tract is not homogenous in term of size and species, as you have noticed two different areas: one a mature mixed species hardwoods-pines and one a pure pine plantation. Therefore, you decided that a stratified random sampling procedure is the best sampling techniques to be used to determine the sawtimber volume. Knowing that mixed-species hardwoods-pines have little understory, which allows a good visibility, you decided to use variable radius plot sampling procedure. Based on your experience as a cruiser and the information available online, you decide to use a prism with basal area factor 10, the most common value for a prism in the southern region of the US.

As in every cruise, three steps have to be completed: planning, measurements and processing. The planning phase, which is focused on sample size determination and cruise layout, requires the usage of two statistics, namely the coefficient of variation and the sampling error. Consequently, a preliminary cruise will be performed aiming the identification of the two statistics.

Based on the above information you travel to the tract to perform the preliminary cruise, also known as pre-cruise or reconnaissance cruise. The visual assessment of the stand in the field confirms the non-homogeneity of the stand inferred based on Google Earth images. Therefore, you decide to separate the tract in two distinct areas, one with mixed hardwoods-pines and one with pines only, which will constitute two strata. Being a wise person, you assumed that the remote sensing information will be confirmed by the ground investigation, and you digitized the two distinct areas at the office. Using ArcGIS you also determined the surface of the two strata: which are 20 ac for mixed hardwoods-pines and 40 ac for pines. For each strata you have to identify the two statistics (i.e. coefficient of variation and sampling error), which recommended the usage of five (5) plots on each stratum. You selected five plots to be in agreement with the USFS guideline FSM 2442.04, which recommends the measurement of a minimum of five plots, one being a mirage plot, and at least 50 trees. Considering all the above conditions, the layout of the preliminary cruise is determined as following:

- Determine the area represented by each plot in each stratum:

Mixed hardwoods pines: $A_{represented\ by\ a\ plot} = \frac{A_{mixed}}{\#\ plots} = \frac{20}{5} = 4\ ac = 40\ square\ chains$

Pure pine: $A_{represented\ by\ a\ plot} = \frac{A_{pine}}{\#\ plots} = \frac{40}{5} = 8\ ac = 80\ square\ chains$

- Determine the spacing between the plots within each stratum:

$$Distance\ \ between\ \ plots_{mixed} = \text{int}(\sqrt{A_{represented\ by\ a\ \ plot\ mixed}}) = \text{int}\sqrt{40} = 6\,chains$$

$$Distance\ between\ lines_{mixed} = \text{int}\frac{A_{represented\ by\ a\ \ plot\ mixed}}{distance\ between\ plots} = \text{int}\frac{40}{6} = 6\ chains$$

However, you noticed that a 5 x 8 chains spacing will ensure the desired 40 sq.ch. representing the area associated with each plot from the mixed hardwoods-pines stratum.

You have to replicate the computations performed for mixed hardwoods-pines stratum to the pure pine stratum. Therefore,

$$Distance\ between\ plots_{pine} = \text{int}(\sqrt{A_{represented\ by\ a\ plot\ pine}}) = \text{int}\sqrt{80} = 8\,chains$$

$$Distance\ between\ lines_{pine} = \text{int}\frac{A_{represented\ by\ a\ plot\ pine}}{distance\ between\ plots} = \text{int}\frac{80}{8} = 10\ chains$$

To ensure that you have a mirage plot you will place the center of the first plot on the boundary of each stratum. For each stratum, the center of the plot on stratum’s boundary is determined by selecting one random number smaller than the distance between lines. This selection will ensure that the first plot is located within 8 chains, respectively 10 chains, from the next line of plots. Let assume that the random numbers are 3 for mixed hardwoods-pins and 2 for pure pine. Therefore, you will place the center of the first plot on the boundary of the tract, 3 chains from a randomly selected corner for the hardwoods-pines stratum, and 2 chains from one corner of the pine stratum. In the mixed hardwoods-pines stratum, the second plot will be placed 5 chains from the first plot in a direction easy to follow, let say north. In the mixed hardwoods-pines stratum, the third plot will be placed on the same direction but 5 chains from the second plot and so forth. If the line will encounter the tract or stratum boundary before you walked 5 chains, let say 2 chains, you will walk 8 chains on a perpendicular direction, let say east, and from the edge of the tract/stratum and you will measure 3 chains on the south direction. You will repeat the above steps until you will measure all five plots. In the pure pine stratum, the second plot will be placed 8 chains from the first plot in a direction easy to follow, let say north. The third plot in this stratum will be placed on the same direction but 8 chains from the second plot and so forth. If the line will encounter the tract or stratum boundary before you walked 8 chains, let say 4 chains, you will walk 10 chains on a perpendicular direction, let say east, and from the edge of the tract/stratum and you will measure 4 chains on the south direction. You will repeat the above steps until you will measure all five plots.

The layout of the preliminary cruise for the mixed hardwoods-pines stratum could be like in the following drawing (Figure 21):

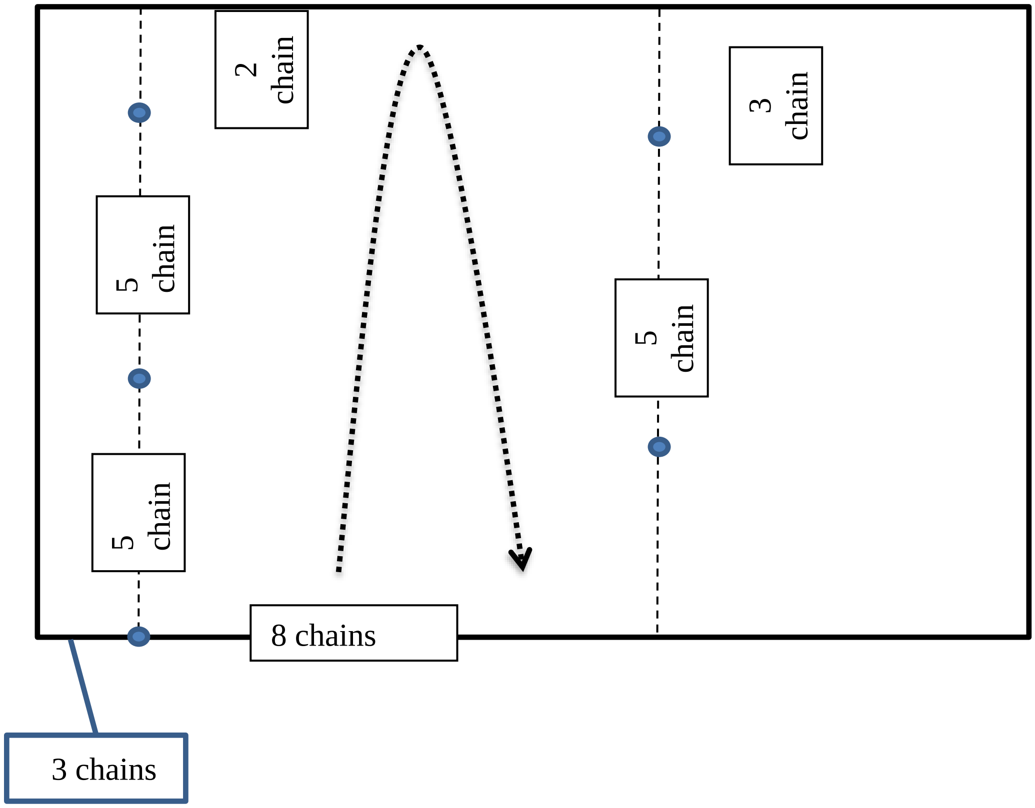


Figure 21. Possible layout of the plots used for cruising the mixed hardwoods-pines stratum

