Research Note No. 30

APPLICATION OF THE VARIABLE PLOT METHOD OF SAMPLING FOREST STANDS

By
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and
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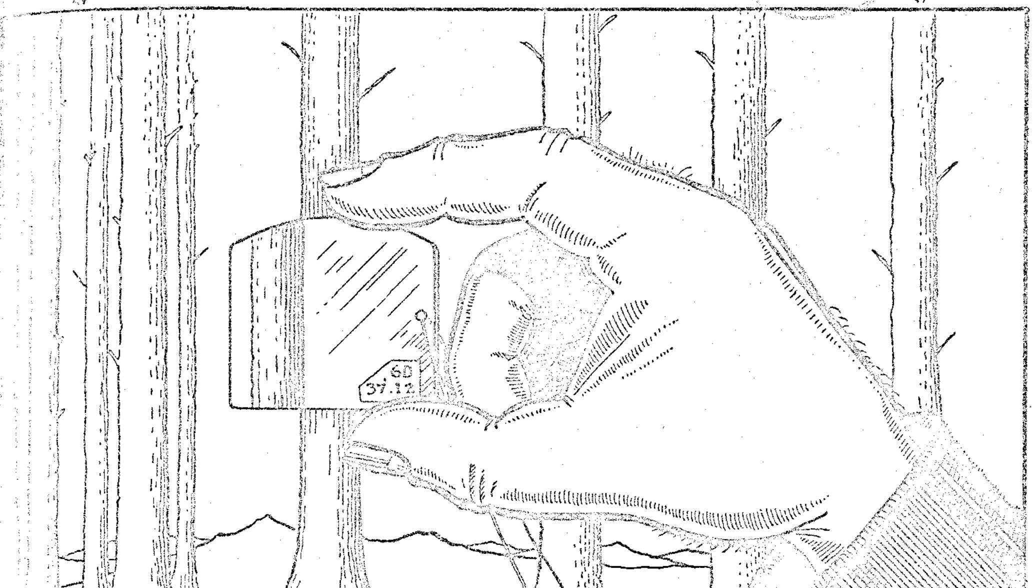

OREGON STATE BOARD OF FORESTRY
Dwight L. Phipps, State Forester
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Salem, Oregon

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FOREWORD

This publication is made possible through the cooperative effort of the Oregon Forest Lands Research program, the Management Division of the State Forestry Department and Lucien B. Alexander of Mason, Bruce and Girard, consulting forestry firm. It is in answer to the many requests for practical information as to the application of the variable size plot method of measuring forest stands.

It is fortunate that senior author John F. Bell had already completed field tests and a practical evaluation of the method. To him we are grateful for the largest personal contribution to the project. We also wish to thank Mr. Alexander for his advice and help in preparing the manuscript, as well as his direct contributions of authorship.

Dick Berry

Research Director

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OF

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John F. Bell
in collaboration with
Lucien B. Alexander

Respectively Staff Forester,
Oregon State Board of Forestry,
and Partner, Mason, Bruce and
Girard, Consulting Foresters.

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TABLE OF CONTENTS

INTRODUCTION

The variable plot method of sampling a forest stand was developed in Europe by Walter Bitterlich (1). It was introduced to American foresters by Dr. L. R. Grosenbaugh (2) in 1952.

Although several papers have been written covering the principle of the variable plot method of sampling a forest stand, little has been written about its field application. This paper is designed for the practicing forester who is interested primarily in the use of the technique for cruising and other inventory work.

Determination of the ratio of basal area or volume to land area with the fixed plot size method of sampling, requires that trees inside the plot boundary be measured and tallied and those outside ignored. The variable plot method in actuality is merely another way of determining which trees to measure and tally. Those trees which are large enough to subtend a predetermined angle are tallied and used to determine the ratio of basal area or volume to land area, while those too small or too far away are ignored.

The variable plot method is a simpler, more rapid method of determining basal area and volume per acre than the conventional plot or strip methods. It reduces the personal error involved since the need to measure plot radii or strip width is eliminated and accurate diameter measurements are not necessary. The variable plot method reduces total field cruising time by approximately one third. The probability that any tree will be sampled is proportional to its basal area. Thus, a greater proportion of cruising time is spent on the larger trees. Since there is a saving in field cruising time and since more time is spent on the larger trees, the accuracy of defect and grade determinations is increased.

The reader will find in the appendix an abstract on the theory of the variable plot method of sampling a forest stand.

THE WEDGE PRISM

The wedge prism is a precise optical instrument which bends light rays establishing the reference or critical angle. Wedge prisms ground to specifications, as developed by the consulting firm of Mason, Bruce and Girard, can be purchased through Bausch and Lomb, 7 Northwest

(1) Bitterlich, W. Die Winkelzahlprobe. Allgemeine Forst - und Holzwirtschaftliche Zeitung 59(½): 4-5. 1948.

(2) Grosenbaugh, L. R. Plotless Timber Estimates - New, Fast, Easy. Journal of Forestry 50: 32-37. 1952.

