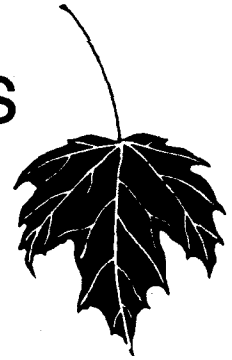# LAKE STATES WOODLANDS

Measuring Trees and Estimating Volume

Jeff Martin

INTRODUCTION

Diameter at breast height (DBH) is the single most important tree measurement when cruising (inventorying) timber stands to determine value. Woodland owners and managers use DBH for estimating the tree's volume and weight, for assessing stand density, for determining merchantability, and for estimating tree height.

MEASURING DBH

DBH is the diameter outside bark of the tree's stem at a point 4½ feet above the ground (Figure 1). When measuring on slopes, stand on the uphill side of the tree to compensate for added stump height.

Sometimes such things as bumps, swellings, depressions, and branches on the tree require modifying your technique. When the irregularities are at or near 4½ feet above ground, measure the diameter above the irregularity, at a point where it no longer affects normal stem growth. If a tree forks immediately above breast height, take the measurement just below the swollen area. Consider stems that fork below breast height as two separate trees, and measure about 3½ feet above the fork. In deep snow, you may have to use a 4½-foot stick and probe to the ground before measuring.

Since growth patterns create a variety of tree shapes, usually the bole's cross-section is not a perfect circle and you are really only estimating diameter. In the following paragraphs, keep in mind accurate measurement really means trying to *estimate* DBH reliably.
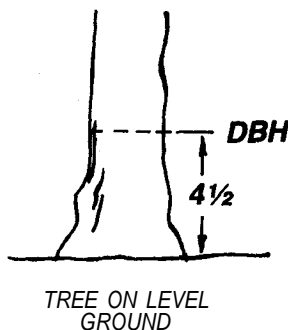
INSTRUMENTS

The most common, and least expensive, instruments are the cruiser's stick (or Biltmore stick) and the diameter tape (D-tape).

The cruiser's stick looks a lot like a wooden yardstick, with a diameter scale stamped on one edge. To use, place the stick crosswise against the tree's bole, 4½ feet above ground at arm's length. Most sticks are designed to be held 25 inches from your eye, but arm's length is usually about right. Adjust the stick so that it looks like it extends to the left side of the tree. Then, moving only your eye, look at the tree's right side. The number at the point where your new line of sight intersects the stick is the tree's DBH (Figure 2).

The cruiser's stick is fast to use, fairly inexpensive (under $10), and typically contains other useful scales for estimating height, volume, and additional items. However, the stick is not very precise; two people (or

CROSS SECTION OF TREE
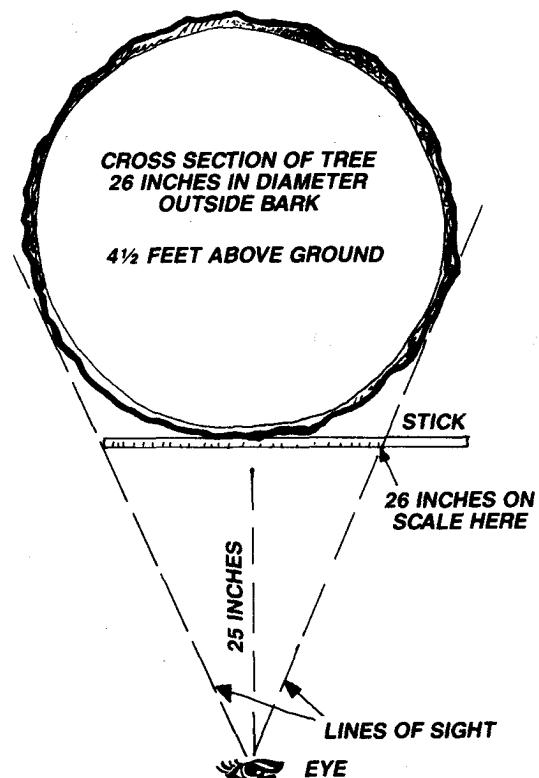26 INCHES IN DIAMETER
OUTSIDE BARK

4½ FEET ABOVE GROUND

STICK

26 INCHES ON SCALE HERE

25 INCHES

LINES OF SIGHT

EYE

Figure 2. Using a Biltmore stick to measure DBH.

