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Conducting a Simple Timber Inventory

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Conducting a Simple Timber Inventory

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Purpose and Audience

This publication is an introduction to the terminology and methodology of timber inventory. The publication should allow non-professionals to communicate effectively with forestry professionals regarding timber inventories. The reader is not expected to have any prior knowledge of the techniques or tools necessary for measuring forests.

The publication is in two sections. The first part provides background information, definitions and a general introduction to timber inventory. The second part contains step-by-step instructions for carrying out a timber inventory.

A note of caution

The methods and descriptions in this publication are not intended as a substitute for the work and advice of a professional forester. Professional foresters can tailor an inventory to your specific needs. They can help you understand how an inventory may be inaccurate and provide margins of error for estimated values. However, this publication should allow you to readily discuss timber inventories with a professional, and may allow you to perform intermediate inventories to monitor the status of a forested tract or gather data to supplement and support professional inventory and management.

The authors are confident that if the guidelines described herein are closely adhered to, someone with minimal experience and knowledge can perform an accurate timber inventory. No guarantees are given that methods will be appropriate or accurate under all circumstances. The authors and the University of Tennessee assume no liability regarding the use of the information contained within this publication or regarding decisions made or actions taken as a result of applying this material.

Part I – Introduction to Timber Inventory

What is timber inventory? Why is it done?

Timber inventories are the main tool used to determine the volume and value of standing trees on a forested tract. A timber inventory, like any inventory, involves taking stock of how much material is available. While timber inventories have traditionally been performed to place a value on a stand before sale, they are also useful for providing information for the development of management strategies, estate planning, tax basis or litigation.

Terminology and tools

If this is your first introduction to measuring forests, you will find that there is a lot of terminology and an array of specialized tools. The following sections will help define some terminology and introduce you to the tools necessary for inventory.

A timber inventory will establish two key pieces of information: 1) the number of ***trees per acre*** (tpa) on a forested tract, and 2) the ***volume per acre*** of wood that could be extracted from those trees.

The two most common products of a timber harvest are ***saw timber*** and ***pulpwood.*** Saw timber is generally more valuable than pulpwood. The volumes of standing trees designated as saw timber are typically estimated in ***board feet*** (bf). The volumes of standing trees designated as pulpwood are often estimated in ***cubic feet*** (cu. ft.), ***cords*** or tons.

The volume of a standing tree is generally estimated by representing the tree with a series of cylinders, then making deductions for how the tree differs from a cylindrical shape. To determine the volume of a cylinder, two pieces of information are needed: diameter and length. For trees, you measure the diameter at breast height (***DBH***) and the ***merchantable height***.

A professional forester will normally use a diameter tape (***d-tape***) or ***Biltmore stick*** to measure tree diameter. However, tree diameter is commonly measured in 2-inch classes (i.e., rounding to the nearest even number) and with some practice, DBH can be accurately estimated by eye.

Merchantable height is the number of ***logs*** that a tree will be sawn into when harvested. Professional foresters will generally use a ***clinometer*** or ***Merritt hypsometer*** to measure merchantable heights. Again, with practice, heights in logs can be accurately estimated by eye. Merchantable heights are measured to a minimum small-end tree diameter. The minimum small-end diameter depends on whether the tree represents pulpwood or saw timber. Minimum small-end diameters can differ by market, so check with local mills for limits in your area.

For the person performing his or her first inventory, a ***cruiser's stick*** or ***tree and log scale stick*** that

Definitions

trees per acre - the average number of trees, of a given size, present on any one acre of a forested tract. Abbreviated as *tpa*.

volume per acre - the average volume of wood that could be harvested from any one acre of a forested tract.

saw timber - trees of a species, size and quality that, when harvested, would be sawn into boards.

pulpwood - trees of a species, size and quality that, when harvested, would be processed into pulp. Pulpwood trees are typically too small in size, of an undesirable species or contain too many defects (such as crookedness or knots) to be sawn into boards.

board feet - units of solid wood volume equivalent to a 1ft × 1ft × 1 in. green and unsurfaced board. Board foot volume estimates for standing trees contain corrections for the volume of a tree that is lost by sawing a round stem into boards. 1,000 bf = 1 mbf.

cubic feet - a unit of solid wood volume equivalent to 1ft × 1ft × 1ft.

cord - a measure of wood volume equivalent to a stack of wood measuring 4 ft × 4 ft × 8 ft, typically including air and bark.

DBH - the diameter of a standing tree measured 4.5 ft above ground.

Merchantable height - the height of logs in a standing tree that will be harvested. Merchantable height is often limited by a minimum diameter for the small end of a log that a mill will accept for a given product class.

d-tape - a specially graduated measuring tape used to measure the DBH of standing trees.

has both a Biltmore stick and a Merritt hypsometer is recommended. This is a simple tool that will allow a first-timer to make all the necessary tree measurements to complete a timber inventory.

Once you have measured the DBH and merchantable height of a tree, you are ready to determine the tree's volume. Saw timber volumes for each combination of height and diameter can be found in a ***volume table***. There are a number of available volume tables, each differing in how they estimate the volume that could be extracted from a standing tree. Appendix A includes two of the more common sawtimber volume tables, the Doyle and International ¼". Deciding which table to use depends on the interests of the end-users of your estimates. Most mills in the Southeast United States use Doyle volume estimates. However, the International ¼" volume estimates are often considered more accurate and are commonly used in other regions of the United States (Avery and Burkhart, 2002).

Volume tables have been created that make some allowance for the form or rate of ***taper*** of a tree. The Doyle and International ¼" volume tables in Appendix A are for ***Girrard form classes*** 78 and 80. The form class number represents how quickly a tree tapers. Form class is time-consuming to measure and is therefore not directly determined in most forest inventories. However, different species typically fall into different form classes and selecting the form class 78 or 80 table based on tree species is a rough rule of thumb that can improve volume estimates. Use form class 80 for black cherry, American beech, upland ash, basswood, southern pines, old growth white oak and old growth tulip poplar (Wenger, 1984). Use form class 78 for all other hardwood species (Wenger, 1984). It is accepted practice to use form class 78 if you are unsure which form class to use. However, using a lower form class than is appropriate for your trees will underestimate their volume.

One common calculation that is performed as part of many timber inventories is to convert DBH into ***basal area*** (BA). In some cases, it is necessary to calculate basal area to be able to determine trees per acre or volume per acre from a timber inventory. Determination of the basal area per acre of a forested tract is a useful summary statistic for foresters, because it incorporates both the average size and the density of the trees.

Biltmore stick - a scale printed on a cruiser's stick that can be used to measure the DBH of standing trees.

Logs - a measure of merchantable height that is equivalent to the number of 16-foot long logs that can be harvested from a tree. Merchantable height is typically measured to the nearest ½ log, or 8-foot section.

clinometer - a device that can be used to measure the slope to points on a tree, which can subsequently be used to determine the tree's height.

Merritt hypsometer - a scale commonly printed on a cruiser's stick that can be used to determine the merchantable height of standing trees.

cruiser's stick or ***tree and log scale stick -*** a device used in timber inventory that typically incorporates a Biltmore stick and Merritt hypsometer in a single tool that can be used to measure trees.

volume table - a table that provides estimated volumes for trees of a given DBH and merchantable height.

taper - a measure of how quickly a tree's diameter decreases with height above the ground. The greater the taper, the less wood volume a tree can contain.

