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PRACTICAL POINT-SAMPLING

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FOREWORD

Point-sampling is a valuable tool in the kit of the practicing forester. It is employed for permanent and temporary sampling and for growth studies. Since the concept of point-sampling is new in American forestry, different approaches have been employed to explain its application. This bulletin consists of a synthesis of point-sampling lectures and lesson plans developed at Stephen F. Austin State College and presented as a forestry short course in 1963. It explains these sampling techniques and suggests choices in methodology and computational procedures. As a series of lectures, it was written in outline form, and this form was retained because the organization and use of the ideas seemed to be facilitated in this way. It is a revision of the first part of a two-part bulletin on point-sampling published by the School in 1964.

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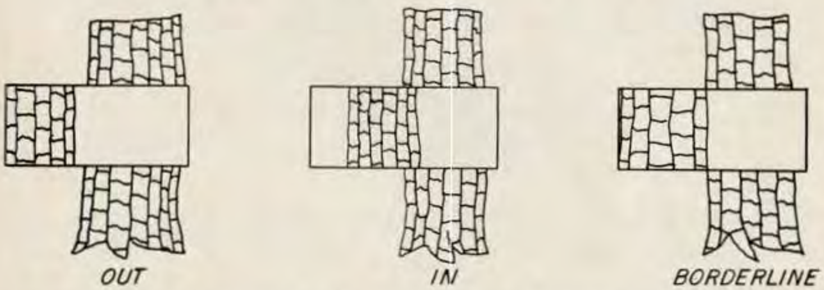
PRACTICAL POINT-SAMPLING

Ellis V. Hunt, Jr., and Robert D. Baker

POINT SAMPLING—THEORY

Mr. L. R. Grosenbaugh (1952) introduced point-sampling to American foresters, citing Mr. W. Bitterlich's earlier work in Europe. Primarily it is, he said, "A rapid method of sampling tree basal area per acre . . ." It *is rapid* and in 1952 it was *revolutionary!* Since then, it has been explained, re-explained, embellished, tested and discussed. Here is *how* it is done and *why* it works.

I. Tally the selected trees at the point.
   A. With the angle-gauge, tally all trees appearing larger than the angle.
   B. With the prism, tally all trees that are not wholly offset.
   C. Be sure to look at trees at dbh (diameter breast height, 4.5 feet above ground line).
   D. Tally every borderline tree (those exactly coinciding with the angle or those just exactly offset by the prism) as ½ tree.



II. Multiply the number of trees tallied per point by the BAF (basal area factor) that fits the instrument used, to obtain basal area per acre in square feet.
   A. For an angle-gauge describing 104.18 minutes, the BAF = 10.
      1. A gauge 33 inches long with a cross arm 1 inch wide describes an angle of 104.18 minutes.
      2. A 3.03 diopter prism does the same job.
   B. This is why it works—using a BAF of 10 as an example:
      1. The area of a circle is $0.7854\ D^2$.
         a. Area of a circle $= \frac{\pi D^2}{4} = \frac{3.1416\ D^2}{4} = 0.785\ D^2$.

2. The area of the "tree circle" is $66^2 \times$ BA (basal area) of the tree.
   a. The "tree circle," with the tree at its center, has a diameter $66 \times$ the diameter of the tree; it describes the boundaries within which one *must* stand if he is to tally the tree with an angle gauge of 104.18 minutes or a 3.03 diopter prism.
   b. These are examples of "tree circles" showing maximum distance one may stand from a tree and still tally it (radius of "tree circle").
      (1) For a tree of 1 foot dbh, one must stand not more than 33 feet away.
      (2) For a tree of 2 feet dbh, stand not over 66 feet away.
      (3) For a tree of 3 feet dbh, stand not over 99 feet away.

III. Now consider a tree which is 0.5 foot dbh:

A. BA (basal area) of the tree is $0.7854\,D^2 = 0.196$ square feet.

B. One could count such a tree if he stood not farther than 16.5 feet away from it.

C. The diameter of the "tree circle" for this tree is therefore $2 \times$ the radius, or 33 feet.

D. The area of this "tree circle" is $0.7854\,D^2$ or 0.7854×33^2 or 0.7854×1089 or 855.3 square feet.

E. Statement II.B.2. said the area of the "tree circle" was exactly the BA of the tree $\times\ 66^2$. If this is true for this 6-inch dbh tree, then:

1. BA of the tree = 0.196 square feet,
   area of the "tree circle" = 855.3 square feet,
   66 squared = 4356.
2. 855.3/4356 = 0.19630.

IV. Then, for a tree that has a BA of 1 square foot (approximately 13.55 inches dbh):

A. The "tree circle" has 1×66^2 square feet of area (as stated in II.B.2. and proved in III.E.) or 4356×1 square foot or 4356 square feet.

B. Visualize this tree in the center of its "tree circle," the latter being in the center of an acre of land (Figure 1).

1. Tree BA is 1 square foot.
2. "Tree circle" area is 4356 square feet.
3. Acre area is 43,560 square feet.

V. If a cruiser stands at random inside this *acre*, what chance would he have of being inside the "tree circle" (i.e., close enough to the tree to count it with an angle gauge or prism defining an angle of 104.18 minutes)?

Figure 1. A one-square foot BA tree in its 4356-square-foot "tree circle" inside a circular acre of 43560 square feet.

A. The chances are equal to the proportion of the areas of the "tree circle" and the acre, or 4356 to 43560, or 1 to 10.

VI. If there were a single tree on each of 100 such acres and each tree contained 1 square foot of BA, and if the cruiser were on each acre at random, he would tally 10 trees in 100 chances.

VII. Change tally to total BA of trees by multiplying the tally by 10, because $10 \times 10 = 100$, and on 100 acres there would be 100 square feet of BA.

VIII. Compute BA per acre from such a tally by multiplying the tally by 10 and dividing by the number of "points" the cruiser visited, or $10 \times 10 \div 100 = 1$ BA per acre.

IX. Conclusion: The BAF of an angle gauge or prism defining an angle of 104.18 minutes is 10, and the formula for computing BA in square feet per acre is:

$$\text{BA per acre} = \frac{\Sigma X}{N} (\text{BAF})$$

where X = number of trees tallied,
N = number of points, and
BAF = basal area factor of the instrument.

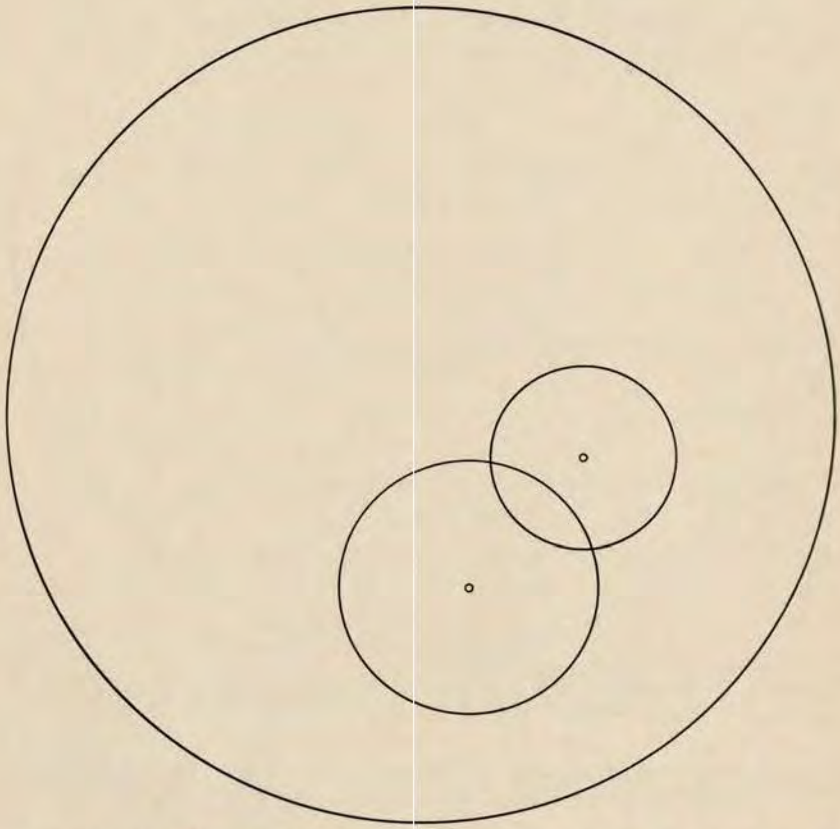


Figure 2. 10-BAF—Illustration of 3.03 diopter count. A 9.55-inch tree of BA = 0.5 square feet has "tree circle of (0.5) (66^2) = 2178 square feet and a random tally chance in 1 acre of $\frac{2178}{43560} = \frac{1}{20}$ or 1 in 20. A 13.55-inch dbh tree has a BA = 1.0 square foot, a "tree circle" of (1) (66^2) = 4356 square feet and a random chance of 1 in 10. The "tree circle" overlap area, because of the position of trees, is 871.5 square feet with a random chance of 1 in 50. In 100 random counts, one would get:

2 overlaps of count 2 each	total	4
8 other big tree counts of 1	total	8
3 other little tree counts of 1	total	3
	total	15 in 100 random-chances.

BA per acre is $\frac{\Sigma X}{N}$ (BAF) or $\frac{15}{100} \times 10$ or 1.5 square feet per acre.

CALIBRATING AN ANGLE-GAUGE OR PRISM

I. As explained earlier, the BAF is the reciprocal of the random chance one has of being in the "tree circle" of a single tree containing 1 square foot BA, if this tree is in a circular acre, and one is taking a point-sample in this acre.

II. One can find the radius of the "tree circle" by sighting at the tree with the instrument from such a distance that the angle just coincides with the tree's diameter at breast height (with a prism, just so opposite sides of the tree coincide). High accuracy prisms, which are more expensive, are calibrated at the factory. Uncalibrated prisms, available at about $1.00 each, must be calibrated by the user.

III. Procedure

A. Set up a rectangular target of a convenient width, such as 1 foot.

B. Lay a steel tape along the center line, perpendicular to the target.

C. Move back along this line until one side of the target image seen through the prism is precisely aligned with the other side seen over the prism. Make sure the axis of the prism is perpendicular to the line of sight.

D. Measure accurately the distance from prism to target.

E. Compute the BAF using the following formula:

$$BAF = \frac{43{,}560}{1+4(d/w)^2}$$

where w = target width in feet,
d = distance from prism to target in feet.

IV. As an alternate procedure, Dixon (1958) suggests using the same formula but measuring "the amount of deflection at a fixed distance:

A. Fix prism in position at one end of a long table.

B. At the other end, at a right angle to face of the prism, set up a target of two vertical pins that can be moved.

C. Measure accurately (d) the distance between the target and prism.

D. Move pins until the displaced image of one pin coincides exactly with the image of the other. Measure the distance between the pins (w) precisely."