DBH

4½

TREE ON LEVEL GROUND

Figure 1. DBH—diameter at breast height.

one person measuring twice) seldom get the same estimate. For greater accuracy you should take a second reading (at 90 degrees to the first) and then average the two for your DBH estimate—especially on irregular-shaped trees.

With a diameter tape, wrap the tape around the tree's bole at 4½ feet above ground and measure circumference. The tape has graduations on one side that automatically convert circumference to the nearest 1/10 inch diameter.

The diameter tape is also easy to use, fairly inexpensive ($10 to $35) and reasonably precise—considerably more than the cruiser's stick. However, the less the tree's cross-section resembles a perfect circle the less accurate the measure will be, because the tape is still measuring a circumference and dividing by pi (3.1416) to get a diameter estimate. Furthermore, you can't move around the tree, take another reading, and average the two, as you could with a cruiser's stick, so use caution when reading to the nearest 1/10th inch with irregular-shaped trees.

If you don't have either of these instruments and don't care to purchase them, you can still estimate DBH reliably by measuring the bole's circumference with a flexible tape 4½ feet above ground, and dividing by pi (3.1416).

MEASURING TREE HEIGHT

Total height—the height from the ground to the tree tip (the terminal bud if it could be seen or identified)—is useful for helping estimate site index (a measure of how good the stand or site is for growing trees), total tree volume, some merchantable volumes, and tree weight in some of the more elaborate equations.

Merchantable height, generally defined as the height above a 6-inch or 1-foot assumed stump to the upper limit of merchantability, is used for estimating product volumes. The upper limit is usually in terms of a stem diameter (either inside or outside the bark). While merchantable height is typically estimated for the stem's sawlog portion or the pulpwood portion, in some cases the pulpwood height above the sawlog portion is recorded separately.

Unlike total height which is usually estimated in feet, merchantable height is presented in a variety of units—feet, number of 16-foot logs, number of bolts or pulpwood sticks (such as 8-foot bolts or 1 W-inch sticks), etc.

Estimating tree heights requires more judgment or subjectivity than estimating DBH, starting with determining exactly where the tree tip or upper limit of merchantability is located. This is often fairly easy with softwoods, but can be difficult with hardwoods, particularly when leaves are present or when the tree has many branches.

Instruments used for estimating tree heights are collectively called hypsometers and are based on trig-

onometric principles. While many different types have been developed ranging from inexpensive to very costly, the practicing forester commonly uses only a few inexpensive tools. When using a hypsometer, stand a fixed horizontal distance from the tree base, usually 50 feet, 66 feet (1 chain), or 100 feet. Many hypsometers that you might use will work best when you stand at a distance equal to about one-half the tree height.

For best results, trees shouldn't lean more than 5 degrees from the vertical, and the fixed horizontal distance must usually be determined by taped measurement or by careful pacing. View leaning trees at right angles to the direction of lean to minimize height errors.

The most common and easiest to use instrument is the Merritt hypsometer. This simple scale is often printed on the back of a Biltmore stick. It is usually used for estimating merchantable height in terms of 16-foot logs and half-logs. Like the Biltmore stick, the Merritt hypsometer must be positioned at a fixed distance from the eye and the observer must stand a specified distance from the tree base. The distance is usually 66 feet, but since this may vary be sure to use the distance stamped on the hypsometer you are using. Hold the Merritt hypsometer vertically with the lower stick end on a line-of-sight to tree-stump height. With the stick held firm, glance up to find the log height at the desired point on the upper stem (Figure 3). This instrument is useful for estimating merchantable height but it isn't very reliable for precise estimates or for total tree height.

For more reliable estimates use the Abney level, clinometer, or specialized height measuring instruments. Whether or not the expense, and trouble, of using the higher priced equipment is worth undertaking depends on the purpose intended (as well as on your budget).