The layout of the preliminary cruise for the pure pine stratum could be like in the following drawing (Figure 22):

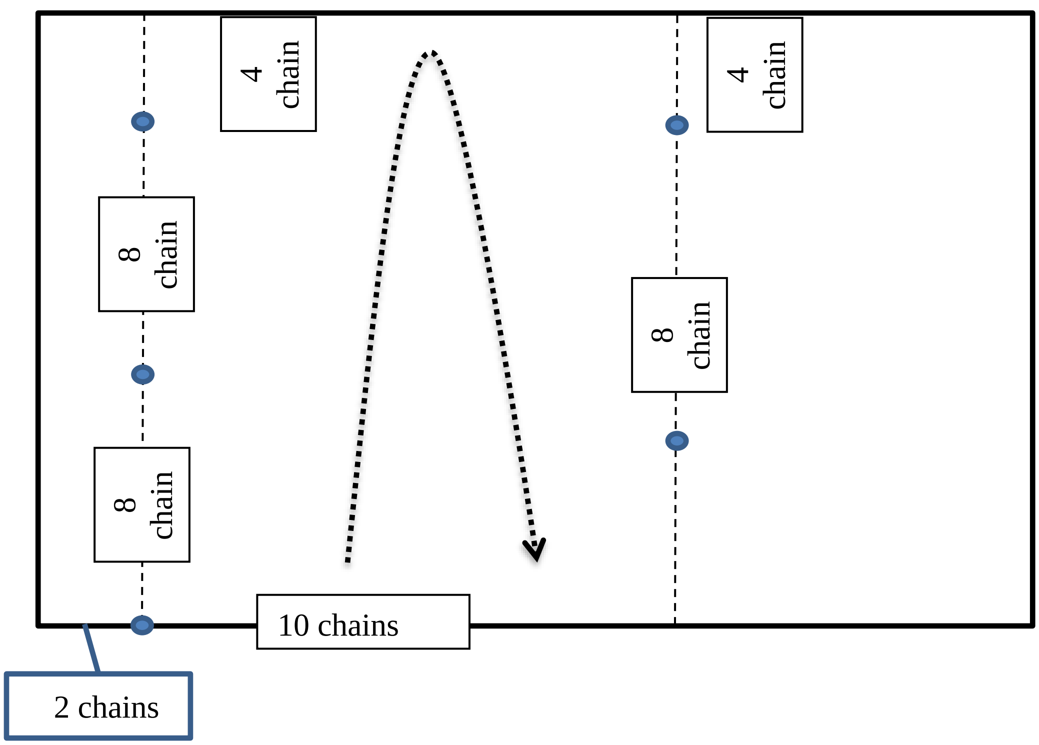


Figure 22: Possible layout of the plots used for preliminary cruise of the pure pine stratum.

With the above information you start the preliminary cruise, and obtained the following tally sheets for the mixed hardwoods-pines stratum (Table 2) and for the pure pine stratum (Table 3). To ensure a larger array of products that can be obtained from the available woody biomass you are measuring dbh and total height of each tree. The mixed hardwood – pines area is located in an area that can be used for recreation, therefore, you decided to record data without identifying the species (i.e., pulled all the species under one generic name, let say "mixed")

Table 2. Tally sheets of the mixed hardwood – pines stratum

DBH	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5	
	Height	# trees	Height	# trees	Height	# trees	Height	# trees	Height	# trees
12	80	1	75	1	80	2	85	2	75	3
14	80	2	80	2	80	1	80	2	90	2
14	90	2	90	2	90	2	90	3	100	1
16	90	3	80	2	80	1	90	1	80	2
16	100	1	90	1	90	2	100	1	100	1

Table 3. Tally sheets of the pure pine stratum

DBH	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5	
	Height	# trees	Height	# trees	Height	# trees	Height	# trees	Height	# trees
12	80	2	70	2	80	3	80	1	80	2
14	80	2	80	1	80	1	80	2	90	2
14	90	1	90	2	90	1	90	1	100	1
16	90	3	80	2	80	1	90	1	80	1
16	100	1	90	1	90	1	100	1	100	1

To calculate the volume in cubic feet, up to 4-in diameter top, the values determined by Clark and Souter (1994) in the USFS Research Paper SE-290 *Stem cubic-foot volume tables for tree species in the South* (Table 151 for mixed hardwoods-pines stratum and Table 22 for the pure pine stratum) were used.

As this is a preliminary cruise you are not interested in all the details of the stand and stock table, only the volume. Therefore, you will not compute the trees per acre and basal area at this stage.

The volume per acre is calculated by summing across all DBH measured in a plot the product of the number of trees tallied for each DBH with the Tree Factor (which makes the expansion from plot level to per acre level), and with the volume of the tree that has the respective DBH and height. The final computations for mixed hardwoods-pines are presented in Table 4, and for the pure pine stratum are presented in Table 5.

Table 4. Volume per acre for the mixed hardwoods- pines stratum.

Plot	DBH [in]	Height [ft]	# trees	Tree volume [bf]	Tree factor	Volume/ac [bf/ac]	Vol./ac [bf/ac]
1	12	80	1	21	12.73	267.33 (1 tree×21bf×12.73)	2640.982
	14	80	2	29	9.35	542.3 (2 trees×29bf×9.35)	
	14	90	2	32	9.35	598.4	
	16	90	3	42.1	7.16	904.31	
	16	100	1	45.9	7.16	328.64	
2	12	70	1	18.8	12.73	239.32	2172.636
	14	80	2	29	9.35	542.3	
	14	90	2	32	9.35	598.4	
	16	80	2	34.3	7.16	491.18	
	16	90	1	42.1	7.16	301.44	
3	12	80	2	21	12.73	534.66	2279.878
	14	80	1	29	9.35	271.15	
	14	90	2	32	9.35	598.4	
	16	80	1	38.1	7.16	272.8	
	16	90	2	42.1	7.16	602.87	
4	12	80	1	21	12.73	267.33	1738.91
	14	80	2	29	9.35	542.3	
	14	90	1	32	9.35	299.2	
	16	90	1	42.1	7.16	301.44	
	16	100	1	45.9	7.16	328.64	
5	12	80	3	21	12.73	801.99	2600.941
	14	90	2	32	9.35	598.4	
	14	100	1	34.9	9.35	326.32	
	16	80	2	38.1	7.16	545.59	
	16	100	1	45.9	7.16	328.64	

Table 5. Volume per acre for the pure pine stratum.

Plot	DBH [in]	Height [ft]	# trees	Tree volume [bf]	Tree factor	Volume/ac [bf/ac]	Vol./ac [bf/ac]
1	12	80	2	28.8	12.73	733.248 (2 tree×28.8bf×12.73)	3486
	14	80	2	38.5	9.35	719.95 (2 trees×38.5bf×9.35)	
	14	90	1	43.0	9.35	402.05	
	16	90	3	55.5	7.16	1192.14	
	16	100	1	61.2	7.16	438.192	
2	12	70	2	25.4	12.73	646.684	2920
	14	80	1	38.5	9.35	359.975	
	14	90	2	43.0	9.35	804.1	
	16	80	2	49.7	7.16	711.704	
	16	90	1	55.5	7.16	397.38	
3	12	80	3	28.8	12.73	1099.87	2615
	14	80	1	38.5	9.35	359.975	
	14	90	1	43.0	9.35	402.05	
	16	80	1	49.7	7.16	355.852	
	16	90	1	55.5	7.16	397.38	
4	12	80	1	28.8	12.73	366.624	2324
	14	80	2	38.5	9.35	719.95	
	14	90	1	43.0	9.35	402.05	
	16	90	1	55.5	7.16	397.38	
	16	100	1	61.2	7.16	438.192	
5	12	80	2	28.8	12.73	733.248	2649
	14	90	2	38.5	9.35	719.95	
	14	100	1	43.0	9.35	402.05	
	16	80	1	49.7	7.16	355.852	
	16	100	1	61.2	7.16	438.192	

With the above information you are able to determine the statistics required to determine the sample size of the actual cruise for each stratum, namely the mean and the standard deviation of the volume/acre.