Girard form class - diameter inside the bark at the top end of the first 16-foot log divided by the DBH and multiplied by 100.

basal area - the cross-sectional area of a tree at breast height. Basal area is typically reported in square feet and is calculated for an individual tree using the formula: $BA = 0.005454 \times DBH^2$, where DBH is measured in inches.

Types of inventories

There are three basic types of inventory. The measurements made on individual trees are identical, regardless of the type of inventory. The methods differ in two significant aspects. The first difference is in the method for selecting the trees that will be measured. The second difference is in the formulas used for calculating the volume per acre and the trees per acre. This guide focuses on methods for *sampling* — measuring only a portion of the forested tract and extrapolating the results to create estimates for the whole tract. Any sample has some error, because the entire tract was not measured. Inventories performed by a professional forester should always include some estimate of this margin of error. Error estimates require knowledge of statistics and are therefore beyond the scope of this guide.

Inventory type 1 – 100 percent tally

The simplest type of inventory to understand is the 100 percent tally. In this type of inventory, you measure all the trees on your forested tract. However, 100 percent tallies are only performed for relatively small forested tracts (< 5 ac) or for timber that is of high value. Measuring all the trees on a tract becomes time-consuming for larger tracts.

A more efficient and commonly used method of timber inventory is to sample. In sampling, a selected portion or sample of the forested tract is measured. It is assumed that this sample is representative of the entire tract. Estimates of trees per acre and volume per acre of the entire tract can be determined based on the data collected on the sample. The rest of this publication will focus on conducting a forest inventory using fixed and variable radius plot-sampling methods.

Inventory type 2 – fixed-radius plot sampling

In fixed-radius plot sampling, instead of measuring all the trees in a forested tract, only trees occurring on a number of selected circular plot areas are measured. The fixed-radius plots provide a means for determining which trees to measure. One key consideration with fixed-radius plots is which size plot to use. To avoid unnecessary confusion, this publication will only consider 1/10-acre plots with a radius of 37.24ft (≈37 ft 3 in.). Once the location of the center of a plot is determined, all trees that are "in" the plot are measured (Figure 1). For a 1/10-acre plot "in" trees have their center at breast height within a horizontal distance of 37.24ft of the center of the plot (i.e., plot-center).

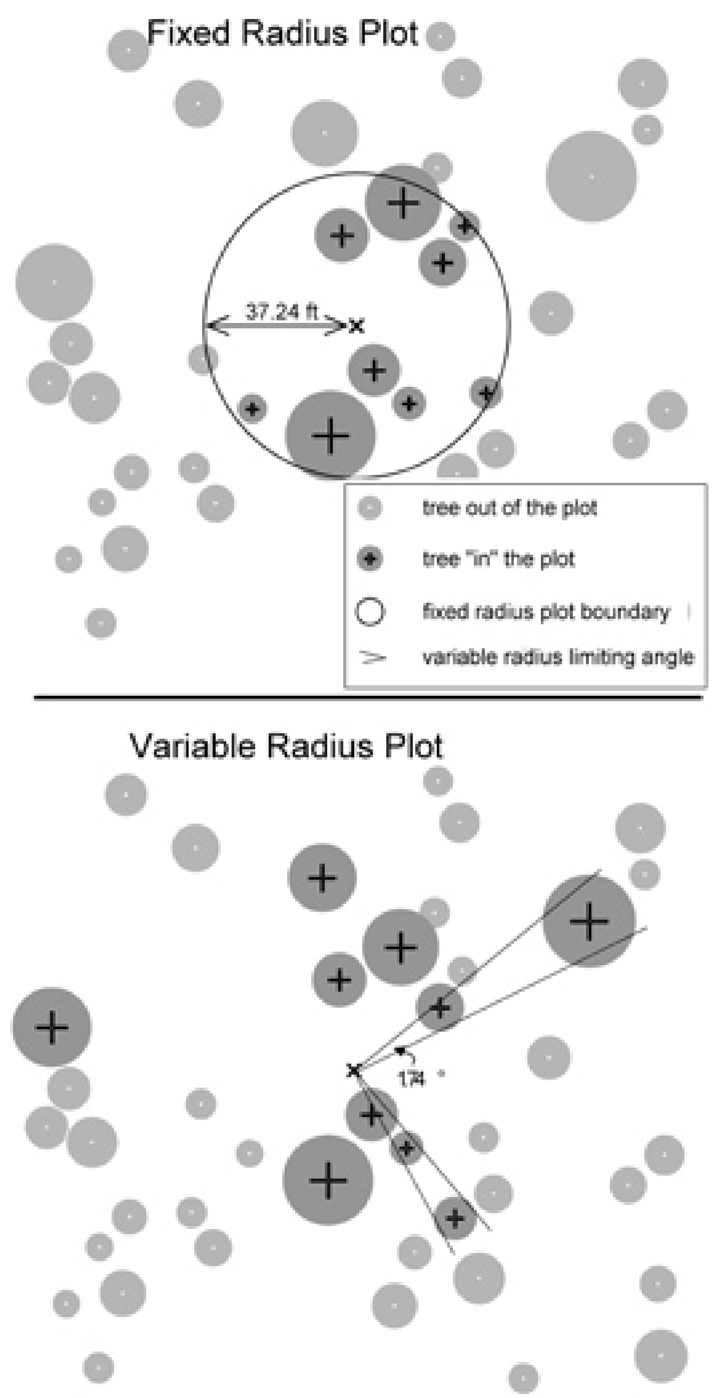

Figure 1. Example determination of "in" trees using 1/10-acre fixed-radius and 10BAF variable-radius plots. Circles represent tree diameters. Using the same plot-centers, 9 trees were found to be "in" with fixed-radius plot sampling and 10 trees were found to be "in" with variable-radius plot sampling.

Inventory type 3 – variable-radius plot sampling

Variable-radius plot sampling (also known as angle-gauge sampling, prism sampling or point sampling) is one of the most common and efficient sampling methods for timber inventory. It is helpful to understand that variable-radius plot sampling is just another method for selecting which trees to measure.

In variable-radius plot sampling, a tree is "in" the plot if the DBH of the tree is wider than a given angle when sighted from plot-center (Figure 1). If the tree is wider than the angle, then it is "in" and should be measured. Deciding which angle to use is equivalent to deciding which plot radius to use in fixed-radius plot sampling.

For the sake of simplicity, only an angle of 1.74 degrees, which has a basal area factor (BAF) of 10, is considered in this publication. The BAF is a multiplier that allows for a quick calculation of the stand basal area (measured in ft^2/ac) represented by one plot. To determine the stand basal area from a given plot, multiply the number of "in" trees by the BAF. So, if there are six "in" trees on one plot, the estimated stand basal from that plot would be 60 ft^2/ac using a 10BAF angle gauge.

A number of angle-gauge tools have been developed to help determine if trees are "in" or "out" of a variable-radius plot and they are generally referred to by their BAF value. Specially ground prisms are the most common tool for determining "in" trees on a variable-radius plot among forestry professionals, but other simple tools and approximations can work well with practice. One common approximation for a 10BAF angle gauge is a penny held approximately 25 inches from the eye. Any tree that appears wider than the penny when you are standing at plot-center is "in." Retail angle gauges function in a similar manner. There are some complexities in determining "in" trees for variable-radius plot sampling, including accounting for sloping terrain. To achieve the most accurate estimates using these methods, the authors recommend training by a forestry professional.