E. BAF "calculated using formula above. It is essential that *d* and *w* be measured in the same units."

CONSTRUCTING A STAND TABLE

I. The probability of a tree dbh class being sampled is in direct ratio to its BA.

A. Consider a tree with BA of 0.5 square foot in the center of a circular acre.

1. Its "tree circle" contains 66^2 times as much area, or 2172 square feet, or 1/20 acre if an angle of 104.18 minutes is used.
2. Its chance of being tallied in any one sample is therefore 1 in 20.

B. It was stated earlier that under the same circumstances a tree of 1 square foot BA had 1 in 10 chances of being tallied. Thus the chance of a tree being in a sample is exactly proportional to its BA.

II. To construct a stand table, it is necessary to measure the dbh of tallied trees.

A. Formulating a conventional stand table most simply requires two steps.

1. Convert the tree count to BA in each dbh class per acre.
2. Then divide each of these BA's by the BA of the tree at nominal class center.

B. As an example, if an angle-gauge having 104.18 minutes is used, the following trees are tallied at 5 points:

1. Point	Tally by DBH—Inches
1	6, 12, 16, 20
2	10, 18, 14, 6, 16, 10, 8, 8, 12, 14
3	10, 2, 20, 18, 12, 18
4	16, 10, 10, 12, 12, 10, 14, 14, 14, 8
5	14, 16, 18, 16, 8, 10, 12, 12, 10, 4

2. The total tally is 40 trees at 5 points.

C. In our example, from Grosenbaugh (1952), we have two 6-inch, one 4-inch and one 2-inch trees.

1. To convert these to BA per acre, multiply by BAF and divide by the number of sample points.
2. To convert to trees per acre, divide this (Item 2) by BA of the the tree of nominal class midpoint (Item 3).

Item		2-Inch Class	4-Inch Class	6-Inch Class
1.	Count	1	1	2
2.	Sq. ft. BA per acre	2	2	4
3.	Sq. ft. BA per tree	.022	.087	.196
4.	Trees per acre	90.90	22.98	20.40

D. The entire stand table could be constructed in this manner from tree dbh's recorded for the trees counted as samples at the points.

III. In summary, to get frequency per acre (f), multiply the tree count by the BAF, divide the product by N (number of points), and divide this quotient by BA of a tree at nominal midpoint diameter ($0.00545415\ D^2$). Putting this in equation form, we get:

$$f = \frac{\text{Count} \times \frac{\text{BAF}}{\text{N}}}{0.00545415\ D^2}\ \text{, or}$$

$$f = \frac{\frac{BAF}{N}}{0.00545415\ D^2} \times \text{Count},$$

$$\text{so } \textit{factor} \text{ is } \frac{\frac{BAF}{N}}{0.00545415\ D^2}.$$

COMPUTING BOARD FOOT AND CUBIC FOOT VOLUMES

Note: The first step (as for any volume estimating) is to secure an appropriate volume table.

I. A suitable standard volume table in cubic feet or board feet may be modified (for instance, a Girard Form Class Volume Table).

  A. To modify the table, divide each tree volume in the table by its tree BA. Enter these quotients, called bff [board foot factor] or cff [cubic foot factor], in a new table by tree dbh and height class.

   1. This table may be used as follows:

    a. Tally trees in each point sample by dbh and height.
    b. Secure the sum of the bff or cff for the trees in the sample.
    c. Divide this sum by the number of trees.
    d. Multiply this quotient by BA per acre when:

$$\text{BA per acre} = \frac{\text{no. trees}}{\text{no. points}} \times \text{BAF}.$$

  B. To further modify the tables of factors (described in I.A.) divide each value by 10 to reduce the size of the numbers for easy mental arithmetic, and round off all values to whole numbers.

   1. This will not introduce any serious errors where samples of reasonable size are to be collected to compute volume per acre.

   2. This table may be used exactly as outlined before except that the quotient (I.A.1.d.) will need to be multiplied by 10 before multiplying by BA per acre.

II. A different kind of table may be similarly produced giving a bff or cff for height classes only, instead of dbh and height classes.

  A. This is true because the height-tree-volume relationship is *practically* a straight line.

   1. Thus for Mesavage & Girard Form Class 80, Grosenbaugh (1952) showed these bff's divided by 10 (International ¼-inch log rule):

DBH	1 Log	2 Log	3 Log	4 Log
10	7	12	—	—
12	8	12	16	—
14	8	13	17	20
16	8	14	18	22
18	8	14	19	23
20	8	14	20	23

B. From the table, it can be seen, for instance, that if 2-log trees average 14 inches dbh, the Bff is 13.

C. Using the table, the procedure for determining volume per acre is:

1. Tally point sample trees by height classes.
2. Total the trees in each height class.
3. Multiply each sum by the appropriate Bff.
4. Total these products.
5. Divide this total by the number of points in the sample.
6. Multiply by BAF to get board feet per acre.

(Note that since Bff was obtained by dividing tree volume by BA × 10, it will be necessary as a final step to multiply final answer by 10.)

(Note, too, that the procedure above is simplified, but like I.A.1., where:

$$\text{Volume} = \frac{\Sigma \text{ bff}}{\text{no. trees}} \times \frac{\text{no. trees}}{\text{no. points}} \times \text{BAF},$$

here:

$$\text{Volume} = \frac{\Sigma \text{Bff}}{\text{no. points}} \times \text{BAF} \times 10.$$

III. If no suitable volume table is available the bff or cff may be determined by felling timber in each height class or, if preferred, each dbh-height class, and measuring it for volume.

A. The following procedure is used:

1. Fell the sample trees.
2. Secure suitable tree measures (usually d.i.b. at some regular length interval, and dbh).
3. Apply a suitable log rule to obtain log volume.
4. Total to obtain tree volume.
5. Calculate the average tree volume and basal area for each dbh-height class, or each height class.
6. Divide tree volume by tree BA, or usually in case of Bff divide by 10 times BA.

IV. Appropriate factors for southern pine were suggested by Grosenbaugh (1952a).

A. Bff's based on Mesavage and Girard Form Class 80 (about average for reasonably well-stocked *second-growth southern pine*):

	Bff		
Merch. Length	International ¼ Inch	Scribner	Doyle
zero log	0	0	0
1	7	6	4
2	13	11	8
3	18	16	12
4	23	20	15
5	28	25	21

B. The cff's for reasonably stocked southern pine:

Merch. Length, feet	cff	Merch. Length, feet	cff
0	0	40	26
10	7	50	31
20	14	60	36
30	20	70	39

V. A formula suggested by Grosenbaugh (1955) for International board foot volume per acre in southern pine is:

$$\text{Board foot volume per acre} = \frac{(\Sigma L)\ (60)\ (BAF)}{N},$$

where L is merch. height of trees in 16-foot logs,
N is number of sample points.

A. The factor 60 is based on average southern pine and allows for an increase in tree dbh and form class with tree heights.

SAMPLING TECHNIQUES

I. Point-sampling is tree sampling proportional to tree BA. This was shown in the section concerning construction of a stand table, where the equation for computing the stand table blow-up factor was:

$$\text{Factor} = \frac{\frac{BAF}{N}}{0.00545415\ D^2}$$

A. The factors for three common values of BAF are:[1]

DBH Class	Stand Table Blow-up Factors		
Inches	5-BAF	10-BAF	20-BAF
4	57.30	114.59	229.20
6	25.47	50.93	101.86
8	14.32	28.66	57.30
10	9.16	18.33	36.67
12	6.37	12.73	25.47
14	4.68	9.35	18.71
16	3.58	7.16	14.32
18	2.83	5.66	11.32
20	2.29	4.58	9.16
22	1.89	3.79	7.58
24	1.59	3.18	6.37

[1]Some values in the tabulation are slightly different from those which would be computed from values in Table 6, due to rounding off.

B. These are easily computed using the equation shown as, for instance, the 10-BAF and dbh class of 4 inches:

$$\text{Factor} = \frac{\frac{10}{1}}{(0.00545415)\ (4^2)},$$

$$= \frac{10}{(0.00545415)\ (16)},$$

$$= \frac{10}{0.0872664},$$

$$= 114.5916.$$

C. Hence, the smaller the dbh class, the smaller the percent of sample, and therefore the larger the multiplier must be to convert to per-acre values. This is an advantage over some other sampling methods since the bulk of counting or measuring labor is used on the more valuable, larger dbh classes.

II. Several other kinds of sampling are proportional to area, as for instance plot-sampling.

A. In plot-sampling, if one wanted to change count of sample trees on a 1/5-acre plot to trees per acre, the same multiplier (5) would be used for all dbh classes.

B. Generally, the same principle applies to line sampling and transect-sampling. Counts along a line or transect are related to the count for an area, and all dbh class counts are multiplied by a constant to obtain per acre counts.

C. Actually, as the typical uneven-aged stand table clearly shows, there are far more small trees than large trees in the forest, so a cruiser spends more time than warranted, by volume or value, in measuring or counting them. (For instance, on 110 circular 1/5-acre CFI plots established in Sabine County by the School of Forestry, over half of the stems came from the 5- and 6-inch diameter classes.)

D. The same considerations would be valid for a mixture of small even-aged stands. One would expect to stratify and sample differently in even-aged stands large enough to be treated separately.

III. Some problems perhaps best solved by a sampling method other than point-sampling are:

A. To determine survival of seedlings in plantings, sample-row counting is practicable.

B. In natural reproduction inventories, random quadrat counts or transect or line counts may be more reasonable.

C. For forage volume inventories, quadrat clippings may be desired.

D. When a count is not directly related to area, transect or line counts may suffice.

IV. There are many considerations involved when trying to devise a point-sampling scheme. Some of the most obvious are discussed, but many others are encountered in the field. One must be alert to note them and to make field time as productive as possible.

A. Random sampling principles should be used whenever reasonable because any measure which is averaged will be of limited value if not accompanied by a measure of variability or accuracy.

B. Systematic samples may be subjected to analyses suitable for random samples but the results must be accepted with reservation. Nevertheless, the systematic forest sample will generally be more precise than other kinds of samples of the same size, so systematic sampling does have some advantage.

C. Two-prism sampling may be advantageous when two arbitrarily defined populations occupy the same area.

   1. A sawtimber population and a pulpwood population are present. To count the sawtimber trees with a 5-BAF prism would be too time consuming, but to count pulpwood size trees with a 10-BAF prism might admit too few trees for an adequate sample.

   2. The obvious solution is to sample each arbitrarily defined population with the instrument best suited to measure it.

D. Combined plot and point-sampling may be suitable for some situations similar to that discussed above, or perhaps combined point and transect or line-sampling would be better.

   1. For timber volume and reproduction counts, one might use point-samples for volume, and stocked quadrats for reproduction.