The mean volume per acre for mixed hardwoods-pines stratum is:

$$\bar{V}_{mixed} = \frac{\sum_{i=1}^{5} V_i}{5} = \frac{2640+2172+2279+1738+2600}{5} = 2286.7\ ft^3$$

The standard deviation is consequently:

$$s_{mixed} = \sqrt{\frac{\sum_{i=1}^{5}(V_i - \bar{V})^2}{5-1}} = \sqrt{\frac{(2640-2286)^2+(2172-2286)^2+(2279-2286)^2+(1738-2286)^2+(2600-2286)^2}{4}}$$

$$s_{mixed} = 366.5$$

The mean volume per acre for pure pine stratum is:

$$\bar{V}_{pine} = \frac{\sum_{i=1}^{5} V_i}{5} = \frac{3486+2920+2615+2324+2649}{5} = 2798.8\ ft^3$$

The standard deviation is consequently:

$$s_{pine} = \sqrt{\frac{\sum_{i=1}^{5}(V_i - \bar{V})^2}{5-1}} = \sqrt{\frac{(3486-2799)^2+(2920-2799)^2+(2615-2799)^2+(2324-2799)^2+(2649-2799)^2}{4}}$$

$$s_{pine} = 438.08$$

The estimated tract volume is:

$$V_{tract} = \bar{V}_{mixed}/ac \times A_{mixed} + \bar{V}_{pine}/ac \times A_{pine} = 2286.7 \times 20 + 2798.8 \times 40 = 157685\ ft^3.$$

The estimated timber sale, according to the Louisiana Quarterly Report of Forest Products, volume 57 report 1, the stumpage price is $42.4 / ton, which makes the value of the tract at least $ 131,000 (157,685 ft^3 × $42.4 / ton × 0.02 ton/$ft^3$), assuming 0.02 ton/$ft^3$ (as found by Haynes (1990) in *An analysis of the timber situation in the United Sates: 1989-2040*).

You have now all the information needed to determine the number of plots to perform the cruise that will provide estimates within the USFS guidelines:

- The number of plots for each strata will be performed using proportional allocation
- Standard deviation mixed stratum = 366.5
- Standard deviation pine stratum = 438.1
- Weight of mixed hardwoods-pines: w_{mixed}= 20 ac / 60 ac =0.33
- Weight of pure pine: w_{pine} = 40 ac / 60 ac = 0.67

- SE=10%→using proportional allocation: $SE = 0.1 \times \left(\frac{20}{60} \times 2286.7 + \frac{40}{60} \times 2798.8 \right) = 260.2 \ ft^3$
- CL = 0.95 → α = 0.05

Assuming that the number of plots for executing the inventory is large (i.e., n>30), the total number of plots to be cruised using proportional allocation is

$$n = \frac{{t_{n-1,\alpha/2}}^2 \times \sum_h w_h s_h^2}{SE^2} = \frac{1.96^2 \times (0.33 \times 366.5^2 + 0.67 \times 438.1^2)}{260.2^2}$$
$$n = 9.8 \approx 10$$

As the end *n* is smaller than 30, you should iterate until starting *n* and final *n* is less than one unit apart.

Therefore, assume *n*=10 →DF=9→ t=2.26 and

$$n = \frac{t^2 \times \sum_h w_h \times s^2{}_h}{SE^2} = \frac{2.26^2 \times (0.33 \times 366.5^2 + 0.67 \times 438.1^2)}{260.2^2}$$
$$n = 13.05 \approx 14$$

As initial *n* was 10 and the final *n* was 14, you should continue to iterate.

For *n*=14→DF=13 and t=2.16→ $n = \frac{t^2 \times \sum_h w_h \times s^2{}_h}{SE^2} = \frac{2.16^2 \times (0.33 \times 366.5^2 + 0.67 \times 438.1^2)}{260.2^2} = 11.9 \approx 12$

As before, the starting *n* differs than the computed *n*, which indicate the continuation of the iteration process.

For n=12→DF=11 and t=2.2→ $n = \frac{t^2 \times \sum_h w_h \times s^2{}_h}{SE^2} = \frac{2.2^2 \times (0.33 \times 366.5^2 + 0.67 \times 438.1^2)}{260.2^2} = 12.4 \approx 13$

Considering that the initial and last *n* is one unit apart the final *n* is 13 plots.

The number of plots for each stratum determined using the proportional allocation procedure is therefore:

$$n_{mixed} = w_{mixed} \times n = \frac{20}{60} \times 13 = 4.3 \approx 5\, plots$$

$$n_{pine} = w_{pine} \times n = \frac{40}{60} \times 13 = 8.6 \approx 9 \ plots$$

As you can see the total number of plots is 5 + 9 =14, which is larger than the computed number of plots 13. This situation occurs commonly in stratified random sampling as the number of plots in each stratum has to be rounded up to avoid lower accuracy.

NOTE: You should note that the formula from the notes used to determine sample size includes N_h and N (i.e., the number of plots in stratum h and the total number of plots, respectively), which can be determined if the size of the plot is known. However, for variable radius plot or for line intersect sampling this condition is not met, case for which N_h and N cannot be determined. In this situation the formula is replaced with the weight of each stratum, weight computed using the formula: $w_h = A_h / A_{tract}$. Consequently the sample size using proportional allocation is:

$$n = \frac{t_{n-1,\alpha/2}{}^2 \times \sum_h w_h s_h^2}{SE^2}$$

With this information you will layout the cruise similarly to the pre-cruise:

- Determine the area represented by each plot in each stratum:

Mixed hardwoods pines: $A_{represented\ by\ a\ plot} = \frac{A_{mixed}}{\#\ plots} = \frac{20\ ac}{5\ plots} = 4\ ac/plot = 40\ square\ chains$

Pure pine: $A_{represented\ by\ a\ plot} = \frac{A_{pine}}{\#\ plots} = \frac{40\ ac}{9\ plots} = 4.44\ ac/plot = 44\ square\ chains$

- Determine the spacing between the plots within each stratum:

$$Distance\ between\ plots_{mixed} = \text{int}(\sqrt{A_{represented\ by\ a\ plot\ mixed}}) = \text{int}\sqrt{40} = 6\ chains$$

$$Distance\ between\ lines_{mixed} = \text{int}\frac{A_{represented\ by\ a\ plot\ mixed}}{distance\ between\ plots} = \text{int}\frac{40}{6} = 6\ chains$$

However, you noticed that a 5 x 8 chains spacing will ensure the desired 40 sq.ch. representing the area associated with each plot from the mixed hardwoods-pines stratum.

$$Distance\ between\ plots_{pine} = \text{int}(\sqrt{A_{represented\ by\ a\ plot\ pine}}) = \text{int}\sqrt{44.4} = 6\ chains$$

$$Distance\ between\ lines_{pine} = \text{int}\frac{A_{represented\ by\ a\ plot\ pine}}{distance\ between\ plots} = \text{int}\frac{44.4}{6} = 7\ chains$$

For actual cruise, the first line of the grid representing the systematic sampling is located at half the line interval inside the stratum and the first plot will be placed at half the plot interval inside the stratum on the first line, regardless the stratum. For example for the mixed hardwoods-pines stratum the layout could by as in Figure 23.