You may be wondering why this type of sampling is called "variable-radius." The result of using the angle gauge to determine if a tree is "in" the plot is that different-sized trees effectively have different-sized plots. A very small tree would have to be very close to plot-center to appear wider than the minimum angle. Conversely, a very large tree could be relatively far from plot-center and still appear wider than the minimum angle (Figure 1). So the radius of the plot varies depending on the size of the tree measured, hence v*ariable-radius plot sampling*.

Should variable-radius plots or fixed-radius plots be used?

Variable-radius plot sampling is typically more efficient than fixed-radius plot sampling for timber estimation for two reasons. First, variable-radius plot sampling concentrates sampling efforts on bigger trees, because they are more likely to be wider than the minimum angle. Big trees account for a greater percentage of the volume and value of a tract, so measuring relatively more big trees and fewer small trees can improve the accuracy of estimates. Second, it is typically easier and more efficient to determine if a tree is "in" the plot using an angle gauge in variable-radius plot sampling than using a tape measure in fixed-radius sampling.

If this is your first time performing an inventory, you should start with fixed-radius sampling until you get comfortable with the equipment, plot layout and summary calculations. Once you are comfortable performing fixed-radius sampling, you can try variable-radius sampling. The only differences between the methods are in determining which trees are "in" the plot and performing the summary calculations. These differences are highlighted in the step-by-step procedure in this publication. Either method will provide accurate estimates when properly performed.

Navigating in the forest – compass and pacing

Before undertaking a forest inventory, you should be comfortable finding your way around the forest. Foresters rely on a hand-held compass for direction determination and on pacing for distance determination. For the purpose of timber inventory, the use of compass and pacing are necessary for determining the location of plots.

A good handheld compass will have a sighting system for determining a direction of travel and a method for setting declination. Declination is the difference between true north and magnetic north. Declination differs depending on where you are on the earth and it also slowly changes over time. The National Oceanic and Atmospheric Administration (NOAA) operate a Web site that provides the declination for a given zip code (http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp). You should be comfortable using a compass to navigate and determine direction before attempting a forest inventory.

Pacing provides a simple method for estimating distance that does not require any additional equipment. To estimate distance by pacing, you need to determine how many paces it takes you to travel a given distance. A pace is equal to two steps, so you could count one pace every time your left foot hits the ground. In forestry it is common to determine how many paces it takes to travel one chain. A chain is equivalent to 66 feet. To determine how many paces you take per chain, set up a straight line course in a wooded area that is a known number of chains in length. Pace this course a number of times, at a comfortable walking tempo, and determine how many paces it takes you on average to travel one chain. You will use this paces-per-chain measurement to locate sample plots in your forested tract during the forest inventory.

Part II – Step-by-step instructions for a basic timber inventory

The steps are divided into three parts. The first part, *Getting Ready*, covers inventory planning. The second part, *In the Forest*, covers the practical methods of plot layout and tree measurement in the forest. The third part, *In the Office*, provides the methods for calculating values of interest from the collected data.

Getting ready

One way to help ensure a successful timber inventory is to plan properly before you start measuring trees. Good preparation will increase your efficiency in the field and increase the accuracy of your final estimates. It is important that you understand how to measure tree DBH and merchantable height, as well as how to navigate in the forest using compass and pacing, before you begin an inventory.

Step 1 – Determining the acreage and boundaries of your tract

All of the subsequent steps depend on accurately estimating the number of acres of forested land you will be inventorying and where the boundaries of that forested area lie. If the tract of interest has been surveyed, you may already have a good estimate of acreage. Accurate acreage estimates can also be obtained from aerial photographs, online maps or using GPS units.

An extensive description of methods for area determination is beyond the scope of this publication. However, it is important to note that the accuracy of any estimates of tract totals from timber inventory will directly depend on how accurate your estimate of area is. For example, if you estimated that you had 2,500 bf/ac of saw timber and you thought your tract was 30 ac in area, you would estimate that you have 2,500 bf/ac × 30 ac = 75,000 bf of saw timber. However, if the true tract area was 32 acres, then you actually had 2,500 bf/ac × 32 ac = 80,000 bf and you underestimated your total volume and subsequent value by more than 6 percent.

The boundaries of your forested tract should be clearly marked before undertaking any sampling to avoid accidentally sampling outside the tract of interest. In many cases, boundaries are obvious, but in cases where there might be some confusion, flagging or paint can be applied to boundary trees.

Often there will be considerable variation in the size, distribution and species of trees across a forested tract. These variations can result from previous land use, soil conditions, slope, etc. To maximize the accuracy and utility of your inventory results, it is best to map your tract into *stands* that are similar in the size and species of trees present prior to collecting field data. For instance, a forest stand that originated following abandonment of row cropping would have different attributes than a stand that had been continuously forested. By mapping the forest into different stands and collecting and summarizing data for each of those stands, you can gain valuable insight into which stands it would be best to harvest and what treatment management actions may be necessary to increase the value of other stands.

Step 2 – Gather the necessary equipment

Before you go into the forest, gather together the equipment listed below. Forestry professionals use vests with many pockets to hold all the equipment and make it easily accessible in the field.

- *handheld compass* – for navigating to plot locations
- *d-tape* or *Biltmore stick* – for measuring tree diameters
- *hypsometer* or *clinometer* – for measuring tree heights
- *tape measure* – for determining if trees are "in" plots
- *clip board* and *tally sheets* – for recording your individual measurements (see Appendix B for example tally sheets)
- *pencils* – for recording measurements and making notes
- *prism* or *angle gauge* – only necessary for variable radius plot sampling
- *calculator* – generally only necessary for variable radius plots but it can be useful for doing quick calculations to see if your numbers are reasonable
- *plot-center marker* – a highly visible flag or pole will help you keep track of where the center of the plot is and aid in the determination of "in" trees

Since sawtimber values differ by species, it is recommended that you separately tally each of the most common species on your tract that may be harvested as saw timber. Creating a catch-all "other species" tally sheet for species that are present in the stand but not common is a good practice. Additionally, use one tally sheet for all the hardwood trees classified as pulpwood and one tally sheet for all the pine (or softwood) trees classified as pulpwood.

Step 3 – Determine the number of plots

Simple rules of thumb may be used to determine how many plots to measure. Depending on how much time you have and how many plots you are willing to measure, you can use 5, 10 or 20 percent sampling intensity for fixed-radius plots. The 20 percent sampling intensity means that your sample plots will cover 20 percent of the area of your forested tract. On a 23-ac tract, 20 percent is 23 ac × 0.2 = 4.6 ac. Since you are using 1/10-acre plots, this means you need a total of 4.6 ac × 10 plots / ac = 46 plots. For variable-radius plots using the 10BAF angle gauge, you should use an equivalent number to the 1/10-acre fixed radius.

In the forest

Once you have done the appropriate planning, you are ready to find your first plot and begin measuring. Take your time on your first few plots and make sure that you are collecting all the necessary data and measuring "in" trees correctly. Steps 4 – 6 should be repeated at each plot.

Step 4 – Locating your first plot (and those that follow)

The *line-plot* method of sampling is a simple method for locating plots. It spreads the plots evenly across your forested tract and makes traveling between plots efficient.