   2. For timber volume and thinning prescription, one could use row tree counts for prescribing, and point-sampling for timber volume estimating.

E. Subsampling (to save time) may be desirable in situations when some attribute with small variance is needed in combination with some other of larger variance, or where economics may dictate fewer measurements of a difficult nature.

   1. For estimating volume in pulpwood size plantations, use point-sampling to count trees, and randomly select trees out of the point-sample count for height measures (height is a time-consuming measure, and all the merchantable trees may be nearly the same height).

   2. The same kind of solution might apply if one were sampling to construct a stand table or to obtain volume when volume factors are based on dbh.

   3. Particularly, in IV.E.2., the *random* selection of individual sample trees for the measured subsample would be important (avoid the idea of measuring trees *you* select on the premise that a set number should be measured in each class).

   4. Because some size class may be limited by the nature of the stand (40-inch dbh trees for example), perhaps all individuals of some classes should be measured in the subsample. When this is done, computational procedures must take this into account.

F. Proportional sampling might be used in areas where stands can be stratified.

1. Separate hardwood from pine stands or young timber from old timber, etc.; then sample each stand.
2. This may involve not only variance of the populations, but also total stand area, value per unit, etc.

G. Cluster sampling may be better than the selection of a single sampling unit at each location.

1. In 1957-58, an area was sampled using the average of two 10-BAF samples as a measure of BA per acre with the following results, compared to 1/5-acre plots also measured in 1957-58 and a subsequent single 10-BAF sample in 1962 at the same location:

Sampling Unit	BA per A (Sq. Ft.)	σm (Sq. Ft.)	C (Per Cent)
Avg. of 2 prism samples 1957-58	70.18	2.17	30.92
1/5-acre plot 1957-58	70.72	2.20	31.11
One prism sample 1962	62.87	2.80	44.53
1/5-acre plot 1962	70.99	2.44	36.00

2. The sampling scheme referred to above contained 110 sampling units, so a σm of about ± 10% could have been obtained in the 1957-58 inventory with only about 10.52 or 11 points, but using only one prism count, as the sampling unit in 1962, would have required about 21 points for similar precision. (Note: The probability is 68 in 100 chances.)
3. Also, the 1957-58 point-sampling was as precise as 1/5-acre plot-sampling, showing that on this area it is just as efficient for BA data as the larger plot-sample.
4. Point-sampling is now employed in the Southern Forest Survey where 10 points, each a chain apart on varying azimuths, are used with limiting distances for a 37.5-BAF prism.

H. Prescription sampling with the prism may be done advantageously.

1. Grosenbaugh (1955) described a method of prescribing and marking thinnings in southern forests. With a 50-BAF prism, the count should *never* be 3 (over 2) when the "leave" BA target is about 83 square feet.
2. Similarly, where one-fourth or more points contain zero potential crop trees with 50-BAF prism, the area needs special attention for restocking or increasing stocking.
3. On the Texas National Forests, a 37.5-BAF prism is similarly used in sampling during pre-sale planning.
4. Seed tree marking, or checking of marked stands, may well be accomplished after marking standards have been formulated. For instance, if the goal is 7 large (average 19-20-inch dbh) trees per acre to be left as seed trees, then BA per acre of seed trees would be about 15 square feet; so with a 5-BAF prism, seed tree counts should average 3.

V. The choice of a point-sampling instrument (choice of a BAF) might make point-sampling *somewhat* comparable to plot-sampling in the concept of percent of sample.

   A. This concept is disclaimed by authorities contacted by the authors and by published material on point-sampling or forest sampling because sampling varies with BA.

   B. Nevertheless, a case example from a Texas industrial forest is presented here because it may have value for *some* situations:

      1. Trees on company land average slightly over 12 inches dbh, and with a 10-BAF prism, this size tree has a tree circle (or plot) of about 0.08 acre; thus plot size averages 0.08 acre.
      2. 500 points will be located on 200,000 acres.
      3. Equivalent acres tallied: $(500)\ (0.08) = 40.00$ acres.
      4. Percentage cruise: $100 \times 40.00/200{,}000 = 0.2$ percent.

VI. Bias in point-sampling is as important a consideration as in any sampling. *It is to be avoided.*

   A. Systematic instead of random samples may cause bias.

      1. As a result of the coincidence of the natural population distribution and sample point locations, all points could fall in high site-class areas, thus omitting ridge tops and dry sites.
      2. Bias could happen as a result of man's activities. By random selection of a starting point for a systematic cruise, one might select a spot 2 chains southeast of the northwest corner of each 160-acre square block of forest land, not knowing that 50 years ago a steam skidder yard was located in each of these spots, making each such spot non-representative of the *whole* forest.

   B. Improper use of tools causes bias.

      1. If the prism is hand-held and by some quirk always 4-5 degrees out of horizontal (which would not be compensating), the count will be in error.
      2. If the cruiser swings the prism around him instead of *vice versa*, the count will be wrong.
      3. If one measures distance from the point to the *nearest* edge of a borderline tree instead of to center of tree, the count will be incorrect. (Note if one-half dbh is subtracted, then nearest edge of tree would be correct.)

   C. Ignoring slope correction *may* be acceptable for *some* southern forests; for many in East Texas it would not.

   D. Borderline trees, if not properly handled, may be a source of bias.

      1. As a result of erroneous reading or writing of a rule, bias may be introduced.
         a. The rule should be: "Include border trees on the west side, exclude those on the east side" or, rephrased, "Count every borderline tree as ½ tree."

b. The rule should not be: "At each point, count the first borderline tree, omit the second, count the third, etc." (Because borderline trees will be about 1 in 20, and because ordinarily only one would be found on 2 or 3 plots, all would get counted.)

2. If borderline trees are not measured to accurately determine whether in or out, an unconscious bias may develop wherein many "out" trees are counted, or *vice versa.* This may not be compensating.

3. Looking at trees always at eye level or some place other than 4.5 feet above average ground line would not be compensating.

E. "Brush bias" (trees behind brush or other trees) may cause count to be low, but never high.

1. Proper use of the prism and proper selection of BAF can *usually* overcome this in southern forests (a problem in "Big Thicket" country).

2. In the Pacific Northwest this bias is controlled by looking at each tree at top of first 16-foot log instead of breast height (Bruce 1961).

VII. Point-sampling statistical analysis is similar to that for any sampling, particularly where one is working with relatively large samples and a continuous variable. Actually, tree counts, as in BA estimation with point-samples, are discrete; but this should not be a barrier to the use of normal statistical analyses for continuous variables, since basal area per acre is a continuous variable.

Statistical analysis uses variance as measured in a sample. If X is the measured variable, then its value must be ascertained for *each* sample point. The variance is computed with the equation:

$$V = \frac{\Sigma X^2 - \frac{(\Sigma X)^2}{N}}{N - 1},$$

where V = variance of X,
X = measurement at a point,
N = number of points.

Other statistical values normally needed from point sample cruises are:

A. Standard deviation $= \sigma = \sqrt{V}$.

B. Standard error of the mean $= \sigma m = \sqrt{\frac{V}{N}}$.

C. Coefficient of variation $= C = \frac{\sigma(100)}{M}$.

D. Proportional limit of error $= \text{Ple.} = \frac{2\ \sigma m\ (100)}{M}$.

E. Number of observations for 68 percent confidence in $\sigma m = N = \frac{V}{\sigma m^2} = \frac{\sigma^2}{\sigma m^2}$.

Number of observations for 95 percent confidence in $\sigma m = N = \frac{4V}{\sigma m^2}$.

F. Sampling error of mean in percent $= S = \frac{C}{\sqrt{N}}$.

G. Combined sampling error in percent = Se%, where

$Se\% = \sqrt{(S \text{ of bff (or cff)})^2 + (S \text{ of tree count})^2}$.

CONSTRUCTING POINT-SAMPLE VOLUME FACTORS

I. There are many ways of computing timber volumes from point-samples. Five are illustrated:

A. The first is similar to the standard volume table approach in plot cruising, sample trees being classified by height and diameter.

B. The second is based on local volume tables as used in conventional plot cruising, sample trees being classified by diameter only.

C. The next is *like* the local volume table approach except that sample trees are classified by height rather than dbh, with a volume factor for each height class.

D. The fourth method is like I.C. except that a single average factor is used for all height classes.

E. The last method involves converting trees tallied in the field into volumes per acre in a cumulative tally.

II. The system wherein sample trees are classified by height and dbh is simple and direct.

A. A *good standard volume* table is needed. To illustrate the procedure, a volume table for an area on the Sabine National Forest for loblolly pine is shown in Table 1.

B. Each tree volume in the table is divided by the BA of the dbh class to which it belongs.

1. For 10-inch dbh, 1 log, the volume is 23 bd. ft., and

$$\text{bff} = \frac{23}{(3.1416)\ (10)^2/144(4)}$$
$$= 23/0.545,$$
$$= 42.$$

2. As a further refinement, each of the basal area factors thus derived is commonly divided by 10 to reduce the size of the numbers involved; thus

$$\text{Bff} = \frac{\text{bff}}{10},$$
$$= 42/10,$$
$$= 4.2 \text{ which is frequently rounded off to 4.}$$

C. Table 2 was made in that manner from Table 1.

TABLE 1. LOBLOLLY PINE GROSS BOARD FOOT VOLUMES (SCRIBNER LOG RULE), SABINE NATIONAL FOREST.

Form Class	74	76	77	79	80	82
	Height in Logs					
DBH Class	1	1.5	2	2.5	3	3.5
10	23	31	39	50	53	
11	30	41	52	68	74	
12	38	52	65	88	93	106
13	47	65	83	112	119	137
14	56	77	101	136	144	166
15	66	93	119	163	174	201
16	76	110	138	190	205	236
17	88	127	162	222	239	279
18	101	144	186	254	273	322
19	114	163	212	291	312	365
20	128	182	238	327	351	410
21	142	203	266	368	394	461
22	157	225	293	409	437	511
23	174	250	327	456	488	570
24	191	274	362	503	537	630
25	208	302	396	550	592	693

TABLE 2. LOBLOLLY PINE BOARD FOOT FACTORS BY DBH AND HEIGHT CLASSES, SABINE NATIONAL FOREST.