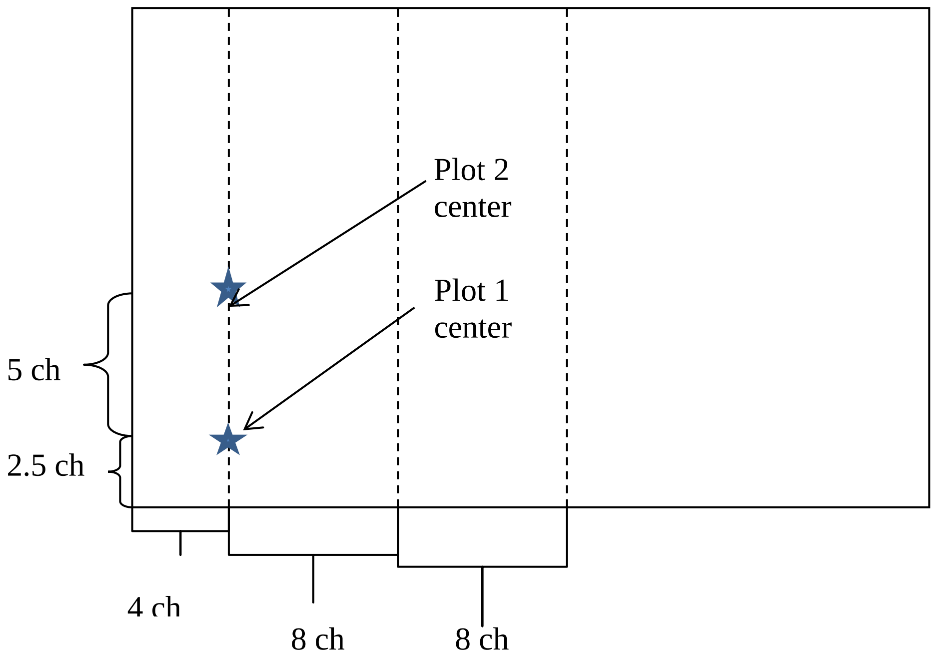


Figure 23. Layout of the cruise of the mixed hardwoods-pines stratum

After you cruised the 14 plots (i.e., 9 in the pines and 5 in the mixed hardwoods-pines) you have obtained 14 tally sheets that you will be processing. The tally sheets are presented in Table 6 for mixed hardwoods-pines stratum, and Table 7 for pure pin. Regardless the stratum, the tally sheets present the information without delineating the species, to maintain the computations clear, and not to clutter the methodology, basically for simplicity.

Table 6. Tally sheets for the mixed hardwoods-pine stratum

Plot	DBH	Height	# trees	Plot	DBH	Height	# trees	Plot	DBH	Height	# trees
1	12	80	3	3	12	80	2	5	12	70	2
	14	80	2		14	80	3		12	80	4
	14	90	2		14	90	2		14	80	2
	16	90	2		16	80	1		14	90	2
	16	100	1		16	90	2		16	90	1
2	12	70	3	4	12	80	3				
	14	80	1		14	80	2				
	14	90	2		14	90	1				
	16	80	2		16	90	1				
	16	90	1		16	100	2				

Table 7. Tally sheets for the pure pine stratum

Plot	DBH	Height	# trees	Plot	DBH	Height	# trees	Plot	DBH	Height	# trees
	12	80	3		12	80	2		12	80	3
	14	80	1		14	80	2		14	80	2
1	14	90	1	4	14	90	1	7	14	90	1
	16	90	3		16	90	1		16	90	2
	16	100	1		16	100	1		16	100	2
	12	70	3		12	80	3		12	70	3
	14	80	1		14	90	2		14	80	1
2	14	90	1	5	14	100	2	8	14	90	2
	16	80	2		16	80	1		16	80	2
	16	90	2		16	100	1		16	90	2
	12	80	2		12	80	2		12	80	2
	14	80	2		14	90	2		14	80	2
3	14	90	1	6	14	100	2	9	14	90	1
	16	80	1		16	80	1		16	80	1
	16	90	1		16	100	2		16	90	2

The processing phase of stratified sampling includes two phases, similarly to simple random sampling for fixed area plot or variable radius plot, namely 1) computations and 2) reporting. While the reporting phase is similar to simple random sampling the computation phase incorporate a hierarchy in the computations, namely the strata level estimations first, and tract level estimations second.

The strata level estimations mirror the computations performed in pre-cruise, with the comment that the final computations includes not only the volume, but also the number of trees and the basal area, as the final product of the cruise is a stand and stock table. Therefore, trees/ac, basal area /ac and volume / ac for each plots are determined for each dbh class. The results are presented in Table 8 for mixed hardwoods-pine stratum and in Table 9 for pure pine stratum. The volumes were computed using the values supplied by Clark and Souter (1994) in the USFS Research Paper SE-290 Stem cubic-foot volume tables for tree species in the South.

Table 8. Estimation of trees/ac, BA/ac and volume/ac for the mixed hardwoods-pine stratum

Plot	DBH	Height	# tree	Tree volum	Tree facto	Trees/ac	BA/ac	Volume/ac	Vol./ac
1	12	80	3	21	12.73	38.19 (3trees×12.7	30 (3trees×10	802 (3	2874
	14	80	2	29	9.35	18.7 (2trees×9.35)	20 (2trees×10	542.3 (2	
	14	90	2	32	9.35	18.7	20	598.4	
	16	90	2	42.1	7.16	14.32	20	602.872	
	16	100	1	45.9	7.16	7.16	10	328.644	
2	12	70	3	18.8	12.73	38.19	30	717.972	2380

	14	80	1	29	9.35	9.35	10	271.15	
	14	90	2	32	9.35	18.7	20	598.4	
	16	80	2	34.3	7.16	14.32	20	491.176	
	16	90	1	42.1	7.16	7.16	10	301.436	
3	12	80	2	21	12.73	25.46	20	534.66	2822
	14	80	3	29	9.35	28.05	30	813.45	
	14	90	2	32	9.35	18.7	20	598.4	
	16	80	1	38.1	7.16	7.16	10	272.796	
	16	90	2	42.1	7.16	14.32	20	602.872	
4	12	80	3	21	12.73	38.19	30	801.99	2602
	14	80	2	29	9.35	18.7	20	542.3	
	14	90	1	32	9.35	9.35	10	299.2	
	16	90	1	42.1	7.16	7.16	10	301.436	
	16	100	2	45.9	7.16	14.32	20	657.288	
5	12	70	2	18.8	12.73	25.46	20	478.65	2990
	12	80	4	21	12.73	50.92	40	1069.32	
	14	80	2	29	9.35	18.7	20	542.3	
	14	90	2	32	9.35	18.7	20	598.4	
	16	90	1	42.1	7.16	7.16	10	301.44	