9th Avenue, Portland, Oregon, or through Kollmorgan Optical Corporation, Northampton, Massachusetts. The former company does not produce prisms which can be interchanged without a change in basal area factors. Their prisms cost about $2.50 each. The latter company produces prisms with exact factors such as 20, 25, or 30, but the prisms are $15.00 each and must be purchased in quantities.

FUNCTIONS OF WEDGE

What Prism Diopter to Use

One prism diopter is equal to a right angle displacement of one unit per 100 equal units distance. The general rule to follow is to select a prism diopter that will give an average tree count of four to six trees per observation point. It is best to employ the same diopter in any one given stand. The smaller the trees, the lower the diopter. The larger the trees, the higher the diopter. The more open the stand, the smaller the diopter. The more dense the stand, the larger the diopter. A compromise between size and density, with size the dominant factor, determines the diopter to use.

Listed below are some examples for the Pacific Northwest:

2 - 3 Diopter - small immature stands

4 Diopter - larger immature Douglas fir stands and selectively cut Ponderosa Pine.

5 Diopter - second growth Douglas fir sawtimber and uncut Ponderosa Pine.

6 Diopter - old growth Douglas fir or Cascade Mountain mixed sawtimber.

8 Diopter - dense old growth Douglas fir, Redwood, or other very large sawtimber.

The Wedge Prism Basal Area Factor

The wedge prism would be of little use to the forester in determining stocking density or in the estimation of volume without the basal area factor. This factor, when multiplied by the average number of trees per observation point, will result in square feet per acre occupied by tree stems.

Determination of the Basal Area Factor

The basic method followed in determining a basal area factor is relatively simple. Place a rectangular target of any convenient width (1'-2'-3') on a vertical surface. The wedge is first moved away from the target until the target image is completely displaced so that one side of the image as seen over the prism is aligned with the other side as seen through the prism. The distance at which this occurs is measured in feet. Next the wedge is moved toward the target until the displacement occurs again. Again the distance is measured.

An average distance calculated from six such trials is placed in the Basal Area Factor formula.

$$B.A.F. = \frac{43,560}{1+4\left(\frac{d}{w}\right)^2}$$

Where d is distance to target in feet, w is the width of target in feet.

A question that may arise is, how much can the measured distance from target to wedge be in error and still be within reasonable limits of giving a good answer?

(It should be noted that a given per cent error in the basal area factor will produce the same per cent error either in basal area calculations or in cruise volume calculations.)

The following table shows how much this distance (an average for six trials) may vary for a one and two per cent error in the basal area factor using various diopter wedges with a one-foot target.

DISTANCE ALLOWANCE IN CALIBRATING

Diopter	B.A.Factor within ± 1% limits		B.A.Factor within ± 2% limits	
	* ± ft.for ± 1%	Total Distance Allowance	* ± ft.for ± 1%	Total Distance Allowance
4.0	.13 ±	.25 ±	.25 ±	.50 ±
5.0	.10 ±	.20 ±	.20 ±	.40 ±
6.0	.08 ±	.17 ±	.17 ±	.34 ±
8.0	.06 ±	.12 ±	.12 ±	.25 ±

* ± feet allowance from exact distance from wedge to target center.

Example: An exact 4.0 diopter wedge is to be given a basal area factor. The range is set up and the previously described procedure followed. The true distance, by formula, from wedge to target is 25.00' when a one foot target is used. The average of, for example, six trials is 25.105' with a calculated basal area factor of 17.272. The correct factor of 17.417 varies 0.83% from the calculated factor of 17.272. Thus, any cruise made with the wedge marked as having a basal area factor of 17.272 will be 0.83% low when the volume calculations are made.

FIELD PROCEDURE USING THE WEDGE PRISM FOR BASAL AREA DETERMINATION

How to Establish the Sample Point

A series of sample points is established on the ground in the same manner as the center points of fixed-radius sample plots. Either full points (360 degrees) or half points (180 degrees) may be taken.

The half point is established as follows:

1. The point is established in the normal manner.

2. From the point, the compassman faces downhill regardless of the direction of the cruise line. (Whenever the crew consists of two or more men the compassman selects the half point to eliminate any bias that might be introduced if the cruiser established the point.)

3. He next picks a reference tree on his left that is on contour with the point. A stake may be set if a reference tree is not available. When it is desired that the point can be reestablished at a later date, the tree is blazed and marked with a 2.

4. The half point is established from the reference tree by extending an imaginary line across the plot center. All the trees on the downhill side of this line are potential "in" trees.

Normally a wedge of one diopter lower is used when half points are taken.