The Abney level and clinometer usually provide readings within 2 to 5 percent of the true height. These are both optical instruments designed to estimate slope, angles, or height. If the instrument is calibrated to read in percent slope, you can stand any distance from the tree and then simply multiply the percent reading by the horizontal baseline distance to obtain tree height. If the instrument has a topographic scale (instead of slope) you can read feet directly. Usually the observer must stand 66 feet (1 chain) from the tree base. An Abney level costs around $100, a good clinometer about $50. The clinometer is not only cheaper, it is also much easier to use.

To use the Abney level or clinometer, point the instrument at groundline or stump height and take a reading; then take another reading with the instrument pointed to the height you want to know (either a merchantable point or the tree top). If both readings are on the same side of zero the height estimate is the difference between the two readings. When one reading is below zero and the other above zero, add the two (Figure 4).
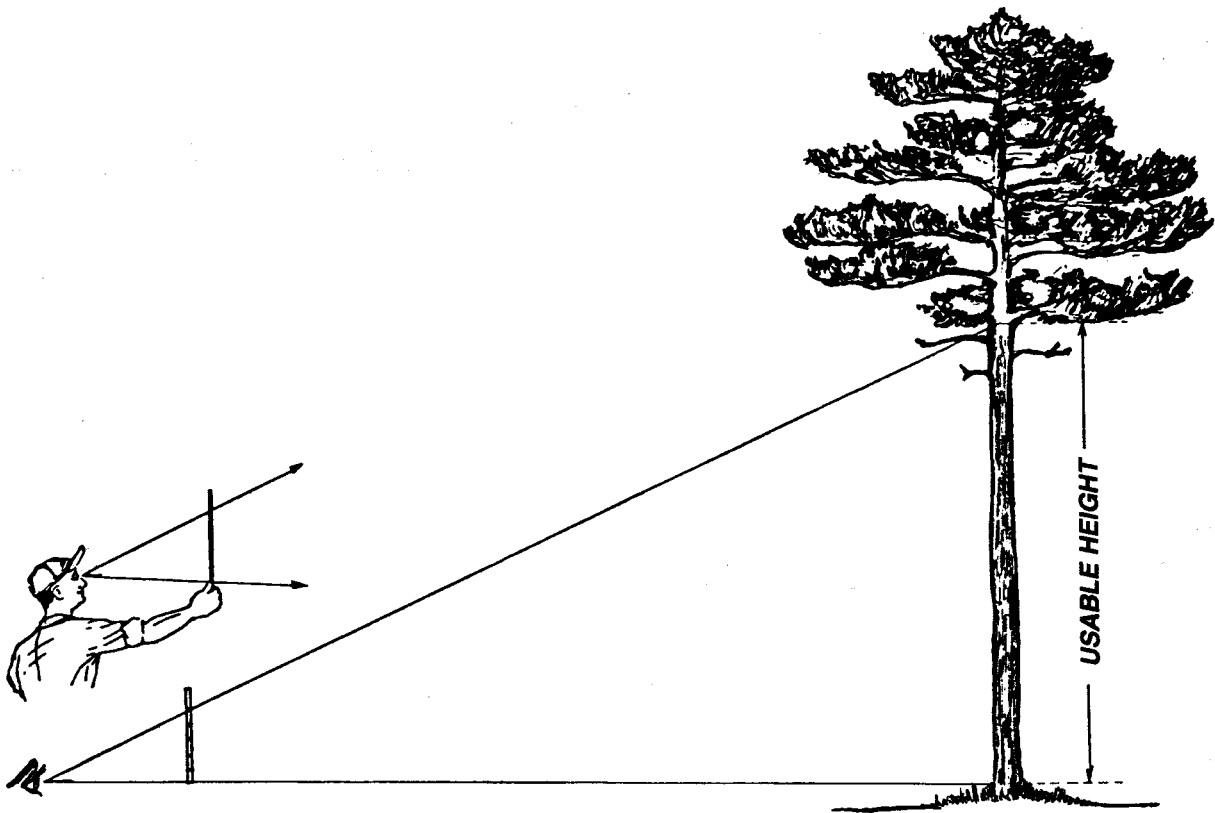
Figure 3. Using a Merritt hypsometer to measure merchantable tree height.

33 ft.

When base of tree is below
the eye level of observer: sight
top, sight base and add readings
33 + 9 = 42
FEET TOTAL TREE HEIGHT

33

9

9 ft.

66 ft.

52 ft.

When base of tree is above
observer's eye level: sight top,
sight base and subtract base reading
from top reading 52 – 11 = 41 FEET
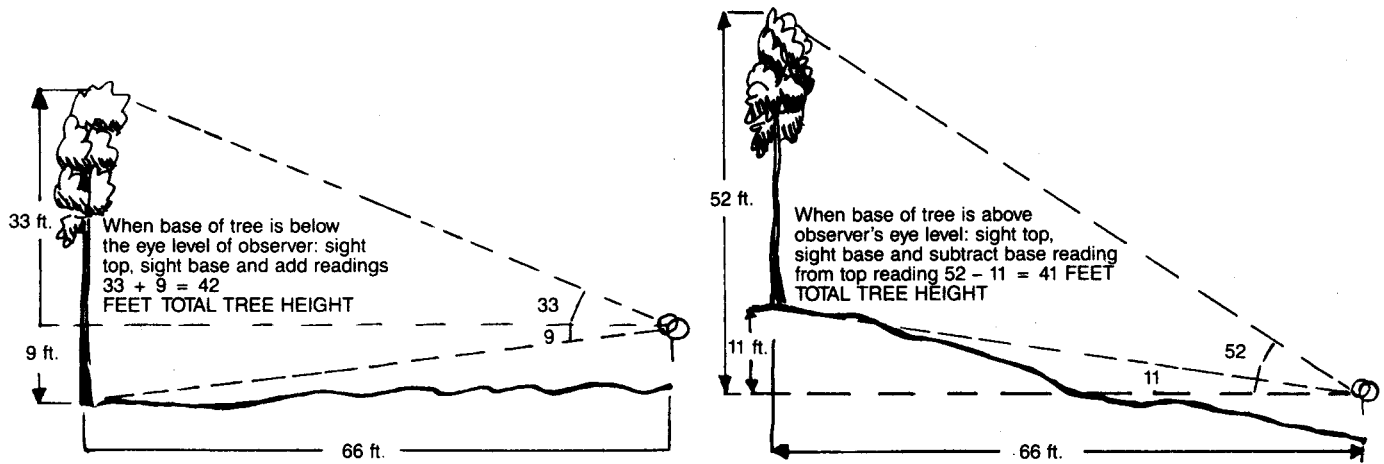TOTAL TREE HEIGHT

52

11

11 ft.

66 ft.

Figure 4. Using a clinometer or Abney level to estimate tree height.

Table 1. Composite table: gross volume[1] in board-feet (Scribner rule) by number of 16-foot logs.[2]

Diameter Breast High (inches)	Volume (in board feet) when number of 16-foot logs is								
	½	1	1½	2	2½	3	3½	4	5
8	10	16	24	31					
9	13	23	31	39	46				
10	17	30	40	49	57	62			
11	22	38	51	62	71	78			
12	28	48	66	78	89	100	108		
13	34	59	81	96	112	126	138	145	
14	40	70	96	116	141	160	170	178	
15	47	81	113	137	166	188	204	220	
16	54	93	129	158	191	224	248	263	
17	63	106	148	182	218	257	285	308	340
18	72	122	168	207	248	292	325	355	395
19	81	137	190	234	280	328	368	405	455
20	90	156	212	262	317	366	415	450	520
21	100	173	238	293	351	405	460	595	585
22	111	194	262	328	392	450	510	450	660
23	123	215	290	360	435	500	560	620	730
24	137	236	319	400	470	550	620	690	800
25	149	258	348	440	520	600	680	760	880
26	165	281	381	480	565	650	740	820	950
27	179	305	415	520	620	710	800	890	1,030
28	195	331	450	560	670	760	860	960	1,120
29	210	356	485	600	720	830	930	1,030	1,200
30	227	383	520	650	770	890	1,000	1,110	1,290
31	245	410	560	700	830	950	1,080	1,200	1,380
32	260	440	600	740	890	1,020	1,150	1,280	1,470
33	279	470	640	790	950	1,080	1,230	1,370	1,560
34	294	500	680	840	1,010	1,160	1,300	1,460	1,670
35	312	530	720	900	1,080	1,230	1,390	1,560	1,790
36	330	565	770	960	1,140	1,310	1,480	1,650	1,900
37	349	600	820	1,020	1,210	1,390	1,570	1,750	2,010
38	365	630	860	1,070	1,270	1,470	1,660	1,840	2,120
39	364	660	900	1,130	1,330	1,550	1,750	1,940	2,240
40	405	700	950	1,180	1,400	1,630	1,850	2,050	2,350

[1] The figures underscored in the upper portion of the table show volume to a top diameter of 6.0 or more, but lees than 6.0 inches and hence are applicable only to softwoods.

[2] Taken from Gevorkiantz, S. R. and Olsen, L.P. 1955. Composite volume tables for timber and their application in the Lake States. USDA Tech. Bull. 1104.

ESTIMATING TREE VOLUME

The true volume can only be determined by immersing logs or trees in a tank full of water, and then measuring the displaced water volume. However, this is very time consuming and costly, so woodlot owners and foresters usually use indirect methods to estimate tree and product volumes.

If trees produced boles (trunks) that were perfect cylinders estimating volume would be easy. Everyone could use the equation for calculating volume of a cylinder for all species in all locations. However, because trees taper from ground to tip, and because all species don't do this in the same manner, foresters have designed numerous equations and volume tables for different species, different regions, etc. In fact there are so many methods for estimating volume that it would be impossible to cover them all in one publication. Therefore, this discussion will be aimed at understanding the general points of estimating volume.

You can estimate tree volume using DBH and height (or in some cases DBH alone) and a volume table or a volume equation.

Tables are generally easier to use if you're only interested in looking up a few trees. And Biltmore sticks often have a volume table stamped on one side of the stick, simplifying things even more. However, if you have a long list of trees from a cruise of your wood-

Table 2. Composite table: gross volume[1] in rough cords to a variable top diameter inside bark, by number of bolts.[2]

Diameter Breast High (inches)	Volume (in cords) when number of 8-foot bolts is:							
	1	2	3	4	5	6	7	8
4	0.007	0.011						
5	.011	.019	0.022					
6	.017	.028	.040	0.047				
7	.023	.038	.053	.068	0.076			
8	.031	.050	.068	.087	.106	0.116		
9	.040	.065	.088	.109	.130	.153	0.170	
10	.049	.082	.111	.133	.160	.188	.211	
11	.060	.100	.137	.165	.190	.221	.250	0.270
12	.070	.121	.165	.198	.225	.260	.300	.330
13	.082	.143	.197	.236	.268	.305	.350	.42
14	.095	.167	.228	.273	.311	.353	.40	.47
15	.107	.193	.262	.318	.364	.41	.46	.52
16	.122	.220	.300	.367	.42	.47	.53	.59
17	.138	.250	.340	.42	.48	.54	.59	.66
18	.155	.282	.382	.47	.55	.60	.65	.73
19	.173	.318	.43	.53	.61	.68	.73	.81
20	.194	.353	.48	.59	.68	.76	.81	.89
21	.217	.395	.54	.66	.76	.84	.90	.98
22	.240	.44	.60	.73	.84	.93	1.00	1.07
23	.262	.48	.66	.80	.92	1.03	1.10	1.17
24	.288	.52	.72	.88	1.00	1.12	1.21	1.28
25	.312	.58	.78	.96	1.10	1.23	1.33	1.38
26	.340	.62	.84	1.04	1.19	1.33	1.44	1.51
27	.363	.67	.91	1.13	1.29	1.45	1.56	1.63
28	.388	.72	.97	1.20	1.38	1.55	1.67	1.76
29	.41	.76	1.03	1.29	1.49	1.66	1.80	1.90
30	.43	.80	1.10	1.37	1.59	1.7	1.93	2.04

[1] The figures underscored in the upper portion of the table are to a minimum top diameter (inside bark) of 3.0 or more, but lees than 4.0 inches. Other top diameters are variable but not less than 4.0 inches.