	Height in Logs					
DBH Class	1	1.5	2	2.5	3	3.5
10	4.2	5.7	7.2	9.2	9.7	
11	4.5	6.2	7.9	10.3	11.2	
12	4.8	6.6	8.3	11.2	11.8	13.5
13	5.1	7.0	9.0	12.1	12.9	14.9
14	5.2	7.2	9.4	12.7	13.5	15.5
15	5.4	7.6	9.7	13.3	14.2	16.4
16	5.4	7.9	9.9	13.6	14.7	16.9
17	5.6	8.1	10.3	14.1	15.2	17.7
18	5.7	8.1	10.5	14.4	15.4	18.2
19	5.8	8.3	10.8	14.8	15.8	18.5
20	5.9	8.3	10.9	15.0	16.1	18.8
21	5.9	8.4	11.1	15.3	16.4	19.2
22	5.9	8.5	11.1	15.5	16.6	19.8
23	6.0	8.7	11.3	15.8	16.9	19.8
24	6.1	8.7	11.5	16.0	17.1	20.1
25	6.1	8.9	11.6	16.1	17.4	20.3

D. A three-step procedure then determines volume per acre from point-samples.

1. Tally sample trees by dbh and height at the sample points.
2. For each tree tallied, extract the appropriate Bff from the table.
3. Sum the Bff's, divide by the number of points, and multiply by 10 × BAF to obtain board foot volume per acre.

E. A suitable tally sheet is shown in Figure 3.

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Point-Sample Tally Sheet

DBH	Tree Height in 16 Foot Logs					
Class	1	1.5	2	2.5	3	3.5
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						

Line ________ Type ________ Date ________

No. of Points ________ Estimator ________

Figure 3. A tally sheet for use when all point-samples in a line or unit are tallied together as a single unit.

III. The system wherein the sample trees are tallied by dbh class only simplifies field work.

A. A local volume table is used without modification.

B. Stand blowup factors, one for each dbh class, are computed as follows:

$$\text{Stand blowup factor} = \frac{\text{BAF}}{\text{BA per tree}},$$

where: BA per tree is in square feet,
and BAF is determined by the prism.

C. For the 5-inch class and for a 3.03 diopter prism, for instance:

$$\text{Stand blowup factor} = 10/0.1364,$$
$$= 73.3$$

D. With the local volume table and the stand blowup factor, to get volume per acre in each dbh class, multiply sample tree count by stand blowup factor, then multiply that product by volume per tree (Figure 4).

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TALLY SHEET -- FOR POINT SAMPLES ONLY

Line ______ Type ______ Date ______

Point ______ Estimator ______ ______

Diameter Class	Field Tally	Trees per Point	Stand Table Blowup Factor	Trees per Acre	Cubic Foot Volume Blowup Factor	Board Foot Volume Blowup Factor	Cubic Foot Volume per Acre	Board Foot Volume per Acre
Shortleaf Pine								
5			73.3		1.44			
6			50.9		2.57			
7			37.4		4.28			
8			28.6		6.09			
9			22.6		8.49			
10			17.3			49.4		
12			12.7			84.5		
14			9.4			140.7		
16			7.1			203.1		
18			5.7			281.5		
20			4.6			353.6		
22			3.8			448.7		
24			3.2			548.0		
26			2.7			664.8		
28			2.3			790.8		
30			2.0			922.0		
Total								
Loblolly Pine								
5			73.3		1.43			
6			50.9		2.63			
7			37.4		4.36			
8			28.6		6.20			
9			22.6		8.69			
10			17.3			40.3		
12			12.7			82.0		
14			9.4			130.7		
16			7.1			203.4		
18			5.7			280.1		
20			4.6			384.9		
22			3.8			457.7		
24			3.2			559.0		
26			2.7			678.1		
28			2.3			808.6		
30			2.0			940.4		
Total								

Sawtimber Volume by Scribner Log Rule

Figure 4. A tally sheet for use when point-sample tree dbh only will be measured and local volume table employed.

IV. When sample trees are classified by height only, field time is saved.

A. To develop the factors needed for this point-sampling, start with a curve of dbh over height and a standard volume table as, for instance, Table 1 from which Table 2 could be developed.

B. Then, for each height class from the curve, determine average dbh, and from Table 2 extract the proper Bff for that height class.

C. If a suitable volume table is not available, derive the factors from basic data.

D. The necessary tree measurements by height classes will be:

1. Tree volume, and
2. Tree dbh.

Note: To show the procedure, Table 3 presents some data from the Sabine National Forest.

E. Compute a bff for each height class by dividing average volume by average BA in each height class (Table 3).

TABLE 3. LOBLOLLY PINE SAWTIMBER TREE MEASUREMENTS FROM SABINE NATIONAL FOREST, 1958 (300 trees)

Ht. Class (feet)	Trees (number)	Avg. dbh (inches)	Avg. Vol. (bd. ft. Scrib.)	Ht. Class (feet)	Trees (number)	Avg. dbh (inches)	Avg. Vol. (bd. ft. Scrib.)
12	1	10.3	36.4	46	21	16.3	220.0
16	3	9.8	37.9	48	16	16.8	240.1
18	6	10.7	46.6	50	12	16.4	231.3
20	5	10.9	51.3	52	13	17.3	273.0
22	4	11.1	55.8	54	8	16.7	258.9
24	12	11.4	61.0	56	12	16.7	270.6
26	9	11.0	60.3	58	9	17.5	308.4
28	9	11.5	69,4	60	8	17.7	323.8
30	19	11.9	78.1	62	4	20.4	456.5
32	23	11.5	74.9	64	4	17.6	335.9
34	20	13.2	107.2	66	5	18.1	377.7
36	13	13.5	115.8	68	5	17.6	354.6
38	23	12.8	110.0	70	2	18.1	384.6
40	13	14.6	149.1	72	3	20.1	506.8
42	7	14.2	143.0	76	1	19.2	477.9
44	10	15.1	176.8	Total	300	—	—

F. Make a curve of bff over height. This may be done graphically or mathematically. From Table 3 the equation for this line was $y = 15.2 + 2.9x$ (When y was bff and x was height class).

G. For each height class, take from the curve (or compute by the equation of the curve) the bff.

1. The equation from Table 3 gave these:

Ht. Logs	bff	Ht. Logs	bff
0	—	3	154
0.5	38	3.5	178
1	62	4	201
1.5	85	4.5	224
2	108	5	247
2.5	131	5.5	270

H. To use these in point-sampling, tally sample trees by height classes and determine the sum of bff by multiplying the number of trees in each class by the appropriate bff.

I. Then compute volume per acre with the equation:

$$\text{Vol., bd.ft. per acre} = \frac{\Sigma \text{ bff}}{\text{no. points}} (\text{BAF}).$$

J. Table 4 shows similar basic data and Table 5 the cff's from cubic foot volumes from the Sabine National Forest.

V. The system where one average factor is used to compute volume in board feet when sample trees are classified by height only is explained by Grosenbaugh (1955). Hunt (1961) said that the bff (a number normally near 60 for average southern pine timber volumes based on International ¼-inch log rule) could be derived from tree height and stock and stand tables usually available.

A. When the bff has been obtained, board foot volume may be computed by the equation:

$$\text{Vol., bd. ft. per acre} = \frac{(\Sigma L)(\text{BAF})(\text{a number near 60})}{N},$$

where N is the number of points, and
ΣL is the sum of sample tree heights in 16-foot logs at those points.

B. A suitable field form when using a factor like this is shown in Figure 5, where the bff is 55 for hardwood and 60 for pine, and the local cord volume factors are given.

Note: Throughout this discussion, bff and board foot volumes generally have been used, but cff's are similarly computed.

VI. A cumulative tally sheet using adapted values obtained from a standard volume table may be preferred in converting point-sample measurements into per acre volumes rather than to compute special volume factors as in II-V, above.

A. The procedure to convert volume per tree into volume per acre:

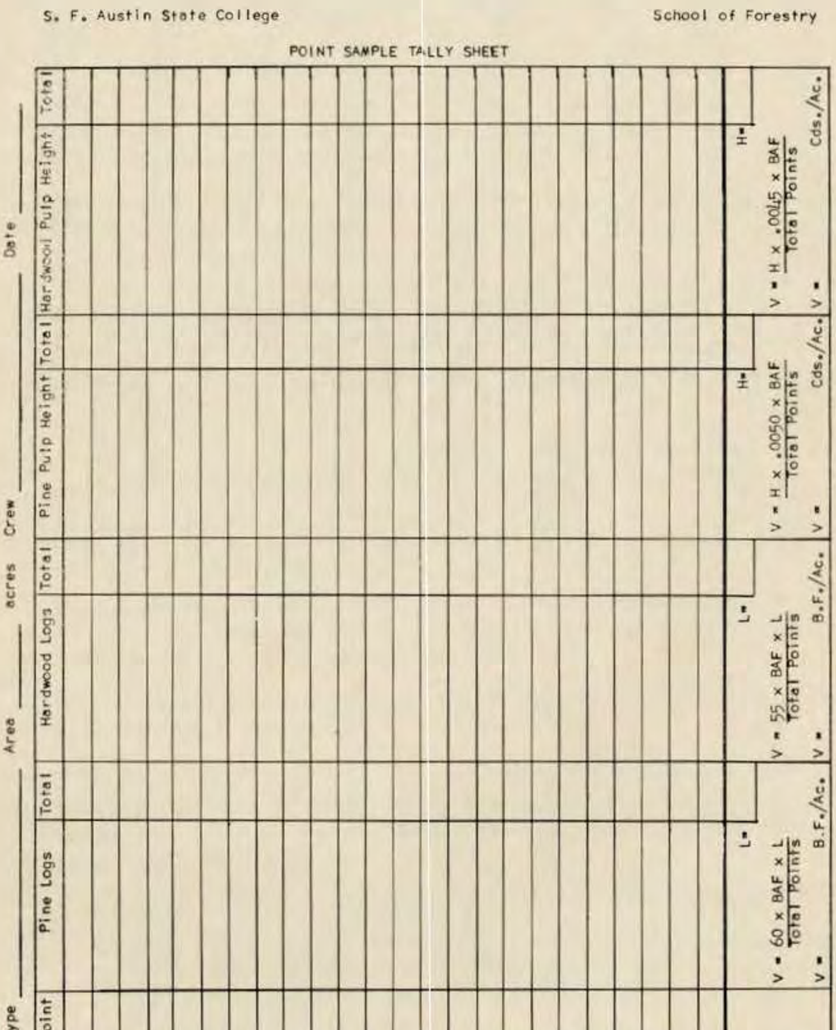
1. Determine the volume of each tree from a standard volume table. For instance, a 12-inch, 3-log loblolly pine tree in the Sabine National Forest has a gross volume of 93 board feet, Scribner Log Rule (Table 1).
2. Multiply volume per tree by stand table blowup factor for the diameter class. A 12-inch tree has a factor of 12.7 (Figure 4): 93 board feet $\times$ 12.7 = 1181.1 board feet per acre.
3. Round this value to the nearest hundred board feet per acre and enter in the cumulative tally sheet (Figure 6). The entries are 12, 24, and 35, respectively under 12 inches, 3 logs.
4. In like manner, cubic-foot volume per acre can be employed in the cumulative tally (Figure 6).

TABLE 4. LOBLOLLY PINE PULPWOOD TREE MEASUREMENTS FROM SABINE NATIONAL FOREST (437 trees).