Table 9. Estimation of trees/ac, BA/ac and volume/ac for the pure pine stratum

Plot	DBH	Height	# trees	Tree volume	Tree factor	Trees/ac	BA/ac	Volume/ac	Vol./ac
1	12	80	3	21	12.73	38.2 (3trees×12.73)	30 (3trees×10)	802 (3 tree×21bf×12.73)	2606
	14	80	1	29	9.35	9.4	10	271	
	14	90	1	32	9.35	9.4	10	299	
	16	90	3	42.1	7.16	21.5	30	905	
	16	100	1	45.9	7.16	7.2	10	329	
2	12	70	3	18.8	12.73	38.2	30	718	2383
	14	80	1	29	9.35	9.4	10	271	
	14	90	1	32	9.35	9.4	10	299	
	16	80	2	34.3	7.16	14.3	20	491	
	16	90	2	42.1	7.16	14.3	20	603	
3	12	80	2	21	12.73	25.5	20	535	1951
	14	80	2	29	9.35	18.7	20	543	
	14	90	1	32	9.35	9.4	10	299	
	16	80	1	38.1	7.16	7.2	10	273	
	16	90	1	42.1	7.16	7.2	10	302	
4	12	80	2	21	12.73	25.5	20	535	2007
	14	80	2	29	9.35	18.7	20	543	
	14	90	1	32	9.35	9.4	10	299	
	16	90	1	42.1	7.16	7.2	10	302	
	16	100	1	45.9	7.16	7.2	10	329	
5	12	80	3	21	12.73	38.2	30	802	2655
	14	90	2	32	9.35	18.7	20	599	
	14	100	2	34.9	9.35	18.7	20	653	
	16	80	1	38.1	7.16	7.2	10	273	
	16	100	1	45.9	7.16	7.2	10	329	
6	12	80	2	21	12.73	25.5	20	535	2717
	14	90	2	32	9.35	18.7	20	599	
	14	100	2	34.9	9.35	18.7	20	653	
	16	80	1	38.1	7.16	7.2	10	273	
	16	100	2	45.9	7.16	14.3	20	657	
7	12	80	3	21	12.73	38.2	30	802	2905
	14	80	2	29	9.35	18.7	20	543	
	14	90	1	32	9.35	9.4	10	299	
	16	90	2	42.1	7.16	14.3	20	603	
	16	100	2	45.9	7.16	14.3	20	657	
8	12	70	3	18.8	12.73	38.2	30	718	2682
	14	80	1	29	9.35	9.4	10	271	
	14	90	2	32	9.35	18.7	20	599	
	16	80	2	34.3	7.16	14.3	20	491	
	16	90	2	42.1	7.16	14.3	20	603	
9	12	80	2	21	12.73	25.5	20	535	2253
	14	80	2	29	9.35	18.7	20	543	
	14	90	1	32	9.35	9.4	10	299	
	16	80	1	38.1	7.16	7.2	10	273	
	16	90	2	42.1	7.16	14.3	20	603	

Plot level summary and Stand and Stock table for each stratum are presented in Table 10 and Table 11.

Table 10. Summary of mixed hardwood-pines stratum (summary per plot and dbh of table 7)

DBH	PLOT 1			Plot 2			Plot 3			Plot 4			Plot 5		
	TPA	BA/ac	V/ac	TPA	BA/ac	V/ac	TPA	BA/ac	V/ac	TPA	BA/ac	V/ac	TPA	BA/ac	V/ac
12	38.2	30	802	38.2	30	718	25.5	20	535	38.19	30	802	76.38	60	1547.97
14	37.4	40	1140	28	30	869	46.7	50	1412	28.05	30	842	37.4	40	1140.7
16	21.5	30	931	21.5	30	793	21.5	30	876	21.48	30	959	7.16	10	301.44
Total	**97.1**	**100**	**2873**	**87.7**	**90**	**2380**	**93.7**	**100**	**2823**	**87.72**	**90**	**2603**	**120.94**	**110**	**2990.11**

Table 11. Summary of pure pine stratum (summary per plot and dbh of table 9)

Plot	DBH	TPA	BA/ac	Volume/ac
1	12	38.20	30	802.16
	14	18.71	20	570.64
	16	28.65	40	1233.33
Total	-	85.56	90	2606.13
2	12	38.20	30	718.13
	14	18.71	20	570.64
	16	28.65	40	1094.38
Total	-	85.56	90	2383.15
3	12	25.47	20	534.78
	14	28.06	30	841.92
	16	14.32	20	574.41
Total	-	67.85	70	1951.11
4	12	25.47	20	534.78
	14	28.06	30	841.92
	16	14.32	20	630.27
Total	-	67.85	70	2006.97
5	12	38.20	30	802.16
	14	37.42	40	1251.66
	16	14.32	20	601.62
Total	-	89.94	90	2655.44
6	12	25.47	20	534.78
	14	37.42	40	1251.66
	16	21.49	30	930.37
Total	-	84.38	90	2716.81
7	12	38.20	30	802.16
	14	28.06	30	841.92
	16	28.65	40	1260.54
Total	-	94.91	100	2904.62
8	12	38.20	30	718.13
	14	28.06	30	869.98
	16	28.65	40	1094.38
Total	-	94.91	100	2682.49
9	12	25.47	20	534.78
	14	28.06	30	841.92
	16	21.49	30	875.93
Total	-	75.02	80	2252.63

The stand and Stock table for each stratum can be created using the Central Limit Theorem and the values from Table 10 and Table 11. Therefore, for mixed-species stratum the stand and stock table, with

CI is presented in Table 12, while for the pure pine stratum is presented in Table 13. In developing the two tables the following formulas were used for determining the standard deviation and standard error:

$$\text{Standard deviation:} \quad s = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}}$$

$$\text{Standard error:} \quad s_{\bar{x}} = \frac{s}{\sqrt{n}}$$

where X_i is the variable of interest, namely TPA, BA/ac or Volume/ac, and n is the sample size (# plots).

These formulas were applied in computation, as the sampling procedure was variable radius plot, which does not use a finite population correction.

Table 12. Stand and Stock Table for the mixed species stratum.

DBH	**TPA**	**BA/ac**	**Volume/ac**
12	43.29	34	880.99
14	35.51	38	1080.74
16	18.63	26	772.09
Total	**97.43**	**98**	**2733.82**
Standard deviation	13.74	8.37	242.54
Standard error	6.15	3.74	108.47
t-value	3.18	3.18	3.18
C.I.	**19.55**	**11.90**	**344.93**

Table 13. Stand and Stock Table for the pure pine stratum.