How to Determine Whether a Tree is "in" or "out"

From the sample point the surrounding trees are observed both through and over the wedge prism. The prism bends the rays of light passing through it by a fixed angle so that the transmitted image of the tree is laterally displaced. If the edge of the direct and transmitted images overlap, the tree is considered "in" and it is counted. Figure 1 shows the diagram of an "in", "out", and "borderline" tree. Alternate "borderline" trees may be counted as being "in" or each "borderline" tree may be counted as a half tree. The distance between the eye and the prism does not affect the angular displacement of the prism. However, it is very important to keep the prism over the sample point. The cruiser sights on the tree at the point on the tree where his basic volume table diameters are indicated. Usually, that point is D.B.H. There are advantages to using a point higher on the tree; however, the basic volume table

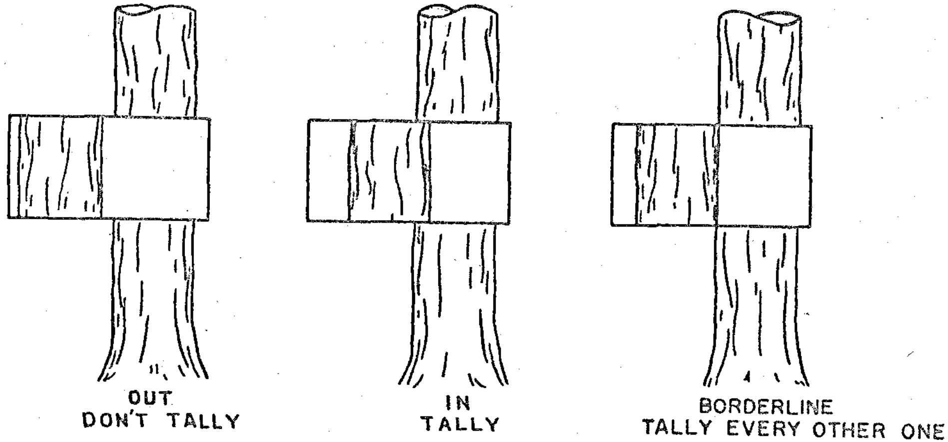

FIGURE 1.

must then be adjusted to give diameters at that new point. The face of the prism should be at right angles to the line of sight and when this condition exists the lateral displacement of the image is minimum. The bottom edge should be horizontal on level ground. To correct for slope, the prism is rotated at exactly the same angle as the slope, but in a plane which is at right angles to the line of sight. Both the slope angle from eye to tree and the amount in which the wedge prism is rotated to correct for slope must be equal. An abney can be used to measure the amount of slope and then used to rotate the wedge to the same angle with the line of sight. Figure 2 shows the correct way to employ the abney and the wedge prism. Note that the line of sight is perpendicular to the face of the wedge prism.

The following are some pointers on determining whether a tree is "in" or "out":

1. For hidden trees the observation center may be moved away from the actual point as long as the distance from the point to the tree in question is maintained. By moving the observation center, it is often possible to get to one side of brush that is obstructing the view. It is necessary to move the center when a possible "in" tree is directly behind another tree.

2. For a leaning tree, rotate the wedge prism so that its vertical axis corresponds with the center of the stem of the tree.

3. Occasionally the displaced image of one tree will overlap an adjacent tree giving the appearance that it should be counted when actually it is "out". This can be avoided by careful observation of the trees involved to see whether the displaced image belongs to the tree that is overlapped. In some instances, having the compassman stand beside the closer tree will facilitate making the distinction.

4. In rare cases it may be necessary to remove some of the brush that is obstructing the view. The use of half points helps to eliminate the brush problem.

5. Normally the prism is held so that the image is displaced to the left. Reversing the prism so that the image is displaced to the right will aid in determining whether a tree is "in" or "out".

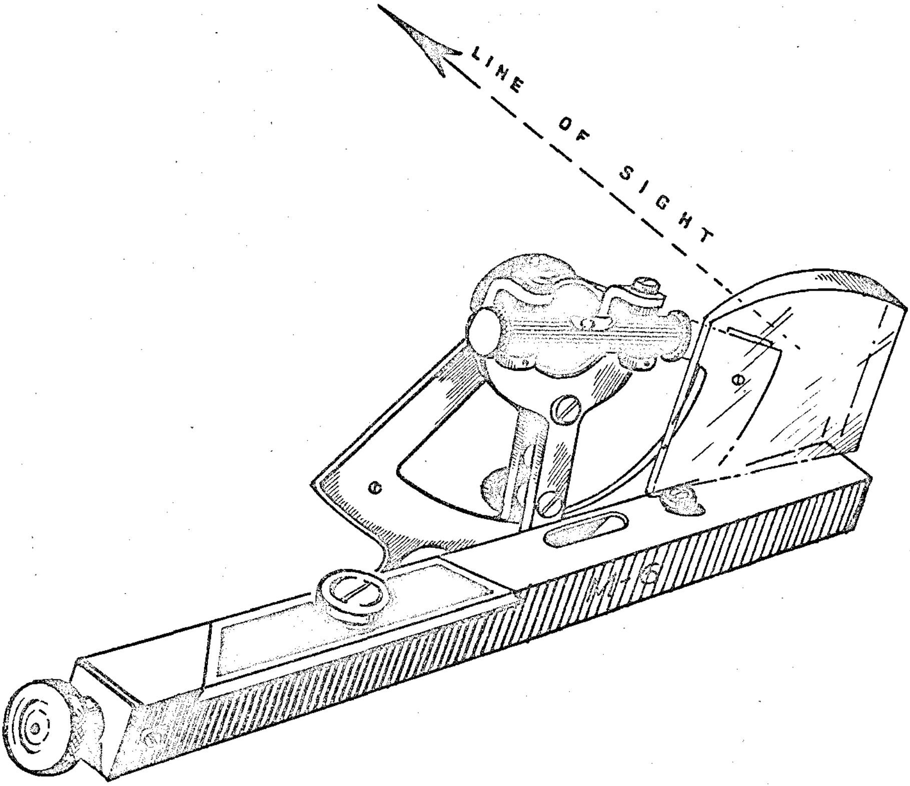

FIGURE 2. THE CORRECT WAY TO EMPLOY THE ABNEY AND THE WEDGE PRISM.

6. Another method of determining whether a tree is "in" or "out" is through the use of a plot radius factor. The distance from the point of observation to a tree that is just "in" is called the plot radius. The D.B.H. of any tree is directly proportionate to the plot radius. Thus, a plot radius factor can be computed for any wedge prism.* The D.B.H. in inches of any tree multiplied by the plot radius factor gives the plot radius in feet for a tree that is just "in". It is easily seen that there is a different plot radius for each different diameter. Thus, this method is often referred to as the variable plot radius method. The plot radius factor is particularly useful as a training aid.

How to Determine Basal Area per Acre

The average tree count per plot multiplied by the wedge prism factor gives basal area per acre.

Example: 21 points are taken which have a total tree count of 87. A wedge prism with a factor of 27.62 was used.

Average tree count = $\frac{87}{21}$ = 4.143 (normally carried out to three decimal places)

4.143 x 27.62 = 114.4 square feet of basal area per acre.

* The plot radius factor is computed from the following formula:

$$\sqrt{\frac{43{,}560 - B.A.F.}{4\ B.A.F.}} \div 12$$ where B.A.F. = Basal Area Factor

The plot radius factor may also be computed from the following formula (for any given wedge prism):

$\frac{d}{12w}$ where d = distance to target in feet
w = width of target in feet

FIELD PROCEDURE USING THE WEDGE PRISM FOR VOLUME DETERMINATION

In order to determine volume per acre it is necessary to obtain two basic statistics, the basal area per acre and the average board foot basal area ratio.

Basal Area per Acre

The method of obtaining basal area per acre has already been described in the previous section. However, in actual practice when obtaining volume per acre, it is generally preferred to sight on the tree at the top of first 16-foot log. (It is to be noted that this gives stem area per acre outside bark.) This eliminates the necessity of determining form class when using form class tables. Also by sighting on the tree at the top of the first 16-foot log the observer is sighting over much of the underbrush. It is particularly advantageous to use half points (always taken on the downhill side) when sighting on the tree at the top of the first 16-foot log as the slope correction may then be kept at a minimum.

Form Class volume tables and the volume tables used by the United States Bureau of Land Management are particularly adapted for use with this method. When using almost any other volume table it will be necessary to sight at breast height. It is possible to obtain basal area per acre at breast height and then convert this to stem area at the top of the first 16-foot log by multiplying basal area per acre at breast height by the appropriate form class squared.

Example: Basal area per acre at breast height is 100 sq. ft. per acre. The form class is .80. Stem area top first 16-foot log per acre equals: $100 \times (.80)^2 = 64$ sq. ft. per acre.

Board Foot Basal Area or Stem Area Ratio

The board-foot to stem-area ratio is the number of board feet per square foot of stem area. The ratio for any given "in" tree is recorded in the field by determining the diameter at the point on the tree that corresponds with the point to which the diameters are keyed to the basic volume table, and the total number of logs of tree height (normally 32 foot logs). A tree count is determined for every plot, but it is necessary to obtain the ratio of the "in" trees on only a proportion of the plots for the major species being sampled. To obtain a satisfactory sample it is necessary to record the ratio of the "in" trees of minor species on every sampling point. For a small cruise the ratio is obtained on every other plot while for a large cruise the ratio is obtained on every third or fourth plot. Normally it is necessary to obtain the ratio on a minimum of 60 trees for any species for any given area on which cruise reports are to be made.

Windfalls

1. Rotate the wedge 90 degrees so that the image is displaced upward.

2. Determine whether the windfall is "in" or "out" by sighting on the tree where the basic volume table diameters are indicated, disregarding where the windfall originally stood.

3. Normally, obtain diameter and log height of each "in" merchantable windfall at every sampling point in order to obtain an adequate sample.

Snags

Normally, obtain diameter and log height of each "in" merchantable snag at every sampling point in order to obtain an adequate sample.

Defect, Breakage, and Log Grade Determination

It is most convenient to record defect, breakage, and log grades in percentages when the ratios have been derived from Board Foot Volume Tables (Form Class Tables) published by Mason, Bruce and Girard. The percentage of tree volume in each log is found in Table 1, page 6, of the tables named above. Defect, breakage and log grades can be recorded in the field in the usual manner. However, in the office the standard method is more cumbersome.