In the line-plot method, plots are located at equal intervals along parallel lines running through your forested tract (Figure 2). To set up your first line, pick a corner of your tract that is a convenient starting point. Pace a distance of one chain along a boundary. Set your compass to a direction that will send you into your tract on a line perpendicular to your boundary (i.e., turn 90 degrees from the direction of your boundary line). Then, pace one chain into your stand and place your plot-center marker. It is important that you place your plot-center exactly when you get to the end of one chain regardless of terrain or habitat. If you consistently avoid steeper slopes, areas of dense brush, briars, wetlands or other impediments when placing your plot-centers, your sample will not be representative of the forested tract. Step 5 explains the details of laying out a plot and measuring trees.

When you are done measuring your first plot, you will want to locate the plot-center of your next plot. To locate your next plot, continue pacing along your line the number of chains indicated in Table 1 for your selected sampling intensity. If you were sampling at 10 percent intensity, you would pace two chains from your previous plot-center along the same compass heading before establishing another plot-center.

Table 1. Spacing of transect lines for indicated cruise intensities for 1/10-acre fixed-radius plots or 10 BAF variable-radius plots.

	Intensity		
	5%	**10%**	**20%**
Along line	4 chains	2 chains	2 chains
Between lines	5 chains	5 chains	2.5 chains

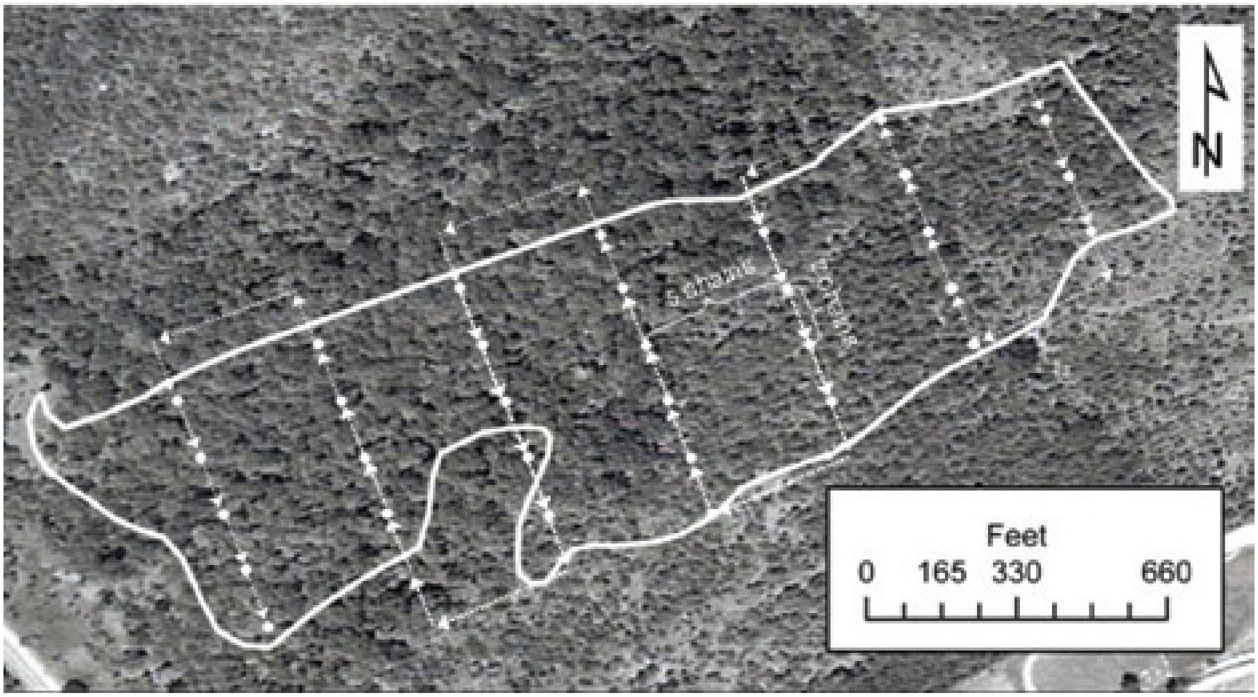

Figure 2. Example line-plot layout for 10 percent sampling intensity (Table 1). Circles represent plot locations and dashed lines while arrows represent paced distances and the direction of travel. The first line of plots, on the far right, was paced at an azimuth (a clockwise angle from true north) of 160°, the between-line distance at an azimuth of 250° and the second line at an azimuth of 340°.

When you reach the boundary of your tract, turn your compass 90 degrees (i.e., back to the direction of the boundary you first paced along) and follow this heading the appropriate between-line distance from Table 1 to locate your next plot-center (Figure 2). The between-line distance should be paced from the tract boundary. This is the first plot on your new line. To establish subsequent plots along this line, use a compass heading 180 degrees from your previous line and establish plots using the along-line distance in Table 1 (Figure 2). This process should be repeated each time you reach the tract boundary to establish subsequent lines of plots.

Step 5 – Measuring a plot

Once you have placed your plot-center marker, it is time to begin recording data. You need to determine which trees are "in" your plot. This is one instance where fixed-radius and variable-radius plots differ.

Fixed-Radius – Determining if a tree is "in"

A tree is in a 1/10-acre fixed-radius plot if the tree's stem center or pith at breast height is within 37.24 ft of plot-center, measured horizontally. Most of the time you can easily tell if a tree is "in" without the help of a measuring tape. However, for trees near the border of the plot, you should use a measuring tape to determine if the tree is "in" or "out." Do not measure the distance to the side of the tree that faces plot-center but to the tree's center. Also, be sure to hold the tape horizontally and measure the distance to breast height (4.5 feet above ground) on the tree.

Variable-Radius – Determining if a tree is "in"

A tree is "in" a 10 BAF variable-radius plot if it is wider than your limiting angle. Using an angle gauge, an "in" tree will appear wider than your gauge when sighted at breast height with your eye over plot-center. With a prism, the offset image of the tree seen in the prism will overlap with the view of the tree stem sighted with the prism held over plot-center for "in" trees (for an example, visit http://en.wikipedia.org/wiki/Wedge_prism).

As with fixed-radius plots, it is important to check borderline trees that are not obviously in or out when viewed from plot-center. Since each tree has a different plot radius, determining if a borderline tree is "in" first requires you to determine that tree's plot radius. To do this, you need to use the *plot radius factor* or PRF. The PRF for a BAF10 angle gauge or prism is 2.75 ft/in. To determine a tree's plot radius, multiply the PRF by the tree's DBH. For example, a tree that has a DBH of 18 inches has a plot radius of, 2.75 ft/in × 18 in = 49.5 ft. If the center of that tree at breast height is equal to or less than 49.5 ft in horizontal distance from plot-center, then the tree is "in" and should be measured and tallied.

Measure trees and record your data

When measuring a tree, you need to first determine the species and product class. For this publication, trees in the 12-inch DBH class or larger are considered merchantable. Saw-timber trees must have at least one ½ log (8 feet) with minimal defects. Typically, merchantable height on sawtimber trees can be measured to a minimum small-end diameter of 11 inches and merchantable height of pulpwood trees can be measured to a small-end diameter of 4 inches. The position at which the limiting small-end diameter occurs should be estimated by eye and the merchantable height measured to this position.