DBH	**TPA**	**BA/ac**	**Volume /ac**
12	32.54	25.56	664.65
14	28.06	30.00	875.81
16	22.28	31.11	921.69
TOTAL	**82.89**	**86.67**	**2462.15**
Standard error	3.47	3.73	110.92
t-value	2.3	2.3	2.3
C.I.	**8.01**	**8.59**	**255.77**

The stratum level information will provide the information needed to finalize the tract level cruise.

$$\text{Mean trees/ac}: \bar{y}_{Tract} = \sum_h (\overline{TPA}_h \times w_h) = (97.43 \times 0.33 + 82.9 \times 0.67) = 86.7\, TPA$$

$$\text{Mean BA/ac}: \bar{y}_{Tract} = \sum_h (\overline{BA}_h \times w_h) = (98 \times 0.33 + 86.7 \times 0.67) = 90.4\ ft^2 / ac$$

$$\text{Mean volume/ac}: \bar{y}_{Tract} = \sum_h (\bar{y}_h \times w_h) = (2774 \times 0.33 + 2462 \times 0.67) = 2551.8\ ft^3 / ac$$

Standard deviation of the mean (aka standard error)

$$TPA: s_{\bar{y}_{Tract}} = \sqrt{\sum_h \left(s_{\bar{y}_h} \times w_h\right)^2} = \sqrt{(6.15 \times 0.33)^2 + (3.47 \times 0.67)^2} = 3.09$$

$$BA/ac: s_{\bar{y}_{Tract}} = \sqrt{\sum_h \left(s_{\bar{y}_h} \times w_h\right)^2} = \sqrt{(3.74 \times 0.33)^2 + (3.72 \times 0.67)^2} = 2.79$$

$$Volume/ac: s_{\bar{y}_{Tract}} = \sqrt{\sum_h \left(s_{\bar{y}_h} \times w_h\right)^2} = \sqrt{(108.47 \times 0.33)^2 + (110.92 \times 0.67)^2} = 82.49$$

$$EDF_{TPA} = \frac{s^4_{\bar{y}_T}}{\sum_h \frac{\left(s_{\bar{y}_h} \times w^h\right)^4}{n_h - 1}} = \frac{3.09^4}{\frac{(6.15 \times 0.33)^4}{5-1} + \frac{(3.47 \times 0.67)^4}{9-1}} = 11.5 \approx 12$$

$$EDF_{BA} = \frac{s^4_{\bar{y}_T}}{\sum_h \frac{\left(s_{\bar{y}_h} \times w^h\right)^4}{n_h - 1}} = \frac{2.79^4}{\frac{(3.74 \times 0.33)^4}{5-1} + \frac{(3.76 \times 0.67)^4}{9-1}} = 11.05 \approx 12$$

$$EDF_{Vol} = \frac{s^4_{\bar{y}_T}}{\sum_h \frac{\left(s_{\bar{y}_h} \times w^h\right)^4}{n_h - 1}} = \frac{82.49^4}{\frac{(108.47 \times 0.33)^4}{5-1} + \frac{(110.1 \times 0.67)^4}{9-1}} = 10.9 \approx 11$$

With the values per tract for mean and standard error you are now able to compute the CI for the attributes of the stand and stock table, namely trees per acre, basal area per acre and Volume per acre, and to present the tract stand and stock table (Table 14).

Table 14. Summary of attributes describing the stand

Level	TPA	BA/ac	Volume/ac	Trees/tract or stratum	Volume/tract or stratum
Mixed hardwoods-pine	91.5	95	2669.6	1830	53392
Pure pine	82.89	86.67	2462.15	3315	98485
Tract	85.7	89.4	2530	5143	151836
t-value	2.23	2.2	2.18	2.23	2.18
CI	5.46	5.88	181.18	327.6	10871.2

As you see the accuracy of the estimate is $\frac{CI}{Volumet_{ract}} = \frac{181.18}{2530} = 7\%$, less than the required sampling error stated by the US Forest Service guidelines.

8. STEM ANALYSIS

8.1 Introduction

Stem analysis provides one way of obtaining a record of the past growth of a tree. This method visually represents how a tree grew in height and diameter, and how its form changed as tree increased in size. In executing a stem analysis, one counts and measures the growth rings on stem cross sections at different heights above the ground. The measurements are commonly made on *cut* cross sections, obtained from felled trees. For site index estimation it should be noted that the fallen tree should be from the dominant or co-dominant Kraft class.

Note

Trees that are currently in the dominant or co-dominant Kraft class have not necessarily been dominant or co-dominant in the past, nor they will they maintain this status in the future.

8.2 Method

Material preparation

1. Determine and record species, dbh and total height.
2. Fell tree and cut stem into sections having the same length (such as 10 ft, 7 ft or 3 ft)
3. Measure and record the height of the stump and length of tip (i.e., last section of the tree is shorter or equal to the rest of the sections).
4. At the top of each section cut a disk, aka “cookie”. The width of the cookie should be established to ensure that the disk will not break during transportation from field to the office, and during the measurements process. Therefore, large diameter cookies have widths (somewhere around 1 inch) larger than small diameter cookies (somewhere around half inch).

Measurements

5. Measure and record average diameter at **top** of each section. Identify the longest diameter of the section. The mean radius (pith to cambium) is the mean of two perpendicular radiuses; one measured along the longest diameter and one perpendicular to it.

Note: The average radius is half the diameter of a section (inside or outside the bark).

6. Find an average radius on each cross section and draw a line along it with a soft pencil or felt-tipped pen.

Note: the radius starts at pith.

7. Along average radius count the annual rings from the cambium **inward**, and mark the beginning of each ring, or other desired period (such as third ring or section). Record the total number of rings at each cross section. In the following example a mark will be drawn every three (3) years. This means that the time step for which the computations will be executed is 3 years.
8. From the center of each cross section, measure **outward** (i.e. toward the cambium) along the average radius the distance from the center to each mark (the change in direction is done for verification purposes).

Note: The marks will be identified by counting them starting from pith to bark (outward) not inward, as they were initially identified.

8.3 Computations and drawings

8.3.1 Age determination

The number of rings will decrease on discs from stump to tree top. The difference between the number of rings at the stump and the number of rings on a disc cut at any other height represents the number of years taken for the tree to grow from stump height to the height of the disc. This information would be used to estimate change in height with age.

The age of the tree at the height of a section *x*, given by the *x*s disk, is determined by using the equation:

$$\text{Age}_{\text{section x}} = \text{Years}_{\text{attain stump height}} + \text{Number}_{\text{rings top section 1}} - \text{Number}_{\text{rings top section x}}$$

The following examples use information from Table 15, which shows the number of rings on each disk, as well as the height of each disk.

Example #1: for the first section

$$\left.\begin{array}{l} \text{Years}_{\text{attain stump height}} = 2 \\ \text{Number}_{\text{rings top section 1}} = 35 \\ \text{Number}_{\text{rings top section 1}} = 35 \end{array}\right\} \qquad \text{Age}_{\text{section 1}} = 2 + 35 - 35 = 2 \text{ years}$$

Example #2: for section 5

$$\left.\begin{array}{l} \text{Years}_{\text{attain stump height}} = 2 \\ \text{Number}_{\text{rings top section 1}} = 35 \\ \text{Number}_{\text{rings top section 5}} = 23 \end{array}\right\} \qquad \text{Age}_{\text{section 5}} = 2 + 35 - 23 = 14 \text{ years}$$

Example #3: for section #12

$$\left.\begin{array}{l} \text{Years}_{\text{attain stump height}} = 2 \\ \text{Number}_{\text{rings top section 1}} = 35 \\ \text{Number}_{\text{rings top section 12}} = 0 \end{array}\right\} \qquad \text{Age}_{\text{section 12}} = 2 + 35 - 0 = 37 \text{ years}$$

Example #1 shows that when the tree had achieved a height equal to the height of the first section (one foot above ground) it was only two years old. By the time the tree reached the height of the fifth section (41 feet) the tree was 14 years old, while the total height was achieved at age 37 (Table 15).

Table 15. Height age determination using the number of rings

Disk	Height	Number of rings	Age
#	ft	count	years
-	0	stump	0
1.	1	35	2
2.	11	31	6
3.	21	27	10
4.	31	25	12
5.	41	23	14
6.	51	20	17
7.	61	18	19
8.	71	15	22
9.	81	13	24
10.	91	9	28
11.	101	6	31
12.	110	0	37

Once the height and age of each disk is known, one can draw the change in height of the tree with age (Figure 24).