[2] Taken from Gevorkiantz, S. R. and Olsen, L. P. 1955. Composite volume tables for timber and their application in the Lake States. USDA Tech. Bull. 1104.

land, using an equation with your programmable calculator or desktop computer is faster.

The Resources Evaluation staff of the USDA Forest Service (the North Central station is located in St. Paul, MN) have produced some very good volume equations and tables over the past few years. However, one of the most reliable and popular sets of volume tables is still the "Composite Volume Tables for Timber and Their Application in the Lake States", by S. R. Gevorkiantz and L. P. Olsen, originally published in 1955 as USDA Technical Bulletin 1104. This booklet, last reprinted in 1966, contains volume tables for several units of measure. Unfortunately, the Forest Service reports the bulletin is out of print, therefore, two of the more useful tables have been reprinted here (Tables 1 & 2).

If you measure a tree and find the DBH is 15 inches and the merchantable height is two and one-half 16-foot logs, Table 1 estimates the volume at 166 board feet. If a tree has a DBH of 7 inches and a mer-

chantable height of three 8-foot bolts, then Table 2 indicates a volume of .053 cords. To be on the safe side, round DBH down to the nearest inch and heights to the nearest ½-log or bolt.

Volume estimates for standing trees are normally limited to the central stem or bole; branchwood volume is usually ignored. The estimated volume of the entire bole, total volume, is usually expressed in cubic feet.

The volume of a bole-section is usually called the merchantable volume and in most cases you would need an appropriate merchantable height to use with DBH. Merchantable volumes are based on some end-use (product) and are usually defined as the volume between the stump and some specified upper limit imposed by utilization standards. Although the upper limit is usually a minimum stem diameter, other tree features, such as excessive crook and/or branching, often determine the merchantability limits. Traditionally, merchantable volumes are in board feet and/or

cords, but they are now sometimes estimated in other units, such as cubic feet or cunits (100 cubic feet of solid wood). In many locations, primarily areas outside the U.S., that use the metric system, tree volume is expressed in cubic meters.

Most volume measures can be converted from one unit to another but this conversion can lead to complications. For example, the board foot is defined as a solid piece of wood 12 inches x 12 inches x 1 inch. In theory, one cubic foot should yield 12 board feet, and it would if we didn't have saw kerf and round trees to deal with. But because sawmills can't cut round trees into lumber without making some sawdust, slabs and edgings in the process, converting cubic feet to board feet is not as straight-forward. The rule of thumb is about 5 board feet per cubic foot of roundwood (trees or logs) when the DBH is 7 inches; and about 6½ board feet per cubic foot when the DBH is about 26 inches. However, when the tree or tree-section is so small sawn products cannot be manufactured, the conversion is meaningless.

The board foot is used for volume estimates involving merchantable tree sections that will go to a sawmill and be sawn into lumber, railroad ties, pallet stock, etc. These sections are referred to as sawlogs or sawbolts.

Because of difficulties in estimating board feet, foresters have developed at least 100 board-foot log rules (volume tables for logs). The most well-known rules are the Scribner, the International, and the Doyle rules. These various rules have been used in a variety of ways to assist in developing board-foot volume tables for trees.

The objective in estimating merchantable tree volume is to obtain a board-foot value which corresponds with the volume obtained when trees are felled, bucked into logs, and scaled (volume determined).

Another volume conversion that is also a bit arbitrary is cubic feet to cords. A standard cord is defined as a stack of wood 4 x 4 x 8 feet with 128 cubic feet of solid wood, bark and air space. How much is air space and how much solid wood is a debatable issue, but the rule of thumb in the Lake States is 92 cubic feet of wood and bark per cord and 79 cubic feet of solid wood per cord. As with most conversion factors there is some disagreement, but the solid wood factor usually reported is somewhere around 76 to 80 cubic feet per cord.

The same precautions apply to converting board feed to cords as when converting cubic feet to board feet. The rough rule of thumb is one cord equals about 500 board feet (2 cords per thousand board feet).