Ht. Class (feet)	Trees (number)	Avg. dbh (inches)	Avg. Vol (cu. ft.)	Ht. Class (feet)	Trees (number)	Avg. dbh (inches)	Avg. Vol. (cu. ft.)
8	15	4.9	.95	28	7	8.2	7.33
10	27	5.1	1.18	30	21	7.9	7.31
12	54	5.4	1.55	32	20	8.2	8.36
14	53	5.9	2.06	34	8	8.2	8.79
16	54	5.9	2.39	36	7	8.5	9.95
18	46	6.5	3.16	38	3	9.2	11.98
20	30	6.8	3.79	40	3	9.3	12.84
22	34	7.1	4.40	42	2	8.4	11.49
24	23	7.5	5.38	44	1	9.1	13.62
26	28	7.3	5.55	48	1	9.3	15.32

TABLE 5. LOBLOLLY PINE CUBIC FOOT VOLUME FACTORS FOR POINT-SAMPLING, FROM THE EQUATION—$CFF = 1.98 + 0.65\ H$.

Merch. Ht. (feet)	Cu. Ft. Factor	Merch. Ht. (feet)	Cu. Ft. Factor
0	——	28	20.18
8	7.18	32	22.78
12	9.78	36	25.38
16	12.38	40	27.98
20	14.98	44	30.58
24	17.58	48	33.18



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POINT SAMPLE TALLY SHEET

Type ____ Area ____ acres Crew ____ Date ____

Point	Pine Logs	Total	Hardwood Logs	Total	Pine Pulp Height	Total	Hardwood Pulp Height	Total
	L=		L=		H=		H=	
	$V = \frac{60 \times BAF \times L}{Total\ Points}$		$V = \frac{55 \times BAF \times L}{Total\ Points}$		$V = \frac{H \times .0050 \times BAF}{Total\ Points}$		$V = \frac{H \times .0045 \times BAF}{Total\ Points}$	
	V = B.F./Ac.		V = B.F./Ac.		V = Cds./Ac.		V = Cds./Ac.	

Figure 5. A tally sheet for use when point-sample tree heights are tallied and a single factor for each product is applied in computing volume per acre.

S. F. A. FORESTRY CAMP

CUMULATIVE TALLY -- 10-BAF POINTS -- HUNDRED BOARD FEET PER ACRE (GROSS), SCRIBNER RULE

Line ____ Point ____ Type ____ Date ____

Running ____ on ____ Location ____ Estimator ____

Number of 16-Foot Logs

	DBH	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5			Total
Shortleaf Pine	10	7 13 20 27	8 16 24 32	9 18 28	10 20 31	12 24 35								
	12	7 13 20 27	8 17 25 34	10 20 30	12 23 35	13 27 40	15 30	16 31						
	14	7 13 20 27	9 17 26 34	11 21 32	12 24 37	15 29 44	16 32	17 34						
	16	6 13 19 26	9 17 26 34	11 21 32	13 25 38	15 30 45	17 34	18 36						
	18	7 13 20 26	9 17 26 34	11 22 33	13 26 39	16 32 48	18 35	19 38						
	20	6 13 19 26	9 17 26 35	11 22 33	13 27 40	16 32 49	18 36	20 39	22 43	23 46				
	22	6 13 19 26	9 18 26 35	11 23 34	14 27 41	16 33 49	19 38	21 41	23 45	24 48				
	24	6 13 19 26	9 18 27 36	12 23 35	14 28 42	17 34 51	19 38	21 42	23 37	25 50				
	26	6 13 19 26	9 18 27 36	11 23 34	14 28 42	17 34 51	19 39	21 42	23 47	25 51				
	28	6 13 19 25	9 18 26 35	12 23 35	14 28 42	17 34 52	19 39	21 42	24 48	26 51				
	30	6 13 19 25	9 18 27 36	12 23 35	14 28 43	17 35 52	20 39	22 43	26 52	28 56				
													Subtotal	
Loblolly Pine	10	4 8 12 16	5 11 16 21	7 13 20	9 17 26	9 18 28								
	12	5 10 14 19	7 13 20 26	8 16 25	11 22 34	12 24 35	13 27	15 30						
	14	5 11 16 21	7 14 22 29	9 19 28	13 26 38	14 27 41	16 31	17 34						
	16	5 11 16 22	8 16 23 31	10 20 29	13 27 40	15 29 44	17 34	19 38						
	18	6 12 17 23	8 16 25 33	11 21 32	14 29 43	16 31 47	18 37	20 40						
	20	6 12 18 24	8 17 25 33	11 22 33	15 30 45	16 32 48	19 38	21 42	23 47	25 49				
	22	6 12 18 24	9 17 26 34	11 22 33	16 31 47	17 33 50	19 39	22 44	24 49	26 52				
	24	6 12 18 24	9 18 26 35	12 23 35	16 32 48	17 34 52	20 40	23 45	25 51	27 54				
	26	6 12 18 24	9 18 27 36	12 23 35	16 32 48	17 35 52	20 41	23 46	26 51	28 55				
	28	6 12 28 24	9 18 27 36	12 23 35	16 33 49	18 35 53	21 41	23 46	26 52	28 56	30 60			
	30	6 12 18 25	9 18 27 36	12 24 36	17 33 50	18 36 54	21 42	24 47	27 53	29 58	31 62			
													Subtotal	

	DBH	1	1.5	2	2.5	3	3.5	ro	wo	po	hi	sq	bq	be		Total
Hardwoods	12	5 10 15 20	7 13 20 27	9 18 26	10 19 30	11 23 34	12 24									
	14	5 11 17 22	8 15 23 30	10 29 39	11 22 33	13 26 39	14 28									
	16	6 12 17 23	8 16 24 32	10 20 31	12 24 36	14 28 42	15 30									
	18	6 12 18 24	8 17 25 34	11 21 32	13 25 38	15 30 45	16 33									
	20	6 12 18 25	9 17 26 35	11 22 34	13 26 39	16 31 47	17 34									
	22	6 12 19 25	9 17 26 35	12 23 35	14 27 41	16 32 48	18 35									
	24	6 13 19 25	9 16 27 36	12 24 35	14 28 42	17 33 50	18 37									
	26	6 13 19 26	9 18 27 36	12 24 36	14 28 43	17 33 50	18 37									
	28	6 13 19 26	9 18 27 37	12 24 36	14 28 42	17 34 51	19 37									
	30	6 13 19 26	9 19 28 37	12 24 36	14 29 43	17 34 52	19 38									
															Subtotal	

Legend: Red Oak ╱ Post Oak — Sweet Gum o Beech ~~~ Other
White Oak ╲ Hickory | Black Gum □

Grand Total ☐

Pine Pulpwood Tally -- Volumes in Cubic Feet per Acre

DBH	5	6	7	8	9	10
Sh.	106 211	131 262	160 320	174 348 523	192 384 576	206 411
Lob	105 210	134 268	163 326	177 355 532	196 393 589	212 424

Sub Total ☐ Grand Total ☐ Repro-duction ☐ Saplings ☐

Figure 6. Cumulative tally sheet for point-samples.

MISCELLANEOUS VOLUME FACTORS

I. Using shortleaf pine tree measurement averages from the Sabine National Forest, and the procedure illustrated for board feet by Hunt (1961), a cff of 0.7 was computed for use as follows:

$$\text{Cubic feet per acre} = \frac{(\text{sum tree merch. ht. in feet})(0.7)(\text{BAF})}{\text{number of sample points}}$$

II. Grosenbaugh (1955) offers the following equation for computing southern pine cord volume per acre, using an instrument with BAF = 10:

$$\text{Volume per acre in rough stacked cords} = \frac{\text{sum of total tree height in feet of all sample trees}}{(20)(\text{number of sample points})}$$

A. If a local factor other than 20 is desired, it can be calculated and is usually between 18 and 21.

B. The procedure:

1. Select several small representative areas.
2. On each, measure to determine individual tree BA and total height in feet.
3. Determine sum of (BA × height) for each area.
4. Cut the trees into pulpwood; stack and measure cords for each area.
5. Compute the factor for each area with the equation:

$$\text{Factor} = \frac{\text{sum of } [(\text{BA})\ (\text{height})]}{\text{sum of volume (cords)}}.$$

III. Grosenbaugh (1955) rewrites his equation so that it may be used for any instrument with a known BAF in sampling southern pines:

$$\text{Volume per acre in rough stacked cords} = \frac{(\text{sum total tree hts.})(0.005)(\text{BAF})}{\text{number of sample points}}.$$

A. This is the same equation as in II, with the BAF inserted and the values rearranged.

B. If a locally more accurate factor than 0.005 is desired, it may be computed in the same manner as described for the 20-factor above, except that the right side of the equation is inverted to read:

$$\text{Factor} = \frac{\text{sum of volume (cords)}}{\text{sum of } [(\text{BA})(\text{hts.})]}.$$

IV. Using the procedure in III., and values from yield tables, classes at Stephen F. Austin State College devised factors for three southern pine species in various localities:

Virginia pine in east Tennessee	0.0047,
Longleaf pine in Georgia	0.00524,
Shortleaf pine plantation of low form class in east Tennessee	0.0045.

A. Note that some of these are appreciably different from 0.005, and therefore a locally derived factor *may* be of some importance.

V. If we rewrite Grosenbaugh's equation in II., to include the BAF, it becomes:

$$\text{Volume per acre in rough stacked cords} = \frac{(\text{no. trees})(\text{BAF})(\text{avg. total tree ht.})}{(10)(20)(\text{no. sample points})}.$$

A. Rearranged, this equation could be shown thus:

$$\text{Volume per acre in rough stacked cords} = \frac{(\text{no. trees})(\text{BAF})}{100(\text{no. sample points})} \times \frac{\text{avg. total tree ht.}}{2}.$$

B. But $\frac{\text{no. trees}}{\text{no. points}}(\text{BAF}) = \text{BA per acre}$,

so, BA per acre in 100 square feet units × half the average total tree height = volume per acre in rough stacked cords.

THE STAND TABLE BLOW-UP FACTOR

I. The stand table blow-up factor (S.T.F.) gives the stand table values when multiplied by point-sample tree counts tallied by dbh class at one point.

A. Therefore, for each dbh class:
Trees per acre = (S.T.F.) (point-sample tree count).

B. A stand table may be made in this manner.

C. In addition, if the count came from N points, the product is divided by N.

II. The S.T.F. for each dbh class and BAF can be computed by the equation:

$$\text{S.T.F.} = \frac{\text{BAF}}{\text{BA per tree}}.$$

A. It would be easier to compute for any particular BAF if multiplication by the constant BAF could be performed.

B. This can be accomplished if the equation is changed to:
S.T.F. = (BAF)(reciprocal of BA per tree)

C. Table 6 is a list of these reciprocals; the values may be used in the above equation to produce the appropriate S.T.F.'s for any BAF.

