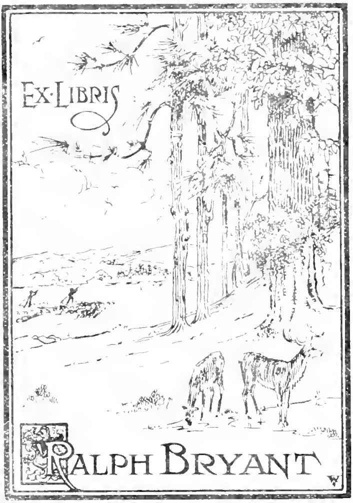
FOREST MENSURATION

HERMAN H. CHAPMAN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FOREST MENSURATION

BY

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TO

Bernhard Eduard Fernow

IN RECOGNITION OF HIS LIFELONG SERVICE
IN PROMOTING FOREST EDUCATION
AND IN DEVELOPING A HIGH STANDARD
OF PROFESSIONAL FORESTRY IN AMERICA

PREFACE

This text is intended as a thorough discussion of the measurement of the volume of felled timber, in the form of logs or other products; of the measurement of the volume of standing timber; and of the growth of trees, stands of timber and forests. It is designed for the information of students of forestry, owners or purchasers of timberlands, and timber operators. The subject matter so treated is fundamental to the purchase or exchange of forest property or of timber stumpage, the valuation of damages, the planning of logging operations, and the management of forest lands for the production of timber by growth.

The publication is intended as the successor of Graves' Forest Mensuration, and was undertaken at the request of the author, H. S. Graves, whose original text, Forest Mensuration, appearing in 1906, set a standard for text-books in forestry and has been of inestimable value to foresters and timberland owners in America. The present text is not a revision of the former publication, but an entirely new presentation, both as to arrangement, methods of treatment and much of the subject matter. The author has in some instances quoted or borrowed portions of the former text and is indebted to it for many of the more fundamental conceptions and descriptions of processes used in Forest Mensuration.

It is the purpose of Part I to bring out the relations of the cubic contents of logs, and their measurement, to the contents as expressed in terms of products, and to encourage the substitution of sound units of measure and methods of measurement for defective standards and methods as far as possible.

The application of these standards to the measurement of standing timber is the subject of Part II. This part presents a complete analysis of the art of timber estimating as practiced in every timber region of the United States, the methods employed by skilled timber cruisers, the principles upon which these methods are based, the relative accuracy of the various systems used, the factors and averages which enter into the use of these methods, and the application of these principles and factors in practical work and in the training of men for timber cruising.

The object sought in Part III is to systematize the principles and problems confronting the student in the study of tree growth, and to so correlate these problems that he is not diverted from the ultimate object of such studies, which is the determination of yields per acre, by details of methods having to do with the measurement of growth of individual trees. Research and field studies of growth per acre are rendered difficult not only by the lack of an accepted unit of measure, but by the great variations in the character of the stands comprising our virgin and second growth forests, yet it is just these stands, and not plantations, whose growth will determine our yields of timber for the next four or five decades.

Attention is called to the substitution of the International $\frac{1}{4}$-inch kerf log rule in the present volume, for the $\frac{1}{8}$-inch kerf rule in Graves' Mensuration. It is hoped that this rule will be accepted as a scientific standard for board feet since it is adapted to conditions of second growth and is conservative in values.

Instead of attempting to include tables of volume or yield, a table of references is printed to such tables as are of standard quality and which are in possession of the U. S. Forest Service, Washington, D. C.

The author wishes to acknowledge the many helpful criticisms received from foresters in the preparation of this book.

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FOREST MENSURATION

PART I

THE MEASUREMENT OF FELLED TIMBER AND ITS PRODUCTS

CHAPTER I

INTRODUCTION TO FOREST MENSURATION

1. Definition and Purpose. Forest Mensuration is that branch of forestry which deals with the determination of the volume of the wood material contained in logs or portions of felled trees, in standing trees, in stands of timber and in forests, expressed in terms of cubic measure, board measure, or any other unit. It also determines the growth and future yields of trees, stands, and forests in any of the above units of volume. The measurement of standing timber is termed *Timber Estimating* or *Timber Cruising.* The commercial measurement of the contents of logs is called *Scaling.*

Forest property is land bearing forest trees as the principal vegetation. The trees may be valued for their appearance, as in parks, their protective influences, as in forests at headwaters of streams, or their wood, as in all forms of commercial use, including by-products such as naval stores and bark. In past logging operations the land has not always been regarded as true forest property, capable of growing other crops of trees; but unless such land has a higher economic value for agriculture, grazing, or other purposes than for any of the three forest uses above mentioned, it is as truly forest property as the timber. The measurement of the volume and growth of timber is an indispensable factor in classifying lands for their highest use, whether for agriculture or forestry.

Forest Mensuration makes possible the systematic management of forest property by ordinary business methods, which require, first, a knowledge of quantities or amount of material, and its location and rate of production,[1] and second, information on which to base the value of the property for the purpose of sale, exchange or the appraisal of damages.

2. Relation between Lumbering and Timber Estimating. The logging of timber is usually conducted as a business venture entirely separate from the growing of trees or management of forest property, but whether this is so, or the forest owner cuts and logs his own timber, the cost of the logging will depend in a great measure on the known quantity of timber which can be brought out over a given route and by a specific method of logging. The greater the volume of standing timber, the greater the investment which is justified in roads, railroads, chutes, or flumes to cut down the expense of hauling. Overestimates cause losses through excessive investments; underestimates cause losses through not investing enough money in these transportation systems. The logger cannot wait until his timber is cut and scaled before planning his operation. Accuracy in timber estimating is therefore an underlying factor in the successful conduct of the business of lumbering.

3. Relation between Forestry and Growth Measurements. Lumbering as a business begins at the stump, while forest production may begin with the seedling, and may well be considered as a separate business enterprise. The growth of trees is the basis of returns on this business, no matter whether these returns are secured on the stump, or by means of the additional operation of logging. The speculator in standing timber hopes to realize a growth in unit prices such as was experienced as a result of the war. But the business of forestry depends for its profits on growth, first, in volume, and second, in quality, of the product by reason of increased sizes and improved texture, increase in prices being merely an additional guarantee of adequate returns. Since growth determines the quantity of products to be expected, any expenditure in planting and care of the forest can be undertaken intelligently only when the probable rate of growth per acre is known. The study of growth is therefore a necessary part of the business of forestry and unless growth data can be obtained, there is no possible method of

[1] *A business* is an undertaking which seeks to supply a public demand. The most common form of business is that which produces raw materials and transforms them into finished products delivered as such to the consumer. Any distinct step in this process may and often does constitute a separate business. To accomplish the purpose of its existence, a business deals with three factors, quantity, location, and time. To supply forest products for the innumerable demands of modern civilization, a well-conducted business operation requires full knowledge of the quantity of raw material and finished products with which it deals, their location, and the time or periods when these quantities will be available. Forest Mensuration is as fundamental to forest production as is inventory and merchandise account to a mercantile business.

determining either the proper investments and expenses, or the probable returns and profits from such an enterprise.

4. Relation between Forest Mensuration, Stumpage Values and the Valuation of Forest Property. In determining the value of forest property for sale, exchange, or the appraisal of damages, it is necessary first to know what the mature standing timber is worth on the stump previous to cutting. This is known as *stumpage value.* The stumpage value of standing timber is derived from the value of the finished products and is influenced by four factors, namely, the species of wood, its quantity, its quality, and the unit price of the product. Forest mensuration by means of a forest survey determines as accurately as possible the first three factors. By determining through an appraisal the price of stumpage for the different kinds and qualities of timber found on the area, the value of the timber may be found.

The value of young timber and of forest soil can be calculated after the possible yields at given ages have first been approximated and the stumpage value has been appraised for this final yield.

5. Relation of Mensuration to Other Forestry Subjects. The relation of Forest Mensuration to other subjects in forestry is shown in Fig. 1. In the threefold division of forestry indicated, mensuration falls in the mathematical or business group, but is included in the physical branch of that group which deals directly with the forest.

Mathematics is the basis of Mensuration, since the latter subject deals primarily with quantities. But as both timber estimating and growth data must usually be expressed on terms of area or acreage, Mensuration rests directly on Surveying.

Mensuration in turn furnishes the quantitative data required by the science of Forest Finance as a basis on which to compute the cost of production and the probable returns from forestry and to indicate the choice of methods to use in forest production. Although it falls in the business group, and is a basic subject underlying Forest Management, Mensuration is a statistical science similar to Forest Finance. Neither subject constitutes an applied science, which is the characteristic of Forest Management. Mensuration is therefore not a direct subdivision of Management, but a distinct subject preparatory to Management.

6. Absolute versus Relative Accuracy in Mensuration. Forest Mensuration attempts to secure as close an approach to mathematical accuracy as the conditions of the problem, the use to which the data are put, and the cost of the work will permit. In scaling, the volumes of logs are determined before sawing, and in timber estimating, the contents of trees and stands are obtained before felling. But no log rule will give the exact quantity of lumber which will be sawed from a given log, and no tree volume table can predict the output in boards from a given tree, since these results will vary with the methods and conditions of sawing and of utilization.

RELATION OF MENSURATION TO OTHER SUBJECTS IN FORESTRY

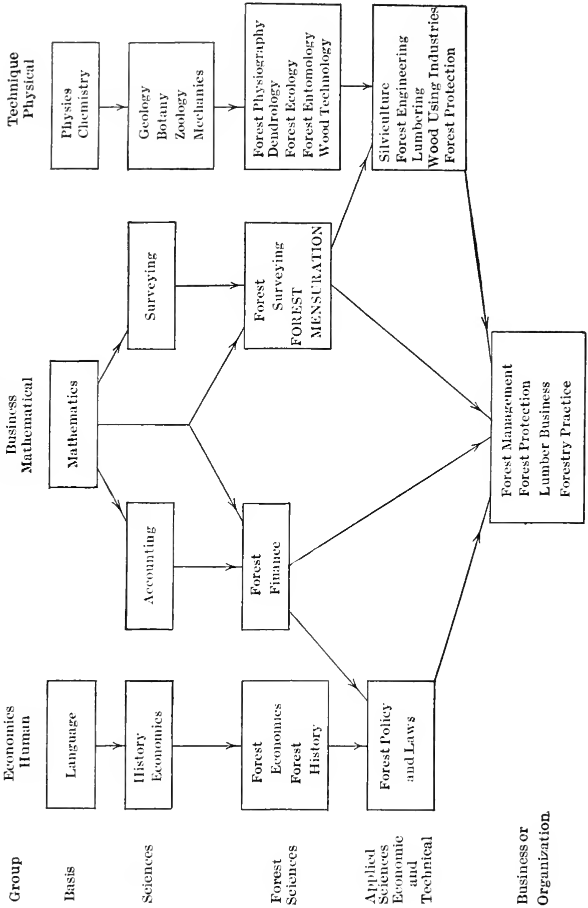

Fig. 1.

Again, in estimating timber it is seldom possible to measure every tree, on account of the time and expense involved. For this reason, only an average portion of the stand may be measured. The laws of averages, or of sampling are applied to solve nearly every problem in Forest Mensuration, in order to bring the cost of the field work within practical limits.

When Mensuration deals with the growth of trees and stands, and of whole forests, its purpose is to predict what will occur in the future. It bases these predictions upon the results which have occurred in the past, under conditions judged to be similar to those which will affect these future stands. The laws of growth of trees, and especially, of stands composed of great numbers of trees competing with each other for existence and supremacy, can only be approximated on the basis of probabilities and averages. The results of living forces cannot be predicted with mathematical accuracy, and the study of growth partakes of the nature of research rather than of routine measurement of definitely determinable quantities.

Neither Forest Mensuration nor Forest Surveying produces any physical change or improvement in the forest, as does the application of silviculture, protection, and lumbering. The achievements of forestry depend upon the amount and character of the actual work done along these latter lines. Misdirected work, done at the wrong time or place and in the wrong quantity, or by too expensive a method when compared with results, means waste, inefficiency, and ultimate ruin and bankruptcy of the enterprise. The data supplied by mensuration and supplemented by forest finance are the balance wheel of forest industry. But the necessity of restricting the funds expended upon the mere collection of data to as small a per cent as possible of the total budget of expenditures, reserving the greater portion for the operations which effect actual change in the forest, is obvious and justifies the use of methods based on averages rather than extreme mathematical accuracy.

7. Forest Survey. Forest Survey is the general term applied to the project of gathering all the quantitative data required regarding a specific forest property. It includes a survey and maps of the area, thus locating the property and its subdivisions, a measurement of the volume and character of the timber, and it may cover other resources such as land classification, waters, forage, game, and fish. Forest Surveying and Forest Mensuration deal with the principles and methods of accomplishing this work. The Survey itself is the enterprise or project of securing the data. Accuracy in the results of a forest survey is judged, not on an absolute standard, but in relation to the balance between utility of the results and the cost of obtaining them, and is therefore always a relative term.

CHAPTER II

SYSTEMS AND UNITS OF MEASUREMENT

8. Systems of Measurement Used in Forest Mensuration. Throughout the United States and Canada the English system of measure is used in all practical applications of Mensuration. In the Philippines the metric system is the standard. (Appendix C, Table LXXIX.) Efforts to substitute the metric system in the United States for the units established by custom have so far failed, though its use was sanctioned by Congress in 1866. Mensuration is applied more generally to the solution of practical problems such as timber estimating than to purely scientific research, and for the former, the results must be expressed in the customary units to be intelligible. Scientific forest measurements have also, except in a few instances, been expressed in English units.

In measuring distances and areas, the chain of 66 feet, or 4 rods, is a commonly used unit. Five chains constitute a tally, or 20 rods; and 16 tallies, or 80 chains, equal 1 mile. One tally forms the side of a square $2\frac{1}{2}$ acres in area. Distances are commonly measured by pacing, or counting the number of paces, the average length of the individual pace having been determined by previous tests. A true pace is the swing of one foot, or twice the length of a step. In counting, the pace rather than the step should be used, since it reduces the count by half.

The acre, containing 160 square rods or 43,560 square feet, is the unit of area. In the rectangular system of survey adopted by the United States the following definitions apply:

Township—a tract approximately 6 miles square containing 36 sections.

Section—a rectangular tract containing approximately 1 square mile or 640 acres, but which may contain more or less than this area in irregular surveys.

Quarter Section—a subdivision of a section containing approximately 160 acres.

"Forty"—a colloquial term describing a $\frac{1}{16}$th section or quarter of a quarter section containing approximately 40 acres.

Lot—a tract ordinarily containing not less than 20 or more than 60 acres, but which may contain less area, of either rectangular or irregular shape, and which takes the place of the "forty" in irregular surveys or bordering lakes or streams.[1]

In measuring trees, the foot is the standard for height, and the inch, divided into tenths of inches, for diameter. *Basal area* is the cross-sectional area of a tree or stand, in square feet, measured at $4\frac{1}{2}$ feet from the ground. This is obtained from area of circles whose diameters equal those of the trees measured.

9. Piece Measure. Wood products which are used in the round, and logs or bolts which are barked, shaped, and reduced to standard dimensions where felled, are usually measured and sold by the piece. These pieces are graded by size and by quality into accepted pieces and culls, or rejects, whose defects render them unfit for the special purpose required. The standard sizes are determined by specifications, which also prescribe the species of tree and the required quality of the product. The principal products purchased on this basis are cross ties, poles, posts, piles, and mine timbers.

Where bolts of uniform size are sawed or split for manufacture into special products, they may be counted and paid for by the piece. Their average volume is determined beforehand. When the number of pieces per cord, or per thousand board feet is agreed on, the payment may be in terms of these latter units.

Linear measure is sometimes used for pieces of standard width and thickness but of variable length. Such products are sold by the linear foot. This standard is widely used for piling.

10. Cord Measure. When the pieces into which trees are sawed or split are of lengths shorter than ordinary logs, and of irregular shape, the expense of determining separately the contents of each piece is avoided by stacking them in regular piles or cording them up, and measuring only the exterior dimensions of the stack to get the total stacked cubic space occupied. This stacked cubic measure does not indicate the solid contents, which may vary widely. But if the average per cent of solid contents per cubic foot of stacked measure is known for sticks of given sizes and character, this stacked measurement becomes a practical and serviceable standard, though not well suited to scientific investigations.

The cord is the standard generally adopted for stacked wood.

[1] References. Manual of Surveying Instruction for the Survey of the Public Lands of the United States and Private Land Claims, Commissioner of the General Land Office, Washington, D. C., Government Printing Office, 1902.

Manual for Northern Woodsmen, Austin Cary, Part I. Section VIII, 1918. Harvard University Press, Cambridge, Mass.

The standard cord is 4 by 4 by 8 feet, containing 128 cubic feet. There are, however, other cord units in use (Chapter IX).

11. Cubic Measure. The cubic volume of trees and logs affords the only basis of accurate and permanent scientific records, and a uniform standard of measurement. For this purpose the cubic foot should be used as the standard unit.

Where cubic volume was employed by lumbermen, other cubic units, whose contents were based on cylinders of given sizes, have been adopted arbitrarily. These units possess no advantages over the cubic foot (Chapter IV).

In most regions, the desire to express the contents of logs in terms of sawed lumber prevented the adoption of the cubic foot as the standard of measurement for logs.

12. Board Measure. Board measure may be defined as a cubic standard for measuring sawed lumber. A board foot is a board 1 foot square and 1 inch thick. Twelve board feet of sawed lumber equal 1 cubic foot. The board-foot contents of sawed lumber is found by multiplying the product of the width and thickness in inches by the length in feet and dividing by 12.

13. Log rules. A log rule is a table giving the contents of logs of different diameters and lengths. The unit of volume used may be based on cubic measure, or board feet. The latter form of table differs from that based on cubic contents since it indicates only the net volume of the product in boards which result from sawing the log. The use of such log rules is to measure the contents in the log before sawing, as a basis of sale of logs or for other purposes requiring such measurement. Fixed or arbitrary values are assigned or agreed upon for logs of each diameter and length. The table thus becomes a standard of measurement based upon a unit of volume.

This method of measuring logs has consequently led to the development of numerous log rules whose construction is discussed in Chapters IV, V and VI. These rules differ, some of them greatly, for logs of the same dimensions.

To secure the universal adoption of a single log rule which is at once accurate and acceptable is probably an impossible task, and several of the more widely used ones will no doubt continue as standards.

14. Measurement of Standing Timber, Postponed till after Manufacture. This lack of standardization as to units for board-foot contents of logs inevitably reacts upon the accuracy and consistency of measurements of the board-foot contents of standing timber. The contents of a given stand will vary widely with the log rule used in estimating.

The custom of estimating standing timber in terms of the product is not confined to measurement by board-foot log rules. Hewn ties, poles, staves and other piece products are customarily used as units for timber estimating, when the timber is to be used for these purposes.

Thus the standard commonly sought in America for measuring standing timber is the net merchantable volume, which results from deducting all forms of waste in manufacture from the total contents of the tree.

There is but one accurate method of measuring this net contents, and that is to postpone the measurement until the timber is logged and manufactured into boards or other products. Since a purchaser of standing timber is always conservative wherever a doubt exists, it is to the owner's interest to sell on the basis of actual mill cut of boards or output of other products, whenever this is possible. This basis is often used in regions where the timber is cut by small portable mills, located in or near the tract and where small amounts are purchased.

15. Measurement of Standing Timber Postponed till after Logging. Where the logs must be driven down streams or hauled long distances by the purchaser, this basis becomes impractical both because of the delay in settlement of account and the difficulty of checking the output of lumber. The timber owner is thus forced to substitute a log scale for a mill tally of lumber. This scale is always based on some log rule agreed upon beforehand, and may or may not give results coinciding with the actual sawed output. If the log rule is known to be inaccurate, the excess or deficiency of manufactured products can be ascertained only by a comparison of the mill tally with the log scale. Such comparisons will give an idea of over-run or under-run (§ 46). The owner can then adjust the price in subsequent sales of logs according to the difference between the scaled contents of his logs and their probable output in sawed lumber.

16. Measurement of Standing Timber in the Tree. But even the log scale is inapplicable when standing timber is purchased in large amounts and a long period is required for completion of logging. The owner desires prompt payment even if based on a less accurate measurement of volume. The volume of the standing timber must be measured as well as possible, and since, at best, only the diameter of the trees together with a few heights can be actually determined and the rest of the work is done ocularly or by guess, the result is only a rough estimate. This method has given rise to the term *Timber Estimating.* The principal sources of error in timber estimating lie in the effort to arrive at the net merchantable contents minus waste, in the use of inaccurate and variable standards of log measure for this purpose, and in the difficulty and cost of determining even the superficial dimensions of standing trees. This leads to short-cut methods, approximations and guess work and calls for the development of system and of personal skill. One improvement in timber estimating widely used by foresters is the tree-volume table, which gives the average contents of entire trees of different dimensions, in terms of standard log rules or other units, thus eliminating a certain amount of ocular work.

17. Need of Standardization for Both Commercial and Scientific Measurements. The justification of the use of standards which give the contents of standing timber in terms of products, rather than actual cubic volume, lies in the fact that the value of the timber, standing or cut, depends upon the volume and quality of these products and not upon the cubic volume.

Had it been possible to secure the adoption of a uniform standard of conversion into board feet, the use of this standard would be more serviceable than the apparently simpler cubic standard. But in practice the same motives which here gave rise to standards based on products have led the French to adopt, as substitutes for cubic measurement, rules of thumb which are less accurate by far than many of our log rules.[1]

The greatest drawback to the use of units intended to measure the product directly lies not in their character but in their inaccuracy and in the multiplicity of standards. It is easily seen that volume tables and measurements of growth which are based on some widely used commercial log rule may coincide with custom, but are incapable of use or comparison with other log rules (§ 77) and are inaccurate as a scientific basis of measuring growth or volume. This fact has led to endless duplication of effort and has been the chief reason for the lack of real progress in accumulating standard data on volume and growth of American trees.

A continuance of such duplication of effort will hinder the progress of forestry in America, which must depend in a large part upon the accuracy of volume and growth data gathered by forest measurements. While the local value of data based on log rules sanctioned by custom will continue, these field data should be gathered in such form as to be of permanent value independent of these variable local standards.

It is possible to convert all measurements to the common standard of cubic feet, which gives a basis of scientific comparison between the volumes of different trees and species, and a permanent basis for measurement of growth for trees and stands. It is also possible to adopt, for the purposes of permanent record, a log rule based on scientific principles which will give an equally reliable comparison of the contents of trees in board feet and the growth of stands expressed in this unit of product.

But for a permanent record from which the volumes of trees may be derived in any unit of product, standard or local, the average form of the

[1] Mensuration in France, Donald Bruce, Journal of Forestry, Vol. XVII, 1919, p. 686.

tree is required, as expressed in diameters at different points on the stem. Investigations of tree form are therefore at the root of all permanent progress in Mensuration (Chapter XVI).

18. Forms of Products into which the Contents of Trees are Converted. The products manufactured from trees may be classed according to the following grouping:

Group I. Manufactured products of definite form, retaining the wood structure and requiring waste in manufacture.

- A. Manufactured from logs.
  - 1. Lumber
    - *a*. For construction.
      - 1′. Structural timbers.
      - 2′. Dimension.
      - 3′. Boards.
      - 4′. Remanufactured or planing mill products.
      - 5′. Special products.
      - 6′. For export.
    - *b*. For remanufacture. Square edge or round edge.
      - 1.′ For mill work, furniture, fixtures.
      - 2.′ For utensils and supplies.
      - 3.′ Boxes and containers.
  - 2. Veneers.
  - 3. Manufactured direct from log for finished articles.
- B. Manufactured from bolts.
  Billets, flitches, squares, blocks, shingles, spokes, staves, etc.
- C. Manufactured from mill refuse, i.e., from slabs, trimmings and edgings. Shingles, lath, boxboards, etc.

Group II. Bulk products in which the form or both form and structure are destroyed.

- 1. Excelsior.
- 2. Wood pulp.
  - *a*. Mechanical.
  - *b*. Chemical.
- 3. Distillates.
- 4. Extracts.
- 5. Fuel.
  - *a*. Charcoal,
  - *b*. Fuel wood.
- 6. Bark.

Group III. Piece products retaining in whole or in part the original form.

- 1. Round products,
  Poles, piling, posts, etc.
- 2. Shaped products,
  Hewn cross ties.
  - 1′. Standard ties.
  - 2′. Mine ties.

Group I. In converting round logs into lumber, there is unavoidable waste in sawing due to the difference in shape between the products desired and the log, and to the saw kerf. The per cent of waste depends upon the dimensions of the smallest board which is merchantable, and upon the thickness of saw used. Further intensive utilization of slabs (pieces slabbed off from the round surface of logs in sawing) and of edgings (pieces cut from the edges of boards to give parallel edges and remove bark), by manufacture into sawed products depends upon finding a market for pieces whose size is small enough to permit of their manufacture from these otherwise waste products.

The waste in manufacturing articles direct from the log depends on the shape of the manufactured article with reference to the bolts from which it is made. Unless profitable use can be found for the portions so wasted, or unless antiquated methods and machinery are in use, the portions of a tree or log lost in manufacture cannot be regarded as wasted, any more than the loss in bulk of a rough block of stone in process of transformation under a sculptor's hand is considered waste. It is for this group that log rules are required.

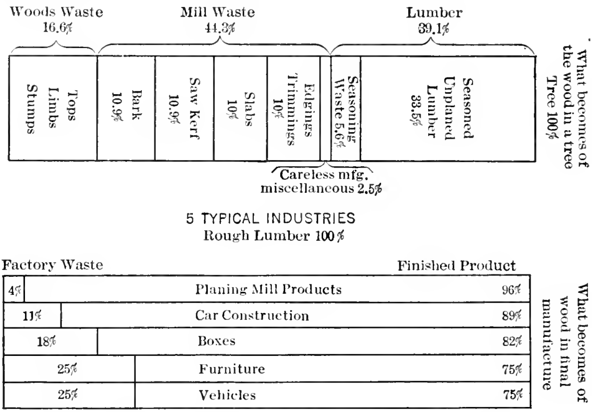

Fig. 2.—The percentage of utilization of the volume of a tree when manufactured into lumber.

Group II. To this group belong also those waste products from Group I for which use as bulk materials can be found. The characteristics of this group are that the entire volume of the log, and a much larger per cent of the volume of the tree is utilized than in Group I. Material may be taken to very small diameters, since size is not a requisite of utility but merely a convenience in handling. For this group, cubic volume is the required standard of measurement, and the use of stacked cubic measure is customary.

Group III. Nearly all the round or shaped products in this group may also be obtained from larger logs by sawing as poles, ties, fence posts, in which case they can be measured for their contents in sawed lumber. For round products, as poles, piles or posts, or for hewn products, as hewn or "pole" ties, the number of pieces of standard sizes and shapes is the simplest method of measurement. For this group the important factor in measurement is the set of specifications which determine the grades of product. The waste to be expected in manufacture under Group I is shown in Fig. 2.

19. The Factor of Waste in Manufacture. A waste product is one for which a profitable use has not been found. It is not sufficient that the product could be used for some purpose if it could be transported to some place other than the site of its first appearance as waste. The value of the product must be such as to bear the cost of manufacture and transportation plus a profit. Unless some portion of a tree yields products which fulfill these conditions, the whole tree remains unutilized to finally die and rot, a true waste product of nature. In inaccessible places, entire stands go to waste.

Waste in tops and limbs represents those portions of the tree which under the existing conditions do not yield profitable products. But little deliberate or inexcusable waste occurs over any long period without discovery and correction. The per cent of waste for unprofitable portions of the trees is often as high as 50 per cent for staves or other special products and 25 per cent or over for lumber. The average of 16.6 per cent shown in Fig. 2 for lumber is far too high for bulk products such as pulp wood or for trees with small limbs and boles of regular form.

Bark is a typical example of a "waste" product. As fuel, it is not wasted. When tannin extract or cork is yielded it is carefully gathered. For lumber, it is entirely wasted, except as incidental fuel. The waste in sawdust, slabs, edgings and factory finishing, when reduced to the lowest possible terms by good machinery, can hardly be regarded as avoidable waste, since the product which results from this apparent waste has a value much higher and a utility much greater than before the "loss" of the extra bulk.

When this sawdust and refuse is used as fuel in the mill, as is now the common practice, it replaces coal, thus not only effecting a great economy but performing an important public function in saving transportation costs on coal. The only real waste in manufacture is where methods are used which unduly increase sawdust and slab waste at the expense of finished products. Waste caused by seasoning of wood is not avoidable, and increases the value of the product in greater ratio than its loss in bulk.

The per cent of actual avoidable waste in utilization of the tree is difficult to determine or to prove. It constitutes the per cent of difference between what *is* utilized in higher forms, and what *could be* utilized under the same economic conditions, at a profit. It is a measure of the efficiency and alertness of the operator, and will seldom exceed from 5 to 10 per cent even under exceptionally bad conditions; while under good management this avoidable waste is probably not over from 2 to 5 per cent.

The utilization of small-sized pieces and bulk products not only reduces the per cent of waste in single trees, but brings entire trees of smaller dimensions into the merchantable class, thus increasing the per cent of volume in a stand of timber which is merchantable, and lowering the age at which trees can be marketed. Since the number of trees per acre rapidly diminishes with increasing size, close utilization of small diameters will very greatly increase the per cent of merchantable volume in young stands and reduce the per cent of waste by natural losses of trees before they reach the larger diameters.

20. Actual versus Superficial Contents of Sawed Lumber. The variation between actual cubic contents of sawed lumber, and the superficial contents as expressed in board measure, must not be overlooked in Forest Mensuration. Log-rules for board feet are uniformly based on the sawing of boards 1 inch thick. Mill tallies of lumber which is sawed scant, such as $\frac{5}{8}$-inch boxboard material, will consequently greatly overrun the scale of the logs, in so-called superficial feet, which is the number of square feet of surface measure regardless of thickness. On the other hand, hardwoods are customarily sawed to thicknesses slightly greater than 1 inch to allow surfacing down to full inch thickness, and this practice reduces the superficial yield in board feet as compared to softwood species which are commonly sawed scant. Either practice causes the actual output measured in board feet (§ 12) to differ from the scaled contents of the logs. The actual dimensions of board which are accepted as inch lumber and other standard thicknesses, and the amount of difference, scanting or extra thickness, permitted, is standardized by trade practice for each region and species.[1]

These differences in sawing affect the over-run of sawed lumber, which for the same log rule would thus be greater for softwoods than for hardwoods.

21. Round-edged Lumber. Most lumber is square edged in sawing. Close utilization by the box, match, sash and blind, woodenware, furniture and certain other industries has led to the sawing of logs "alive" or through and through into boards from which the waney edges are not removed by squaring. These boards, except when sawed from the middle of the log, have one face narrower than the other and owing to the taper of the log, the faces are not of uniform width throughout their length. As the lumber in such boards is closely utilized, its board-foot contents is computed by measuring the average width of the narrow face. The thickness is considered on the same basis as for square-edged lumber. Lumber of this character is usually cut by portable sawmills and sold direct to factories. The scale at the factory is used to check that at the mill. This prevents taking advantage of the uncertainties of the method. The logging and sawing are paid for on the basis of the mill scale, which scale usually becomes the standard for measuring the contents of the standing timber.

Round-edged lumber will yield from 10 to 20 per cent more scale than square-edged, the excess being greater, the smaller the logs sawed. For plank 2 inches or more in thickness, a loss is incurred both in utilization and in scaling by reason of the wane, which causes an excessive difference in width of the two faces. This loss is reduced by cutting 1-inch boards from the sides of the log (§ 51).

Closeness of utilization of the tree and stand is increased by this method of sawing. Tops are sometimes taken down to 2 inches and never to greater than 4 inches. Branches which crook only in one plane are used.

22. Products Made from Bolts and Billets. Bolts are sections of logs still in the round, and less than 8 feet long, i.e., too short to be conveniently measured as logs. Billets are obtained by halving, quartering, or otherwise splitting or sawing bolts lengthwise. Bolts may be split into billets, each of which is intended to produce one finished article, such as a wagon spoke or stave. These are measured by count. Billets of larger size may also be split from bolts. So-called shingle bolts are billets split or sawed from large trees, or blocks from thick slabs.

Billets are also obtained by sawing bolts, and are then termed flitches, squares, slats, or blocks. Squares are used in turning out round articles, such as shuttles, spools and bobbins. On account of their regular form, squares are sold by count, or by bulk, on standards agreed on, the price being based on either the number or the board-foot contents. They may be sold by stacked cords. Bolts, and split or sawed billets of irregular form, not yet manufactured into squares, are sold by stacked cubic measure except in the case of bolts over 12 inches in diameter and over 4 feet long, which may be scaled by a log rule. The width of the stack is determined by the length of the product and may range from 22 inches to 5 feet and over. In

[1] Lumber and its Uses, by R. S. Kellogg, 1914, