FOREST MENSURATION

By

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the Biltmore Estate*

MCMV

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of SEWANEE TENNESSEE

Cadillac Mich
 Madison Mich
 St Ignace " "
 Superior Mich
 Duluth Minn
 Marquette Mich
 Lake Superior Forest Whit
 Marquette Mich
 Wellsville " "
 Marquette " "
 Grand Island Lake Idaho
 " " Forest Forest Idaho
 St Ignace " " " "
 St Ignace Idaho
 Spokane Wash
 Portland Ore
 Marquette "

I Public Forestry

U.S. Forestry
State
County
Township

Legislation
Regulation

(a) Indirect Advantages

NAVIGABILITY
PUBLIC HEALTH & SAFETY
CLIMATE
MILITARY EFFICIENCY
LUMBER INDUSTRY

II Private Forestry

PRODUCTION

UTILIZATION
PROTECTION
SOLICIT

MANAGEMENT
SETTLEMENT
SILVAGE

(a) DIRECT ADVANTAGES

DOLLARS & CENTS

Spaulding rule 11% over cut

16' long 24" dia, 412' b.m.
36" " " 950 " "

out put' b.m. = m x

Decimal C. 5% under run (95' obtained, instead 100' b.m.)

16' long, 20" dia after decimal C yields 25' b.m.

$$(25' \times \frac{95}{100}) = m \times 5 \times 16'$$

$$26.6 = m \times 34.91$$

$$10 \times \frac{26.6}{34.91} = m$$

$$7.6 = m$$

A Standard is equivalent to 25 cubic ft

Massachusetts. Compared upon

- ① part of diameter measurement
- 2 means " " "
- 3 dropping of particles in dia "
- 4 utilization of waste (edging, trimming, slabs).
- 5 Saw ~~large~~ dust
Virt of saw band
average or at
radius
thickness of stock produced
- 6 edging, trimming, ~~done~~
defectiveness of log
roughness
knots
Inspection rules
- 7 coverage in thickness

Presiden method

Estimated weight of log by measuring its diameter in
active zone

I Entire area method

A Counting all trees

B Measure all D.B.H.

C " " " " " all ~~H~~

D. with } cutting representatives for P.H.

E without } or for P.P.

F With or without mill waste.

II Sample area method

A Samples selected at random

B. " " systematically

1 mile equal to 80 chains equal to 320 poles = 160
 2000 paces equal 1 mile 125 paces = 1 furlong = 10 chains

measures $\times$ sectional area $\times$ length = contents ft. S. M.

Form Height

I Form Height is $\frac{\text{vol}}{a} = p \times h$

II Form Height ~~is~~ is form factor multiplied by height

III Form Height is volume in 12 square feet of section ^{standard}

IV Form Height is the height within the ideal cylinder, up to which the liquid ^{tree} will fill ideal cylinder

Form Factor

Form Factor is a reducing factor expressing the influence of volume contained by A the shape or form, B thickness of bark, C the roundness of the multiplier a unit of measurement (Ideal cylinder multiplied by)

Form Factor is volume over S.L. $\frac{\text{vol}}{\text{S.L.}} = p \times h$

" " " " per cubic foot of ideal cylinder

Mill Factor

Mill Factor is number of ft. S. M. which a log will give out of a cubic foot

Volume Tables

Volume Tables show the yield of trees (individual)

Yield Tables show the volume of forests (Stand of Trees)

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PREFACE

DEAR READERS:

In the following pages an attempt is made to treat "Forest Mensuration" from a scientific-mathematical standpoint as well as from the view point of practical application.

Naturally, pamphlets of as restricted a character as this treatise on forest mensuration address themselves to a very restricted circle of readers; and the expense of printing is never covered by the returns from sales.

Thus it becomes necessary, in order to reduce the expense of publication, to omit all, or practically all, lengthy explanation of a mathematical nature which the teacher at a forest school can easily supply in the course of his lectures.

The present Biltmore pamphlet on Forest Mensuration is intended, above all, to assist the students enlisted at the Biltmore School. It contains the teacher's dictation which the students, in former years, were compelled to take down in long or shorthand, to the annoyance of both teacher and students.

It cannot be expected that a present-day lumberman will take a direct and personal interest in any of the following paragraphs. Still, in conservative forestry, in destructive forestry, and in any other business enterprise, the truism is worth remembering that "*knowledge is the best of assets.*"

Knowledge certainly forms the only unalienable factor of production.

With the advent of high stumpage prices, the owner of woodland will be inclined to consider, under many circumstances, the advisability of forest-husbandry—an idea which was as preposterous in past decades of superabundance of timber as the raising of beef cattle, some sixty years ago, in the prairies then abounding in buffalo.

Financially considered, a proper outcome of forest-husbandry is and must be based on a proper application of the theories and principles involved in forest mensuration.

I shall be deeply grateful to a kind reader who, discovering mistakes or incongruities in the following paragraphs, will take the trouble of sending me a timely hint.

Most truly,

C. A. SCHENCK,

*Director Biltmore Forest School, and
Forester to the Biltmore Estate.*

August 1, 1905.

LECTURES ON FOREST MENSURATION

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FOREST MENSURATION

PARAGRAPH I.

DEFINITION AND SUBDIVISION.

Definition: By "Forest Mensuration," the forester ascertains the volume, the age, the increment and the stumpage value of trees, parts of trees and aggregates of trees. As a branch of forestry, forest mensuration may be divided into the following five parts:

- I. Determination of volume of trees cut down, of standing trees and of forests.
- II. Determination of age of trees and of forests.
- III. Determination of increment of trees and of forests.
- IV. Determination of sawn lumber.
- V. Determination of stumpage value.

Circular 445 of the Bureau of Forestry defines mensuration as "the determination of the present and future product of the forest."

American literature is found in Bulletin 20, Division of Forestry; Bulletin 36, Bureau of Forestry; S. B. Green, page 132; Lumber & Log Book and Lumberman's Handbook, edited by the "American Lumberman."

CHAPTER I.—VOLUME.

SECTION I.—VOLUME OF TREES CUT DOWN.

PARAGRAPH II.

UNITS OF VOLUME.

The volume of a tree or of a tree section is expressed:

1. For scientific purposes, on the basis of exact measurements, in cubic feet or cubic meters.
2. For practical purposes, by estimates according to local usage, often assisted by partial measurement, in local units (feet board measure; standards; cords; cubic feet; cord feet; etc.).

PARAGRAPH III.

MATHEMATICAL FORM OF TREES.

Trees do not grow, like crystals, according to purely mathematical laws. Tree growth is deeply influenced by individuality, by surroundings, by accidental occurrences, etc.

The body of a tree, considered as a conoid (a solid body formed by the revolution of a curve about an axis), is very complicated, being formed by a curve of high power. This is the case even in straight and clear boled conifers. The tree bole shows, however, in certain sections of its body frequently a close resemblance to a truncated neilloid, cylinder, paraboloid and cone.

The longitudinal section of conoids is outlined by a curve corresponding with the general equation

$$y^2 = px^n$$

in which y is the ordinate (corresponding with the radius of the basal area), x the abscissa (representing the height of the conoid), n the power of the curve; whilst p is merely a constant factor. The volume v of the conoid is obtained by integral calculus:

$$v = \frac{y^2 \pi x}{n+1}$$

It is equal to sectional area, s , times height, h , over $(n+1)$.

The truncated volumes are developed by deducting a small top conoid from a large total conoid.

$$\text{vol. trunc.} = \frac{s_1 h_1 - s_2 h_2}{n+1}$$

In the general curve equation

$$y^2 = px^n$$

we find represented:

- A. For n equal to 0, the cylinder;
- B. For n equal to 1, the Apollonian paraboloid, wherein the ratio between sectional area and height is constant;
- C. For n equal to 2, the cone, wherein the ratio between radius of sectional area and height is constant;
- D. For n equal to 3, Neill's paraboloid, the truncated form of which is found at the basis of our trees.

The top of the tree resembles a cone or Neilloid; the main bole resembles the cylinder or the Apollonian paraboloid.

The cross section (see Par. XIII.) through a tree taken perpendicular to its axis shows a more or less circular form. Near sets of branches and near the roots, however, the outline is irregular. The center of the circle usually fails to coincide with the axis of the tree.

PARAGRAPH IV.

CYLINDER.

The cubic contents v of a cylinder are equal to the height h of the cylinder, multiplied by the sectional area s of the cylinder.

$$\text{vol. cylinder} = h.s$$

PARAGRAPH V.

APOLLONIAN PARABOLOID.

The volume v of the Apollonian paraboloid is equal to height multiplied by $\frac{1}{2}$ sectional area, or equal to $\frac{1}{2}$ of a cylinder having the same height and the same basal area.

$$\text{vol. apol.} = \frac{h.s}{2}$$

The volume t of the truncated Apollonian paraboloid may be ascertained as:

- A. Height of trunk times arithmetical mean of top sectional area and base sectional area.

$$\text{t. apol.} = h \frac{s_1 + s_2}{2}$$

- B. Height of trunk times sectional area in the midst of the trunk.

$$\text{t. apol.} = h.s_{\frac{1}{2}}$$

PARAGRAPH VI.

CONE.

The volume of the ordinary cone is equal to height of cone times $\frac{1}{3}$ sectional area at the base.

$$\text{vol. cone} = \frac{h.s}{3}$$

The volume t of the truncated cone is equal to $\frac{1}{3}$ height of trunk times sum total of top sectional area s_1 , basal sectional area s_2 , and $\sqrt{s_1 s_2}$

$$\text{t. cone} = \frac{h}{3} (s_1 + s_2 + \sqrt{s_1 s_2})$$

PARAGRAPH VII.

NEILL'S PARABOLOID.

The volume of the Neilloid equals $\frac{1}{4}$ of its height times sectional area at the base.

$$\text{vol. neil.} = \frac{h.s}{4}$$

The volume of the truncated neilloid t equals

$$\text{t. neil.} = \frac{h}{4} \left(s_1 + s_2 + \sqrt[3]{s_1 s_2} \left[\sqrt[3]{s_1} + \sqrt[3]{s_2} \right] \right)$$

wherein h denotes the height of the trunk; s_1 and s_2 the top sectional area and the basal sectional area of the trunk.

PARAGRAPH VIII.

RIECKE'S, HUBER'S AND SMALIAN'S FORMULE.

Formules of practical and scientific application, used here and abroad, to ascertain the contents of logs, are those published by Smalian, Riecke and Huber.

Riecke's formula holds good for n equal to 0, 1 and 2, and is almost correct for the neilloid.

Smalian over-estimates and Huber under-estimates the actual contents of the truncated cone and of the truncated neilloid.

$$\text{Riecke—Vol. of trunk} = \frac{h}{6} (s_1 + 4s_{\frac{1}{2}} + s_2)$$

$$\text{Huber—Vol. of trunk} = h.s_{\frac{1}{2}}$$

$$\text{Smalian—Vol. of trunk} = \frac{h}{2} (s_1 + s_2)$$

$S_{\frac{1}{2}}$ designates the sectional area in the midst of the trunk, whilst s_1 and s_2 represent basal sectional area and top sectional area.

PARAGRAPH IX.

HOSSFELD'S FORMULE.

The formule given by Hossfeld is:

$$\text{Vol. of trunk} = \frac{h}{4} (3 s_{\frac{1}{3}} + s_2)$$

It holds good for cylinder, cone and paraboloid. $S_{\frac{1}{3}}$ designates the sectional area at $\frac{1}{3}$ of the height of the trunk.

PARAGRAPH X.

SIMONY'S FORMULE.

Simony's formule requires measurements of sectional areas at $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{3}{4}$ of the height of the trunk, thus avoiding the irregularities caused by the roots at the base and by the branches at the top of a tree-trunk.

$$\text{Vol. of trunk} = \frac{h}{3} (2 s_{\frac{1}{4}} - s_{\frac{1}{2}} + 2 s_{\frac{3}{4}})$$

This formule holds good for the four standard conoids.

PARAGRAPH XI.

SECTIONAL MEASUREMENT.

The formules given in Paragraphs III. to X. have, in C. A. Schenck's opinion, a historic interest only when applied to whole trees. It is much safer to ascertain the volume of a tree bole by dissecting it into (imag-

inary) log sections of equal length, considering each of such sections as a cylinder or as a truncated paraboloid. The shorter the length of the sections, the greater the accuracy of the result. In scientific research, the length of a section varies from 5 feet to 10 feet. Obviously, at the top of the bole an uneven length is left, which it might be wise to ascertain as a cone (or paraboloid—Bulletin 20). The volume of the total bole, from stump to tip, equals, if the length of such full section is “1,” and that of the top cone is “b,” and

1) if sectional areas $s_1, s_2, s_3, \dots, s_n$ are measured at the big end of each section:

$$\text{vol bole} = \frac{1}{2} (s_1 + 2 s_2 + 2 s_3 \dots + s_n) + \frac{b.s_n}{3}$$

2) if sectional areas $s_I, s_{II}, s_{III}, \dots, s_m$ are measured in the midst of each full section, and sectional area s_n at the basis of the top cone:

$$\text{vol. bole} = 1 (s_I + s_{II} + s_{III} \dots + s_m) + \frac{b.s_n}{3}$$

The former formula is based on Smalian and the latter on Huber.

In a similar way, and with still greater accuracy, the more complicated formulas of Riecke, Hossfeld and Simony might be adapted to sectional measurements.

REMARK: If the diameter in the middle of a log is larger than the arithmetical mean of the end diameters, then the log contains more volume than the truncated cone, and *vice versa*.

If the sectional area at the midst of the log is larger than the arithmetical mean of the end sectional areas, then the log contains more volume than the truncated paraboloid, and *vice versa*.

PARAGRAPH XII.

MEASURING THE LENGTH OF A LOG.

The length of a log is measured with tape, stick or axe handle. In American logging, logs are usually cut in lengths of even feet, increased by an addition of two inches to six inches, which addition allows for shrinkage, for season checks, for damage to the log ends inflicted by snaking or driving, and for the trimming in the saw mill required to removed such end defects.

In Continental Europe, the standard log lengths are multiples of even decimeters. An excess-length of up to eight inches is neglected.

Crooked logs are made straight by deductions either from the length or from the diameter. Crooked trees should be dissected into very short logs.

The standard length of a New England log is 13 feet.

In the case of big logs, great care must be taken by the sawyers to obtain end-cuts perpendicular to the axis of the log.

The sum of the lengths of logs cut from a tree is termed “used length.” The total length of that portion of a bole which is merchantable under given conditions is called “merchantable length.”

*In Douglas
Standard Length*

PARAGRAPH XIII.

MEASURING THE SECTIONAL AREA.

The sectional areas are ascertained with the help of measuring tape, caliper, tree shears, tree compasses, Biltmore measuring stick, etc.

The sectional area is thus derived from the measurement either of the diameter or of the circumference.

For exact scientific investigations the planimeter or the weight of an even-sized piece of paper may be used.

It is best to consider the sectional area of a tree as an ellipse, the surface of which is:

$$\text{surface} = \frac{\pi}{4} D.d,$$

the big diameter D being measured vertically to the small diameter d .

Usually, however, the average diameter of the tree at a given point is found as the arithmetical mean of the big and small diameter at that point measured crosswise and not as the square root of the product of such diameters. Since

$$\frac{D+d}{2} > \sqrt{D.d},$$

the average diameter is invariably, though slightly, over-estimated by crosswise measurement. Hence it is wise to drop, as an arbitrary offset, the excess of fractions of inches over full inches.

The arithmetical mean of the sectional areas belonging to diameters measured crosswise leads to still greater mistakes.

PARAGRAPH XIV.

INSTRUMENTS FOR MEASURING DIAMETERS.

Log calipers are made of pyrus wood or of metal. American make (Morley Bros., Saginaw, Mich.) cost \$4.00 each. The moving leg of the caliper is kept in place by a spring or a screw or a wedge.

The best European makes are the "Friedrich" and the "Heyer and Staudinger." Wimmenauer's "addition-caliper", counts the trees and adds their sectional areas automatically.

Short legged calipers, named "Dachshunds" by C. A. Schenck, can be used for trees the radius of which exceeds the length of the legs. The diameter is, in that case, indirectly found by the help of the secant joining the tips of the legs, which are about 5" long.

"Tree compasses," opening from six inches to thirty-six inches, and made of nickel-plated steel, cost (at Morley Bros.) \$7.50. "Tree shears" (Treffurth) find the angle formed by the shear-legs when pressed against the tree and directly derive therefrom the diameter or the sectional area of the tree.

The "diameter tape" slung around the tree usually yields too large a diameter, since the circle embraces the maximum of surface by the minimum of length.

The "Biltmore Measuring Stick" can be well used in timber cruising. It requires the exact adjustment of distance between eye and fist of observer (usually 26 inches), and gives directly the diameter at the point of the stick where the sight line passes the tree tangentially. The stick is held horizontally against the tree.

26-INCH BILTMORE MEASURING STICK.

Length on the stick.	Diameter with bark.	Contents of butt log.	Contents of two logs.	Contents of three logs.
2.8"	3"	Allowing three inches for bark and three inches for taper, per log; assuming that all logs are 14' long.		
5.4"	6"			
7.7"	9"			
9.9"	12"			
11.9"	15"	22 ft. b. m.	29 ft. b. m.	39 ft. b. m.
13.8"	18"	56 " "	78 " "	85 " "
15.6"	21"	106 " "	162 " "	184 " "
17.3"	24"	171 " "	277 " "	333 " "
18.9"	27"	253 " "	424 " "	530 " "
20.4"	30"	350 " "	603 " "	774 " "
21.9"	33"	463 " "	813 " "	1066 " "
23.3"	36"	591 " "	1054 " "	1404 " "

Mr. Snead recommends to measure the circumference outside the bark at the big end and to divide the result by 4. He claims that the quotient yields the diameter at the small end inside bark in such a way as to offset mistakes made by Doyle, who under-estimates small logs and over-estimates big logs. Snead's suggestion is good, provided, that the cross section of the log is fairly circular, and that the difference between the small diameter inside bark at the small end and the big diameter outside bark at the big end, amounts to about 7 inches.

Diameter at small end inside bark.	Contents of 16 foot logs, in feet b.m.		
	Doyle.	Snead.	Actual saw cut.
10 inches.....	36'	81'	70'
15 "	121'	169'	157'
20 "	256'	289'	279'
25 "	441'	441'	436'
30 "	676'	625'	628'
35 "	961'	841'	856'

The multiples of sectional area (derived from the diameter in inches, but expressed in square feet) by length of log are readily obtained from cylinder tables published by various authors. The log scale or log rule used by the lumbermen (Lufkin rule) gives at a glance the contents of logs 8 to 20 feet long, according to their diameter.

PARAGRAPH XV.

UNITS OF LOG MEASUREMENT IN THE UNITED STATES.

The units of log measurement used in the United States differ greatly. Graves' Handbook gives 43 "rules." The rules can be subdivided into three main groups:

- Board feet group (Par. XVI.);
- Standard log group (Par. XVII.);
- Artificial cubic foot group (Par. XVIII.).

PARAGRAPH XVI.

BOARD-RULES.

A foot board measure is a superficial foot one inch thick, in boards one inch or more in thickness. It is a superficial foot, irrespective of thickness, in boards less than one inch in thickness.

The "board rules" merely guess at the number of feet board measure obtainable from logs of a given diameter. The guess is based upon either graphical considerations, circles of specified diameters being subdivided into parallelograms $1\frac{1}{4}$ inch thick (diagram method), or else on mathematical considerations, with a view to the fact that a cubic foot of timber should theoretically yield 12 board feet of lumber, whilst the actual loss for slab, saw kerf, etc., will reduce the output by 30% to 50%. In the Biltmore band saw mill, by over one thousand tests, the actual loss for logs 12 inches to 40 inches in diameter has been found to amount to 30%, or close to $\frac{1}{3}$. Consequently, it is safe to say that the band saw obtains from a cubic foot of log 8 board feet of lumber.*

The number of board feet which a log actually yields depends on:

1. The actual cubic volume of a cylinder having the length and smallest diameter inside bark of the log.
2. The defects of the log (heart rot, wind shake, bad knots, crooks), which are usually eliminated by edger or trimmer.
3. The gauge of the saw, on which the saw kerf depends. The kerf of band saws amounts to $\frac{1}{8}$ inch, of circular saws to usually $\frac{1}{4}$ inch, of inserted tooth saws (of large diameter) to $\frac{3}{8}$ inch, of resaws to $\frac{1}{16}$ inch.
4. The exactness of the work, especially depending on trueness of saw, proper lining of saw and sawyer's skill; further, on the exactness of the setworks.

5. The thickness of boards obtained; the minimum width of boards permitted; the amount of lumber wasted in the slabs; shrinkage in drying.

The following table compares the contents of logs in cubic feet with their contents in feet board measure as found by C. A. Schenck through a thousand tests of actual yield in yellow poplar, as given by Doyle's rule and by Lumberman's Favorite rule.

The figures given in columns c, f and i show the contents of a log in feet board measure after Schenck's findings, Doyle's and Favorite

rules. They are converted into cubic feet (columns d, g, and j) by dividing by 12. The loss incurred in sawing is shown by percentages (columns e, h, k) representing the ratio between the actual cubic contents of a log (as given in column b), and the cubic contents of inch boards (columns d, g, j) obtained from such log.

It will be observed that the loss in the actual yield according to Schenck forms a nearly constant proportion of the cubic contents of a log in the case of all diameters, whilst, according to Doyle's and Favorite rules, the figures of loss vary greatly.

The table refers to logs 12' long sawed into 1-inch boards.

Diameter of Log. Inches.	Contents. Cubic Feet.	Schenck.			Doyle.			Favorite.		
		Feet b. m.	Cubic Feet.	Loss %	Feet b. m.	Cubic Feet.	Loss %	Feet b. m.	Cubic Feet.	Loss %
a.	b.	c.	d.	e.	f.	g.	h.	i.	j.	k.
8	4.2	.....	.....	.....	12	0.9	76	.....	.....	.....
9	5.3	.....	.....	.....	19	1.6	70	.....	.....	.....
10	6.5	.....	.....	.....	27	2.3	65	.....	.....	.....
11	8.0	.....	.....	.....	37	3.1	61	.....	.....	.....
12	9.4	78	6.5	31	48	4.0	57	49	4.1	56
13	11.0	96	8.0	27	61	5.1	54	62	5.2	53
14	12.8	112	9.3	27	75	6.3	51	74	6.2	52
15	14.7	129	10.7	27	91	7.6	48	90	7.5	49
16	16.8	146	12.2	27	108	9.0	46	107	8.9	46
17	18.9	162	13.5	29	127	10.6	44	125	10.4	45
18	21.2	180	15.0	29	147	12.3	42	148	12.3	42
19	23.6	197	16.4	30	169	14.1	40	170	14.2	39
20	26.2	212	17.7	32	192	16.0	39	186	15.5	41
21	28.9	230	19.2	34	217	18.1	37	214	17.8	38
22	31.7	248	20.7	35	243	20.3	36	243	20.3	36
23	34.6	266	22.2	36	271	22.6	35	268	22.3	36
24	37.7	298	24.8	34	300	25.0	33	294	24.5	35
25	40.9	331	27.6	32	331	27.6	32	326	27.2	33
26	44.2	362	30.2	32	363	30.3	31	358	29.8	33
27	47.7	394	32.9	31	397	33.1	30	390	32.5	32
28	51.3	422	35.2	31	432	36.0	30	422	35.2	31
29	55.0	456	38.0	31	469	39.1	29	448	37.3	32
30	58.9	488	40.7	31	507	42.3	28	474	39.5	33
31	62.9	518	43.2	31	547	45.6	27	509	42.4	33
32	67.0	556	46.3	31	588	49.0	27	544	45.3	32
33	71.3	596	49.7	30	631	52.6	26	589	49.1	31
34	75.7	634	52.8	30	675	56.3	26	634	52.8	30
35	80.2	670	55.8	30	721	60.1	25	662	55.2	31
36	84.8	710	59.2	30	768	64.0	25	690	57.5	32
37	89.6	755	62.9	30	817	68.1	24	734	61.2	32
38	94.5	806	66.7	29	867	72.3	23	778	64.8	31
39	99.5	850	70.8	29	910	75.8	24	824	68.7	31
40	104.7	901	75.0	28	972	81.0	23	870	72.5	31

From column e it is evident that the bandsaw wastes close to 1/3 of the cubic contents of a cylindrical log, or 4' b. m. out of every cubic foot.

Consequently, from hardwood logs 12 feet to 16 feet long, the band-

saw will obtain the following *actual* number of feet b. m. (in 4/4" thickness) :

(a) from 12 foot logs: $\frac{D^2 \times 0.78 \times 12 \times 8}{144}$, almost equal to $D^2 \times .5$

(b) from 14 foot logs: $\frac{D^2 \times 0.78 \times 14 \times 8}{144}$, almost equal to $D^2 \times .6$

(c) from 16 foot logs: $\frac{D^2 \times 0.78 \times 16 \times 8}{144}$, almost equal to $D^2 \times .7$

Hence it can be stated generally, for logs of medium length "L," that their contents in band-sawed inch lumber approximate

$$\frac{D^2}{10} \times \frac{L-2}{2} \text{ feet b. m.}$$

PARAGRAPH XVII.

STANDARD RULES.

The standard rules do not estimate the contents of a log according to output in board feet, but compare the log with a local average log. Such average logs used to have, in the Northeast, formerly, a diameter of either 19 inches (Adirondacks) or 22 inches (Saranac River) or 24 inches, and were in all cases 13 feet long.

The 19 inch standard log rule is known as Dimick's rule. Here the "standard" or "market" is a log 13 feet long and 19 inches thick. On a 22 inch base it is 13 feet long and 22 inches thick. On a 24 inch base it is 13 feet long and 24 inches thick.

The standard contents of a given log are found by dividing the cubic volume of the standard log into the cubic volume of the given log.

$$v \text{ (in standards) equals: } \frac{d^2 \times h}{19^2 \times 13}$$

Scientifically and mathematically the standard rules are superior to the board rules. One market, at a 19 inch base, is generally considered equivalent to 200 board feet; at a 22 inch base, to 250 board feet; at a 24 inch base, to 300 board feet.

It is easily shown that the output of small logs is not as badly underestimated, and the output of big logs not as badly over-estimated on the basis of standard rules, as is the case when Doyle's rule alone is applied.

PARAGRAPH XVIII.

CUBIC FOOT-RULES.

In a third group of rules, a new unit, the "artificial cubic foot," is introduced. This group of rules is established by law in Maine and New Hampshire. (See Graves' Handbook, page 45.)

The artificial cubic foot corresponds with a log 12 inches long and 16 inches thick, which naturally contains 1.4 cubic feet. The rule assumes that 40/140 or 28.5% of a log goes to waste in the sawing process as dust or slab.

To quickly transform artificial cubic feet into board feet, the laws prescribe certain arbitrary equivalents, instead of allowing 12 board feet to equal one artificial cubic foot of timber. In New Hampshire, 10 board feet equal one artificial cubic foot. In Maine, 11.5 board feet equal one cubic foot. The rules might be used in connection with a cylinder table, deducting 28.5% from the table data and multiplying the remainder by 10 or by 11.5.

REMARK: According to the Forest Reserve Manual, logs over 24 feet long are treated as 16 foot logs and fractions thereof.

PARAGRAPH XIX.

EQUIVALENTS.

One cubic meter equals 35.316 feet or 1.308 cubic yards.

1,000 board feet of sawn lumber, 1 inch and more thick, correspond with 2.36 cubic meters of sawn lumber.

A product of one cubic meter per hectare ($2\frac{1}{2}$ acres) equals a product of 14 cubic feet per acre.

One gallon equals 231 cubic inches in liquid measure, or 268.8 cubic inches in dry measure (which is also $\frac{1}{2}$ peck).

One liter equals 1.0567 quarts; one cubic foot equals 7.4805 gallons or 28.3 liters.

Logs yielding when split one cord of wood, will yield, when sawn:

For log diameter:	Feet board measure:
20"	515'
25"	566'
30"	605'
35"	629'
40"	649'

The Forest Reserve Manual adopts 2 cords as equivalent to 1,000 ~~cubic~~ feet b. m., provided that the wood is split from timber 10 inches in diameter and over.

TABLE SHOWING RELATIVE CONTENTS OF LOGS WITHOUT BARK.

Log diameter.	5"	10"	15"	20"	25"	30"
1 cubic foot equals ft. b. m. Doyle	.....	4.12	6.2	7.3	8.09	8.64
1 cubic meter per hectar corresponds with ft. b.m. Doyle per acre:.....	.....	57.68	86.8	102.2	113.26	120.96
1 cubic meter of log yields ft. b. m. Doyle:.....	44.8	145.5	218.2	258.8	285.7	303.7
1000 ft. b. m. Doyle equal cubic ft:.....	787.4	242.7	161.8	136.4	123.6	116.3
1000 ft. b. m. Doyle equal cubic meters:.....	.....	6.87	4.39	3.86	3.5	3.29
Artificial cubic feet per 1 ft. of log	.....	.4	.9	1.56	2.45	3.51
No. of legal N. H. feet b. m. per 1 ft of log:.....	.....	4.	9.	15.6	24.5	35.1
Ft. b. m. Doyle per 1 ft. of log:.....	.....	2.3	7.5	16.	27.5	42.5

PARAGRAPH XX.

XYLOMETRIC METHOD.

The so-called "physical methods," by which the volume of a (particularly irregular) piece of a tree may be accurately found, require either the submersion of the piece in water (xylometric method) or the weighing of the piece after finding its specific gravity (hydrostatic method, § XXI.).

The xylometric method can be applied in three ways, thus:

a. Submerge the wood in a graded cylinder partly filled with water and find the water level before and after submersion.

b. Submerge the wood in a barrel partly filled with water; dip out the water with a gallon measure until the water is as low as it was before submersion. The number of gallons dipped out equals the volume of the wood submerged. One gallon equals 231 cubic inches.

c. Place a piece of wood in an empty barrel of known contents; fill to the rim with water by the gallon. The difference between the known contents and the number of gallons required gives the quantity of wood in gallons.

In *a*, *b* and *c* it is necessary to use wood dry on the outside, to leave the wood in the water a short time only, and to stir it up while in the water so as to remove air bubbles.

PARAGRAPH XXI.

HYDROSTATIC METHOD.

The hydrostatic method deals with specific gravities. Specific gravity is weight of an object divided by the weight of an equal volume of

water. In the metric system, it equals weight in kilograms over cube-decimeters of volume. The specific gravity is found by weighing a given body, and then weighing it again immersed in water. It equals weight outside water over loss of weight submerged in water. The division of the metric weight of a large body by the specific gravity of a sample piece yields the volume of the body in cubic decimeters.

Since wood is lighter than water, usually, a piece of lead must be attached to the wood in order to submerge it. There must be ascertained:

1. The absolute weight of the piece of lead, H ;
2. The weight of the same piece submerged in water, h ;
3. The absolute weight of the wood and of the lead, G ;
4. The weight of wood and lead submerged in water, g .

The weight of the wood alone is, consequently, $(G-H)$.

The specific gravity of the wood is

$$s = \frac{G - H}{(G - g) - (H - h)}$$

The volume, in cubic feet, of a quantity of wood weighing n pounds, and having the specific gravity s , is

$$\text{volume} = \frac{n}{s} \times \frac{1}{63} = \frac{16n}{1000s}$$

The figure 63 represents the weight in pounds of one cubic foot of water.

The specific gravity of wood is greatest close to the stump and in the branches. For some species the outer layers show the greatest specific gravity; for others the inner layers.

Species.	Spec. gravity, air dry.	Weight of lumber per 1000 ft. b. m. in lbs.	Weight of one cord in lbs.
White oak.....	.75	3900	3985
Beech.....	.71	3692	3767
Hard maple....	.66	3432	3510
Yellow pine....	.52	2704	2761
Spruce.....	.45	2340	2391
White pine.....	.39	2028	2069

Rules to convert specific gravity into weight per 1,000 feet board measure or into weight per cord read as follows:

1. Multiply specific gravity by 5,200. The result is the weight of lumber per 1,000 feet board measure in pounds.
2. Multiply specific gravity by percentage of solid wood contained in a stacked pile; then multiply the product by 8,050. The result gives the weight per cord in pounds.

PARAGRAPH XXII.

FACTORS INFLUENCING THE SOLID CONTENTS OF CORDWOOD.

The solid contents of wood stacks depend on the size and the form of the pieces composing them and on the method of piling. The solid contents of a cord can be found only by the methods described in Paragraphs XX. and XXI. The European experiment stations have collected data to that end on a very large scale, and have established the following laws:

- a. The bigger the pieces of wood in a stack, the larger are the solid contents of the stack.
- b. The longer the pieces of wood, the smaller are the solid contents of the stack.
- c. Pieces piled parallel and tightly greatly increase the solid contents of the stack.
- d. During the drying process, hardwoods shrink approximately by 12%, and soft woods by 9%. The shrinkage is partly offset by the cracking of wood.

These rules are important in the pulp, tanningwood and firewood trade.

PARAGRAPH XXIII.

REDUCING FACTORS FOR CORDWOOD.

The countries using the metric system pile wood in space cubic meters. One space cubic meter equals .274 cord. The pieces contained therein are 3.28 feet long. For such conditions the following figures hold good:

- a. First class split wood, obtained from sound pieces 12 inches in diameter, contains per cord 102.4 cubic feet of solid wood (reducing factor 80%).
- b. Composed of inferior split wood, obtained from round pieces having a diameter of 6 inches, a cord contains 96 cubic feet of solid wood (reducing factor 75%).
- c. In heavy, round branch wood (diameters of about 6½ inches) 87 cubic feet of solid wood are found in a cord (reducing factor 68%).
- d. In round pieces of branch wood, 4 inches in diameter, 77 cubic feet are found in a cord (reducing factor 60%).
- e. In faggots, 25 to 51 cubic feet make a cord (reducing factor 20% to 40%).

The percentages for broad leafed species are smaller than those for conifers, owing to the latter's straight growth.

At Biltmore, one cord of 8 foot split oak contains about 80 cubic feet; one cord of kindling finely split about 90 cubic feet; one cord of blocks 12 inches long about 100 cubic feet of solid wood.

In the sale of tannin wood it is well to sell 5 foot sticks finely split rather than heavy blocks 4 feet long.

In the sale of pulp wood, 12 foot sticks yield much higher returns than 4 foot sticks, if sales are made by the cord.

PARAGRAPH XXIV.

LOCAL PECULIARITIES WITH REFERENCE TO STACKED WOOD.

Tannin and pulp wood industries sometimes figure at a cord containing 160 stacked cubic feet, equal to $1\frac{1}{4}$ ordinary cords of 128 stacked cubic feet.

After Graves (page 65), a cord of firewood is in certain sections understood to be 5 feet long, 4 feet high and $6\frac{1}{2}$ feet wide.

Under "a cord foot" is understood a stack 1 foot by 4 feet by 4 feet ($\frac{1}{8}$ cord or 16 stacked cubic feet).