Intensity of Sampling

Considerable research will be necessary to determine what sampling intensity is necessary in any given stand. However, present experience shows that the same intensity as that used for one-quarter acre plots will result in a statistically better sample than that given by the one-quarter acre plot method.

OFFICE PROCEDURE FOR VOLUME DETERMINATION

Volume Summary Sheet (Board Foot Stem Area Ratio)

Any suitable volume table can be converted to board feet per square foot of stem area for any given diameter and log height by the following steps: (1) convert the diameter as given in the table to square feet of stem area, (2) obtain the volume in a tree for the given diameter and given heights, (3) divide the number of square feet of stem area from Step 1 into the volume from Step 2 which gives the ratio of board feet per square foot of stem area.

Figure 3 contains an example of the ratios (based on 32 foot log scale - Scribner decimal C) for trees with diameters keyed to inside bark at the top of the first 16-foot log, 9" through 70" and log heights 1 through 6.

The ratios given in Figure 3 have been plotted into log height curves as shown in Figure 4. This plotting illustrates that the diameter variable in cruising has been greatly reduced and that log heights determination is as important as in standard methods of cruising.

Gross Volume

Gross volume for each species is determined as follows: (1) plot ratios for all trees recorded in the field on the volume summary sheet (Figure 3), (2) compute the average ratio by dividing the total ratio by the number of trees that contributed to the total ratio, (3) compute the number of square feet of stem area per acre as explained in the section on basal area per acre, (4) where tree counts are made outside bark and volume tables are based on d.i.b., square the wood to bark ratio for species involved and multiply by the stem area outside bark from Step 3 to obtain stem area inside bark. (Studies have shown that for most commercial species the wood to bark ratio at fixed points along the tree is very stable for each species regardless of the size of the tree. The average wood to bark ratio for Douglas fir is .901 and the ratio for hemlock is .94,) (5) the gross volume per acre is computed by multiplying the stem area per acre from Step 4 times the average ratio from Step 2.

Net Volume

Net volume per acre is computed in the same manner as for gross volume except each ratio is adjusted for defect and breakage.

Example: (for one tree)

A tree with a D.I.B. of 24" and 3 logs high -
20% defect and breakage
Gross ratio 441 (board feet per square foot stem area)
Less 20% D & B 88
Net Ratio 353

PROPORTIONAL PLOT -. VOLUME SUMMARY SHEET
32 FOOT LOG SCALE - SCRIBNER DEC. C

T._____ R._____ Sec.____________ Subdiv.________________ Acres____________________ Plots __________

VOLUMES IN BOARD FEET PER SQUARE FOOT OF STEM AREA IB AT 16'

DIB	UTILIZATION HEIGHT - 32' LOGS											TOTAL BY SPECIES		
16'	1	1½	2	2½	3	3½	4	4½	5	5½	6			
9	81													
10	79	174	176											
12	76	162	202	275	349									
14	74	146	218	297	377									
16	73	153	233	314	396	475	555							
18	76	159	242	326	411	493	576							
20	77	163	249	336	423	507	592	674						
22	78	166	255	344	433	518	604	688						
24	80	170	260	350	441	528	615	701						
26	82	173	264	355	447	535	624	711						
28	84	176	268	360	453	542	631	720	808					
30	86	178	271	364	457	547	638	727	817	906	996			
32			273	367	461	552	644	734	824	914	1004			
34			275	370	465	556	648	739	830	921	1012			
36			277	372	468	560	653	744	836	927	1018			
38			279	375	471	563	656	748	841	932	1024			
40			281	377	473	566	660	752	845	937	1030			
44				382	478	572	666	759	852	945	1039			
50				387	483	578	672	766	861	955	1049			
60				383	488	585	681	777	873	967	1062			
70				387	493	590	687	783	879	975	1071			

No. of Trees				Basal Area		Volumes		Total Ratio
			X Prism Factor	X Wood to Bark ratio squared	=BA IB per acre sq. ft.	X Average Ratio =Bd. Ft. per acre		Total No. Trees
Species	No.	Plot Ave.				Gross	Net	Average Ratio in Board Feet

Figure 3. Data computed by Mason, Bruce and Girard, Consulting Foresters.