TABLE 6. RECIPROCALS OF BASAL AREA (SQUARE FEET) BY .1 INCH INCREMENT OF DIAMETER BREAST HEIGHT FROM 1 INCH TO 25.9 INCHES.

DBH	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	181.8182	151.5152	126.5822	108.6956	93.4579	81.3008	71.4286	63.2911	56.4972	50.7614
2	45.8716	41.4938	37.8788	34.6021	31.8471	29.3255	27.1003	25.1256	23.3645	21.7865
3	20.3666	19.0840	17.8891	16.8350	15.8479	14.9701	14.1443	13.3869	12.6904	12.0482
4	11.4548	10.9051	10.3950	9.9206	9.4697	9.0580	8.6655	8.2986	7.9554	7.6336
5	7.3314	7.0472	6.7797	6.5274	6.2893	6.0606	5.8480	5.6433	5.4496	5.2659
6	5.0942	4.9285	4.7687	4.6189	4.4763	4.3403	4.2088	4.0850	3.9651	3.8506
7	3.7411	3.6377	3.5373	3.4400	3.3478	3.2595	3.1746	3.0921	3.0139	2.9377
8	2.8645	2.7949	2.7270	2.6617	2.5988	2.5374	2.4789	2.4225	2.3674	2.3148
9	2.2635	2.2139	2.1664	2.1200	2.0751	2.0317	1.9893	1.9486	1.9091	1.8706
10	1.8335	1.7973	1.7621	1.7283	1.6952	1.6631	1.6318	1.6015	1.5718	1.5432
11	1.5152	1.4881	1.4616	1.4360	1.4108	1.3864	1.3626	1.3394	1.3168	1.2947
12	1.2732	1.2523	1.2318	1.2118	1.1925	1.1734	1.1549	1.1368	1.1191	1.1018
13	1.0848	1.0684	1.0523	1.0365	1.0211	1.0060	0.9913	0.9768	0.9627	0.9489
14	0.9355	0.9223	0.9093	0.8966	0.8842	0.8721	0.8601	0.8485	0.8370	0.8258
15	0.8149	0.8041	0.7936	0.7832	0.7731	0.7631	0.7534	0.7438	0.7344	0.7252
16	0.7162	0.7073	0.6986	0.6901	0.6817	0.6734	0.6654	0.6574	0.6496	0.6419
17	0.6344	0.6270	0.6197	0.6126	0.6056	0.5987	0.5919	0.5852	0.5787	0.5722
18	0.5659	0.5597	0.5535	0.5475	0.5415	0.5357	0.5300	0.5243	0.5188	0.5133
19	0.5079	0.5026	0.4974	0.4922	0.4872	0.4822	0.4773	0.4724	0.4677	0.4630
20	0.4584	0.4538	0.4493	0.4449	0.4406	0.4363	0.4321	0.4279	0.4238	0.4197
21	0.4157	0.4118	0.4079	0.4041	0.4004	0.3966	0.3930	0.3894	0.3858	0.3823
22	0.3788	0.3754	0.3720	0.3687	0.3654	0.3622	0.3590	0.3558	0.3527	0.3496
23	0.3466	0.3436	0.3406	0.3377	0.3348	0.3320	0.3292	0.3264	0.3237	0.3210
24	0.3183	0.3157	0.3131	0.3105	0.3080	0.3054	0.3030	0.3005	0.2981	0.2957
25	0.2934	0.2910	0.2887	0.2864	0.2842	0.2820	0.2798	0.2776	0.2754	0.2733

CONSTRUCTING A TABLE OF "LIMITING DISTANCES"

I. A diopter is 1 centimeter of displacement of a light ray at a distance of 100 centimeters from the optical lens—in our case a prism.

II. A wedge or triangular prism is a piece of optical glass which refracts a light beam the refraction (or deflection) being a factor of the rate of convergence of its non-parallel sides.

A. Therefore, with a 10-BAF prism, which is 3.03 diopters, a 12-inch dbh tree would be on the borderline at 33 feet:

$$\frac{12 \times 100}{3.03} = 12 \times 33 \text{ inches} = 33 \text{ feet.}$$

B. By like reasoning, a 12-inch dbh tree viewed through a 20-BAF prism, having 4.29 diopters, would be borderline at 23.3 feet:

$$\frac{12 \times 100}{4.29} = 12 \times 23.3 \text{ inches} = 23.3 \text{ feet.}$$

C. For ease in computation, derive a multiplying factor for inches of dbh to get the borderline, or limiting distance. For a 10-BAF prism, 12 inches of dbh had 33 feet to its borderline and, therefore, the "tree circle" factor is 2.75:

$$\frac{33}{12} = 2.75 \text{ the "tree circle" factor.}$$

D. The "tree circle" factor for a 20-BAF prism is 1.944:

$$\frac{23.3}{12} = 1.94$$

E. In like manner, by knowing the BAF of the prism and its diopter power, we can calculate the multiplying factor for dbh to convert to feet for the borderline distance (Hovind and Rieck, 1961).

III. Tables 7 through 10 give the borderline distances by tenth-inch dbh classes for 5-, 10-, 20-, and 37.5-BAF prisms. Actually, by chaining to the center of each tree and measuring its diameter, point-sampling is performed without a prism.

TABLE 7. LIMITING DISTANCES FOR 5-FACTOR PRISMS—HORIZONTAL.

DBH	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
					FEET					
5	19.44	19.83	20.22	20.61	21.00	21.39	21.78	22.17	22.56	22.95
6	23.33	23.72	24.11	24.50	24.89	25.28	25.67	26.06	26.45	26.83
7	27.22	27.61	28.00	28.39	28.78	29.17	29.56	29.95	30.33	30.72
8	31.11	31.50	31.89	32.28	32.67	33.06	33.45	33.83	34.22	34.61
9	35.00	35.39	35.78	36.17	36.56	36.95	37.33	37.72	38.11	38.50
10	38.89	39.28	39.67	40.06	40.45	40.83	41.22	41.61	42.00	42.39
11	42.78	43.17	43.56	43.95	44.33	44.72	45.11	45.50	45.89	46.28
12	46.67	47.06	47.45	47.83	48.22	48.61	49.00	49.39	49.78	50.17
13	50.56	50.95	51.33	51.72	52.11	52.50	52.89	53.28	53.67	54.06
14	54.45	54.83	55.22	55.61	56.00	56.39	56.78	57.17	57.56	57.95
15	58.34	58.72	59.11	59.50	59.89	60.28	60.67	61.06	61.45	61.84
16	62.22	62.61	63.00	63.39	63.78	64.17	64.56	64.95	65.35	65.72
17	66.11	66.50	66.89	67.28	67.67	68.06	68.45	68.84	69.22	69.61
18	70.00	70.39	70.78	71.17	71.56	71.95	72.34	72.72	73.11	73.50
19	73.89	74.28	74.67	75.06	75.45	75.84	76.22	76.61	77.00	77.39
20	77.78	78.17	78.56	78.95	79.34	79.72	80.11	80.50	80.89	81.28
21	81.67	82.06	82.45	82.84	83.22	83.61	84.00	84.39	84.78	85.17
22	85.56	85.95	86.34	86.72	87.11	87.50	87.89	88.28	88.67	89.06
23	89.45	89.84	90.22	90.61	91.00	91.39	91.78	92.17	92.56	92.94
24	93.34	93.72	94.11	94.50	94.89	95.28	95.67	96.06	96.45	96.84
25	97.22	97.61	98.00	98.39	98.78	99.17	99.56	99.95	100.34	100.73
26	101.11	101.50	101.89	102.28	102.67	103.06	103.45	103.84	104.23	104.61
27	105.00	105.39	105.78	106.17	106.56	106.95	107.34	107.73	108.11	108.50
28	108.89	109.28	109.67	110.06	110.45	110.84	111.23	111.61	112.00	112.39
29	112.78	113.17	113.56	113.95	114.34	114.73	115.11	115.50	115.89	116.28
30	116.67	117.06	117.45	117.84	118.23	118.61	119.00	119.39	119.78	120.17

TABLE 8. LIMITING DISTANCES FOR 10-FACTOR PRISMS—HORIZONTAL.

DBH	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
					FEET					
5	13.75	14.02	14.30	14.57	14.85	15.12	15.40	15.67	15.95	16.22
6	16.50	16.77	17.05	17.32	17.60	17.87	18.15	18.42	18.70	18.97
7	19.25	19.52	19.80	20.07	20.35	20.62	20.90	21.17	21.45	21.72
8	22.00	22.27	22.55	22.82	23.10	23.37	23.65	23.92	24.20	24.47
9	24.75	25.02	25.30	25.57	25.85	26.12	26.40	26.67	26.95	27.22
10	27.50	27.77	28.05	28.32	28.60	28.87	29.15	29.42	29.70	29.97
11	30.25	30.52	30.80	31.07	31.35	31.62	31.90	32.17	32.45	32.72
12	33.00	33.27	33.55	33.82	34.10	34.37	34.65	34.92	35.20	35.47
13	35.75	36.02	36.30	36.57	36.85	37.12	37.40	37.67	37.95	38.22
14	38.50	38.77	39.05	39.32	39.60	39.87	40.15	40.42	40.70	40.97
15	41.25	41.52	41.80	42.07	42.35	42.62	42.90	43.17	43.65	43.72
16	44.00	44.27	44.55	44.82	45.10	45.37	45.65	45.92	46.20	46.47
17	46.75	47.02	47.30	47.57	47.85	48.12	48.40	48.67	48.95	49.22
18	49.50	49.77	50.05	50.32	50.60	50.87	51.15	51.42	51.70	51.97
19	52.25	52.52	52.80	53.07	53.35	53.62	53.90	54.17	54.45	54.72
20	55.00	55.27	55.55	55.82	56.10	56.37	56.65	56.92	57.20	57.47

21	57.75	58.02	58.30	58.57	58.85	59.12	59.40	59.67	59.95	60.22
22	60.50	60.77	61.05	61.32	61.60	61.87	62.15	62.42	62.70	62.97
23	63.25	63.52	63.80	64.07	64.35	64.62	64.90	65.17	65.45	65.72
24	66.00	66.27	66.55	66.82	67.10	67.37	67.65	67.92	68.20	68.47
25	68.75	69.02	69.30	69.57	69.85	70.12	70.40	70.67	70.95	71.22
26	71.50	71.77	72.05	72.32	72.60	72.87	73.15	73.42	73.70	73.97
27	74.25	74.52	74.80	75.07	75.35	75.62	75.90	76.17	76.45	76.72
28	77.00	77.27	77.55	77.82	78.10	78.37	78.65	78.92	79.20	79.47
29	79.75	80.02	80.30	80.57	80.85	81.12	81.40	81.67	81.95	82.22
30	82.50	82.77	83.05	83.32	83.60	83.87	84.15	84.42	84.70	84.97

TABLE 9. LIMITING DISTANCES FOR 20-FACTOR PRISMS—HORIZONTAL.