Under "a cylindrical foot" is understood a stacked cubic foot equal to $1/128$ cord. The number of such feet (a misnomer for stacked cubic feet) in a stick is

$$\frac{d^2 \times l}{144}$$

(l equals length of stick in feet; d equals its diameter in inches).

In New England, a cord of pulp wood is sometimes measured by calipering the round sticks composing it, and tables are constructed to facilitate calculation. Proceed as follows:

Ascertain diameter of sticks in inches, square them singly, total the results and divide by 144. Multiply the quotient by length of sticks in feet and divide by 128.

PARAGRAPH XXV.

BARK.

Bark is usually sold and bought by the cord. The tanneries, however, instead of measuring a cord of 128 cubic feet, apply the misnomer "one cord" to a weight of 2,240 lbs. (the long or European ton).

Twelve cords of bark fill one common (old) freight car.

A stack of bark contains from 30% to 40% solid bark. The specific gravity of fresh oak bark is 0.874; dried, it is 0.764.

The bark of white oak has been found (at Biltmore), to comprise:

In trees 20 years old, 55% of the wood, or 35% of the whole bole;

In trees 60 years old, 41% of the wood or 28% of the whole bole;

In trees 100 years old, 29% of the wood or 22% of the whole bole;

In trees 140 years old, 21% of the wood or 17% of the whole bole.

Chestnut oak peeled at Biltmore yields the following results per tree, arranged according to the diameter of the trees 4½ feet above ground:

Diameter of tree chest high in inches.	Dry Bark in Kilogram = $\frac{1}{1000}$ cord, per Tree.		
	Minimum	Average.	Maximum.
6	5	13	27
7	6	17	36
8	8	24	48
9	12	33	61
10	18	45	77
11	26	60	95
12	37	73	114
13	50	88	135
14	65	105	158
15	81	126	180
16	98	150	204
17	116	172	234
18	136	195	266
19	159	224	314
20	181	250	365
21	205	275	...
22	230	305	...
23	265	336	...
24	275	375	...

If the percentage of bark in a log or tree (scaled with the bark) is p , then the bark percentage in ratio to the solid wood alone is:

$$\frac{100 \times p}{100 - p}$$

According to thickness of bark and diameter of logs, the following percentages can be given for the ratio:

$$\frac{\text{bark}}{\text{bark plus timber}}$$

Diameter with bark—inches.	Thickness of bark.			
	$\frac{1}{2}$ "	1"	1½"	2"
10	19 %	36 %	51 %	64 %
15	12 %	24 %	36 %	46 %
20	9 %	19 %	27 %	36 %
25	7 %	15 %	22 %	29 %
30	6 %	12 %	19 %	24 %

SECTION II.—VOLUME OF STANDING TREES.

PARAGRAPH XXVI.

METHODS OF OBTAINING THE VOLUME OF STANDING TREES.

The volume of standing trees may be ascertained

By estimating it (Par. XXVII.);

By measuring heights and diameters (Par. XXVIII.);

By the form factor method, which combines estimates and measurements (Par. XXIX. f.f.).

By these means can be obtained the volume of the bole (from roots to top bud), or the volume of saw timber in any of the 43 log scales, or the volume of firewood in cords, etc., or the total volume, including brush and roots.

Under "used volume," Circular 445 of the United States Bureau of Forestry understands the sum of the volumes of logs cut from a tree; under "merchantable volume" the total volume of that portion of the tree which is merchantable under certain conditions.

PARAGRAPH XXVII.

HELPS AND HINTS TO FIND THE VOLUME OF STANDING TREES.

It is difficult to estimate the cubic contents, wood contents or lumber contents of a standing tree. In the case of estimates in board feet, the result depends on the exclusion or inclusion of crooked and defective pieces, on the taper of the bole, on the soundness of the heart, and on the minimum diameter admissible in the top log. Compare end of Paragraph XXXII.

Most hazardous is the volume estimate of over-aged trees, especially in the case of hardwoods (chestnut).

The following helps might guide the novice:

1. The volume of a sound tree bole, in cubic meters, is equal to

$$\frac{1}{1000} D^2$$

for example, diameter (breast high) 30 c. m.; contents 0.9 cubic meters.

2. The contents of a standing tree, in cubic feet, are about

$$\frac{2}{10} D^2$$

for example, diameter (breast high), 25 inches; contents (from butt to tip), 125 cubic feet.

3. The number of feet Doyle in a tall sound tree equal

$$\frac{3}{2} D^2$$

for example, diameter (breast high), 20 inches; contents 600 feet board measure.

4. The contents of a tree in feet Doyle approximate, assuming that the bole is cut into 16 foot logs, and that the tree tapers 2 inches per log:

$$N \times D (D - 12)$$

wherein N represents the number of logs obtainable; D the diameter of the butt log without bark at breast height.

5. The cordwood contained in a sound bole is:

$$\frac{D^2}{1000} \times C$$

wherein C amounts to:

- 1.5 in the case of trees 8" through;
- 2.0 in the case of trees 16" through;
- 2.5 in the case of trees 24" through.

PARAGRAPH XXVIII.

SCIENTIFIC METHODS OF ASCERTAINING THE CUBIC CONTENTS OF STANDING TREES BY MERE MEASUREMENT.

The cubic volume of the bole, on the basis of diameter measurement and height measurement, in the case of a standing tree, may (with the help of climbing iron, ladders, camera or instruments constructed for the purpose) be figured out:

1. According to the formulas of Hossfeldt, Riecke and Simony. In this case, the upper diameters must be measured indirectly.
2. According to Huber's and Smalian's formulas, the diameters of equal sections of the trees being indirectly measured.
3. According to Pressler's formula, which is, for the volume of the bole lying between chest height and top bud, $\frac{2}{3}$ of sectional area "S" at chest height times "rectified" height of bole. The rectified height "r" is the distance of chest height from that point of the tree bole which has $\frac{1}{2}$ of the chest height diameter (from the "guide point"). The equation $\frac{2}{3} r \times S$ holds good for paraboloid, cone and, at a slight mistake, for the neilloid.

The volume of that part of the tree bole which lies below chest height is ascertained (as a cylinder) as being equal to sectional area chest high times 4.5.

REMARK: 4.3' is the chest height usually recognized by the authors; Pinchot adopts 4.5'.

The Pressler formula does not hold good for truncated boles.

PARAGRAPH XXIX.

FORM FACTOR METHOD.

The form factor or form figure method relies on the measurement of the sectional area—usually the one at breast height,—the measurement or the estimation of the total height and the estimation of the form figure.

The form factor is a fraction expressing the relation between the actual contents of a tree, in any unit, and the ideal contents which a tree would have if it were carrying its girth (like a cylinder) up to the top bud undiminished.

The form factor may be given in reference to the volume of the entire tree, inclusive of branches in cubic feet; or in reference to the volume of the bole only; or in reference to the merchantable part of the bole; in the latter case either in feet board measure or in standards or in cords.

HISTORIC REMARKS: Some of the older authors on mensuration saw in the cone and not in the cylinder the ideal form of the tree, basing their form factors on the ideal volume $\frac{s \times h}{3}$.

PARAGRAPH XXX.

KINDS OF FORM FACTORS MATHEMATICALLY.

Scientifically we distinguish between:

1. The absolute form factors which have reference only to the volume standing above chest height. They can be readily ascertained with the help of Pressler's formula. Generally speaking, V equals $S \times H \times F$. After Pressler, V equals $S \times \frac{2}{3} \times r$; thus $\frac{\frac{2}{3}r}{H}$ equals F .

For the cone the absolute form factor is one-third; for the neiloid one-fourth; for the paraboloid one-half, whatever the height of the tree may be. Hans Rienicker, the author of these form factors, finds for trees up to 50 years old a form figure of 35% to 43% (in regular, dense German woods); in trees 50 to 100 years old, F increases up to 50%; thereafter occurs a slight decrease below 50%.

2. The normal form factors which were recommended by Smalian, Pressler and other old-time authors. They have reference to the entire volume and necessitate the measurement of the diameter at a given fraction (usually $1/20$) of the total height of the tree. Frequently, in case of tall trees, the point of measurement cannot be reached from the ground. The bole form factor for diameters measured at $1/20$ of the height is: For a paraboloid, 0.526; for a cone, 0.369; for a neiloid, 0.292. These form factors, like the absolute form factors, are independent of the height.

3. The so-called "common form factors" which do not express, as a matter of fact, the form of the tree, since they do not bear any direct ratio to the degree of the tree curve. They should be termed, more

properly, "reducing factors." These form factors alone are nowadays practically used. They are based on diameter measurements, chest high, and have reference not merely to the bole of the tree, but as well to any parts of the bole, to root and branch wood, to saw logs, etc. These form factors depend entirely on the height. If, for instance, a paraboloid is one rod high, the form factor is 0.673; and if it is 8 rods high, the form factor is 0.517.

PARAGRAPH XXXI.

KINDS OF COMMON FORM FACTORS IN EUROPEAN PRACTICE.

The following kinds of form factors may be distinguished:

1. Tree form factors. The tree is considered as bole plus branches.
2. Timber form factors. The term timber, in Europe, includes all parts of the tree having over 3 inches diameter at the small end.
3. Bole form factors. Bole is the central stem from soil to top bud. For America, form factors would be of great value ascertained by exact measurements and arranged according to diameter, height and smallest log diameter used.

Tables of form factors may be constructed, for instance, for shortleaf pine, on the basis of Olmsted's working plan, pages 17-33.

PINUS ECHINATA.

Diameter.	Merchantable length of bole.	Cubic feet Ideal cylinder.	Form fig.	Contents b. m. Doyle.
16"	36'	50.3	3.6	180'
18"	47'	83.1	3.6	300'
20"	51'	112.1	4.0	440'
22"	56'	147.8	4.0	600'
24"	59'	185.3	4.2	780'
26"	61'	224.9	4.4	980'
28"	62'	263.1	4.5	1190'
30"	62' 6"	306.7	4.6	1420'
32"	63'	351.8	4.7	1680'
34"	63' 6"	400.3	4.8	1930'
36"	64'	457.3	4.9	2200'

The influence of age, soil, density of stand, height, diameter and species on the various form factors, with cubic measure as a basis, has not been fully ascertained.

For the tree form factor, the most important influence, in the case of trees less than 150 years old and raised in a close stand, seems to be that of the height of the tree; with increasing height the tree form factor decreases—*e. g.*, for Yellow Pine:

One pole high	.93
Two poles high	.65
Four poles high	.53
Six poles high	.49

The timber form factor, based on cubic measure of a tree, rises with increasing age and increasing height up to a certain point (for Yellow Pine at 3 poles), provided that the term timber includes all stuff over 3 inches in diameter. The timber form factor is a function more of the diameter than of the height. Timber form factors of Yellow Pine are:

Trees 1 pole high	.07
Trees 2 poles high	.36
Trees 3 poles high	.48
Trees 4 poles high	.46
Trees 7 poles high	.45

The timber form factor in shade bearers is a little higher than that in light demanders (within an age limit of 150 years, for trees in close stand).

The bole form factor can be found, in fact, only for species forming a straight bole free from large branches (hence especially for conifers). The bole form factors, to begin with, are large; with increasing height, they decrease gradually to a par with the timber form factors—*e. g.*, for Yellow Pine:

1 pole high.....	.70	3 poles high.....	.49
2 poles high.....	.55	4 poles high.....	.47
7 poles high.....	.45		

European common form factors are collected by thousands of measurements taken in a large variety of localities. It must be remembered that a form factor read from a table is never applicable to an individual tree, and is only applicable to an average tree amongst thousands.

For trees less than 120 years old, the branch wood (stuff less than 3 inches in diameter) comprises from 15% to 28% of the entire tree volume; this figure, in the case of broadleaved species, rises from 25% up to 33%. For trees as now logged in America, the branchwood percentage is naturally very much smaller.

The tree form factor equals $\frac{\text{stump plus bole plus branches}}{\text{ideal cylinder}}$

The timber form factor equals $\frac{\text{all stuff having over 3" diameter}}{\text{ideal cylinder}}$

The bole form factor equals $\frac{\text{bole from ground to tip}}{\text{ideal cylinder}}$

By form height is meant the product of height (total height of tree) times form factor, or else that much of the height of the ideal cylinder which the tree volume, poured into the ideal cylinder, would fill. Since the form factor on the whole decreases with increasing height, the form height is a fairly constant quantity; at least for trees of merchantable size. Hence the helps and hints given in Paragraph XXVII (to quickly find the volume of standing trees from mere diameter-measurement) may

lay claim to correctness in many cases. For instance: The cubic contents of a tree are supposed to be equal to

$$\frac{\pi}{4} \times \frac{D^2 \times H \times F}{144}$$

After Paragraph XXVII., 2, these contents are also

$$\frac{2}{10} \times D^2$$

$$\frac{D^2}{5} = D^2 \times 78 \times H \times F$$

$$H \times F = \frac{288}{7.8} = 37$$

As a matter of fact, the form height of trees 1 foot to 2 feet in diameter is close to 37. And for such trees the equation holds good.

The form height may also be defined as "volume (standards, cords, bark, etc.) per square foot of sectional area chest-high."

PARAGRAPH XXXII.

MEANS FOR EXACT MENSURATION OF STANDING TREES.

The means used to find the exact solid volume of standing trees are instruments for measuring the total height of the merchantable length of a tree; instruments for measuring the diameter at given heights; further tables based on scientific research and experience, or tables merely meant to facilitate calculation. Instruments for measuring diameters far above ground are needed for the use of the formulas given by Riecke, Hossfeldt, Pressler, etc.

The six paragraphs following next dwell upon these topics.

PARAGRAPH XXXIII.

MEASURING THE HEIGHT OF A STANDING TREE.

The height of a tree can be measured by comparing its shadow with the shadow of a stick, say 10 feet long. The "Lumber and Log Book" gives another old method (page 133) of height measurement. If the observer places himself in such a way that a small pole stands between him and the tree at a distance e , and if he marks on the pole two points where his sight, directed towards the top and base of the tree, touches the small pole, and if he further ascertains the distance E separating him from the tree, then the height of the tree H equals

$$\frac{E}{e} \times h$$

wherein h represents the number of feet between the two points marked on the pole.

Instruments (hypsometers) for height measuring are sold in many forms. The following are frequently used: Rudnicka's instrument; Pressler's "Measuring Jack;" Faustmann's "Mirror Hypsometer;" Weise's Telescope; Koenig's "Measuring Board;" Brandis' "Clinometer;" Klausner's instrument; Christen's "Non plus ultra."

Compare Woodman's Handbook, pages 136 to 137, for staff method; page 138 for Faustmann's; page 140 for tangential clinometer; page 143 for mirror clinometer.

Christen's stick is not accurate enough for the measurement of trees over 100 feet high. It does not require the measurement of distances. Its form is improved by Pinchot.

PARAGRAPH XXXIV.

FACTORS INFLUENCING THE EXACTNESS OF HYPOMETRICAL OBSERVATIONS.

The best results are obtained if the distance between tree and observer equals the height to be measured. In sighting towards the spreading top of a hardwood tree, the observer is apt to overrate the height, the tip being buried in the spreading crown. The line of sight strikes the edge of the crown instead of striking the apex of the crown.

Timber cruisers are usually satisfied to determine the number of logs obtainable from the bole instead of determining the length of the bole. As a matter of fact, where the tree furnishes saw logs only, the total height of the tree is a less reliable indicator of the total contents than the length of the merchantable bole.

Instruments like Faustmann's, Koenig's and Pressler's cannot be used in windy and rainy weather. Dense undergrowth and dense cover overhead render exact measurement impossible.

PARAGRAPH XXXV.

INDIRECT MENSURATION OF DIAMETERS.

The following instruments are used to measure the diameter of the tree at any point of bole:

- a. Winkler, an addition to Koenig's measuring board.
- b. Klausner.
- c. An ordinary transit.
- d. Wimmenauer's telescope.

PARAGRAPH XXXVI.

PRESSLER'S TELESCOPE.

Pressler's telescope is used to find the "guidepoint" and the "rectified height," as defined in Paragraph XXVIII., 3. The diameter chest-high is taken between the nails at the end of the instrument. Then the telescope is pulled out to a length double the original, divided by the cosin

of the angle found between the horizon and the probable sight to the "guidepoint" (at which the observer expects to find one-half the diameter chest-high). Thus, actually, the instrument merely examines the correctness of an original estimate.

The Pressler telescope can be used for finding the merchantable length of any bole. Merely place a stick, equal in length to twice the minimum diameter permissible in a merchantable log, at the foot of the tree, catch it between the nail points and proceed as described.

PARAGRAPH XXXVII.

AUXILIARIES FOR CALCULATION.

Auxiliaries for calculation are:

1. Sectional area tables (Schlich, Vol. III.); engineering books like Haswell's; Bulletin 20; also Green.)
2. Ideal cylinder tables (Schlich and Bulletin 20).
3. Multiplication tables and logarithm-tables.
4. Tables showing contents of logs in any of the 43 rules, according to length and diameter.

PARAGRAPH XXXVIII.

TREE VOLUME-TABLES.

Tree volume tables have been constructed on a very large scale for the leading species in the old country. In the United States, the Government is now beginning to make such tables. The tables give the cubic, lumber and cord wood contents of trees, according to species, diameter and sometimes according to total height and merchantable height (number of logs).

Bulletin 36 reprints the following tree volume tables:

A. According to diameter measure merely.

- Page 92. Adirondack White Pine, volume in standards.
- Page 94. Pennsylvania Hemlock, volume in feet, b. m., Scribner.
- Page 94. Adirondack Hemlock, in standards.
- Page 95. Adirondack Spruce in standards.
- Page 96. Adirondack Birch, Beech, Linden, Sugar Maple in Scribner, feet, b. m.
- Page 96. Adirondack Balsam, in standards.
- Page 97. Adirondack White Cedar, in standards.
- Page 98. Arkansas Shortleaf Pine, in feet, b. m., Doyle.
- Page 98. Missouri Ash, Elm, Maple, Cypress, Gum, Oak, Hickory, Poplar, in feet, b. m., Doyle.
- Page 99. Western Yellow Pine, in feet, b. m., Doyle (Black Hills), distinguishing between the volume of first and second growth.
- Page 99. Yellow Poplar in Pisgah Forest in feet, b. m., Doyle, distinguishing between good, average and poor conditions of growth.

All tables, except Yellow Poplar tables, are based on the measurement of a large number of trees. The Yellow Poplar tables are based on stem analyses of a small number of trees.

B. According to measurement of height and diameter combined.

- Page 93. Wisconsin White Pine (height expressed by the number of logs obtainable from merchantable bole) in feet, b. m., Doyle.
Page 103. Adirondack Spruce expressed in feet, b. m., Scribner, the total height of trees being measured.
Page 104. The same in cubic feet.
Page 105. The same in cords for pulp wood.
Page 106. New Hampshire Spruce in feet, b. m., in New Hampshire cubic feet sanctioned by law.
Pages 108 and 111. Adirondack White Pine with bark, expressed in cubic feet.
Page 110. Adirondack White Pine in feet, b. m., Doyle.

Monographic investigation into the growth of the leading American species is of great importance. The trees of virgin forests are very defective, however, and tree tables can never be constructed giving the contents of defective trees.

SECTION III.—VOLUME OF FORESTS.

PARAGRAPH XXXIX.

SYNOPSIS OF METHODS FOR ASCERTAINING THE VOLUME OF FORESTS.

The methods used to find the volumes of entire forests, of forest compartments, tracts, quarter sections, coves, etc., are:

1. Estimating (Par. XL.).
2. Exact calculation after measurements (Par. XLI., f. f.).
3. Combined measuring and estimating (Par. IL., f. f.).

Obviously, measuring without estimation is possible only in forests containing little unsound timber.

PARAGRAPH XL.

ESTIMATION OF FOREST VOLUME.

In primeval woods, where a few assortments only are salable and where stumpage is cheap, the estimation of stumpage necessarily takes the place of the measurement. If any measurements are taken, they are merely meant to back the estimation of the cruiser. The more defective the trees are, the more preferable is judgment and local long experience in the mill and in the woods on the side of the cruiser to mere measuring.

The volume of a wood is ascertained by cruisers' estimates in the following ways:

- a. By estimating the number of trees and the volume of the average tree with due allowance for defects.
- b. By counting the trees and estimating the volume of average trees with allowance for defects.
- c. By estimating the volume of each tree separately, sounding it with an axe, when necessary, and judging its soundness from all sides.

The above methods (*a*, *b*, *c*) are applied either to sample plots or to sample strips or to the entire area.

A blazing hammer is often used to prevent duplication; the revolving numbering hammer might be used in case of scattering trees, so as to allow of control of the estimates by the owner, his forester or the prospective purchaser of stumpage.

In irregular forests—hardwood forests of the United States—the only safe way is separate estimating of each individual tree after careful inspecting. Incredible errors result from wholesale and rapid estimates.

In the case of even aged woods, a look at the height growth and a knowledge of the age gives a good idea of the forest's volume. Under very poor conditions of growth, the annual timber production per acre and year is as little as 15 cubic feet; under the best conditions it is as much as 250 cubic feet per acre and year. On an average (on absolute forest soil), 50 cubic feet per acre and year may be considered as the production of healthy and densely stocked forests.

PARAGRAPH XLI.

PRINCIPLES UNDERLYING THE EXACT MENSURATION OF FOREST VOLUME.

The basis of any exact measurement of volume is formed by a survey of the sectional area, combined with an account of the number of stems; sectional area and number are found by calipering (valuation survey). Whatever rule of log measurement may be at stake, the total sectional area of the forest is always of first importance for a survey of forest volume. Next in importance is the calipering of sample trees, followed by an exact survey of their volume. The ratio *r* existing between the volume of the sample trees (expressed in any unit or mixture of units) and the sectional area of the sample trees is identical with the form height (compare Par. XXXII., towards end) of the sample trees. The form height of sample trees properly selected is the form height of the forest. The sample trees are usually cut and worked up into logs, cordwood, tannin wood, etc., for the purpose of volume survey.

$$\frac{V}{S} = \frac{v}{s} = \frac{f. h. s.}{s} \quad \text{and} \quad V = S. f. h$$

If the trees of the forest are defective, the sample trees should exhibit average defects.

PARAGRAPH XLII.

FIELD WORK FOR EXACT VALUATION SURVEYS.

The valuation survey requires:

1. Calipering of all trees; the diameter is taken in inches or in multiples of inches. Each species and each height class or age class are or may be taken separately.

2. Entering the takings on tally sheets, arranged as follows:

Diameter.	Spruce.		Beech.	
	Height classes.		Height classes.	
	I	II	I	II
10"				
11"				
12"				
13" etc.				

The larger the trees are, the bigger is the permissible interval of calipering. If trees average two feet in diameter, an interval of 3 inches is permissible, provided that a large number of trees are calipered.

It is a strange fact that the diameter measured from east to west is larger on the whole than the diameter from north to south.

PARAGRAPH XLIII.

BASAL ASSUMPTIONS.

The only assumption made in calculating the volume of the forest after Paragraph XLI. is that the form height of the sample trees equals the form height of the forest. No other estimate or assumption is being made. This premise is much safer than the assumption that the volume of the forest bears the same ratio to the volume of the sample trees which the number of trees in the forest bears to the number of the sample trees. More unsafe is the assumption that the volumes of forest and sample trees bear the ratio of the acreage occupied by the forest on the one hand and by the sample trees on the other hand.

PARAGRAPH XLIV.

SELECTION OF SAMPLE TREES.

Sample trees are selected either irregularly or after a regular plan. In the latter case, it is best to distribute them equally among the diameter classes composing the forest (Draudt-Urich method and Robert Hartig method), instead of selecting sample trees of average diameter.

It is more important that the sample trees should have proper average class-form height (and average defects) than that they should have exact average class-diameters.

PARAGRAPH XLV.

DRAUDT-URICH METHOD.

The Draudt-Urich method is in common use abroad for measuring the forest. The trees of the forest are divided into a number of classes (usually five). Each class contains an equal number of trees, class 1 containing the largest and class 5 the smallest trees. In each class an equal number of sample trees, having about the average diameter of the class, are felled and worked up into logs, cordwood, ties, poles, etc. The form height of all sample trees is obtained as the quotient of their volume (in any unit or mixture of units) divided by their sectional area. Multiplying the sectional area of the forest with this form height, the exact volume of the entire forest and its composition (logs, poles, cords, etc.) are given by one operation.

Sample trees of the average diameter of a class are found by dividing the sectional area of the entire class by the number of trees per class. It is wrong to find the average diameter by dividing the sum total of the diameters by the number of trees.

Diameter Breast High.	Number of Trees.	Diameter Classes of Trees.	Number of Sample Trees.	Average Diam- eter of Sample Trees.
40"	310	I	11	29"
35"	240			
30"	506			
25"	1226			
20"	9	II	11	17"
15"	1040			
	1233	III	11	14"
	1847			
	435	IV	11	10"
10"	2282			
	2282	V	11	10"

The advantages of the Draudt-Urich method are:

1. All sample trees can be worked up in a bunch.
2. Not only the entire volume but as well the different grades of timber, fuel, ties, etc., composing the volume are found by one operation.

A large number of sample trees are, however, required, and, since the volumes of the various classes are unequal, a negative mistake made in establishing the volume of one class is not apt to be counter-balanced by a positive mistake made in finding the volume of another class.

PARAGRAPH XLVI.

ROBERT HARTIG METHOD.

Robert Hartig's method forms tree classes containing equal sectional areas—not equal numbers of trees. An equal number of sample trees is cut in each class and worked up separately for each class. The volume of the forest is also obtained separately for each class. Otherwise, the manner of proceeding is identical with that of Paragraph XLV.

Preferable it would seem to cut in each class a number of sample trees having, in the aggregate, the same sectional area. This scheme, however, would represent the big-diameter class by an absurdly small number of samples.

PARAGRAPH XLVII.

AVERAGE SAMPLE TREE METHOD.

If average trees of the entire forest are taken as samples, then the volume of the forest is obtained with smaller accuracy.

The proportion which the different assortments of timber, wood, bark, etc., form in the entire output is not clearly shown by such sampling.

In a normal, even-aged wood the tree of average cubic volume is found by deducting 40% from the total sectional area, beginning with the deduction at the biggest end. The largest tree then left is, or happens to be, *the* average tree of the wood.

PARAGRAPH XLVIII.

EXACT MENSURATION WITHOUT CUTTING SAMPLE TREES.

Frequently the cutting of sample trees for the purpose of a valuation survey is not feasible. The volume of the forest in cubic feet—but not the assortments composing the volume—may then be ascertained as follows:

- a. Take the total sectional area of the forest according to diameters and species and, if necessary, according to height classes.
- b. Ascertain the bole volume of some available trees with the help of Pressler's tube or by indirect measurement of heights and diameters.

c. Proceed as indicated in the last three paragraphs, keeping in mind, however, that only the cubic volume of the boles is thus obtainable. The branch-wood-percentage or the timber-percentage of the bole must be estimated.

The Hartig method (Paragraph XLVI.) might be combined with the use of Pressler's telescope, and the bole volume of a wood above breast height might be ascertained as $\frac{2}{3}$ of the total sectional area of the forest, multiplied by the arithmetical mean of the rectified heights of the sample trees representing the various diameter classes.

$$V = \frac{2}{3} \times \frac{S(r_1 + r_2 + r_3 + r_4 + r_5)}{5}$$

The bole volume below breast height in cubic feet is equal to the sectional area of the wood times $4\frac{1}{2}$.

PARAGRAPH XLIX.

COMBINED MEASURING AND ESTIMATING.

If measuring and estimating are combined, the following typical methods may be used to ascertain the volume of woods:

1. The form factor method (Paragraph L.).
2. The form height method (Paragraph LI.).
3. The volume table method (Paragraph LII.).
4. The yield table method (Paragraph LIII.).

These methods might be used in connection with the so-called "distance figure" of Paragraph LIV.

In applying these methods, one or the other of the three factors of volume (sectional area, height and form factor) are obtained by estimation.

The paragraphs following Paragraph LVIII. give a number of methods practically used and also based on combined measuring and estimating.

PARAGRAPH L.

FORM FACTOR METHOD.

The form factor method ascertains the sectional area by calipering, according to species, and, if necessary, according to height classes. The average height of the wood (by species, classes) is obtained by actual hypsometric measurement. The form factor is read from local form factor tables.

The average height is obtained—not as the arithmetic mean of a number of heights measured, but much more—correctly from the ratio existing between the sum total of the ideal cylinders and the sum total of the sectional areas of the trees hypsometrically measured. The form factors appearing in form factor tables must be averages obtained by many hundreds of local measurements.

Mistakes amounting to up to 25% in the sum total of the volume obtained by the form factor method are not impossible, since average form factors appearing from a form factor table are often at variance with the actual form factor.

Form factor tables for American "second growth" are still lacking. In primeval woods the form factor method seems out of place.

PARAGRAPH LI.

FORM HEIGHT METHOD.

The form heights of merchantable trees are, generally speaking, subject to only small variations. Those, *e. g.*, for Adirondack White Pine scaling from 18" to 36" in diameter breast-high are (for standard rule) close to 1.25.

Multiplying the sectional area of a White Pine woodlot (say 100 square feet) by the form height previously obtained through official measurements (like those by T. H. Sherrard), the volume of the woodlot—in the present example about 125 standards—is easily obtained.

Form height tables based on feet b. m., Doyle, are not as simple as those based on the standard rules and cubic foot rules, owing to the mathematical inaccuracy of Doyle's rule, which causes the form heights to be pre-eminently dependent on the diameters.

Form height tables should be constructed for the leading merchantable species in the United States. Of course, such tables are more readily applicable to second growth than to first growth.

The form height tables should exhibit the number of standards, cords, ties, etc., obtainable per square foot of sectional area in each diameter class. In case of defective trees, proper allowance must be made for defects—rather a hazardous risk in primeval hardwoods.

PARAGRAPH LII.

VOLUME TABLE METHOD.

In Paragraph XXXVIII. a number of volume tables have been enumerated, from which the volume of trees of given species and diameter (and height) can be readily read.

A valuation survey of the forest (or of a woodlot or of a sample plot) yields the diameters of the trees stocking thereon. The number of trees found for each diameter class is multiplied by the contents of a tree of that diameter appearing from the volume table. The sum total of the multiples is the sum total of the volume of the forest.

SAMPLE.

Diameter.	Yellow Pine.			Hickory.			Oak.		
	No. trees.	Average volume.	Total volume.	No. trees.	Average volume.	Total volume.	No. trees.	Average volume.	Total volume.
12	30	60	1.800	7	140	980	14	160	1.400
15	42	120	5.040	9	240	2160	5	200	1.000
18	17	300	5.100	18	370	6600	23	350	8.050
21	36	520	18.720	5	500	2500	22	520	11.440
24	33	780	25.740	12	660	7920	22	730	16.060
27	20	1080	21.600	6	840	5040	7	940	6.580
30	10	1420	14.200	3	1050	3150	10	1150	11.500
33	1	1800	1.800	.....	.....	.....	5	1400	7.000
36	1	2200	2.200	.....	.....	.....	5	1800	9.000
Totals.			96.200			28.350			72.030

Grand total.....196,580' B. M.

The volumes of the column "Average Volume" are taken from tables published by the Bureau of Forestry.

PARAGRAPH LIII.

YIELD TABLE METHOD. *- volume of stands of trees*

All over Europe local yield tables are used to quickly ascertain the volume of pure, sound, even aged woods. For America, such yield tables—normal local yield tables—exist only in the white pine tables given in Pinchot and Graves' pamphlet, "The White Pine."

The method of construction of yield tables appears from Paragraph XCII. and following.

Under yield tables are understood "acre-volume-tables," whilst under volume tables are understood "tree-yield-tables."

Normal yield tables specify the age of even aged and pure woods, the height of such woods and the volume (by assortment) of such woods, according to the productiveness of the soil. An indication for the latter is found in the height growth.

Such yield tables hold good only for woodlots normally stocked. A woodlot is normally stocked "when all local factors of wood production have pronounced themselves unhampered in the annual production of fibre." Normal woods, even of small extent, are extremely rare. In Germany the average wood lacks 25% of being normal. Since the normal yield tables give the yield for normal conditions only, a deduction must be made from the volume indicated by the yield table when applied to a given woodlot, according to the abnormality of the same.

Proceed as follows:

Ascertain age and average height of the trees; find the yield table which gives a similar height for the same age; reduce the volume indicated by this yield table and for this age, by estimating the deficiency of the growing stock.

Obviously, there is much room for guessing, since neither height nor form figure nor sectional area in woodlots abnormally stocked can lay claim to normality.

Schuberg, denying a truism otherwise generally acknowledged, claims that the height alone does not indicate the productiveness of the soil.

At present, normal yield tables are of little use in American forestry.

PARAGRAPH LIV.

DISTANCE FIGURE.

Under "distance figure," an invention of Koenig's, is understood the quotient a formed by the side l of the average growing space of a tree (considered as a square) and by the diameter of the average stem d .

$$a = \frac{l}{d}$$

The average distance from tree to tree and the average diameter of a number of trees is obtained by a number of measurements in the forest. If the area of the forest is F square feet, then the sectional area of the forest is

$$= \frac{\pi}{4} \times \frac{F}{a^2} \text{ square feet}$$

The actual test proves the fallacy of Koenig's assumptions. The explanation lies in the fact that the average diameter of a wood is not the arithmetical mean of the diameters composing it. Further, the growing space of a tree is not a square.

The actual growing space per tree can be correctly ascertained by laying a sample strip through the forest, counting at the same time the trees within the strip. The sectional area of the forest is obtainable, however, without greater trouble and with much greater accuracy, from the product calipered sectional area of trees in the sample strip times area of the forest over area of the sample strip.

On an acre of average soil, there is on an average room for the following numbers of healthy trees, according to age:

At 20 years	1,600 specimens.
At 50 years	600 specimens.
At 100 years	240 specimens.
At 150 years	150 specimens.

PARAGRAPH LV.

ALGON'S UNIVERSAL VOLUME TABLES.

So-called "universal volume tables" have been constructed by H. Algon, a Frenchman. For a description of these tables see "Indian Forester" of July, 1902.

The volumes given for each diameter of trees, whatever the species be, are presented on a number of tables as follows:

Diameter.	Volume in Cubic Feet.				
	Table 1.	Table 5.	Table 10.	Table 15.	Table 20.
6"	2.	3.	4.	6.	8.
9"	5.	8.	10.	16.	18.
12"	9.	15.	21.	27.	33.
15"	19.	28.	39.	50.	61.
18"	27.	39.	59.	69.	84.
21"	43.	60.	83.	109.	128.
24"	54.	78.	108.	138.	168.
27"	72.	107.	147.	188.	228.
30"	87.	129.	177.	228.	276.
33"	111.	163.	221.	288.	349.
36"	129.	189.	258.	333.	405.

The tables are used as follows:

1. Caliper the entire forest according to diameters and species.
2. Measure a number of type trees, selected at random, after felling them.
3. Find that volume table amongst the 20 tables given which best corresponds with the diameters and volumes of the type trees. Apply the volume table, which is found to be the proper one, to all diameter classes calipered in the woods.

Objections to the method are:

- a. The danger of mistakes is very great. In an absolutely even aged wood, one tree of 15 inches diameter may easily show 50% more volume than another tree of the same diameter, the latter being more tapering and shorter.
- b. In an uneven aged wood the tables are necessarily wrong because the form height is a function of age as well as of height and diameter.
- c. The method does not give any idea of the proportion of logs, fuel, bark, etc.

Algon calls these tables "universal" assuming that they hold good for all species of the universe.

PARAGRAPH LVI.

SCHENCK'S GRAPHIC METHOD.

This method, as well, can be used only for sound woods. No calculation is required. The procedure is:

1. Caliper the whole wood.
2. Cut sample or type trees of small, big and average diameters, find the contents of each tree separately, together with the composition of contents as logs, fuel and bark.
3. On a piece of cross section paper, use as many units along a horizontal line as there are trees (or tens or hundreds of trees) calipered.
4. Mark the unit which each sample tree, according to its diameter, would occupy if the biggest tree were placed to the right and the smallest to the left of the horizontal line.
5. Enter over the marked units the volume of the type trees (according to the composing factors, if required) in square units. A square unit might correspond with ten feet board measure, or with $1/100$ of a cord, etc.
6. Draw a line joining the ends of the columns, adjusting it by an average curve.
7. Measure the space (in square units) between the curve and the horizontal line with the help of a planimeter; the number of square units giving directly the number of feet Doyle, or of cords, etc.

If there are several assortments of volumes, several curves must be drawn. This method allows of separating the volumes of trees allotted to the several diameter classes. Mathematical errors are, practically, excluded.

PARAGRAPH LVII.

FACTORS GOVERNING THE SELECTION OF A METHOD OF VALUATION SURVEY.

In the case of a valuation survey ("stock taking") in the woods, the following points must be considered:

- a. The degree of exactness required, which depends on the purpose at stake (*e. g.*, scientific investigations, or preparation for logging, or taxation).
- b. The regularity, uniformity and soundness of the growing stock.
- c. The minimum diameter of logs; assortments; marketability of species.
- d. The possibility of cutting sample trees.
- e. The expense permissible.

The question usually arises whether the entire forest or sample plots only must be surveyed. The answer depends on the configuration of the ground, uniformity of the growing stock as to size, age, species and quality of its components; further on the value of stumpage, on the accuracy required, on the available time and on the available funds.

The following *METHODS OF VALUATION SURVEYS* might be distinguished:

I. *Cutting sample trees.*

- a. Sample trees selected for about five diameter classes, each class containing about one-fifth of the number of trees present (Draudt-Urich method).
- b. Sample trees selected for about five diameter classes, each class containing about one-fifth of the sectional area of all trees present (Robert Hartig method).
- c. Sample trees selected as average-diameter-trees of the entire forest (Old Bureau method).
- d. Sample trees selected at random—*e. g.*, from dead and down trees (C. A. S. method—applied in the Balsams; Algon Universal tables; Graphic method).
- e. Stem analysis, together with investigations as to thickness of bark.

II. *Without cutting sample trees.*

- a. Measuring height and diameter and estimating form figure of sample trees.
- b. Measuring rectified heights and diameters.
- c. Measuring merely diameters and estimating form heights.
- d. Photographing sample trees, having a scale—say a stick 6 feet long—on the picture.

III. *With the help of volume tables.*

IV. *With the help of yield tables.*

PARAGRAPH LVIII.

FACTORS INFLUENCING THE SELECTION OF SAMPLE PLOTS.

If sample plots are taken, there must be determined:

- a. The number, situation and distribution of the sample plots.
- b. The absolute and relative size of the sample plots. The Bureau of Forestry prescribes sample plots equalling from 1 to 4½% of the forest. The "Forest Reserve Manual" prescribes 5% or more.
- c. The form of the sample plots and the manner by which the size of the sample plot is ascertained.

In Europe an ordinary workman calipers, on an average, 5,000 trees (in maximo 12,000 trees) per day. In Pisgah Forest 500 trees is a good day's work for one estimator and one helper.

PARAGRAPH LIX.

SIR DIETRICH BRANDIS' METHOD.

The Brandis method is indicated where the object at stake consists in a rapid survey of the stumpage on large tracts, like the vast Teak and Bamboo forests of upper Burmah.

Traversing existing trails of known length on horseback, the estimator records the diameter of each tree within a given distance (say 200 yards) on either side of the trail.

The widths of the strips traversed multiplied by the length of the trail yields the area of the sample plot. The number of the trees of the various diameters found on the sample strip appears from the records.

PARAGRAPH LX.

PINCHOT-GRAVES METHOD ADOPTED ON DR. WEBB'S ESTATE.

1. Sample acres, measuring 4 x 40 poles, are irregularly laid into swamps, hardwood slopes and spruce slopes. The sum total of the sample acres is $3\frac{1}{2}\%$ of the total acreage.

2. The length of a sample acre is actually chained off, whilst the width is ascertained (two poles to the left and two poles to the right of the chain) by tape, by pacing and by estimating.

3. The sites of the sample acres are not marked on maps.

4. All trees on the sample acres are calipered; a number of heights are taken on each sample acre; for each sample acre the average diameter, the average height and the number of trees are ascertained.

5. From these averages is deduced, for all sample acres, the average diameter, the average height and the number of trees. All these data, of course, must be given for the various species separately.

6. From volume tables previously constructed the volume of the trees having average height and average diameter is obtained and is multiplied by the average number of trees.

7. This multiplication yields the volume of the average sample acre.

Objections to this method of valuation survey are:

- a. The tree of average diameter has neither average volume nor average height.
- b. The average diameter should be obtained from the fraction "total sectional area over number of trees." It cannot be obtained correctly from the fraction "sum total of diameters over number of trees." Similar objections hold good for average height.
- c. Guessing at the width of a strip, in dense growth, is rather risky.

REMARK: Bulletin 36, page 125, states that volumes are now computed by the Bureau either by averaging the volumes found for the sample acres, thus obtaining the volume of a model acre as

$$\frac{v_1 + v_2 + v_3 + \dots + v_n}{n}$$

(wherein n equals the number of sample acres); or by summing up all trees of each diameter class, by dividing each sum by the number of sample acres, and by thus finding for a model acre the average number of trees for each diameter class. In both cases the volumes for each diameter class are read from volume tables.

Allowance for defects is made according to local experience, all trees being calipered as if they were sound.

PARAGRAPH LXI.

THE GRIDIRONING METHOD.

1. Work with compass (if a topographical map is required, also with barometer or clinometer) and with several tapes or ropes. These ropes are meant to denote the sides of a strip; within the strip the sectional areas are taken with calipers or Biltmore sticks.

2. The tapes move continuously with the caliper men, and there is no stopping. The compass man keeps ahead of the measuring crew. One of the outside "tapers" has the correct length desired for a section. His tape must be run straight. The inner tapes may make snake lines. The tally man uses a fresh tally sheet for each section.

3. All strips lie parallel and are equidistant. The width of the strips depends on the density of growth, smallest diameter calipered, available help and accuracy required.

4. The distance between two parallel strips depends upon accuracy required, width of strip and variety of configurations.

5. Each strip is divided into sections of equal length. The tally sheet gives for each section the diameters (with bark) of the trees in that section; further, remarks on the run and altitudes of ridges and creeks traversed, on roads, settlements, existing surveyor's marks, forest fires, forest pasture, previous lumbering and regeneration. The number of seedlings in a section might be approximately given under the same head.

for C. A. SCHENCK & CO., Baltimore, N. C.

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Handwritten text: "Horse Shovel" and a sketch of a horse-drawn shovel.

Advantages of the gridironing method are:

- a. A topographical map is obtained at a slight extra expense. The original survey is controlled and the area of the tract is re-ascertained.
- b. Cruisers are forced to traverse all sorts of country and are not allowed to skip swamps, cliffs, etc.
- c. The proportion of flats, ridges, slopes, swamps, farms, or farm soil, pastures, etc., is found at the same time.
- d. The strips may be used as permanent statistical sample plots, if they start from definite points (corners) and run in definite directions.
- e. The procession of the cruisers is uninterrupted by stops; hence no loss of time.

For a picture of a convenient tally sheet holder see Graves' Handbook, page 123.

The gridironing method has been adopted by the working plan division in a somewhat altered form as follows (Bulletin 36, page 120):

1. Strips are always one chain (66 feet) wide. A section invariably comprises one acre equaling 1×10 chains.
2. The measuring tape is trailing in the center of a strip; two caliper men (proceeding one at the left, the other at the right hand of the tape) caliper a belt one-half chain wide, estimating the width at either side of the central tape.
3. The compass man or tally man with the front end of the tape attached to his belt goes ahead and stops at the end of every chain, allowing the calipers to catch up.
4. Thus there are ten stops for every acre; after 10 chains the tally man enters general notes.
5. Heights may be measured by a separate crew.

A crew of four men calipers in merchantable timber 20 to 40 acres per day; in small and merchantable timber from 15 to 25 acres per day; in longleaf pine up to 65 acres per day.

PARAGRAPH LXII.

FOREST RESERVE METHODS.

Roth's Forest Reserve Manual gives three methods of valuation survey, No. 1 and No. 2 being sample-area-methods, and No. 3 an entire-area-method.

1. Sample circles with a radius of 20 yards, the circle containing $\frac{1}{4}$ acre; the radius is estimated, or paced from a central stick. Two sub-methods are permitted, namely:

- a. Count the number of trees of merchantable size; estimate the average tree according to log length, taper and thickness of bark; estimate the percentage of defectiveness (from 10% to 40% after Manual, page 49).

b. Caliper the trees in the circle into two-inch classes; estimate the average tree for each class and allow for defects as before.

In both cases a map must show the site of the sample circles. The circle method is not allowed in scattering timber. At least 5% of the entire area must be sample-circled.

2. Sample strips. Strips should be four rods wide, should run across ridges, should be shown on a map. Otherwise proceed as under 1.

3. The "forty" method is used on surveyed land. It is an entire-area method applied to 40 acres. The sides of a "forty" are 80 x 80 rods, equal to 440 x 440 yards. Prescriptions:

a. Traverse each "forty" on lines about 100 yards apart, thus crossing 4 times.

b. Halt at every 100 yards and estimate the trees within a square of 100 yards surrounding the stopping place.

c. If possible, have a compass man control the length and the direction of your runs.

PARAGRAPH LXIII.

SAMPLE SQUARES.

Sample squares containing about one acre are used in Maine and in Northern New York. The side of a sample square is 14 rods. A cruiser, from the center of the square, under the density of the growth existing in Maine and New York, can overlook a circle of 7 poles radius surrounding him. Hence, as a matter of fact—or rather of theory—he skips the corners of the square, counting only the trees in a circle which has the side of the square for its diameter. The square contains 196 square rods, whereas the circle of 7 poles radius contains 155 square rods. The cruiser estimates the contents of all trees within the "square" from his central standpoint.

PARAGRAPH LXIV.

PISGAH FOREST METHOD OF 1896.

1. The diameters of all trees promising to yield a log are measured in diameter classes of $\frac{1}{2}$ foot interval by a crew of 4 to 5 helpers armed with Biltmore sticks.

The diameters are measured (or often estimated if beyond reach) at the point above which the tree is supposed to be sound.

2. Each tree measured is marked by a blaze. The foreman enters on a tally sheet the species and the diameters called out by the helpers. A special tally sheet is used for each cove.

3. The average contents of the diameter classes are estimated with the help of sample trees selected for each species and each diameter—a very uncertain estimate owing to the unsoundness of the trees.

4. Each cove is numbered or lettered to correspond with the tally sheet on a tree standing at the outlet of the cove.

PARAGRAPH LXV.

PISGAH FOREST METHOD FOR STUMPAGE SALE, BARK SALE AND LUMBERING OPERATIONS.

1. Each tree is approached individually, its diameter measured and its defects, especially its hollowness, examined by "sounding." The diameter measure and the estimated volume are entered on a tally sheet opposite the number of the tree, which is inserted in the stump of the tree by a stroke of the "revolving numbering hammer."

2. One cruiser and one helper tally 400 trees per day.

3. The method allows of ready control by the owner, the forester and the buyer. It is adapted to hardwood forests in a rough mountainous country where the merchantable trees per acre are few; and where no tree is, practically, free from defects. (Compare Graves' Bulletin No. 36, page 115).

PARAGRAPH LXVI.

HENRY GANNETT'S METHOD, ADOPTED FOR THE TWELFTH CENSUS.

1. Base the estimate on the cruising reports obtainable from the local lumber companies and railroad companies.

2. Control the applicability of the estimates to huge tracts by traversing them and by overlooking them from a mountain top.

Mr. Gannett expects that mistakes made in one county will be offset by those made in another.

PARAGRAPH LXVII.

A "FORTY" METHOD USED IN MICHIGAN.

1. A "forty" (a square of 80 x 80 poles) is subdivided into 10 rectangles of 4 acres each, measuring 16 x 40 rods.

2. The cruisers estimates when entering a rectangle. He counts the number of trees on every 4 acres and multiplies the number by the size of the average tree.

3. For each "forty" the cruiser records in a memorandum the factors influencing the logging operations or the timber values, notably the swamps, ridges, forest fires, degree of defectiveness, facilities of transportation.

A central line traversing the "forty" in a north and south direction is sometimes kept by a compassman assisting the cruiser. The outer lines of the "forty" are plain from the official survey marks.

A number of variations of this method exist, according to the custom of local cruisers and according to the predilections of the lumbermen, largely governed by the value of stumpage. Compare Graves' Bulletin 36, page 116.

PARAGRAPH LXVIII.

DR. FERNOW'S "FORTY" METHOD USED AT AXTON.

1. Each "forty" is subdivided into 16 squares of $2\frac{1}{2}$ acres each, the sides of a square being 20 x 20 poles.
 2. The head estimator, stepping from the corner of the square 10 poles east (or west) and 10 poles north (or south) places himself in the center of the square.
 3. Helpers (students) are sent out, four in number, towards the north-east, northwest, southeast and southwest, each helper reporting the diameter and species of the trees found in that one-quarter of the $2\frac{1}{2}$ acres which is allotted to him.
 4. The "forties" are carefully surveyed and surrounded by carefully trimmed lines. The outlines of the $2\frac{1}{2}$ acre sections are merely paced.
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CHAPTER II.—AGE

PARAGRAPH LXIX.

AGE OF TREES CUT DOWN.

The age of trees cut down is found by counting the annual rings on a cross section (preferably an oblique cut) made as low above the ground as possible. Allowance must be made for the "stump years," by which is understood the number of years required by the top bud of the seedling, after sprouting, to reach the stump height ("cutting height," after Circular 445).

Ring-counting in the case of even-porous hardwoods requires the use of a lens and of some coloring liquid (aniline and ferro-chloride) on a disc planed with a knife, a chisel or a hollow planer.

The difference of the ring-numbers on the stump and the ring-numbers at any place higher up indicates the number of years used by the top bud of the tree to traverse the intervening distance. Endogenous trees do not form any rings.

False rings are formed under the influence of late frost, early frost, drought, fire and insect pests. They do not run all around the tree.

As long as the tree lives, it must annually form a ring of growth (or rather an additional coat, the sleeves of which cover the branches), the outside of which becomes a layer of bark, the inside of which is a layer of wood. In tropical countries this rule does not hold good provided that there is no change of season.

The formation of rings in the branches is regular. Branch-rings are, however, eccentric and elliptical. The formation of rings in the roots is said to be irregular, not representing the age of the root, possibly because there is no or little change of seasons in the soil.

PARAGRAPH LXX.

AGE OF STANDING TREES.

The age of standing trees can be estimated only when regular annual whorls of branches can be counted.

The records of seed years and the history of the forest kept by many forest administrations usually give an idea of the age of the trees.

PARAGRAPH LXXI.

AGE OF A FOREST.

The age of a forest is the average age of the trees composing it.

In the case of a thicket suppressed for a long time by the superstructure of a leaf canopy overhead, a so-called "economic age" is frequently substituted for the actual age. In the case of Adirondack spruce, for example, a diameter of 1 inch in the center of the trunk had better be counted, as, say, 15 years, although it may contain as many as 60 rings.

The mean age of an uneven-aged wood is defined as follows:

1. That number of years which an even-aged wood would require on the same soil, in order to produce the same volume as is now at hand.
2. That number of years which an even-aged wood would require in order to produce at the time of maturity the same volume which the uneven-aged wood is likely to produce.

The latter definition is scientifically more correct. Unless it is adopted,* an uneven-aged wood may get over 20 years older in 20 years, owing to the fact that the trees dying in the meantime are mostly minors in age.

CHAPTER III.—INCREMENT

SECTION I.—INCREMENT OF A TREE.

PARAGRAPH LXXII.

THE KINDS OF INCREMENT.

The following kinds of increment must be distinguished:

- a. Increment of height, diameter, sectional area and volume.
- b. Current annual increment, current periodic increment and total increment.
- c. Average annual increment, average periodic increment and average increment at the age of maturity.
- d. Increment of the past and increment of the future.
- e. Absolute increment and relative increment.

The increment of stems cut down is found by counting and measuring the annual rings on several cross sections.

The term "stem" or "tree analysis" designates an investigation into the past height growth, diameter growth and volume growth of a tree.

Circular 445 of the Bureau of Forestry defines the term "increment," somewhat narrowly, as follows: "The volume of wood produced by the growth in height and diameter of a tree or of a stand."

For definition of the term "tree analysis," see Circular 445 of Bureau of Forestry.

This circular distinguishes between:

1. Stump-analysis, being a tree analysis which includes measurements of the diameter growth at given periods on the stump only, no matter what other measurements it may comprise;
2. Section-analysis, being a tree analysis which includes measurements of the diameter growth at given periods upon more than one section of a tree;
3. Partial tree (stump or section) analysis, wherein the measurement of the diameter growth at given periods covers a portion only of the total diameter growth.

PARAGRAPH LXXIII.

HEIGHT INCREMENT.

The height increment, from the silvicultural standpoint, is of interest to the forester dealing with mixed woods.

The difference between the number of rings found on two separate cross sections through the bole indicates the number of years which the tree

has required to grow through the distance lying between these two sections. By counting the number of rings at several cross sections, one of which is made as close to the ground as possible, the current and the average height growth (increment) may be obtained by arithmetical or by graphical interpolation.

A dense cover favors height increment. In rare instances, however, the stand of saplings or poles is so close that the height increment of the individual suffers from lack of food.

PARAGRAPH LXXIV.

THE CURRENT HEIGHT INCREMENT.

In the high forest the current annual height increment reaches a maximum at an early age; passing this maximum, it sinks more or less rapidly. The culmination of the current annual height increment occurs the much earlier and its slackening after said culmination goes on at a more rapid rate if

1. the species is fast growing and light demanding;
2. the tree observed belongs to the dominant class;
3. the soil is good.

For yellow pine the culmination of the current annual height increment occurs amongst dominant saplings between the 10th and 15th years; for spruce at about the 20th year; for beech and fir between the 25th and 30th years. Suppressed trees show the maximum of current height growth much later than dominant trees.

As a general rule for all species, in case of dominant trees, the longest shoot is made 10 to 15 feet above ground. Slow growing species, shade bearers and trees stocking on poor soil reach that level at a later date than trees and species growing under reversed conditions.

In the case of coppice forest, the maximum of the current height growth lies in the first three years of the life of the shoot. For oak coppice, the following table may serve as an illustration of height growth:

GROWTH IN FEET.

Age in years.....	10	20	30	40	50
Actual height	13'	23'	30'	37'	43'
Current annual increment.....	1.3'	1.0'	0.7'	0.65'	0.63'

PARAGRAPH LXXV.

THE AVERAGE HEIGHT INCREMENT.

The average annual height increment culminates later than the current annual height increment, and, after the culmination, it decreases at a less

rapid rate than the current annual height increment. The average annual height increment culminates at the very age at which it is equal to the current annual height increment.

As long as the average increment increases the current increment is larger than the average. The average increment still rises during a period of decrease of current increment.

These laws hold good not only for height growth, but also for the growth of diameter, sectional area and volume. They are based merely on mathematical principles and are, for that reason, independent of species, climate and soil.

If "a" denotes the current annual increment, and if "d" denotes the average annual increment, whilst the indices 1, 2, 3, etc. (up to n), indicate the year of increment, then the following five equations hold good:

$$\begin{aligned}n \times d_n &= a_1 + a_2 + a_3 \dots\dots + a_n \\(n+1) d_{n+1} &= a_1 + a_2 + a_3 \dots\dots a_n + a_{n+1} \\(n+1) d_{n+1} &= n \times d_n + a_{n+1} \\n \times d_{n+1} &= n \times d_n + a_{n+1} - d_{n+1} \\n (d_{n+1} - d_n) &= a_{n+1} - d_{n+1}\end{aligned}$$

PARAGRAPH LXXVI.

RELATIVE INCREMENT OF THE HEIGHT.

The percentage of height increment forms, from the start on, an irregularly descending progression.

If the height is h at the beginning of a period of n years of observation and H at the end of that period, then

$$\begin{aligned}h \times 1.0^n &\text{equals } H \\ \text{and} \\ p &\text{equals } 100 \sqrt[n]{\frac{H}{h}} - 100\end{aligned}$$

Pressler substitutes for this formula in case of short periods of observation the following:

$$p = \frac{200}{n} \times \frac{H-h}{H+h}$$

This formula is derived as follows: Imagine that we are in the midst of the period of n years. At that time, the increment is apt to be $\frac{H-h}{n}$, whilst the height at that time is apt to be $\frac{H+h}{2}$; hence, for that middle year, the equation is:

$$\frac{p}{100} = \frac{H-h}{n} \times \frac{2}{H+h}$$

PARAGRAPH LXXVII.

DIAMETER INCREMENT.

The current diameter increment is obtained by counting and measuring the rings on a disk through the tree. It is generally best to count from the bark towards the center, along two radii standing perpendicular to each other.

The general laws of diameter growth are identical with those of height growth relative to culmination, decrease and increase of absolute (Paragraph LXXV.) as well as of relative (Paragraph LXXVI.) increment.

If we exclude the butt-piece below chest-height, the annual rings along the tree bole measured at various elevations above ground show a gradual increase of width with elevation, provided that the leaf canopy of the forest is complete and uninterrupted—*e. g.*, the width of the ring 50 feet from the ground, formed in 1903, is greater than the width of the ring formed 20 feet above ground in the same year.

For trees standing in open crown-density, the width of the ring decreases with the elevation above the ground, especially within the crown itself.

A tree standing in a thin crown-density may show an even width of ring all over the tree bole.

For very old trees in closed stand it is sometimes found that the diameter, say 40 feet above ground, is larger than the diameter, say, 20 feet above ground.

The rings on a disk are not actually circles; they more closely approach the form of eccentric ellipses (see Paragraph XIII.).

PARAGRAPH LXXVIII.

SECTIONAL AREA INCREMENT.

The increment of the sectional area is obtained from the increment of the diameters. Where greater exactness is required, and especially in case of irregular rings, the planimeter or the weight of a piece of paper having the form of the sectional area may be used for measuring to good advantage (Paragraph XIII.).

The increment of the sectional area at chest height depends on the crown density overhead; further, on the quality of the soil. At chest height the culmination of the current annual sectional area increment takes place, in the case of dominant trees, fast growing species and complete cover overhead, between the years 40 and 70.

The culmination of the current annual sectional area increment occurs always later than the culmination of the current height and diameter increment. After culmination it remains uniform for a long time.

The absolute increment of a sectional area higher up on the bole, compared with the absolute increment at chest height, is found to be equal to it in the case of dominant trees; larger in the case of suppressed trees; and smaller in the case of isolated trees.

Pressler establishes as the "law of bole formation" the following rule: "The absolute increment of the sectional area at any point of a bole is directly proportioned to the leaf surface above that point."

This rule is, on the whole, correct. An unexpected swelling, however, is often found at 9/16 of the height of the tree. Within the crown of the tree, the decrease of sectional area increment is rapid.

PARAGRAPH LXXIX.

RELATIVE INCREMENT OF DIAMETER AND OF SECTIONAL AREA.

The increment percentage at any point of the bole, like all increment percentages, forms a constantly but irregularly descending progression.

At any point of the bole the increment percentage of the sectional area is the double of the increment percentage of the diameter.

Schneider gives a handy formula for the sectional area increment percentage, viz.:

$$P \text{ equals } \frac{400}{nd}$$

wherein d represents the diameter at the beginning of the period of observation, and wherein n indicates the number of rings per inch at the time of observation.

The percentage of the sectional area increment increase along the bole with increasing height of the disk measured, excepting, however, possibly, the case of very isolated trees.

The average sectional area increment percentage of the bole is found at a point a little below one-half of the total height, namely, at about 0.45 of the total height from ground.

PARAGRAPH LXXX.

VOLUME INCREMENT.

The (current and future) volume increment of standing trees is of great interest to forest financiers; it can be estimated only, and cannot be measured exactly.

The volume increment of trees cut down may be ascertained as follows:

1. By the sectional method, or by "section analysis" (Paragraph LXXXI.).
2. From the increment of sectional area chest high, height increment and form figures (Paragraph LXXXIV.).
3. From the increment of sectional area in the midst of bole (Paragraph LXXXV.).
4. On the basis of the average annual increment (Paragraph LXXXVII., last 4 lines).

PARAGRAPH LXXXI.

SECTION ANALYSIS.

The section-method is a complete tree analysis by sections. The entire bole is divided into a number of sections, preferably of even length, at both ends, or, better, in the midst of which the periodical increment of the sectional area is ascertained (compare Paragraph XI.).

In the latter case, multiplying such sectional areas (in square feet) as belong to the same age of the tree by the length (in feet) of the sections, the volumes (in cubic feet) of the different sections at given ages are obtained.

The "top pieces," however, must be figured out separately, their length differing from the even length of the sections. These top pieces are usually considered as cones, and their volumes are ascertained as one-third height times basal area of top piece. The basal area of the top piece is identical with the upper area of the uppermost full section of a given age.

EXAMPLE FOR HUBER-SECTIONS TEN FEET LONG.

Total height.....	25 feet.	40 feet.	67 feet.
Total age.....	20 years.	40 years.	60 years.
Sectional area of Section 1.....	0.34 sq. ft.	0.78 sq. ft.	1.23 sq. ft.
Sectional area of Section 2.....	0.15 sq. ft.	0.45 sq. ft.	0.87 sq. ft.
Sectional area of Section 3.....	.....	0.25 sq. ft.	0.64 sq. ft.
Sectional area of Section 4.....	.....	0.03 sq. ft.	0.53 sq. ft.
Sectional area of Section 5.....	.....	.....	0.25 sq. ft.
Sectional area of Section 6.....	.....	.....	0.04 sq. ft.
Summary of sectional areas.....	0.49 sq. ft.	1.51 sq. ft.	3.56 sq. ft.
Summary sectional areas x 10.....	4.90 cu. ft.	15.10 cu. ft.	35.60 cu. ft.
Volume of top piece.....	0.05 cu. ft.	0.09 cu. ft.	0.08 cu. ft.
Total volume.....	4.95 cu. ft.	15.19 cu. ft.	35.68 cu. ft.

The volume of the top pieces forms in the older age columns an insignificant part of the total volume.

If the logs as cut in the woods are used as sections, then each section has a separate length and its volume must be separately ascertained for every decade of age of tree.

REMARK: It is wise to first ascertain the full age of the tree, allowing for stump years. It is further wise to throw off that number of years which exceeds full decades—*e. g.*, in case of a tree 117 years old, 7 years.

At the stump the rings had best be counted from the inside out, allowing for stump years. Instance: Age of tree, 117; stump years, 4 years; counting on the stump, from the inside, 6 rings establishes the ring formed in the year 10. Continuing, the rings of the years 20, 30, 40, 50, etc., up to year 110, are pencil marked. The outside seven rings are thrown off.

At all other disk-sections, count and measure from the outside in, after discarding the 7 years exceeding full decades of tree life.

PARAGRAPH LXXXII.

NOERDLINGER'S PAPER WEIGHT METHOD.

The total length of the tree is divided into 8 Huber sections, and cuts are made in the midst of these sections, at the height of $1/16$, $3/16$, $5/16$, $7/16$ and up to $15/16$ of the bole. On each cross section the radii are measured, not with the rule, but with dividers.

On a piece of paper folded 4 times and thus divided into 8 sectors the measurements are entered with the help of the dividers, one sector being allotted to the first cross section, the next sector to the next cross section, etc. Multiplying the total weight of the zone indicating, say, the year 70, by height of the tree and dividing the product by the weight of a square foot of paper, the volume of the tree when 70 years old is directly obtained in cubic feet. Similarly the zones corresponding with the year 50, 60, etc., are cut out, weighed and multiplied.

If the volume increment percentage p alone is to be obtained, then it is enough to divide, say, the "weight" of the year 70 by the weight of the year 60, and the 10th root of the quotient will equal 1.0p.

PARAGRAPH LXXXIII.

SCHENCK'S GRAPHIC TREE ANALYSIS.

Graphic tree analysis offers the following advantages:

1. Mistakes are impossible, being at once noticeable on the diagram paper.
2. The volume in feet Doyle can be readily obtained for any stated minimum diameter.
3. The graphical sketch is adaptable to any of the 43 scales in use in the United States, as well as to the metric system.
4. The thickness of heart wood and sap wood and bark readily appears.
5. It is immaterial whether measurements are taken in meters or in feet, the graphical sketch readily allowing of transfers into other units.
6. Height growth and diameter growth appear at the same time, and from the same entries.
7. The length of the sections taken need not be uniform.

The method of proceeding is as follows: On millimeter paper a system of co-ordinates is established; heights are entered as ordinates, diameters

or radii as abscissas. The scale for the height entries should be much smaller than that of the diameter entries.

Diameter points, at the different section-heights, corresponding to a given decade of years are joined (beginning at the outside), by which procedure the outline of the tree at that decade is established.

Th top cones are obtained by prolonging such outlines arbitrarily until they intersect with the height-axis.

The merchantable bole for each decade is dissected, on the diagram, into logs the length and diameter of which are measured on the diagram.

PARAGRAPH LXXXIV.

WAGENER'S METHOD AND STUMP ANALYSIS.

Wagener recommends a partial stem analysis for cases in which a knowledge of the absolute increment, not a knowledge of the absolute tree volume, is required. Tree volume is sectional area chest high times height of tree times form factor.

Wagener analyses:

- a. the height growth by counting the rings at various altitudes along the bole;
- b. the growth of the sectional area at chest height by measurement in decades in the usual way.

Wagener then estimates the form factor according to form factor tables.

In the latter proposition, obviously, lies the danger of mistakes. Since, however, increment is a difference of volumes, merely the difference of mistakes—a comparatively small item—enters into the problem. »

Age in years.....	60	80	100	120
Diameter b. h.....	14.	17.	19.	21.
Sectional area b. h.....	0.25	0.35	0.50	0.71
Height in feet.....	75.	85.	93.	105.
Form factor.....	0.50	0.50	0.50	0.50
Volume in cubic feet.....	9.4	13.	23.	36.
Increment in cubic feet.....	3.6	10.	13.	

The "stump analysis" (compare Paragraph LXXII.) introduced by the Bureau of Forestry rests on premises similar to those proffered by Wagener.

If the form height for the stump-diameters (or the number of feet b. m. per square foot of stump area for given stump diameters) is known, the rate of volume increment can be quickly ascertained by mere stump analysis.

It is, however, a well known fact that the diameter growth at the stump—especially at a low stump—is particularly unreliable as an index of volume growth, owing to the exaggerating influence on stump growth exercised by light, by water, by depth of soil and by superficial roots.

Stump analysis as a means to bring a volume in reference to a sectional area at the stump is permissible only as a necessary evil.

PARAGRAPH LXXXV.

PRESSLER'S METHOD.

Frequently the task before the forester is merely that of ascertaining the increase of bole volume during the last 10 or 20 years. Then after Pressler, one single investigation into the growth of the sectional area is sufficient when made with the help of the accretion borer in the midst of the "decapitated" bole. The volume increment in cubic feet equals the sectional area increment in question multiplied by the height of the tree.

The bole is decapitated by that number of top shoots which have been formed during the period of observation. This operation corresponds very well with the usual practice of judging the bole increment percentage from the sectional area increment ascertained at 0.45 of height of tree.

Pressler measures the sectional area at the end of the period of observation too large, measuring it at too low a point. He multiplies this sectional area, however, by too small a height—namely, the decapitated height; thus a mistake made in the positive sense is apt to be eliminated by a mistake made in the negative sense.

The axe can be used to better advantage frequently than the accretion borer.

PARAGRAPH LXXXVI.

BREYMANN'S METHOD.

Breymann gives the following formula:

1. For the current annual volume increment T:

$$T = V \left(2 \frac{\delta}{d} + \frac{\lambda}{l} \right)$$

wherein "δ" and "λ" denote the annual increase of diameter "d" and length "l" respectively.

2. For the corresponding increment percentage P:

$$P = 100 \left(2 \frac{\delta}{d} + \frac{\lambda}{l} \right)$$

It appears that for trees of old age and hence of little height growth the increment percentage is merely dependent on the diameter increase.

(40.2 = increment) percent
 7.0
 Should be 5.45
 after the diameter

Breymann, however, neglects:

1. The change of form figure, during the period of observation;
2. A number of small factors which ought to be embraced in the formula.

For stopping height growth or for $\lambda' = 0$, the term given for P can be easily reduced to the term given by Schneider for the sectional area increment percentage.

PARAGRAPH LXXXVII.

FACTORS INFLUENCING THE CUBIC VOLUME INCREMENT.

The culmination of the current annual volume increment takes place at a later year than the culmination of the sectional area increment at breast height. Naturally so, because with increasing age of a tree, its root system as well as the branch system, the feeders of the body, show continuous increase.

Big and long branches, of course, require a great deal of wood fibre to increase and maintain their own strength, like levers increased in length. Hence, from a certain size of branch on, all wood fibre produced by the branch is used up within the branch itself, for its own purposes, instead of being added as increment to the merchantable bole.

After Dr. Metzger, the crown of a tree yields the maximum of bole increment if its crown diameter is, and if the number of trees per acre are:

Quality of soil.	Diameter of crown, in feet.	No. of trees per acre.
Very good.	16.5	203
Good	14.7	256
Medium	12.7	343
Poor	9.3	640
Very poor	8.3	807

From the theoretical standpoint it seems wise, consequently, to force the lower branches of a tree to die, with the help of proper tension and friction within the leaf canopy, when they exceed a length of 8.25, 7.35, 6.35, 4.65 and 4.15 feet respectively (the halves of the diameters).

Metzger's investigations are interesting, but his conclusions seem to be too sweeping.

P. P. Pelton recommends the lopping of branches in order to shorten the length of the branch-levers.

The average annual volume increment of dominant and sound trees

culminates at a very high age only, if ever, owing to the late culmination of the current annual average increment.

The volume increment percentage forms—as in all cases of increment—a steadily but irregularly decreasing progression. This percentage is invariably equal to or higher than the sectional area increment percentage at chest height.

Roughly speaking, the volume increment percentage amounts to from 1 to 1.75 times the sectional area (at chest height) increment percentage, or, as Pressler gives it, to from 2 to 3½ times the diameter (at chest height) increment percentage.

Crown covers part of bole	Height Growth.			
	Seemingly nil.	Medium.	Good.	Excellent.
$\frac{1}{2}$ or more.	2.334.66	2.675.53	3.00 000	3.176.34
$\frac{1}{3}$ to $\frac{1}{2}$.	2.508.00	2.835.76	3.176.34	3.336.66
Less than $\frac{1}{3}$.	2.675.53	3.00 000	3.336.66	....

Since the average volume increment of a tree is equal or closely equal to the current annual increment at a high age only, it is usually not permissible to substitute the average increment, which is easily ascertained, for the current annual increment.

PARAGRAPH LXXXVIII.

VOLUME-INCREMENT PERCENTAGE OF STANDING TREES.

In the case of standing trees the volume increment percentage cannot be measured, owing to the impossibility of ascertaining a change of form height.

The Pressler data given in the preceding paragraph allow of estimating the volume increment percentage of standing trees on the basis of a diameter-increase, measured at breast height.

The Pressler "accretion borer" is used for the purpose, or an axe.

Stoetzer, Director of the Forest Academy at Eisenach, modifies the Schneider formula for sectional area percentage, writing it

$$p = \frac{C}{nd}$$

wherein n indicates number of years (rings) required to form one inch; d represents the diameter at the beginning of the period of investigation, whilst C (the so-called "constant factor of increment," which is not a constant factor at all) must be ascertained for a given species, soil, diameter, age and position by actual tests on felled trees.

In old dense beech woods C is, e. g., 540. After a seed cutting in the same woods during the final stage of regeneration C is only 450 (observation by Dr. Wimmenauer).

Trees growing as cones would grow, have C equal to 600; trees growing as Apollonian paraboloids would grow, have C equal to 800; after Stoetzer, C might amount to as much as 930, in case of suppressed trees. The minimum possible (in sound trees) for C is 400.

The Pressler values given in the table of the preceding paragraph closely correspond with the constant factors of increment ascertained after Stoetzer. In the case of the Pressler table (at end of Paragraph LXXXVII.) we find, for medium height growth and very small crown, a factor 3.00 by which the diameter increment percentage is to be multiplied. This factor 3.00 corresponds with 600 for a constant factor of increment.

If the diameter in the midst of the bole is $\frac{1}{2}$ of the diameter at the end, then the tree, it seems, is conical, and an increment factor of 600 might be assumed. If the sectional area in the midst of the bole equals $\frac{1}{2}$ the sectional area at the end, then the tree is a paraboloid, and the increment factor seems apt to be 800.

It must be remembered, however, that a tree forming a paraboloid grows as a paraboloid only, if its percentage of height growth is equal to its percentage of growth of sectional area—a rare case in merchantable trees.

Similarly, a tree growing as a cone must have the height increment percentage equal to its diameter increment percentage.

If n and ν represent the number of rings per inch added to original diameters d and δ at chest height and at 0.45 of the height of the tree respectively, then the "constant factor of increment C " is found as follows:

$$p \text{ (volume)} = \frac{400}{\nu \delta} = \frac{C}{nd}$$

$$C = 400 \frac{nd}{\nu \delta}$$

PARAGRAPH LXXXIX.

INTERDEPENDENCE BETWEEN CUBIC INCREMENT AND INCREMENT IN FEET B. M. DOYLE.

Doyle's rule under-estimates the contents of small logs and over-estimates those of big logs.

Consequently, the growth of a tree bole in feet b. m. Doyle is (for small trees yielding logs under 28" diameter) relatively faster than the growth of a tree bole expressed in cubic feet. The figures of Column D denote, in the following table, this excess rate of growth:

A Diameter of logs without bark.	B No. of ft. b. m. per one cu. ft. of tim- ber estimated after Doyle.	C Differences of con- secutive figures in Column B.	D "Extraordinary" percentage of incre- ment Doyle co-in- ciding with 1" growth.
12"	5.09		8.1
13"	5.50	0.41	6.4
14"	5.85	0.35	5.7
15"	6.18	0.33	4.2
16"	6.44	0.26	4.3
17"	6.71	0.27	3.3
18"	6.93	0.22	2.1
19"	7.07	0.14	3.2
20"	7.33	0.26	2.5
21"	7.51	0.18	2.2
22"	7.67	0.16	2.0
23"	7.82	0.15	1.7
24"	7.95	0.13	1.8
25"	8.09	0.14	1.4
26"	8.20	0.11	1.5
27"	8.33	0.12	1.1
28"	8.41	0.09	1.1
29"	8.52	0.11	1.0
30"	8.60	0.08	...

For the standard rules, the increment percentage of a tree can be ascertained by cubic measure as well as by standard measure.

If n years are required to form one additional inch of diameter, then the extraordinary percentage of Doyle-increments amounts annually to $\sqrt[n]{1.0D}$, wherein D represents the values of Column D in the foregoing table.

By this factor $\sqrt[n]{1.0D}$, the cubic volume increment percentage of a bole may be converted, *ceteris paribus*, into Doyle increment percentage, provided that

1. The cubic increment percentage of the total bole coincides with the cubic increment percentage of the merchantable bole;
2. The merchantable bole does not increase in length during the period of observation.

PARAGRAPH XC.

CONSTRUCTION OF VOLUME TABLES.

Volume tables are "tree yield tables" from which the volume of a tree of given species, given age, given diameter breast high or stump high, given height, given merchantable bole, given position (suppressed, dominant, etc., or isolated, crowded, etc.), given locality and so on can be readily read. The units of volume are cubic feet, board feet, standards, cords, etc., according to the requirements of the case.

Obviously, volume tables give, or should give, the volumes of average trees; they may give, in addition, the maximum and minimum volume possible in a tree of stated description.

Volume tables are constructed either on the basis of hundreds (thousands) of measurements taken from trees actually felled in the woods (possibly also sawn at a saw mill, to ascertain the grades) or on the basis of a smaller number of complete section analyses.

The rapidity of volume growth of a species and the development of its form height depend on many local factors—notably on climate, soil, silvicultural systems at hand, influence of fires, fungi, insects, etc.

Owing to the multitude of local factors influencing the volumes and the changes of volumes, local volume tables alone are entitled to a place in exact mensuration.

Volume tables for second growth are more reliable than volume tables for first growth.

Circular 445 of Bureau of Forestry defines volume table as "a tabular statement of the volume of trees in board feet or other units upon the basis of their diameter breast high, their diameter breast high *and* height, their age, or their age *and* height."

The method of construction of volume tables is either mathematical or graphical.

1. *Mathematical method.*

The volumes ascertained for trees of a given diameter (breast high or stump high with or without bark), a given merchantable length or total length, a given age or a given quality or locality are added up.

The sum total of these volumes divided by the number of trees forming it yields the average volume of the tree of stated description.

These averages are shown, for the various diameters, lengths, ages and localities, in tabular form.

The volumes corresponding with such diameters, lengths, ages and localities, for which sample trees were not cut and measured, are found by arithmetic interpolation.

Finally, the differences in volume shown by average trees of similar description (*i. e.*, differing but slightly in diameter, length, etc.) are formed and rounded off in a manner causing the volumes to show a more steady mathematic progression.

2. *Graphic method.*

The volume of each tree measured is entered as the abscissa on a diagram-system of co-ordinates, whilst the diameters of the trees (or the age, etc.) are registered on the ordinate axis. Similarity of length is indicated by color of mark representing the tree; similarity of locality is indicated by the form of the mark (square, triangle, cross, circle, etc.).

Corresponding marks are then joined by chains (having square, circular, triangular links) of the proper color.

Finally, average curves as well as maximum and minimum curves are drawn for the various colors and forms of marks.

Maximum and minimum curves should not represent the very best and the very worst possibilities; they should represent the average of very good and very bad trees.

The graphic method is more reliable, because less depending on mere figures, than the mathematical method. Both methods are frequently combined.

A number of complete tree analyses furnishes more reliable results than a large number of mere volume measurements because it yields more reliable curves (guide-curves) of development for one and the same locality, and because it prevents the forester from drawing curves of growth at random.

If the sample trees (or sample logs) are sawn up at a saw mill where the lumber is properly graded according to the inspection rules prevailing for the species in question, the volume tables may also give the actual average output of specified trees in lumber of the various grades.

SECTION II.—INCREMENT OF A WOOD.

PARAGRAPH XCI.

INCREMENT OF FORESTS.

The volume increment of the virgin forest is on the whole nil.

In America the value increment of a primeval forest is based more on a price increment of stumpage than on a volume increment of trees. The volume increment, in addition, can scarcely be ascertained with sufficient accuracy for a given piece of forest at a reasonable expense.

In second growth forests, on the other hand, say in Virginia, an absolute knowledge of the productiveness of the forest renders forestal investments safer in the eyes of the owner; and the safety of the investment it is which alone can tempt the capitalist to invest in forestry. A knowledge of

the increment in second growth woodlands can be obtained from tabulated statements ("yield tables") showing the rate of growth for woodlands of a given species in a given locality. Under normal yield tables are understood such tables which give the rate of growth for even-aged, pure, normally stocked, well thinned woodlots for given localities (compare Paragraph LIII. and XCIV..).

Such normal yield tables are constructed abroad for beech, pine, spruce, fir and oak. In this country they exist only in Pinchot's and Graves' yield tables for white pine. In America, pure even-aged woods are found in rare cases only (taeda, echinata, rigida, jack and longleaf pines, tamarack, coppicewood).

In the construction of normal yield tables the following points require consideration:

1. The different methods of construction (Paragraph XCII.).
2. The combination, interpolation, adjustment and correction of the results (Paragraph XCIII.).
3. The contents and use of yield tables (Paragraph XCIV.).

PARAGRAPH XCII.

METHODS OF CONSTRUCTION OF NORMAL YIELD TABLES.

Normal yield tables may be based on:

A. Repeated survey of some typical woodlots during their entire lifetime.

B. Repeated survey of different woods standing on an equal quality of soil, during a period of years equal at least to the longest difference in age found amongst them.

C. One-time, simultaneous survey of a very large number of woods of different ages standing on different qualities of soil. Missing links are here obtained by graphic or mathematical interpolation (Paragraph XCIII.).

If tables are constructed by repeated survey of several woods (B), it is often found that the links cross one another for unexplainable reasons.

PARAGRAPH XCIII.

GATHERING DATA FOR NORMAL YIELD TABLES.

In order to see whether or not two woods, in the case C of the preceding paragraph, belong to the same chain of growth, two methods are in use:

- a. The horn or curve method, after Baur.
- b. The stem analysis method.

Remarks on *a*:

The contents and age of all woods (normal) surveyed are plotted in a diagram, the age forming the abscissa and the volume the ordinate of the system.

Curves are then drawn outlining the maxima and minima of growth observed.

The horn-shaped space between these curves is divided into a number of sectors equal to the number of yield classes to be distinguished. The middle line of each sector illustrates the productiveness of its class.

The average height growth is obtained in a similar way, the height data forming the ordinates in a system of co-ordinates.

Baur finds that the allotment of a given plot to a volume-sector corresponds with its allotment to a height sector. In other words, the height is, after Baur, an absolutely reliable indicator of the quality of the soil, or, what is the same, of the yield class.

The growth of sectional area, height and volume being known, the development of the form factors for the various sectors is readily obtained from the fraction $\frac{v}{s \times h}$.

Remarks on *b*:

An analysis of the average stems in lots surveyed would not throw any light on their connection as members of one and the same chain of observation. After Robert Hartig, the 200 strongest trees are analyzed. After Wagener, the ideal cylinders merely of these 200 strongest stems are analyzed by ascertaining their height growth and their diameter growth at breast height. Weise and Schwappach are satisfied with an analysis of the heights merely of the 200 best stems.

The selection of sample plots is not easy, even in second growth raised under forestal care. A valuation survey establishes for each plot the number of stems and the sectional area for each diameter class of stems (usually divided into 5 classes); further, the average age and the average height of the plot. The volume is then figured out, usually, according to the Draudt-Urich method.

The experiment stations maintained by the European Governments control the growth of a large number of experimental plots, which should not be smaller than $\frac{1}{2}$ acre each.

The sample plots are corner marked, and, more recently, the individual trees contained therein are numbered consecutively. Surveys of these plots are made every five years. The point of measurement is indicated by a chalk line.

In America normal sample plots have not been established as yet by the Bureau of Forestry in second growth. The sample plots at Biltmore do not represent a normal second growth.

PARAGRAPH XCIV.

NORMAL YIELD TABLES, THEIR PURPOSES AND CONTENTS ABROAD.

Normal yield tables are especially used for the following purposes:

1. To ascertain the quality of the soil (*e. g.*, for taxation).
2. To ascertain the volume of the growing stock.
3. To ascertain future yields of the forest.
4. To solve problems of forest finance, especially those of forest maturity (length of rotation).

German normal yield tables have the following contents:

A. Tables for the main forest—the secondary forest comprising such trees on the same lot as are about to be removed by way of thinning:

- (1) Age, graded at five year intervals.
- (2) Number of trees.
- (3) Sectional area at chest height, inclusive of bark.
- (4) Average diameter.
- (5) Average height and height increment.
- (6) Volume in cubic measure arranged according to assortments as logs, fuel, bark, etc.
- (7) Periodical and average annual volume increment.
- (8) Increment percentage.
- (9) Form factor.
- (10) Normal growing stock.

B. Tables for the secondary forest, giving merely its volume, which, as stated, is to be removed by way of thinning.

Circular 445 of the Bureau of Forestry defines "future yield tables" as follows: "A tabular statement of the amount of wood which, after a given period, will be contained in given trees upon a given area expressed in board feet or some other unit."

PARAGRAPH XCV. RECONSTRUCTION OF

RETROSPECTIVE YIELD TABLES. STAND (OLD)

In "retrospective" yield tables an attempt is made to rebuild the growing stock as it was before lumbering from the stumps found on the ground and from stem analyses of the trees now standing. Prerequisite is a knowledge of the year in which lumbering took place and of the conditions of growth since prevailing.

Method of proceeding:

1. Make stem analyses and construct tree volume tables, showing the probable contents of trees for stumps of a given diameter and for given diameters *b. h.*

2. On land cut over n years ago, find by valuation survey and stem analyses:

- a. The present volume "F."
 - b. The volume "y" of the trees now standing as it was "n" years ago with the help of tree volume tables.
 - c. From the stumps the volume "x" of the trees logged "n" years ago.
3. A product of "F" units (with an undergrowth not fit for logging) has been derived in "n" years from an original stand aggregating "y" plus "x" units of volume.
4. Grouping hundreds of sample plots together, yield tables for local use are obtained. Misleading is, of course, the multiplicity of conditions (mixture of species, soils, original stands, pasture and fire) surrounding a second growth which check the applicability and the combination of the tables found.

The tables are way signs, not ways, toward a true knowledge of the productiveness of cut-over woodlands.

PARAGRAPH XCVI.

YIELD TABLES OF THE BUREAU OF FORESTRY.

Bureau yield tables are meant to show the growth on cut-over land occurring within the next 10, 20 or 30 years, if a tract is logged to a 10", 12" or 14" (or any other) limit. Bureau yield tables are based on tree volume tables and on an account of the numbers of tree individuals found in the various age classes of forest, viz., diameter classes of trees.

The influence of the different qualities of soil on tree growth is not given, only one average volume table being constructed. The volume tables show the number of years which a tree requires to increase its diameter b. h. by one inch. The volume tables record, in addition, the volume increase corresponding with such diameter increase. Applying these findings to the stumpage presumably left after logging, the volume can be ascertained which is expected to be on hand 10, 20 or 30 years later. The volume growth is forecasted, as if it were taking place under primeval conditions.

The Bureau neglects entirely the death rate of trees, due to natural causes and especially high amongst seedlings and saplings, or else due to the logging operations themselves. The results forecasted in this way must be invariably too high.

Pinchot's Spruce Tables (The Adirondack Spruce, p. 77) are based on similar premises:

a. Construct volume tables by stem analysis (stump-analysis) on land cut over for a second time, thus showing rate of growth for trees left standing at the first cut.

b. Construct tables, by actual measurements in the woods, giving the

number of trees of the various diameters, composing a stumpage of from 1,000 to 12,000 feet board measure.

c. Predict the number of trees and their exact diameters to be found 10, 20 or 30 years after logging, according to severity of logging (diameter limit).

d. With the help of the volume tables, give the contents of these trees.

In these tables as well, the death rate amongst trees is disregarded. For normal death rate, compare Pinchot's "White Pine," p. 80, ff; also remarks at end of Paragraph LIV.

PARAGRAPH XCVII.

THE INCREMENT OF A WOODLOT.

The current as well as the annual average increment of normal, even-aged woods culminates at a much earlier date than the increment of the trees composing such woods. The explanation lies in the death rate of the trees.

Under a close crown density in even-aged, normal woods, the stronger half of the trees yield, from the pole stage on, practically all the increment, the weaker half of the trees being almost inactive.

The better the quality of the soil, the earlier occurs the culmination of the increment; consequently, on good soil, shorter rotations are apt to be advisable than on poor soil.

Light demanding (intolerant) species show an earlier culmination than shade bearers (tolerant) species.