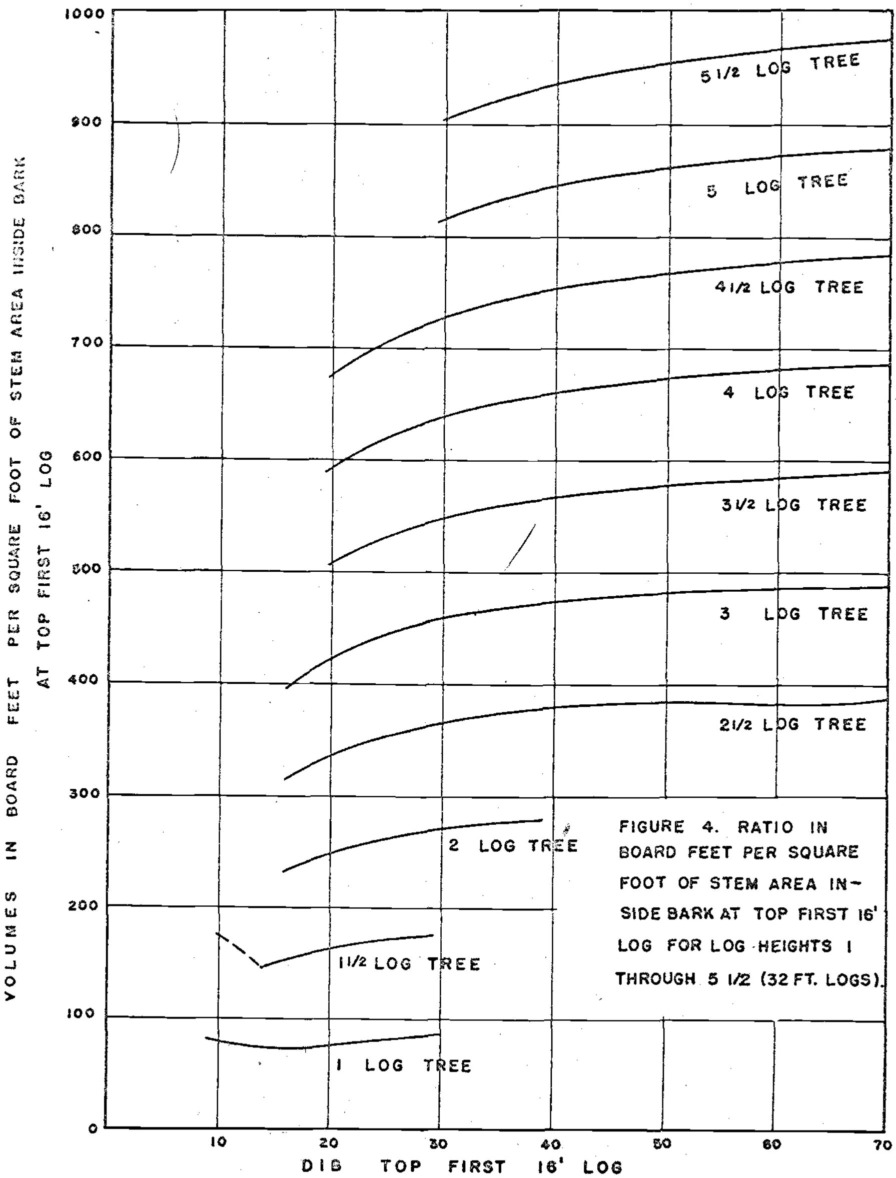

FIGURE 4. RATIO IN BOARD FEET PER SQUARE FOOT OF STEM AREA INSIDE BARK AT TOP FIRST 16' LOG FOR LOG HEIGHTS 1 THROUGH 5 1/2 (32 FT. LOGS).

Volume by Log Grade

Volume by log grade is determined by applying the appropriate percentages of each log grade to each ratio and then computing in the same manner as for gross volume.

Example: (for one tree)

20% No.2 peeler, 10% No.3 peeler, 40% No.2 sawlog, 20% No.3 sawlog, and 10% defect and breakage.

Gross Ratio 441

No.2 peeler	No.3 peeler	No.2 sawlog	No.3 sawlog	D & B	Total
88	44	177	88	44	441

Volume Determination with the Aid of International Business Machine

It is quite easy and economical to compute the volumes with business machines. It is particularly time saving to compute the log grades with IBM. Gross and net ratio tables are punched into IBM master cards and the calculations completed through standard IBM procedures.

Volume Determination Short Cuts:

Detailed steps of the computation may be expressed as follows:
(assuming trees on all plots are cruised)

$$\left[\frac{(\text{Total Tree count})}{(\text{Number of plots})}(\text{basal area factor})\right]\left[\frac{\text{Sum of board foot ratios}}{\text{total tree count}}\right]\left[(\text{Bark thickness ratio})^2\right] =$$

$$\frac{(\text{total tree count})\ (\text{basal area factor})\ (\text{sum of board foot ratios})\ (\text{bark thickness ratio})^2}{(\text{number of plots})\ (\text{total tree count})} =$$

$$\frac{(\text{basal area factor})\ (\text{sum of board foot ratios})\ (\text{bark thickness ratio})^2}{\text{number of plots}} = \text{board feet per acre}$$

Basal area factor = constant for any one prism or for set factor prisms.

Board foot ratios are in table and vary by height and diameter.

Bark thickness is by species and point of height on tree, used only when d.i.b. table is used.

Assuming every 4th plot is a cruised plot

$$\left[\left(\frac{\text{tree count on all plots}}{\text{number of plots}}\right)(\text{basal area factor})\right]\left[\frac{\text{sum of board foot ratios}}{\text{tree count on }\frac{1}{4}\text{ of plots}}\right]\left[(\text{Bark thickness ratio})^2\right] =$$

$$\frac{(\text{Tree count on all plots})\ (\text{basal area factor})\ (\text{sum of board foot ratios})\ (\text{bark thickness ratio})^2}{\text{number of plots x tree count on }\frac{1}{4}\text{ of plots}} =$$

$$\left[\frac{\text{tree count on all plots}}{\text{tree count on }\frac{1}{4}\text{ of plots}}\right]\left[\frac{(\text{basal area factor})\ (\text{sum of board foot ratios})\ (\text{bark thickness ratio})^2}{\text{number of plots}}\right] = \text{board feet per acre}$$

Volume Determination Short Cuts for Set Factor Prisms

When prisms with but one basal area factor are used, there are short cut procedures in which much of the computation can be combined into a board foot per acre volume table. If one species only is involved, the table can be simplified to include bark thickness corrections.