If a tree is "in" your plot, you should measure its height and diameter. Diameters are measured to the nearest even number and merchantable heights are measured to the nearest half log. These values can be recorded using the dot dash tally system (Figure 3). This system is commonly used because it simplifies the process of recording data and minimizes any trouble interpreting those data. For a tree of a given height and diameter, make dot or dash marks in the appropriate spot on your tally sheet. You do not need a different tally sheet for each plot; just keep adding dots or dashes to the appropriate cells on the tally sheet (Appendix B—Tally Sheet). You must also keep track of the total number of plots visited, The dot dash tally can be used for this purpose as well.

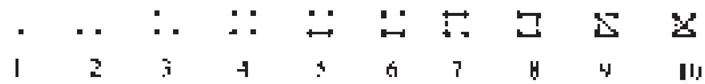

Figure 3. The dot dash tally system. For each "in" tree on your plot, you should add a dot or dash to the appropriate square on your tally sheet.

Working in a systematic fashion and following the same procedures on each plot will increase your efficiency and minimize mistakes. Missed or double-counted trees are one of the biggest sources of errors in timber inventories. It is a good self-check to count the number of "in" trees one last time before you leave the plot to make sure that you recorded them all.

In the office

This section provides a brief description of the calculations for estimating trees per acre and volume per acre in a timber inventory. More involved examples are included in Appendix C. These calculations can get tedious. The use of a spreadsheet program will minimize the chance of errors and allow you to efficiently repeat calculations for each plot.

Step 6 – Calculations

The calculations are divided into two stages: first, calculating the trees per acre, and second, calculating the volume per acre. The trees-per-acre calculations differ significantly between the fixed- and variable-radius sampling methods.

Fixed radius – Calculating trees per acre

On the cumulative tally sheets you will have counted the total number of trees you had in each DBH and height category for each species. To calculate how many of these trees per acre you had, you first need to figure out how many you averaged on your plots.

Average number of trees per plot (of a given species, height and DBH)
= number of these trees on all plots /number of plots

Since 10 1/10-acre plots fit in an acre, each tree on a 1/10-acre plot represents 10 trees per acre. To convert a plot-average number of trees to a per-acre value, multiply the plot-average number of trees by the per-acre expansion factor of 10.

Number of trees per acre = average number of trees per plot × per-acre expansion factor

The equations above can be combined to give:

Trees per acre (1/10-acre fixed radius) = (number trees on all plots / number of plots) × 10

To calculate the trees per acre of a given species, repeat this calculation for each height-diameter category on that species' tally sheet and sum those values. To calculate the total trees per acre of all species, complete these calculations for each species and sum those values.

Example - During your inventory you measured 23 1/10-acre fixed-radius plots. On those plots, you counted five white oaks in the 18-inch diameter class with merchantable heights of two logs. Using the equation above:

Trees per acre = (5 / 23) × 10 = 2.174 white oaks (in the 18 in., 2 log category) / acre

Variable radius – Calculating trees per acre

From the cumulative tally sheets you will have counted the total number of "in" trees you had in each DBH and height category for each species. To calculate trees per acre, you first need to figure out how many trees you had, on average, on your plots.

Average number of trees per plot (of a given species, height and DBH) = number of these trees on all plots / number of plots

Unlike fixed radius plots, there is no simple per-acre conversion factor for all trees. Each tree with a different DBH has a different-sized plot. However, you still must determine how many trees per acre are represented by one "in" tree of a given DBH. This is the per-acre expansion factor. The formula to calculate this value is:

Per-acre expansion factor = BAF / BA

Different-diameter trees will have different per-acre expansion factors. This is the key difference between fixed- and variable-radius sampling. The following calculations need to be done for each measured DBH class. To calculate the trees per acre, multiply the average number of trees per plot by the calculated per-acre expansion factor.

Number trees per acre (for a given DBH class) = average number of these trees per plot × per-acre expansion factor for this DBH

The equations above can be combined to give:

Trees per acre for a given DBH (variable radius) = (number of these trees on all plots / number of plots) × (BAF / BA)

Since BA = $0.005454 \times DBH^2$ the equation can be simplified one step further to:

Trees per acre (variable radius) = (number of trees on all plots / number of plots) × (BAF / $0.005454 \times DBH^2$)

To calculate the trees per acre of a given species, you repeat this calculation for each height/diameter category on that species' tally sheet and sum those values. To calculate the total trees per acre of all species, complete calculations for each species and sum those values.

Example - During your inventory you measured 15 variable-radius plots, using a 10 BAF angle gauge. On those plots you counted five total white oaks that were in the 18-inch diameter class with a merchantable height of two logs. Using the equation above:

Trees per acre = (5 / 15) × (10 / (.005454 × 18^2))
= 1.886 white oaks (in the 18 in., 2 log category) / acre.

Calculating volume per acre

The volume-per-acre calculations are identical for variable-radius and fixed-radius sampling. To calculate the volume per acre for a given DBH and merchantable height category, you first need to determine the volume of one tree in that category from a volume table (Appendix A). Then multiply the volume of one tree by the number of those trees per acre to get volume per acre. The volume-per-acre calculation is:

Volume per acre = Volume of one tree × trees per acre.

To calculate the volume per acre for a species or product class, calculate the volume for each height-diameter class and sum those values. To calculate the volume per acre of all species, complete calculations for each species and sum those values.

Example - Continuing the examples from the trees-per-acre calculation, you can determine the volume of one white oak that has a DBH of 18 inches and a merchantable height of two logs. For this example, using the Doyle, form class 78 table in Appendix A, the volume of an 18 in, 2 log tree is 164 bf.

For the fixed-radius plot example above:

Volume per acre of an 18 in., 2 log, white oak = 164 bf × 2.174 tpa = 356.5 bf/acre

For the variable-radius plot example:

Volume per acre of an 18 in., 2 log, white oak = 164 bf × 1.886 tpa = 309.3 bf /acre

Calculating tract totals

An estimate of the total volume or number of trees (of a given species or product class) can be obtained by multiplying the area of the tract you sampled by your estimated volume or trees per acre.

Total volume on tract = volume per acre × tract area in acres

Total number of trees on tract = trees per acre × tract area in acres

Example - If you estimated that you had 120 saw timber trees per acre with a volume per acre of 5,300 bf per acre on a 65-acre tract, the tract totals would be:

Number of trees on tract = 120 tpa × 65 ac = 7800 trees on tract.

Volume of saw timber on tract = 5,300 bf/ac × 65 ac = 344500 bf = 344.5 mbf on tract.

Concluding Remarks

This publication has served as an introduction to the terminology and methodology of timber inventory. Timber inventory can be a very complex and subjective process. Even trained professional foresters and experienced loggers often arrive at differing volumes and values when inventorying a tract. Because most private forest landowners are not comfortable with inventorying their own timber, professional assistance is highly recommended. This is particularly the case when decisions related to timber value have lasting consequences.

References

Avery, T.E. and H.E. Burkhart, 2002. Forest Measurements, Fifth Edition. McGraw Hill, Boston, Massachusetts.

Parker, R.C., T. G. Matney, and K.L Belli, 2007. Field and Laboratory Exercises for Forest Description and Analysis, edition 11.0. Mississippi State University.

Wenger, Karl. 1984. Forestry Handbook. Second Edition. Edited for the Society of American Foresters. John Wiley & Sons. New York.

Appendix A

Volume tables

International ¼” and Doyle volume tables are presented for form class 78 and form class 80. All saw-timber board foot volume tables are originally from Wenger, 1984.