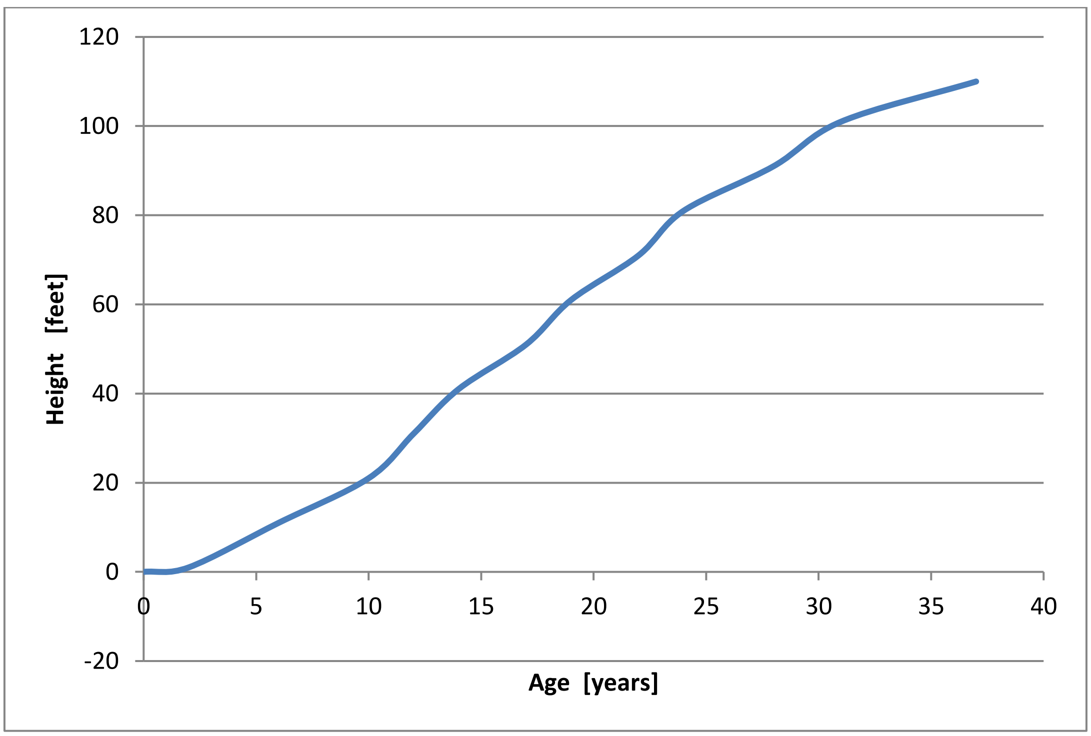


Figure 24. Increase in height with age.

8.3.2 Drawing the stem evolution

The final step in analyzing the data from Stem analysis method is to draw a series of graphs on a single sheet of paper. To draw the outer limit of the stem at different ages one should focus on the data that recorded the distance from pith to the i^{th} mark on each disc. To understand this information one should consider that the outer mark (i.e., the outer edge of each disk) represents the contour of current stem. The next mark toward the pith recorded information representing the contour of the stem as it looked three years ago (e.g., if one time period before the moment when the tree was cut is 3 years). The interpretation of all the reminding marks for which information was recorded is similar, and will continue to the final mark (i.e., the mark next to the pith).

The contour of the stem is obtained by joining the points (i.e., height vs. diameter) that have the same age. The points with the same age at different heights are located same number of cells from the last cell with a positive value (Table 16). For example, the diameter corresponding to age 31 is located two cells left from the last positive value (i.e., six years from the moment when the tree was cut). Therefore, regardless the section, all the cells located two cells from the last positive value would be 31 years old. The age of the i^{th} mark on the *x* section is determined using the formula:

Age of the i^{th} mark = age of the tree – length of time step x (# marks on disk x - i^{th} mark).

For example, for the 4th mark on section 7, the age would be 37 – 3 x (5 - 4) = 34 years

Table 16. Raw data used in stem analysis

Sect.	Ht above ground	Age at section height	DIB	Distance from pith to each ___th mark (inches)											
				1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
1	1	2	14.8	1.05	1.95	2.7	3.25	3.95	4.35	4.6	5.25	6	6.65	7.4	
2	11	6	13.7	1.1	2.05	2.5	3.05	3.7	4.25	4.95	5.55	6.25	6.85		
3	21	10	12.9	0.95	1.85	2.4	2.95	3.55	4.2	5.05	5.8	6.45			
4	31	12	11.8	0.85	1.75	2.45	3.1	4	4.7	5.35	5.9				
5	41	14	10.9	0.75	2	2.55	3.15	4.05	4.9	5.45					
6	51	17	10.1	1.1	2.05	2.6	3.3	4.35	5.05						
7	61	19	8.8	0.75	1.9	2.55	3.75	4.4							
8	71	22	7.2	0.65	1.45	2.95	3.6								
9	81	24	5.5	0.55	1.9	2.75									
10	91	28	3.5	1	1.75										
11	101	31	1.8	0.9											
12	110	37	0												

The stem at cutting moment

The stem 3 years before cutting moment

The stem 6 years before cutting moment

Note1: The diameter is the double distance from pith to last mark.
Note2: The DIB is recovered also from the last cell having positive value.

If Excel is used in performing the stem analysis, the information containing the distance from pith to the i^{th} mark should be recorded in a table with information transposed, as in following figures (Table 17).

Table 17. Table showing the change in stem contour with age .

Height	DIB @total age (37 years)	DIB @ total age-3 (34 years)	DIB @ total age-6 (31 years)	DIB @ total age-9 (28 years)
1	14.8	13.3	12	10.5
11	13.7	12.5	11.1	9.9
21	12.9	11.6	10.1	8.4
31	11.8	10.7	9.4	8
41	10.9	9.8	8.1	6.3
51	10.1	8.7	6.6	5.2
61	8.8	7.5	5.1	3.8
71	7.2	5.9	2.9	1.3
81	5.5	3.8	1.1	-
91	3.5	2.0	-	-
101	1.8	-	-	-
110	0	-	-	-

8.3.3 Stem analysis drawing

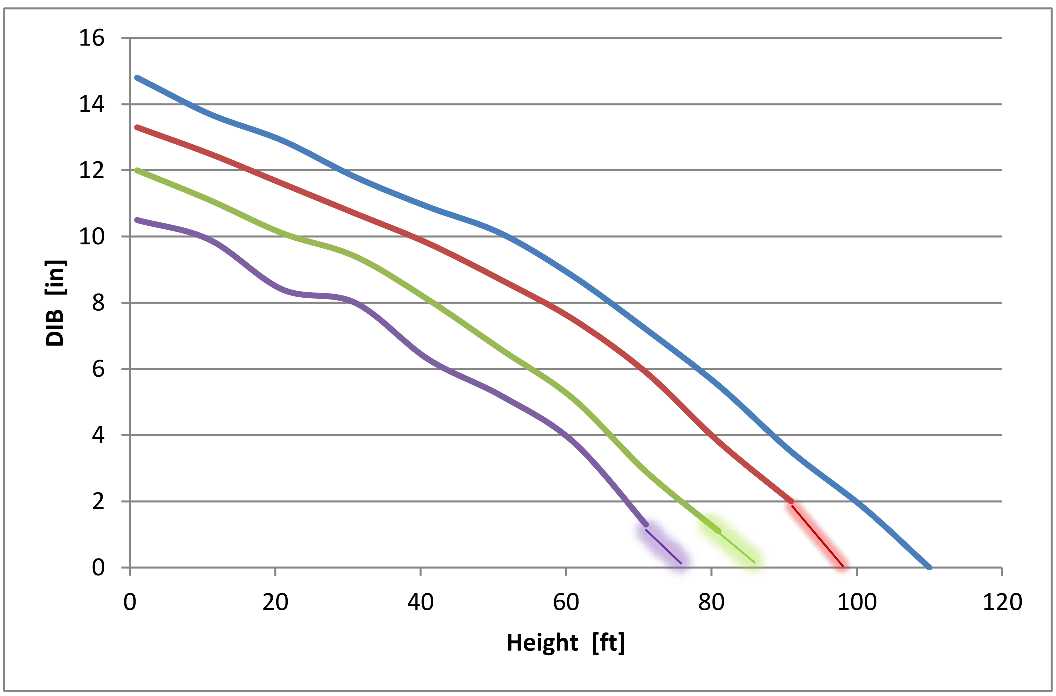


Figure 25. Change in DIB with height

The section of the outer stem corresponding to diameters close to 0 is draw "by hand", assuming that the growth for that period mimic the growth for the last three years (i.e., a parallel line with the present outer stem of the upper stem portion).

The final stem analysis drawing is obtained by producing a chart that is showing diameter on the abscissa (i.e. x-axis) and height on the ordinate (i.e., y –axis), which is the transpose of the above graph. Once the stem analysis is finalized the past age and height of the tree can be obtained by interpolation, and the information can be used for site index or growth and yield investigations.

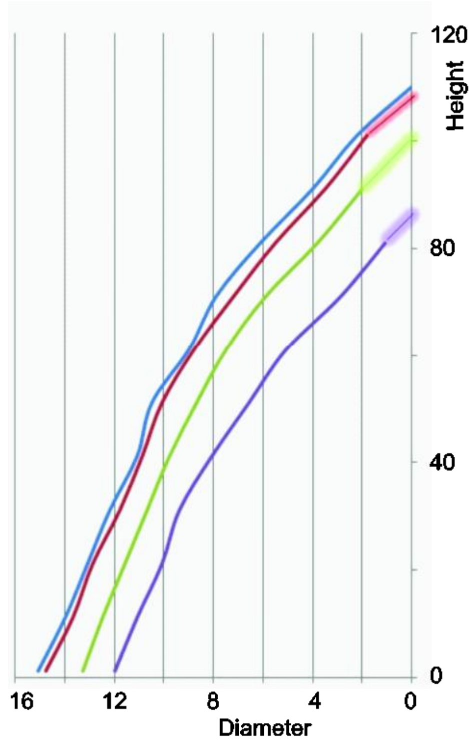


Figure 26. Stem analysis

Stem analysis can be performed by a variety of software. Some of them have evolved to execute complicated tasks that are mostly encountered in dendrochronological studies. Some of the most popular packages are WinDendro, LignoVision or C-dendro, all fee based. School of Forestry in collaboration with the Computer Science Department at Louisiana Tech University developed a free, simple, and intuitive software aiming solely the completion of stem analysis, called SALATech.

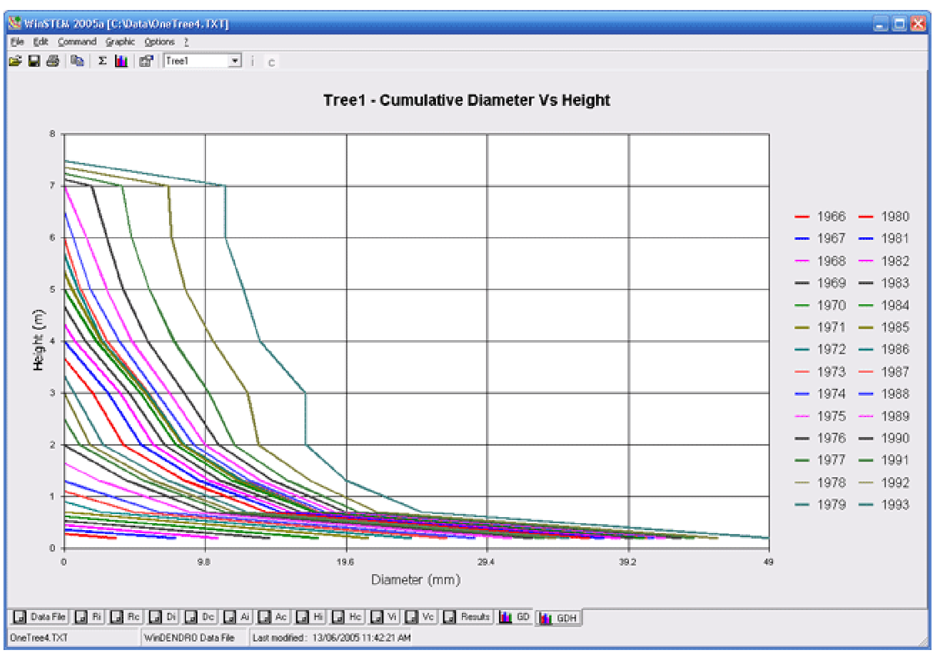


Figure 27. Stem analysis performed using WinStem, a program of the WinDendro package.

9. REFERENCES

Avery, T.E., and H. Burkhart. 2001. Forest Measurements. Mcgraw-Hill Ryerson, New York. 1-480 p.

Beers, T.W. 1977. Practical correction for boundary overlap. Southern Journal of Applied Forestry 1:16-18.

Clark, A., and R.A. Souter. 1994. Stem cubic-foot volume tables for tree species in the South Southeastern Forest Experiment Station. 252.

Ducey, M.J., J.H. Gove, and H.T. Valentine. 2004. A Walkthrough Solution to the Boundary Overlap Problem. Forest Science 50(4):427-435.

Gillis, M., V. Sundstrom, A.Y. Omule, K. Iles, Inselberg, A., N. Shaw, D. Campbell, J. Parminter, D. Meidenger, and D. Clark. 2007. Vegetation Resources Inventory Ground Sampling Procedures. Forest Analysis and Inventory Branch. 1-240.

Husch, B., T.W. Beers, and J.A. Kershaw. 2002. Forest Mensuration. Wiley. 456 p.

LeMay, V.M., and P.L. Marshall. 1990. Forest Mensuration. Distance Education and technology, Continuing Studies, Vancouver. 1-213 p.

Marshall, P.L., G. Davis, and V.M. LeMay. 2000. Using Line Intersect Sampling for Coarse Woody Debris. BC Forest Service. 34.

Schmid-Haas, P. 1969. Stichproben am waldrand. Mitt. Schweiz. Anst. Forstl. Versuchswes. 45:2324-2303.

Schmid-Haas, P. 1982. Sampling at the forest edge. P. 263-276 in Statistics in theory and practice: Essays in honor of Bertil Matern, Rannebey, B. (ed.). Swedish University of Agricultural Sciences, Umea, Sweden.

United States. Forest Service, and U.S.B.o.L. Management. 1994. Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents Within the Range of the Northern Spotted Owl: Standards and Guidelines for Management of Habitat for Late-successional and Old-growth Forest Related Species Within the Range of the Northern Spotted Owl. Interagency SEIS Team, Portland OR.

van Laar, A., and A. Akca. 1997. Forest Mensuration. Cuvillier Verlag, Gottingen DE. 1-418 p.