DBH	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
					FEET					
5	9.72	9.92	10.11	10.30	10.50	10.69	10.88	11.08	11.28	11.47
6	11.66	11.86	12.06	12.25	12.44	12.64	12.83	13.03	13.22	13.42
7	13.61	13.81	14.00	14.19	14.39	14.58	14.78	14.97	15.17	15.36
8	15.56	15.75	15.94	16.14	16.33	16.53	16.72	16.91	17.11	17.31
9	17.50	17.69	17.89	18.08	18.28	18.47	18.67	18.86	19.06	19.25
10	19.44	19.64	19.83	20.03	20.22	20.42	20.61	20.81	21.00	21.19
11	21.39	21.58	21.78	21.97	22.17	22.36	22.56	22.75	22.95	23.14
12	23.34	23.53	23.72	23.92	24.11	24.31	24.50	24.70	24.89	25.08
13	25.28	25.47	25.67	25.86	26.06	26.25	26.45	26.64	26.83	27.03
14	27.22	27.42	27.61	27.81	28.00	28.20	28.39	28.58	28.78	28.97
15	29.17	29.36	29.56	29.75	29.95	30.14	30.33	30.53	30.72	30.92
16	31.11	31.31	31.50	31.70	31.89	32.08	32.28	32.47	32.67	32.86
17	33.06	33.25	33.45	33.64	33.83	34.03	34.22	34.42	34.61	34.81
18	35.00	35.20	35.39	35.58	35.78	35.97	36.17	36.36	36.56	36.75
19	36.95	37.14	37.33	37.52	37.72	37.92	38.11	38.31	38.50	38.70
20	38.89	39.08	39.28	39.47	39.67	39.86	40.06	40.25	40.45	40.64
21	40.83	41.03	41.22	41.42	41.61	41.80	42.00	42.20	42.39	42.58
22	42.78	42.97	43.17	43.36	43.56	43.75	43.95	44.14	44.33	44.53
23	44.72	44.92	45.11	45.31	45.50	45.70	45.89	46.08	46.28	46.47
24	46.67	46.86	47.06	47.28	47.45	47.64	47.83	48.03	48.22	48.42
25	48.61	48.81	49.00	49.20	49.39	49.58	49.78	49.97	50.17	50.36
26	50.56	50.75	50.95	51.14	51.33	51.53	51.72	51.92	52.11	52.31
27	52.50	52.70	52.89	53.08	53.28	53.47	53.67	53.86	54.06	54.25
28	54.45	54.64	54.83	55.03	55.22	55.42	55.61	55.81	56.00	56.20
29	56.39	56.58	56.78	56.97	57.17	57.36	57.56	57.75	57.95	58.14
30	58.34	58.53	58.72	58.92	59.11	59.31	59.50	59.70	59.89	60.09

TABLE 10. LIMITING DISTANCES FOR 37.5-FACTOR PRISMS—HORIZONTAL.

DBH	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
					FEET					
5	7.13	7.26	7.39	7.52	7.66	7.79	7.92	8.12	8.25	8.38
6	8.51	8.65	8.78	8.98	9.11	9.24	9.37	9.50	9.64	9.77
7	9.97	10.10	10.23	10.36	10.49	10.63	10.82	10.96	11.09	11.22
8	11.35	11.48	11.62	11.81	11.95	12.08	12.21	12.34	12.48	12.61
9	12.80	12.94	13.07	13.20	13.33	13.46	13.66	13.79	13.93	14.06
10	14.19	14.32	14.45	14.65	14.78	14.92	15.05	15.18	15.31	15.51
11	15.64	15.77	15.91	16.04	16.17	16.30	16.50	16.63	16.76	16.90
12	17.03	17.16	17.36	17.49	17.62	17.75	17.89	18.02	18.15	18.35
13	18.48	18.61	18.74	18.88	19.01	19.14	19.34	19.47	19.60	19.73
14	19.87	20.00	20.20	20.33	20.46	20.59	20.72	20.86	20.99	21.19
15	21.32	21.45	21.58	21.71	21.85	22.04	22.18	22.31	22.44	22.57
16	22.70	22.84	23.03	23.17	23.30	23.43	23.56	23.69	23.83	24.02
17	24.16	24.29	24.42	24.55	24.68	24.88	25.01	25.15	25.28	25.41
18	25.54	25.67	25.87	26.00	26.13	26.27	26.40	26.53	26.73	26.86
19	26.99	27.13	27.26	27.39	27.52	27.72	27.85	27.98	28.12	28.25
20	28.38	28.51	28.71	28.84	28.94	29.11	29.24	29.37	29.57	29.70
21	29.83	29.96	30.10	30.23	30.36	30.56	30.69	30.82	30.95	31.09
22	31.22	31.42	31.55	31.68	31.81	31.94	32.08	32.21	32.41	32.54
23	32.67	32.80	32.93	33.07	33.20	33.40	33.53	33.66	33.79	33.92
24	34.06	34.25	34.39	34.52	34.65	34.78	34.91	35.05	35.24	35.38
25	35.51	35.64	35.77	35.90	36.10	36.23	36.37	36.50	36.63	36.76
26	36.89	37.09	37.22	37.36	37.49	37.62	37.75	37.88	38.08	38.21
27	38.35	38.48	38.61	38.74	38.94	39.07	39.20	39.34	39.47	39.60
28	39.73	39.93	40.06	40.19	40.33	40.46	40.59	40.79	40.92	41.05
29	41.18	41.32	41.45	41.58	41.78	41.91	42.04	42.17	42.31	42.44
30	42.57	42.77	42.90	43.03	43.16	43.30	43.43	43.63	43.76	43.89

SLOPE CORRECTIONS IN POINT-SAMPLING

I. Sloping land complicates point-sampling just as it complicates plot-sampling. If slope correction is neglected, the errors will be of significant magnitude when slope is more than about 10 percent.

A. A slope factor (s.f.) may be easily determined using the average slope at each point, because:
s.f. = secant of angle of slope.

B. With this factor, point-sample tree counts may be corrected by merely multiplying:
Corrected count = (tree count) (s.f.)

C. Using this method, the correction can be made for any slope situation although, in some western states, cruisers have encountered a great deal of difficulty and noted some significant inaccuracies in actual application.

D. Grosenbaugh (1955) gives correction factors for most slopes (Table 11). Note the equation at the foot of the table.

II. Slope may be corrected also by rotating the prism through a vertical angle equal to the angle of the slope.

A. Certain prisms are manufactured with a rounded top to facilitate use in the rotated position.

B. This is perhaps the best solution of the slope problem.

C. It has been used throughout the United States and, in some western point-sampling—wherein the tree is *always* viewed at the top of the first 16-foot log as a hedge against brush-bias—almost every tree is on a slope (Bruce 1961).

TABLE 11. APPROPRIATE CORRECTION FACTORS FOR BA OR VOLUME PER ACRE CALCULATED FROM UNADJUSTED ANGLE-GAUGE TALLIES TAKEN ON A SLOPE, WHERE SLOPE PERCENT IS MEASURED AT RIGHT ANGLES TO CONTOUR.

Limits of Percent Slope	Slope Correction Factor	Limits of Percent Slope	Slope Correction Factor	Limits of Percent Slope	Slope Correction Factor
10.0		55.8		80.7	
	1.01		1.15		1.29
17.4		57.8		82.3	
	1.02		1.16		1.30
22.5		59.8		83.9	
	1.03		1.17		1.31
26.7		61.7		85.4	
	1.04		1.18		1.32
30.4		63.6		86.9	
	1.05		1.19		1.33
33.6		65.4		88.4	
	1.06		1.20		1.34
36.6		67.2		89.9	
	1.07		1.21		1.35
39.5		69.0		91.4	
	1.08		1.22		1.36
42.1		70.8		92.9	
	1.09		1.23		1.37
44.6		72.5		94.3	
	1.10		1.24		1.38
47.0		74.2		95.8	
	1.11		1.25		1.39
49.3		75.8		97.2	
	1.12		1.26		1.40
51.5		77.5		98.7	
	1.13		1.27		1.41
53.7		79.1		100.1	
	1.14		1.28		1.42
55.8		80.7		101.5	

Correction factor for steeper slopes is:

$$\sqrt{1 + \left(\frac{\text{Slope percent}}{100}\right)^2}$$

Source: Grosenbaugh, L. R. "Better diagnosis and prescription in southern forest management." U. S. Forest Service, Southern Forest Experiment Station, Occasional Paper 145, 1955.

CONTINUOUS FOREST INVENTORY WITH POINT-SAMPLING

I. Point-sampling techniques are just as suitable for continuous forest inventory (CFI) as are plot sampling techniques.

A. Point-sampling has the special advantage of taking a smaller percent sample of the many small stems in uneven-aged forests, while sampling the fewer large stems in much the same proportion as in fifth-acre plot-sampling.

B. This is illustrated from experience with CFI in the Sabine National Forest:

DBH Class	Number of Trees Tallied—110 Locations	
	1/5-Acre Plots (1957-58)	10-BAF Point Samples (1962)
5 - 9	1782	239
10 - 14	601	211
15 - 19	248	184
20 - 24	55	50
25+	2	5

II. The techniques of point-sampling, and the resulting calculations, are as convenient for electronic data processing as are the mechanics of plot-sampling.

A. U. S. Steel in Alabama (University of Georgia, 1959) used point-sampling in its CFI plan and measured six to eight stems at each point. They measured all trees due to the small number at each location, and thus have a permanent record of trees from seedling-size up.

B. The Southern Forest Survey, a large-scale CFI system, now employs point-sampling as its inventory technique. Samples are on a 3 x 3-mile grid. Clusters of ten 37.5-BAF samples are collected at each survey location.

III. Several problems not attributed to plot-sampling are present when point-samples are used in continuous forest inventory.

A. Trees grow into the sample according to their size *and* distance from the point, not just according to their size. In other words, a 20.0-inch tree 79.34 feet from the point will come into the sample when it grows to 20.4 inches dbh, if the sample is being taken with a 5-BAF prism. Since its total volume is not really ingrowth, the volume per acre and the number of stems per acre it represents will be used for future growth determination, but will not necessarily figure in past growth calculations.

B. Unless dbh and distance are both remeasured, omitted or extra trees will severely affect stand and stock table values. In brushy areas, obscured trees may be omitted accidentally in the point-sample.

C. Since a CFI sample is exceedingly small and blowups are large, extreme care must be exercised in taking the CFI point-sample.

GROWTH PROJECTION WITH POINT-SAMPLES

I. Point-sampling can be applied to growth projection studies (Fender and Brock, 1963) for future volume or basal area as well as to determine actual current volume or basal area.

II. To show the principle involved, in an exceedingly simplified method, trees in a southern pine plantation were bored to determine average projected 5-year diameter growth. Using a table of limiting distances for the "new" diameters, the projected stand 5 years hence was "tallied," giving the following results:

Present		Future	
Count	BA/Acre	Count	BA/Acre
8	160	9	180
9	180	10	200
9	180	13	260
9	180	10	200
6	120	8	160
Average	164	Average	200

NUMBER OF POINTS TO ACHIEVE STATED PRECISION

I. The forester, contemplating a point-sample cruise, must know how its accuracy compares with that of the conventional plot cruise he has previously employed. He needs to know the total number of points to observe on a property of given acreage to yield the required precision.

A. Bruce (1961) says that in western timber, point-sampling requires about the same number of points as 1/4- or 1/5-acre plots to achieve a stated precision of volume estimate, if the prism is properly matched to tree size in the stands sampled. This means that counts per point must average about 5 trees.

B. For southern forests, Grosenbaugh (1955) wrote, "The reconnaissance would require a minimum of about 20 unbiased sample points well distributed throughout the record unit for a standard error of about ± 25 percent in volume per record unit. A volume total of 25 such record-units would have a standard sampling error of only about ± 5 percent for the ownership or working circle as a whole."

C. Bell and Alexander (1957) said, "present experience shows that the same intensity as that used for one-quarter-acre plots will result in a stastically better sample than given by the one-quarter acre plot method."

D. Putnam *et al.* (1960) wrote, "The reconnaissance preceding the first managed cut should ordinarily be an inexpensive affair. An inspection and sight estimate may suffice for experienced men, though a more formal approach will be necessary for most foresters. The point-sampling technique makes it possible to get approximate estimates of volume with very little effort. If a prism or angle gauge with a basal area factor of 10 is employed to select sample trees, 25 sample points distributed systematically over management unit will usually give a sampling error for board-foot volume of less than 23 percent. The aggregate volume on four management units will ordinarily be estimated within twelve percent. The goal is not extreme accuracy but rather rough estimates obtained as quickly and cheaply as possible.

"If a more intensive survey is needed, the following tabulation may be used to obtain approximate and usually conservative sampling errors as a percent of the total volume.

Points (number)	Error (percent)
25	23
50	17
100	12
200	8
400	6
1600	3

"For cruises of the specified intensity, differences between sample volume and volume by 100-percent tally will be exceeded, on the average, in only one cruise in three. Five percent of the time, the difference might be twice the chosen limit, but 50 percent of the time the difference will be less than 68 percent of the tabulated error.

"This means, for example, that a cruiser choosing 12 percent as his limit of sampling error may be wrong by more than this amount on one cruise out of three. In fact, one time in twenty his actual error may be more than 24 percent, but half the time his error will be less than 8 percent. In the rare cases where a sample of low intensity might deviate from the true mean considerably, an experienced cruiser will suspect the lack of representativeness and intensify the sampling accordingly.

"Whether sample points are located systematically or at random, the area of the tract has little effect on the number of points required for a given sampling error. The important thing is the variability among the aggregate volumes sampled at various points. The tabulation is based on average variation over a large portion of an entire southern state. Errors may be larger in extremely irregular stands and smaller where stands are relatively uniform."

E. Kendall and Sayn-Wittgenstein (1959) said, ". . . The number of point samples required to give a precision equal to that from conventional 1/5-acre-plots varied with the type of stand and averaged 2.8.

NUMBER OF POINT SAMPLES (N) EQUIVALENT TO 1/5-ACRE PLOT

(basal area factor = 10)

Location	Type of Stand	Stocking (trees per acre)	Diameter Range (inches)	Modal Diameter (inches)	N (by random selection)
Eagle Depot	even-aged pine	340	1-25	5	3.1
Forbes Depot	pine-spruce	760	1-14	4	2.3

"Although no detailed time study was undertaken, it is estimated that with the relascope, BA was sampled to a given precision in one-half or one-third the time required when 1/5-acre plots were used. In the tests carried out in the Forbes Depot and Eagle Depot areas in 1957, the number of trees tallied for volume calculations in the point samples numbered, 1,290, whereas 12,301 were tallied in the corresponding 1/5-acre plots. This is partly due to the fact that with the relascope each tree size is sampled on a land area which is proportional to its BA. A greater proportion of large trees is therefore sampled, and the time consuming measurement of small trees is largely eliminated."

F. For 110 double sample points, the error of BA would be only about ± 3.1 percent and for 110 single points the error would be about ± 4.5 percent on a pine-hardwood area in the Sabine National Forest (see page 16).

COMPARING METHODS OF PER ACRE POINT-SAMPLE VOLUME ESTIMATES

I. The School of Forestry, Stephen F. Austin State College, maintains 110 permanent continuous forest inventory plots on the Sabine National Forest, Texas. These were measured in 1957-58 and remeasured in 1962. At the time of remeasurement, a point-sample using a 10-BAF prism was made in addition to the fifth-acre plot-sample. As an indication of the various per acre volumes, using various methods and factors in computation, the following data are presented from *ten* of the 110 point samples. The range of per acre volumes may be less if data from the entire array of 110 points were presented (Table 12).

TABLE 12. SUMMARY OF THE FACTORS BY POINTS USED TO COMPUTE VOLUMES IN VARIOUS WAYS

Point	Σ Bff Saw-timber (1)	Σ bff Saw-timber (2)	Σ Logs Saw-timber (3)	Σ Bd. Ft. Saw-timber (4)	Σ Cu. Ft. Pulp Trees (5)	Σ cff Pulp Trees (6)	Σ Feet Pulp Trees (7)
2	27.9	193.0	3.5	2677.70	105.552	12.38	15.9
12	42.5	416.8	8.0	4326.71	366.048	42.96	57.1
22	10.8	131.2	2.5	1442.01	701.001	72.92	102.2
32	20.0	239.2	4.5	2395.73	893.298	95.08	128.0
42	19.1	239.2	4.5	2515.16	120.813	14.98	18.9
52	84.0	980.2	18.5	9972.11	494.318	55.34	73.4
63	30.4	308.8	6.0	3209.10	705.422	77.50	100.2
72	60.2	594.4	11.5	6299.68	0	0	0
82	17.3	216.0	4.0	1927.77	541.352	49.52	71.1
92	38.8	393.6	7.5	4100.79	450.957	47.54	62.9
10	351.0	3712.4	70.5	38866.32	4388.761	468.02	629.7

(1). Using the standard volume table type of approach:

$$\text{Vol. bd. ft. per acre} = \frac{\Sigma\ \text{bff}}{N}\ (\text{BAF})\ (10) = \frac{351.0}{10}\ (10)\ (10) = 3510.0$$

(2). Using the board foot factor per height class method:

$$\text{Vol. bd. ft. per acre} = \frac{\Sigma \text{ bff}}{N} (BAF) = \frac{3712.4}{10} (10) = 3712.4$$

(3). Using the 60 factor and sum of logs method:

$$\text{Vol. bd. ft. per acre} = \frac{(\Sigma \ L)(60)(BAF)}{N} = \frac{(70.5)(60)(10)}{10} = 4320.0$$

(4). Using the stand table approach with volume for each d.b.h. class:

$$\text{Vol. bd. ft. per acre} = \frac{\Sigma[(T)(S.T.F.)(Vol)]}{N} = \frac{38{,}866.32}{10} = 3886.6$$

(5). Using the stand table method for cubic foot volume of pulpwood:

$$\text{Vol. cu. ft. per acre} = \frac{\Sigma[(T)(S.T.F.)(Vol)]}{N} = \frac{4388.761}{10} = 438.9$$

(6). Using the c.f.f. for each height class in pulpwood trees:

$$\text{Vol. cu. ft. per acre} = \frac{\Sigma \text{ cff}}{N} (BAF) = \frac{468.02}{10} (10) = 468.02$$

(7). Using the cubic foot factor 0.7052 and merchantable pulp tree height (in feet) method:
Vol. cu. ft. per acre =

$$\frac{(\Sigma H)(.7052)(BAF)}{10} = \frac{(629.7)(.7052)(10)}{10} = 444.06$$

For comparison: 1958 volumes of 10 fifth-acre plots at same location: 410.02 cu. ft. per acre and 4806.8 bd. ft. per acre.

A TEST OF POINT-SAMPLING IN A PLANTATION

I. Whether point-sampling gives adequate results in a plantation is not readily resolved. The Nacogdoches City Plantation was inventoried in 1966 by several methods. The results indicate that point-sampling does adequately inventory plantations, although the 1/20-acre circular plots yield basal area and cubic foot volumes which were closer to the 100% tally than were the point-samples (Table 13).

TABLE 13. METHODS OF SAMPLING, NACOGDOCHES CITY PLANTATION, 1966.

Inventory Method	Number of Samples	Basal Area per Acre (sq. ft.)	Proportional Limit of Error (Percent)	σM of Basal Area	Cubic Feet Per Acre	Proportional Limit of Error (Percent)	σM of Cubic Volume	Trees Per Acre
100% Stand Table	—	91.643	none	none	1960.98	none	none	236
Systematic Point-Sample[2]	20	103.000	13.3	6.860	2229.47	13.9	156.280	254
Systematic 1/20-acre Circular Plot	20	88.488	7.8	3.456	1835.34	9.9	90.620	241
Random Point-Sample	20	108.000	16.0	8.632	2359.82	16.7	196.620	238
Random 1/20-acre Circular Plot	20	91.082	6.7	3.062	1899.21	7.8	74.320	243
Random 1/20 Row Plot	20	99.698	14.9	6.807	2073.74	14.4	149.54	267
Swinford's Progressive Point-Sampling[1]	12	106.660	15.6	8.310	2343.22	15.7	183.74	264
Systematic 1/20-acre Row Plot	20	94.356	12.4	5.831	2094.89	13.8	141.660	226
Swinford's Progressive Point-Sampling[1]	8	100.000	21.4	10.690	2251.18	22.8	256.160	236

[1]Adapted from Swinford (1966).

[2]All systematic samples taken at same locations.

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ABBREVIATIONS

BA	basal area
BAF	basal area factor
bff	board foot factor
Bff	modified board foot factor
C	coefficient of variation
CFI	continuous forest inventory
cff	cubic foot factor
d	distance between target and prism
D	tree diameter in inches
dbh or DBH	diameter at breast height
f	frequency
F	tree total height in 10 foot units
H	total height of tree in feet
ht.	height
L	merchantable height of trees in 16-foot logs
M	mean
N	number of points or observations
Ple.	proportional limit of error
S	sampling error of a mean in percent
Se.	combined sampling error in percent
s.f.	slope factor
S.T.F.	stand table blowup factor
T	tree count in a diameter class
V	variance
w	target width, or distance between pins
Σ	sum of
σ	standard deviation
σm	standard error of the mean

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