International 1/4” board foot volume

Form Class 78

	Merchantable Height in Logs									
DBH (in)	1/2	1	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5
12	30	56	74	92	106	120	128	137		
14	40	78	105	132	153	174	187	200		
16	60	106	143	180	210	241	263	285		
18	70	136	184	233	274	314	344	374		
20	90	171	234	296	348	401	440	480	511	542
22	110	211	290	368	434	500	552	603	647	691
24	130	251	346	441	523	605	664	723	782	840
26	160	299	414	528	626	725	801	877	949	1021
28	190	347	482	616	733	850	938	1027	1114	1201
30	220	403	560	718	854	991	1094	1198	1306	1415
32		462	644	826	988	1149	1274	1400	1518	1637
34		521	728	934	1119	1304	1447	1590	1727	1864
36		589	826	1063	1274	1485	1650	1814	1974	2135
38		656	921	1186	1428	1670	1854	2038	2224	2410
40		731	1030	1329	1598	1868	2081	2294	2494	2693

International 1/4” board foot volume

Form Class 80

	Merchantable Height in Logs									
DBH (in)	1/2	1	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5
12	33	59	78	98	112	127	136	146		
14	45	83	112	141	164	186	201	216		
16	66	112	151	190	223	256	280	305		
18	78	144	196	248	292	336	369	402		
20	100	181	248	314	370	427	470	512	546	580
22	120	221	304	387	458	528	583	638	685	732
24	145	266	368	469	556	644	708	773	836	899
26	176	315	436	558	662	767	849	931	1008	1086
28	210	367	510	654	779	904	1000	1096	1190	1284
30	241	424	591	758	904	1050	1161	1272	1388	1503
32		485	678	870	1042	1213	1346	1480	1606	1733
34		550	770	989	1186	1383	1537	1691	1838	1984
36		620	870	1121	1346	1571	1746	1922	2093	2264
38		693	974	1256	1514	1772	1970	2167	2368	2568
40		770	1086	1403	1690	1977	2204	2432	2646	2860

Doyle board foot volume

Form Class 78

	Merchantable Height in Logs									
DBH (in)	1/2	1	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5
12	20	29	36	43	48	53	54	56		
14	30	48	62	75	84	93	98	103		
16	40	72	94	116	132	149	160	170		
18	60	100	132	164	190	215	232	248		
20	80	135	180	225	261	297	322	346	364	383
22	100	174	234	295	344	392	427	462	492	521
24	130	216	293	370	433	496	539	582	625	668
26	160	266	362	459	539	619	678	737	793	849
28	190	317	434	551	650	750	820	890	961	1032
30	230	376	517	658	778	898	984	1069	1160	1251
32		441	608	776	922	1068	1176	1283	1386	1488
34		506	700	894	1064	1235	1361	1487	1608	1730
36		581	808	1035	1234	1434	1583	1732	1878	2023
38		655	912	1170	1402	1635	1805	1975	2148	2322
40		740	1035	1330	1594	1858	2059	2260	2448	2636

Doyle board foot volume

Form Class 80

	Merchantable Height in Logs									
DBH (in)	1/2	1	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5
12	23	31	39	47	52	57	60	62		
14	37	52	67	82	93	104	109	114		
16	53	77	101	125	143	161	174	186		
18	72	108	144	179	206	234	254	273		
20	95	144	193	242	282	321	348	374	396	417
22	120	185	250	315	368	420	458	497	529	561
24	148	231	314	397	466	536	583	630	678	725
26	178	282	386	489	576	663	727	791	852	912
28	212	339	466	592	700	807	885	963	1040	1118
30	248	400	552	703	832	961	1055	1149	1248	1346
32		467	646	824	980	1137	1254	1370	1481	1592
34		538	746	954	1138	1322	1459	1596	1728	1861
36		615	857	1099	1312	1526	1688	1849	2006	2163
38		697	973	1249	1499	1749	1934	2119	2308	2496
40		784	1099	1414	1696	1979	2196	2413	2616	2819

Pulpwood volume tables are adapted from Parker, et al., 2007.

Pine Pulpwood volume table (cords)

	Merchantable Height in Logs						
DBH (in)	1	1 1/2	2	2 1/2	3	3 1/2	4
6	0.034	0.044	0.054	0.064	0.073	0.083	0.093
8	0.060	0.076	0.092	0.108	0.124	0.140	0.156
10	0.090	0.113	0.137	0.161	0.184	0.208	0.231
12	0.123	0.156	0.189	0.222	0.255	0.288	0.321
14	0.160	0.204	0.248	0.292	0.336	0.380	0.425
16	0.200	0.257	0.314	0.371	0.428	0.485	0.542
18	0.243	0.315	0.386	0.458	0.529	0.601	0.673
20	0.290	0.378	0.466	0.553	0.641	0.729	0.817

Note: One cord of pine pulpwood weighs approximately 2.67 tons. So the volume in cords can be approximately converted to weight in tons by multiplying by 2.67. This is only an approximation, as species and dryness can drastically affect wood weight.

Hardwood pulpwood volume table (cords)

	Merchantable Height in Logs						
DBH (in)	1	1 1/2	2	2 1/2	3	3 1/2	4
6	0.032	0.040	0.048	0.056	0.065	0.073	0.081
8	0.055	0.069	0.082	0.096	0.110	0.123	0.137
10	0.081	0.102	0.123	0.143	0.164	0.184	0.205
12	0.111	0.140	0.169	0.198	0.227	0.256	0.286
14	0.144	0.183	0.222	0.261	0.300	0.339	0.378
16	0.180	0.230	0.281	0.332	0.382	0.433	0.484
18	0.218	0.282	0.346	0.410	0.473	0.537	0.601
20	0.260	0.339	0.417	0.496	0.574	0.652	0.731

Note: One cord of hardwood pulpwood weighs approximately 2.9 tons. So the volume in cords can be approximately converted to weight in tons by multiplying by 2.9. This is only an approximation, as species and dryness can drastically affect wood weight.

Appendix B—Tally Sheet

Property Name ________________________________ Date _________________ No. of Plots _________

Species =

	No. 16' Logs									
DBH	1/2	1	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5
12										
14										
16										
18										
20										
22										
24										
26										
28										
30										
32										
34										
36										
38										
40										

Species =

	No. 16' Logs									
DBH	1/2	1	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5
12										
14										
16										
18										
20										
22										
24										
26										
28										
30										
32										
34										
36										
38										
40										

Species =

	No. 16' Logs									
DBH	1/2	1	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5
12										
14										
16										
18										
20										
22										
24										
26										
28										
30										
32										
34										
36										
38										
40										

Species =

	No. 16' Logs									
DBH	1/2	1	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5
12										
14										
16										
18										
20										
22										
24										
26										
28										
30										
32										
34										
36										
38										
40										

Appendix C

Example calculations

The following are more involved examples of how to process inventory data from variable- and fixed-radius plots. The methods are presented as a spreadsheet, because this is the most straightforward means for summarizing the data. Each example summarizes the data from a tally sheet for one species. Summarizing the data across species can be done by first completing the summaries described here for each species, then adding those summaries to get estimates for all species combined.

Fixed-radius sampling — Example

For this example, a sample was conducted using 21, 1/10-acre plots in a 21-acre forested tract (i.e., a 10 percent sample was conducted). The tract was dominated by chestnut oak, so a summary of the data for that species would be useful. All the data collected in the field are represented in the tally sheet in Figure 4. Figure 5 shows how the data in Figure 4 could be summarized to create trees-per-acre and volume-per-acre estimates using spreadsheet software. All formulas used are discussed in the "*In the office*" section of the text.