For white pine woods, after Pinchot, the years of increment culmination are as follows:

Culmination of	For entire volume with bark in cu. ft.			For volume Doyle in ft. b. m.		
	I.	II.	III.	I.	II.	III.
Current incrt....	40th	50th	60th yr.	70th	70th	110th yr.
Average incrt...	60th	80th	100th yr.	135th	160th	210th yr.

I denotes best; II denotes medium, and III denotes poorest quality of soil.

The increment of a woodlot, whether normal or abnormal, can be obtained:

a. With the help of yield tables.

b. By special investigations made into the rate of growth of sample trees (Paragraph XCVIII.).

c. With the help of the average annual increment of the woodlot (Paragraph XCIX.).

The increment of a past period is never exactly equal to that of a future period, unless the age of the woods is close to that year at which the increment culminates. The increment percentage during a past period is always larger than the increment percentage during a coming period (aside of temporary increase due to light-increment).

The general laws (Paragraph LXXV.) relative to the culmination, increase and decrease of increment hold good for the volume increment of woodlots as well as for that of trees.

PARAGRAPH XCVIII.

ASCERTAINING THE INCREMENT OF WOODLOTS BY SAMPLE TREES.

The current annual volume increment and the volume increment percentage of a wood, from which its maturity largely depends, can be correctly found only by a valuation survey, combined with an investigation into the present rate of growth exhibited by a number of sample trees.

Borggreve recommends to gauge the increment of the sample trees by the Schneider increment percentage. This is usually insufficient.

The correct volume increment percentage p of a woodlot is obtained from the volume increment percentage p_1, p_2, p_3, p_4 and p_5 of the class sample trees—which represent class-volumes v_1, v_2, v_3, v_4 and v_5 —as

$$p = \frac{v_1 p_1 + v_2 p_2 + v_3 p_3 + v_4 p_4 + v_5 p_5}{v_1 + v_2 + v_3 + v_4 + v_5}$$

Where the form heights of the classes differ slightly only, the sectional areas of the classes may be substituted for the volumes of the classes.

Again, where classes of equal sectional area are formed (after Robert Hartig), there the volume increment per cent. of the woodlot equals the arithmetic mean of the volume increment percentages of the sample trees, so that

$$p = \frac{p_1 + p_2 + p_3 + p_4 + p_5}{5}$$

PARAGRAPH XCIX.

CURRENT INCREMENT ASCERTAINED FROM AVERAGE INCREMENT.

Within certain limits, a short time previous and a short time after the culmination of the average annual increment, the annual average increment equals the current increment and can be used in its place as a basis for yield calculation. European Governments frequently prescribe this *modus operandi* for yield forecasts in working plans.

CHAPTER IV.—LUMBER

PARAGRAPH C.

UNITS OF LUMBER MEASUREMENT.

For rough lumber one inch thick, or thicker, the unit of measure, known as one foot board measure, is a square foot of lumber one inch thick. This unit is the $\frac{1}{12}$ th part of a cubic foot.

For rough lumber thinner than one inch, the unit of measure, also known as one foot board measure, is the superficial square foot, and the thickness of the lumber is here entirely disregarded.

All dressed stock is measured and described as if it were the full size of the rough lumber necessarily used in its manufacture. "Inch flooring," e. g., is actually $\frac{13}{16}$ inch thick; and " $\frac{3}{8}$ inch ceiling" is actually $\frac{5}{16}$ inch thick.

Standard thicknesses are:

$\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3×4 ".

Standard lengths are:

in hardwoods 6 to 16 feet;

in softwoods 10 to 24 feet.

In both cases, lengths in even feet (not in odd feet) are required.

A shortness of 1" or 2" in the length of hardwood boards is disregarded.

Standard defects are:

- I. In hardwoods: one sound knot of $1\frac{1}{4}$ " diameter;
 one inch of bright sap;
 one split, its length in inches equalling the contents of the board in feet b.m.

II. In softwoods: sound knots, viz.:

- (a) pin-knots of not over $\frac{1}{2}$ " diameter;
- (b) standard knots of not over $1\frac{1}{2}$ " diameter;
- (c) large knots of over $1\frac{1}{2}$ " diameter;

pitchpockets, viz.:

- (a) small pitchpockets $\frac{1}{8}$ " wide;
- (b) standard pitchpockets up to $\frac{3}{8}$ " wide and up to 3' long;

pitchstreaks, viz.:

- (a) small pitchstreaks not wider than $\frac{1}{2}$ the width and not longer than $\frac{1}{6}$ the length of board;
- (b) standard pitchstreaks with dimensions up to twice as large as given under (a);

sap, viz.:

- (a) bright sap;
- (b) blued sap;

splits, wane, scant width, tongues, less than $\frac{3}{16}$ " long.

The point at which a defect is located greatly influences its effect on the grade of the lumber.

The two faces, the two edges and the two ends of a board must be parallel. In case of unevenness, the thinnest thickness, the narrowest width and the shortest length are measured.

Lumber is measured with the help of a lumber rule (Lufkin rule) which yields for inch boards of given lengths and given width the corresponding contents in feet b. m.

In measuring the widths, fractions of an inch are neglected in rough lumber.

PARAGRAPH CI.

INSPECTION RULES AND NOMENCLATURE.

The lumber inspection prevailing in a given market is governed by local custom or by agreement within the body of local associations of lumbermen.

The tendency of all inspection rules is directed toward a gradual lowering of rigidity.

The wholesaler's inspection is generally stiffer than that of the manufacturer. Diversity of rules is a sadly demoralizing element in lumber circles.

Lumber sawn for special purposes (*e. g.*, wagon bolsters) must be inspected with a view to its adaptability for such special purpose.

A. *Hardwood.* The grade of a board depends on

1. Its width and length;
2. Its standard defects;
3. The percentage of clear stock contained therein;
4. The number of cuttings yielding such clear stock.

The following table shows average specifications prevailing for the various grades of hardwood lumber in the U. S. markets.

The defects specified invariably indicate the coarsest stock admissible in a given grade.

Designation of Grade.	HARDWOOD LUMBER SPECIFICATIONS.						
	Minimum		Actual		Allows of		
	Len'h feet.	With inch- es.	Length feet.	Width inches.	No. of standard defects.	Rate of clear stock.	Con'd in c't'ngs not more than
Firsts.....	10	8	10 & over	8 & 9	none	Practically all.	Practically one.
..	..	..	10 & over	10 & over	one		
Seconds.....	8	8	8	8 & 9	none		
..	..	..	8	10 & over	one		
..	10	6	10 & over	6 & 7	none		
..	..	..	10 & over	8 & 9	one		
..	..	..	10 & over	10 & 11	two	Practically one.	Practically one.
..	..	..	10 & over	12 & over	three		
No. 1 Com...	6	6	6	6 to 8	none	all	1
..	..	..	6	9 & over	one	all	1
..	8	4	8	4	none	all	1
..	..	..	8	5	one	all	1
..	..	..	8 & 10	6 & over	.....	all	2
..	..	..	12 to 16	6 & over	.....	all	3
No. 2 Com...	6	3	6 to 10	.....	.....	$\frac{1}{2}$	3
..	..	..	12 to 16	.....	.....	$\frac{1}{2}$	4
No. 3 Com...	4	3	.....	.....	.....	$\frac{1}{4}$	..

B. *Softwoods.* Softwood lumber is inspected from its best side Under "edgegrain" is understood lumber the face of which forms an angle of less than 45 degrees with the plain of the medullary rays contained in the board. All other lumber is termed "flat grain" or "slash grain," also "bastard grain."

I. *Finishing Lumber*, 1" to 2" thick, dressed one or two sides.

1. First and second clear,
up to 8" wide; absolutely clear;
10" wide; one small defect permitted;
12" and over wide; $\frac{1}{3}$ of stock may have one standard knot or its equivalent.
2. Third clear,
allows of twice as many defects.

II. *Flooring*, 1" thick and 3" or 4" or 6" wide before dressing; either with hollow back or with solid back;

1. A, B and C flat grain flooring; wherein "A" is clear and "B" allows of one or two standard defects;
2. A, B and C edgegrain flooring; with the same allowance;
3. No. 1 and No. 2 fence flooring.

- III. *Ceiling*, $\frac{3}{8}$, $\frac{5}{8}$ and $\frac{3}{4}$ inch thick; 3, or 4, or 6 inches wide.
1. "A" ceiling and "B" ceiling, with small defects only;
 2. No. 1 and No. 2 common ceiling, with one and two standard defects, or their equivalent.
- IV. *Drop Siding*, which is either "shiplapped" or "tongued and grooved;" it is $\frac{3}{4}$ " thick and $3\frac{1}{4}$ or $5\frac{1}{4}$ inches wide. Grades A, B and No. 1 common.
- V. *Bevel Siding*, which scales $\frac{3}{16}$ " at the thin edge and $\frac{1}{2}$ " at the thick edge, resawn from stock dressed to $\frac{1}{8}$ " x $5\frac{1}{2}$ ". Grades as under IV.
- VI. *Partition*, measuring $\frac{3}{4}$ " x $3\frac{1}{4}$ " or $\frac{3}{4}$ " x $5\frac{1}{4}$ ". Grades as under IV.
- VII. *Common Boards*, graded as No. 1, No. 2 and No. 3 common boards, 8", 10" or 12" wide, dressed one or two sides, or rough.
- VIII. *Fencing*, graded as No. 1, No. 2 and No. 3 fencing, 3", 4" or 6" wide. The grade "No. 3" includes defective lumber with knot-holes, red rot, very wormy patches, etc., on $\frac{1}{2}$ of the length of the board. Fencing is either dressed or rough.

CHAPTER V.—STUMPAGE VALUES

PARAGRAPH CII.

STUMPAGE VALUES.

Forestry is a business; the forest largely represents its business investment; its purpose is the raising of money, of dividends.

Thus it is with investments and the dividends therefrom that the forester is concerned; and it is the task of "forest finance" and "forest management" to ascertain the factors and to regulate the components of such investments.

Forest mensuration, as a subsidiary to forest management, may well devote a chapter to the measurement of the stumpage value of trees.

Stumpage value is the price which a tree brings or should bring if it were sold on the stump.

The stumpage-value of a tree depends on the value of the lumber contained therein and obtained therefrom, deducting the total expense of lumber production (logging, milling, shipping, incidentals.)

Since the value of lumber fluctuates, as well as the cost of production, stumpage values are subject to continuous variation. The tendency of stumpage prices, all over the world, is a tendency to rise—especially so in countries of rapid development, rapid increase of population and inadequate provisions for re-growth.

The cost of production is composed about as follows:

1. Expense of logging and log transportation, varying locally between \$2 and \$5 per 1,000' b. m.
2. Expense of milling, varying between \$1.50 and \$5 per 1,000' b. m.
3. Expense of freightage of lumber to the consuming market, amounting per 1,000' b. m. to \$1.50 for very short hauls; to \$12 for a haul from Atlanta to Boston; to \$21 for a haul across the continent from Portland (Oregon) to New England.

Freight rates have, in the long run, a decided downward tendency. Still, with a majority of the lumber produced in the U. S., the item "freight" forms the chief expense of production.

For Pisgah Forest a reduction of freight rates equalling 1 cent per 100 lbs. involves a net gain for the owner of approximately \$60,000. In this possibility lies one of the strongest arguments for conservative lumbering.

An increase of the price of lumber from \$20 to \$21 at the place of consumption endears the lumber to the consumer by 5%; the owner of the forest now valuing his stumpage at \$5 will eventually experience this increase as a 20% increase of stumpage values.

The only factors of stumpage-values, which the owner himself—unaided by the development of the country—may influence, consist in the expense of logging and log freighting, and in the expense of milling, the former largely depending on the quality of available means of transportation, the latter governed by the quality of the sawmill.

In ascertaining the stumpage-value of a tree the forester considers:

- a. The cost per 1,000' b. m. of logging it, of milling it and of freighting its timber;
- b. The volume of timber contained in the tree, by grades;
- c. The value of such lumber, by grades.

If a tree contains

45% of lumber worth \$31 per 1,000' b. m.

It is necessary to find Stoetzer's constant factor of increment or to ascertain the relative increment of the sectional areas of the sample trees at 0.45 of their heights.

35% of lumber worth \$21 per 1,000' b. m.

15% of lumber worth \$16 per 1,000' b. m.

5% of lumber worth \$8 per 1,000' b. m.

then the lumber value of the tree, per 1,000' b. m., is

$$\frac{45 \times 31 + 35 \times 21 + 15 \times 16 + 5 \times 8}{100} = \$24.10$$

Deducting from this figure the expense of logging, milling and freighting, the actual stumpage-value, per 1,000' b. m., is derived.

The actual prices paid for stumpage in the U. S. fall deeply below the figures which a test-calculation is apt to yield.

This discrepancy may be explained, above all, by

Ignorance of owners of stumpage;

Agents' and dealers' profits;

Incidental expenses overlooked.

Stumpage-values show a rapid decrease with the increase of the distance separating the tree from the nearest railroad or stream.

The grades of lumber and their proportion obtainable from logs of given species, diameter and soundness (including presence and location of defects) can be ascertained only by test-sawing in the mill.

This has been done in 1896 for yellow poplar at Biltmore (bandsaw mill). The stumpage-values then ascertained are shown by the following table:

MARKET VALUE OF POPLAR STUMPAGE IN WESTERN NORTH CAROLINA, PER TREE, IN CENTS.

At the age of years.	Under good conditions.				Under average conditions.				Under poor conditions.			
	Diam. inches.	Logging and Milling expenses being per 1000 feet B. M.			Diam. inches.	Logging and Milling expenses being per 1000 feet B. M.			Diam. inches.	Logging and Milling expenses being per 1000 feet B. M.		
		\$9	\$10	\$11		\$9	\$10	\$11		\$9	\$10	\$11
100	....	Nega- tive.	Nega- tive.	Nega- tive.	....	Nega- tive.	Nega- tive.	Nega- tive.	....	Nega- tive.	Nega- tive.	Nega- tive.
120	18.8	8	"	"	....	"	"	"	....	"	"	"
140	21.3	40	25	"	18.2	4	"	"	....	"	"	"
160	23.5	105	72	2	20.4	22	5	"	....	"	"	"
180	25.7	265	170	98	22.4	67	35	"	....	"	"	"
200	27.7	445	325	230	24.3	160	103	30	18.5	"	"	"
220	29.6	620	465	350	26.0	287	200	109	20.0	7	"	"
240	....	....	....	....	27.5	430	330	210	21.3	27	3	"
260	....	....	....	....	....	....	460	330	22.1	60	25	"
280	....	....	....	....	....	....	....	....	....	....	45	"
300	....	....	....	....	....	....	....	....	....	....	....	5
320	....	....	....	....	....	....	....	....	....	....	....	30

FOOTNOTE: Dots below a column of figures indicate higher values, not specifically ascertained.

The values above the columns of figures are all negative and were not ascertained specifically either.

It is to be hoped that similar tests will be made for our leading species on a large scale by the U. S. Forest Service or by the various associations of lumber manufacturers. Conservative forestry as a business badly requires data allowing to estimate the actual value of logs, and hence of trees, if the uncertainty of financial results now checking the progress of conservative forestry in America is to be definitely reduced.

Wt = x P. Percent

$$100 \pm p = 100 \times 1.0p$$

$$100 \dots 100 \times 1.0p$$

$$1 \dots 1.0p$$

$$0 \dots 1.0p \times 1.0p$$

$$0 \dots 1000 \times 1.0p$$

$$0 \dots 1.0p \times 1.0p$$

$$0 \dots (1.0p^2) \times 1.0p$$

$$0 \dots N \times 1.0p$$

$$\text{on increment for } 1p = C \times 1.0p^4$$

Estimate of the ...

Tree: High 130
Age 128

Tree 65-80 years old

Reyes. Rate of growth
is proportional to the
growth

$$p_2 = \frac{400}{n_n d_n} = \frac{X}{n_n d_n}$$

$$\frac{400}{n_d} + 100 \frac{t}{\phi}$$

grain
the
is
 $\frac{1}{2}$
you
in
of

will be well
served, and
the
brown
will show
in sizes 6x6 inches
spots of 1" diameter
only $\frac{1}{4}$ of width
of the spots, not
including the
(order size)

must be sound
 from you & take
 " a larger dose
 of those parts
 and with
 suitable for good
 construction and performance
 with always
 the best results in our
 field trials, sound and
 safe ones, with

Can I see you, please, at
convenient for me of time of week.

[illegible]

101 adms 101
has 8 feet space
only 61.33
direction
direction

Equus no 2
no 2
Y₂ 848
SLIGHT YOUNG MICE
SPOTTER WASHES
SLIGHT SMOOTHER KNOTS
100% FOST LAMINATE

1 Perot of wood & measured $1\frac{1}{4}$ inch average
2 small knots not accounting in estimate
Damage & Standard Knot

1 2 ft length in one end of board not longer
in inches than number of surfaces put in for
wound as Standard Subject 2 ft is over
 $\frac{1}{4}$ inch deep $\frac{1}{2}$ inch wide & $\frac{1}{4}$ of length of board
or 3 equivalent

Pine knots, wound knots, quilled knots not
in estimate of damage & Standard Knot

No 1 common is a board which ends $\frac{1}{4}$ inch
wound for knots on one side & must be set
on other side

Factor $\times$ Sect Area $\times$ Length = contents B.M.

$$\text{mill factor} = \frac{\text{contents } \text{cu m}}{5 \times 2}$$

$$\text{mf} = \frac{11.5}{1.4} = 8$$

$\frac{\text{Vol}}{5 \times H}$ = for getting form factor

$\frac{\text{Vol}}{5 \times H}$ for getting different sizes of boxes needed and
wooden stand/docks