Example:

If prisms with a basal area factor of 20 are to be used, the volumes as given on Figure 3 can all be multiplied by the 20 and the table becomes a board foot per acre table. Where the board foot - basal area ratios are obtained for all "in" trees at each observation point, the sum of these board feet per acre figures can be divided by the number of plots and if the 16 foot d.i.b. is the table index diameter multiplied by the bark thickness ratio squared with the final answer being board feet per acre. For species for which only a portion of the trees are cruised, this would have to be further expanded by the ratio of average number of trees on the cruised plots divided into the average number of trees on all plots.

If only Douglas fir is to be cruised, or if a separate volume table by species can be used, each volume figure in the board feet per acre table can be adjusted by the bark thickness ratio squared, and that computation dropped from the individual cruise computations.

Statistical Analysis of a Wedge Cruise

The Tree Count:

ΣX = Sum total number of sample trees

ΣX^2 = Tree count squared and added for each plot

n = Number of sample plots

$\bar{X} = \frac{X}{n}$ = Mean

The Board Foot per Square Foot Ratio:

ΣX = Sum total of each tree's ratio for the sample

ΣX^2 = Sum total of each sample tree's ratio squared

n = Number of trees in the sample

$\bar{X} = \frac{X}{n}$

The following formulae are solved:

(1) Standard Deviation (S.D.) $= \sqrt{\dfrac{\Sigma X^2 - \dfrac{(\Sigma X)^2}{n}}{n - 1}}$

(2) Coefficient Variation $= \dfrac{SD}{\bar{X}} \times 100$

(3) Sampling error of mean in per cent (S.E.) $= \dfrac{C.V.}{n}$

(4) Combined sampling error*

$$S.E.\% = \sqrt{(\text{S.E. of board ft. per sq.ft.ratio in }\%)^2 + (\text{S.E. of the tree count in }\%)^2}$$

SUMMARY OF STEPS TO FOLLOW IN MAKING A VARIABLE PLOT CRUISE

Preliminary Procedure

1. Select appropriate wedge prism (factored).

2. Use same sampling intensity as if ¼ acre plots were employed.

Field Procedure

1. Establish sampling points.

2. Observe all surrounding sawtimber trees both through and over the wedge prism. If the edge of the direct and transmitted images overlap the tree is considered "in" and it is counted. These observations must be made at the same point on the tree that is used to compute the diameter for the basic volume table.

*Such analysis actually divides the total variance into the two main parts. Such treatment assumes the two variables to be independent. Studies to date indicate some correlation between the two with a consequent misstatement of sampling error by the suggested treatment.

3. Tally the diameter and the number of logs of the "in" trees on one-half to one-fourth of the sampling points. Record defect and breakage in percentages for these trees.

Gross Volume Procedure

1. With log heights and corresponding d.i.b.'s tallied in the field, obtain the sum of the ratios from the volume summary sheet.

2. Compute the average ratio by dividing the total ratio by the number of trees that contributed to the total ratio.

3. Compute the number of square feet of stem area per acre at the observation point.

4. If the inside bark diameters are used, square the wood to bark ratio for species involved and multiply by the stem area outside bark from Step 3 to obtain stem area inside bark.

5. Compute gross volume per acre by multiplying the stem area per acre from Step 4 times the average ratio from Step 2.

Net Volume Procedure

1. Reduce each ratio obtained in Step 1 of gross volume procedure by the estimated defect and breakage percentage recorded in the field.

2. Proceed as in Steps 2 through 5 for gross volume procedure.

ADVANTAGES OF THE VARIABLE PLOT METHOD OF CRUISING

1. All determinations of "in", "out", or line trees are done by an accurate optical instrument from the plot center. Care in the use of the instrument results in accurate determination of the average basal area per acre without dependence on accurate diameter measurement of all trees on an accurately determined area.

2. Volume, both net and gross, depends upon accurate use of the optical instrument, but only requires approximate diameters. (Heights, the second most important variable in determining volume under the system, have a low variance and are in units which are easy to check accurately for the average.)

3. The majority of time is spent on larger trees, since the sample is distributed between tree sizes in proportion to the basal area of those sizes.

4. Observations may be made higher on the tree, well above the region affected by variable butt swell where tree taper is fairly uniform.