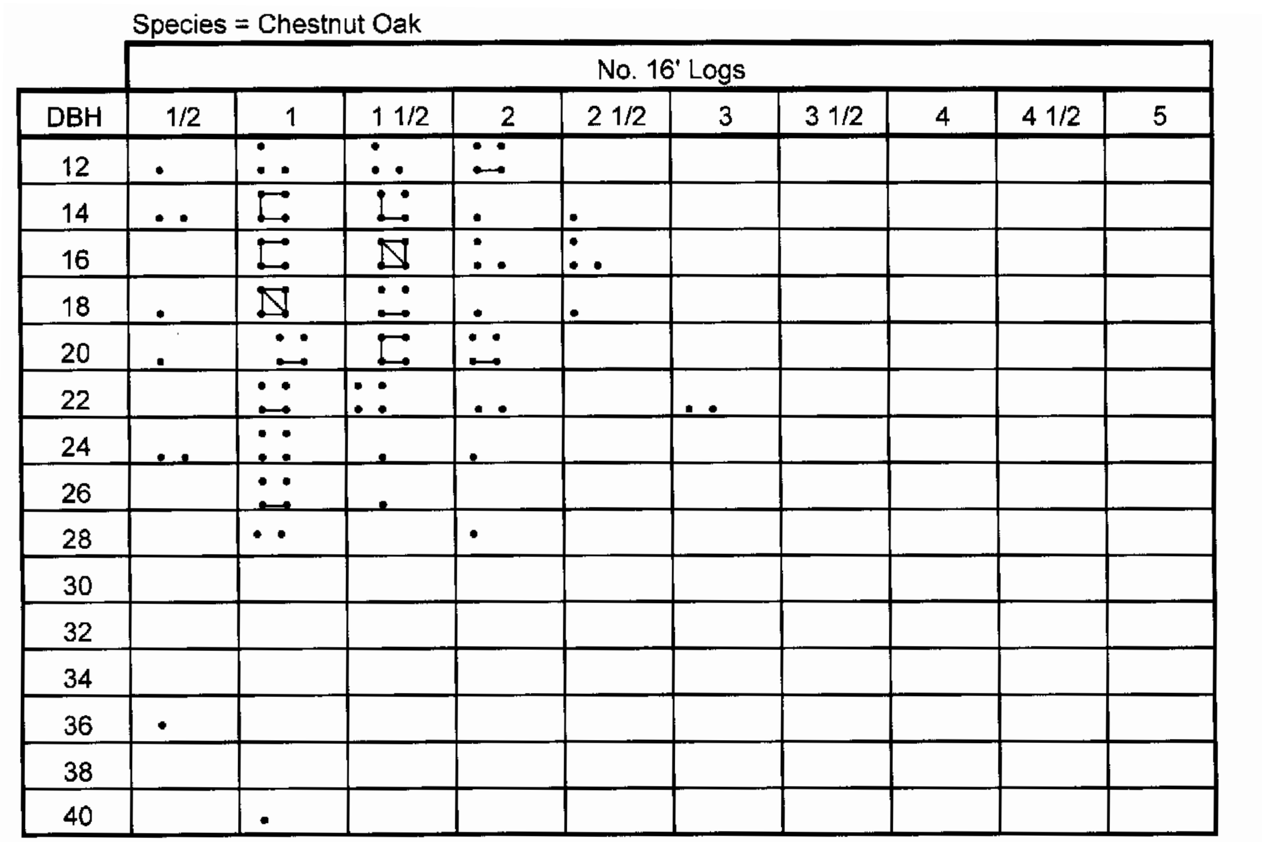

Figure 4. Cumulative tally sheet for all the chestnut oak measured on 21 1/10-acre fixed-radius plots, on a 21-acre forested tract.

Values in these columns were obtained from the tally sheet (Figure 4)

Values in this column were calculated using the equation Trees per acre = # of trees / # of plots × 10

Values in this column were obtained from the Doyle, Form class 78 table in Appendix A, *for the indicated merchantable height and DBH*

*Values in this column were calculated using the formula: Volume per acre = tpa * volume of 1 tree*

The total trees per acre and volume per acre of chestnut oaks are found by summing the appropriate columns

DBH (in)	height (logs)	Number of trees tallied	Trees per acre (#/ac)	Volume of one tree	Volume per acre (bf/ac)
12	0.5	1	0.476	20	9.52
12	1	3	1.429	29	41.43
12	1.5	3	1.429	36	51.43
12	2	5	2.381	43	102.38
14	0.5	2	0.952	30	28.57
14	1	7	3.333	48	160.00
14	1.5	6	2.857	62	177.14
14	2	1	0.476	75	35.71
14	2.5	1	0.476	84	40.00
16	1	7	3.333	72	240.00
16	1.5	9	4.286	94	402.86
16	2	3	1.429	116	165.71
16	2.5	3	1.429	132	188.57
18	0.5	1	0.476	60	28.57
18	1	9	4.286	100	428.57
18	1.5	5	2.381	132	314.29
18	2	1	0.476	164	78.10
18	2.5	1	0.476	190	90.48
20	0.5	1	0.476	80	38.10
20	1	5	2.381	135	321.43
20	1.5	7	3.333	180	600.00
20	2	5	2.381	225	535.71
22	1	5	2.381	174	414.29
22	1.5	4	1.905	234	445.71
22	2	2	0.952	295	280.95
22	3	2	0.952	392	373.33
24	0.5	2	0.952	130	123.81
24	1	4	1.905	216	411.43
24	1.5	1	0.476	293	139.52
24	2	1	0.476	370	176.19
26	1	5	2.381	266	633.33
26	1.5	1	0.476	362	172.38
28	1	2	0.952	317	301.90
28	2	1	0.476	551	262.38
36	0.5	1	0.476	350	166.67
40	1	1	0.476	655	311.90
		Totals	56.190		8292.38

Figure 5. Example spreadsheet showing data entry from tally sheet (Figure 4), trees-per-acre calculations and volume-per-acre calculations for chestnut oak obtained from 21 1/10-acre fixed-radius plots.

Variable-radius sampling — Example

For this example, a sample was conducted using 30 10BAF variable-radius plots in a 30-acre forested tract (i.e., a sample comparable to 10 percent fixed-radius sampling intensity for 1/10-acre plots was conducted). The tract was dominated by chestnut oak, so a summary of the data for that species would be useful. All the data collected in the field are represented in the tally sheet in Figure 6. Figure 7 shows how the data in Figure 6 could be summarized to create trees- per-acre and volume-per-acre estimates using spreadsheet software. All formulas used are discussed in the "*In the office*" section of the text.

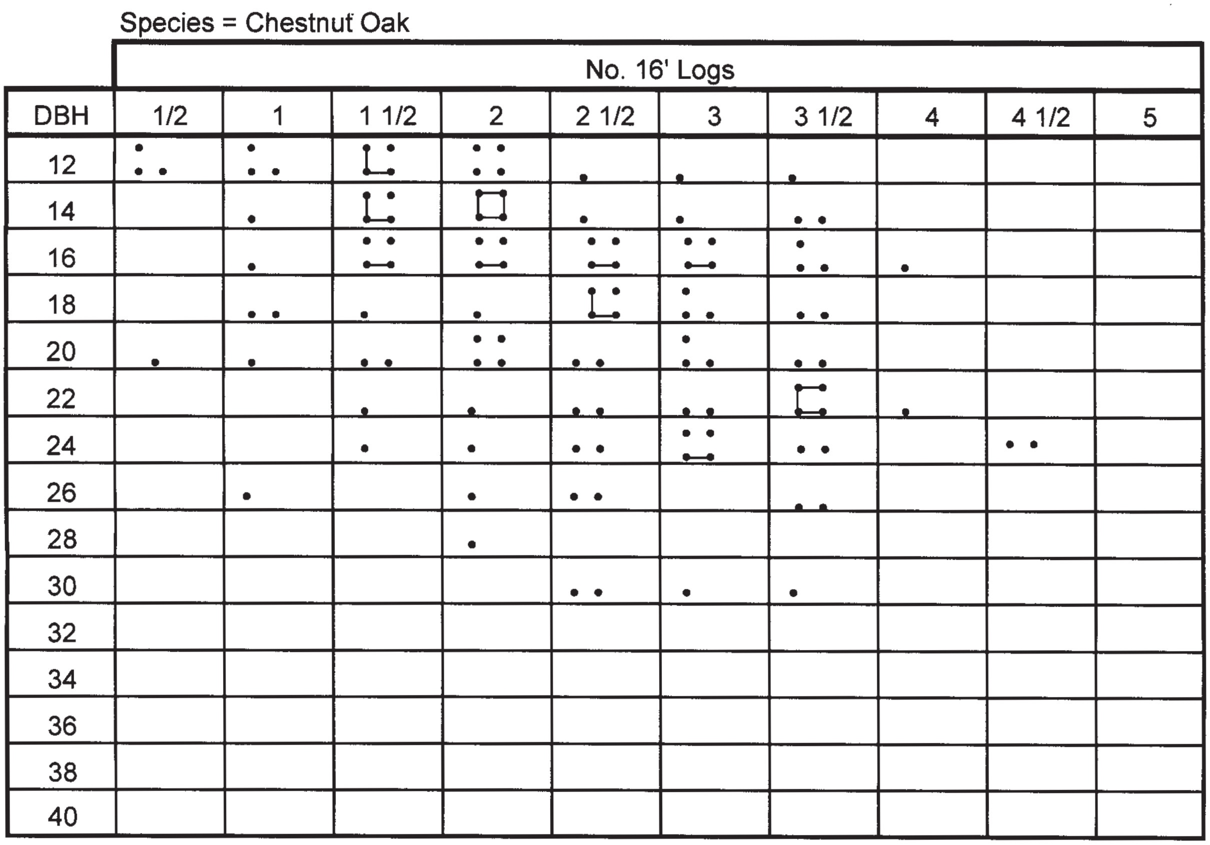

Figure 6. Cumulative tally sheet for all the chestnut oak measured on 30 10BAF variable-radius plots, on a 30-acre forested tract.

Values in these columns were obtained from the tally sheet (Figure 6)

Values in this column were calculated using the equation Basal Area = $0.005454*DBH^2$

Values in this column were calculated using the equation Trees per acre = BAF / Basal area

DBH (in)	height (logs)	Number of trees tallied	Basal Area (ft2)	Trees per acre represente by one tree	Trees per acre (#/ac)	Volume of one tree	Volume per acre (bf/ac)
12	0.5	3	0.79	12.73	1.27	20	25.56
12	1	3	0.79	12.73	1.27	29	36.94
12	1.5	6	0.79	12.73	2.55	36	91.68
12	2	4	0.79	12.73	1.70	43	73.00
12	2.5	1	0.79	12.73	0.42	48	20.37
12	3	1	0.79	12.73	0.42	53	22.70
12	3.5	1	0.79	12.73	0.42	54	22.92
14	1	1	1.07	9.35	0.31	48	14.97
14	1.5	6	1.07	9.35	1.87	62	116.00
14	2	8	1.07	9.35	2.49	75	187.09
14	2.5	1	1.07	9.35	0.31	84	26.19
14	3	1	1.07	9.35	0.31	93	29.00
14	3.5	2	1.07	9.35	0.62	98	61.12
16	1	1	1.40	7.16	0.24	72	17.19
16	1.5	5	1.40	7.16	1.19	94	112.21
16	2	5	1.40	7.16	1.19	116	138.47
16	2.5	5	1.40	7.16	1.19	132	157.57
16	3	5	1.40	7.16	1.19	149	177.86
16	3.5	3	1.40	7.16	0.72	160	114.59
16	4	1	1.40	7.16	0.24	170	40.59
18	1	2	1.77	5.66	0.38	100	37.73
18	1.5	1	1.77	5.66	0.19	132	24.90
18	2	1	1.77	5.66	0.19	164	30.94
18	2.5	6	1.77	5.66	1.13	190	215.04
18	3	3	1.77	5.66	0.57	215	121.67
18	3.5	2	1.77	5.66	0.38	232	87.53
20	0.5	1	2.18	4.58	0.15	80	12.22
20	1	1	2.18	4.58	0.15	135	20.63
20	1.5	2	2.18	4.58	0.31	180	55.01
20	2	4	2.18	4.58	0.61	225	137.51
20	2.5	2	2.18	4.58	0.31	261	79.76
20	3	3	2.18	4.58	0.46	297	136.14
20	3.5	2	2.18	4.58	0.31	322	98.40
22	1.5	1	2.64	3.79	0.13	234	29.55
22	2	1	2.64	3.79	0.13	295	37.25
22	2.5	2	2.64	3.79	0.25	344	86.88
22	3	2	2.64	3.79	0.25	392	99.00
22	3.5	7	2.64	3.79	0.88	427	377.44
22	4	1	2.64	3.79	0.13	462	58.34
24	1.5	1	3.14	3.18	0.11	293	31.09
24	2	1	3.14	3.18	0.11	370	39.26
24	2.5	2	3.14	3.18	0.21	433	91.89
24	3	5	3.14	3.18	0.53	496	263.14
24	3.5	2	3.14	3.18	0.21	539	114.38
24	4.5	2	3.14	3.18	0.21	625	132.63
26	1	1	3.69	2.71	0.09	266	24.05
26	2	1	3.69	2.71	0.09	459	41.50
26	2.5	2	3.69	2.71	0.18	539	97.46
26	3.5	2	3.69	2.71	0.18	678	122.60
28	2	1	4.28	2.34	0.08	551	42.95
30	2.5	2	4.91	2.04	0.14	778	105.66
30	3	1	4.91	2.04	0.07	898	60.98
30	3.5	1	4.91	2.04	0.07	984	66.82
				Totals	29.12		4466.34

Values in this column were calculated using the equation tpa =Per-acre expansion × # trees tallied / # of plots

Values in this column were obtained from the Doyle, Form class 78 table in Appendix A, *for the indicated merchantable height and DBH*

*Values in this column were calculated using the formula: Volume per acre = tpa * volume of 1 tree*

The total trees per acre and volume per acre of chestnut oaks are found by summing the appropriate columns

Figure 7. Example spreadsheet showing data entry from tally sheet (Figure 6), trees-per-acre calculations and volume-per-acre calculations for chestnut oak obtained from 30 10BAF variable-radius plots.

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