To further add to the confusion, foresters often speak of "rough" volume versus "peeled" volume, and "gross" volume versus "net" volume. Rough volume usually means including the bark along with the solid wood. Peeled volume excludes the bark. Gross volume includes both sound and unsound (or unusable) wood. Net volume means that the loss due to rot, crookedness, and other defects has also been estimated and deducted from the gross volume.

Various methods have been devised for estimating the cull or defect in a tree, but all are quite subjective. Most involve assigning the tree a cull class or estimating the percentage loss due to defects. The volume subtracted depends a great deal on the intended manufactured product; some products such as firewood have very low minimum standards (if any at all), whereas other products such as veneer logs allow very few defects.

ESTIMATING STAND VOLUME

Although the discussion has centered around tree volume, an estimate of volume per acre is probably most useful to the landowner and the forester. One option is to measure each tree in your woodland, estimate the individual volumes and then add them up—a formidable task. Another approach involving a lot less work is to devise some way of sampling the woodlot and then converting the sample volumes to volume per acre. The latter is what a forester does during a "cruise" of your woodland acres.

The most straight-forward way to sample a forest stand is to establish a series of circular plots uniformly throughout the woodland. In this case, the plots are equal in size and usually either 1/10th-acre with a 37.2 foot radius or 1/5th-acre with a 52.7 foot radius. First locate the plot center and then measure each tree within a circle about the plot center having the appropriate radius for the plot size you select.

If you have several distinct stands such as a pine plantation, a stand of immature hardwood poletimber, and an area of mature hardwood sawtimber, you would probably want to sample and summarize the results separately for each stand. How many plots also depends on how reliable you want the estimates to be. As a general rule, sample 5 to 10 percent of the acreage within each stand. For example, if you have 80 acres of fairly uniform hardwoods, you should establish a minimum of twenty 1/5th-acre plots.

Twenty 1/5-acre plots constitute 4 acres in the sample and, 4 divided by 80 equals 5 percent. If you also own a 20-acre pine plantation you would want to sample at least another five 1/5th-acre plots in this stand. To sample 10 percent of the acreage, double the number of plots in each stand. Using 1/10th-acre plots requires twice as many plots for the same sampling intensity.

You can locate your plots randomly or establish them a predetermined distance from each other. The latter is probably easier and should be satisfactory for most purposes. Simply pace the distance (along a straight line) between each plot center. Typically, plots are spaced from 3 to 5 chains (1 chain is 66 feet) apart. You'll need to judge this spacing for each stand and generally any uniform spacing is acceptable. However, don't let personal bias affect the locations, like deliberately aiding a thick tangle of brush. You

should also make sure each plot is entirely within the stand's boundaries.

After locating and measuring the trees within each plot you are ready to summarize the results:

1) Add up the volumes for each tree in the first plot.

2) Multiply this value by five for a 1/5th-acre plot, or by 10 for a 1/10th-acre plot. This is the volume per acre estimate for plot number one.

3) Repeat this process for each plot. When finished you will have an estimate of volume per acre for each plot.

4) Then, add these estimates together and divide by the number of sample plots to obtain an average estimate of volume per acre for the stand.

5) Finally, to obtain an estimate of total volume for the stand, multiply the average volume per acre from Step 4 by the acreage in the stand.

Although that is all we require from many inventories of our woodlands, it is possible (and in some cases necessary) to have more information about the stand. One option that doesn't add much time or effort to the procedures described above is to keep track of volumes by species or species groups. It makes sense with valuable hardwoods such as walnut and red oak to have separate totals for each. This will help considerably if you are planning a timber harvest on your property.

SOURCES FOR FORESTRY EQUIPMENT

There are several sources of the forestry instruments described in this publication. Neither the University nor the Cooperative Extension Service is in a position to recommend a specific supplier, but the following companies should have most of the equipment you may need:

Forestry Suppliers
205 West Rankin St.
P.O. Box 8397
Jackson, MS 39204

Ben Meadows Company
3589 Broad St.
P.O. Box 80549
Atlanta, GA 30366

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