APPENDIX

OPERATING PRINCIPLES OF THE WEDGE

The Tree Count - The Basal Area Factor - The Basal Area/Acre

The Following Facts Should be Noted:

1. A wedge prism is an optical instrument that will project an angle. This is called "the critical angle" and it varies between individual prisms.
2. The wedge prism is used to determine if the trees around the plot center (observation point) have a diameter equal to or greater than the tangent of the critical angle.
3. All trees, so long as they are equal to, or greater in diameter than the tangent, are counted.
4. All trees meeting the requirement in No. 3, carry equal weight because a tree represents the sample on a proportionate area. The larger the tree, the greater the area of sampling it represents.
5. When the sample is converted to a per acre basis, all trees counted represent samples of equal weight. The diagram in Figure 5 illustrates this point.

The diagram illustrates the application of a 5.0 diopter wedge prism which has a critical angle of 2° 51' 52".

Note the following:

(a) Tree size and corresponding distance from the observation point.

(b) The trees' basal area in square feet.

(c) The area of a circle with a radius equal to the distance from tree center to observation point.

(d) The basal area per acre.

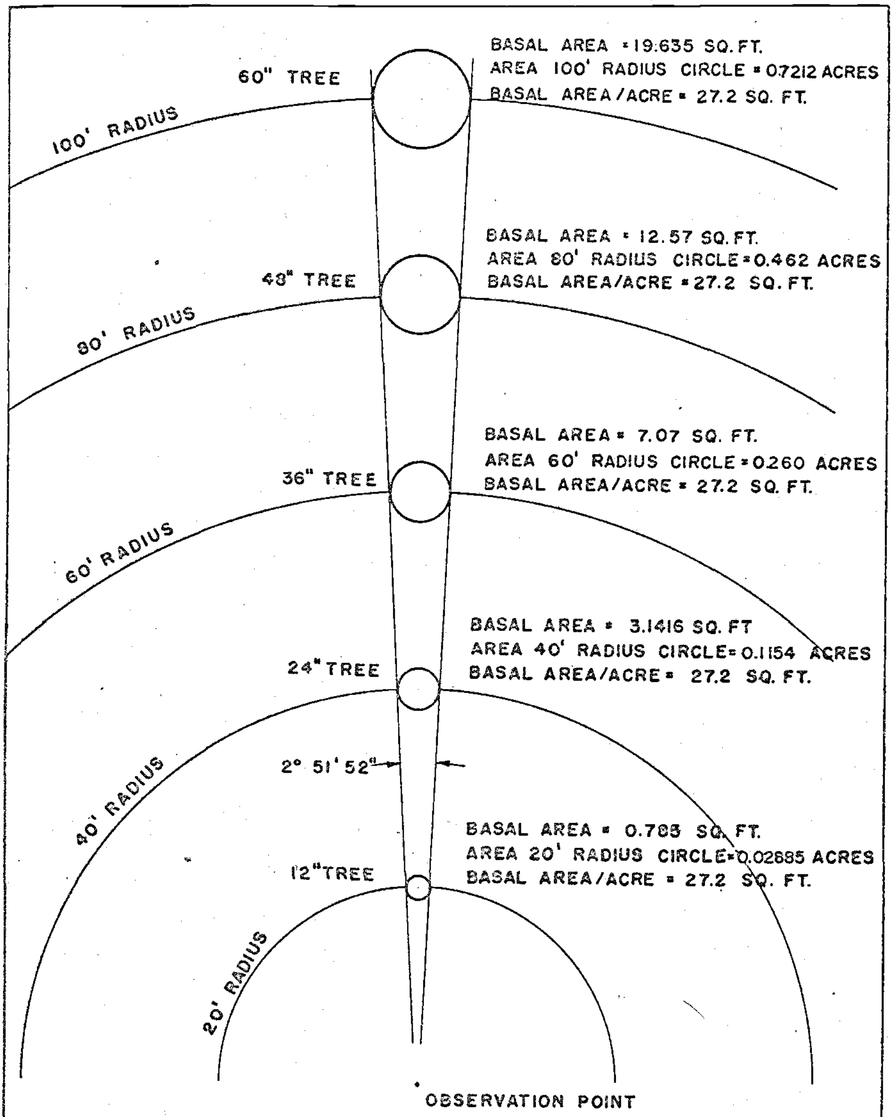

FIGURE 5. ILLUSTRATING THE APPLICATION OF A 5.0 DIOPTER WEDGE PRISM WHICH SHOWS WHY ALL TREES COUNTED REPRESENT SAMPLES OF EQUAL WEIGHT.

As can be seen from the diagram, the basal area per acre is constant for all size trees; this fact demonstrates why each "in" tree is counted as one regardless of its size. This figure, 27.2, is the basal area factor for a 5.0 diopter wedge prism. The formula, basal area factor = $\frac{43,560}{1 + 4\left(\frac{d}{w}\right)^2}$, verifies the above calculation.

Example from Figure 5:

Using 5.0 diopter prism, a tree 60 inches (5.0 feet) in diameter is just "in" at 100 feet from the point of observation.

$$\frac{43,560}{1 + 4\left(\frac{100}{5}\right)^2} = 27.2$$

The Basal Area Factor of a wedge prism times the number of trees counted for a particular plot equals the basl area per acre that the plot has sampled.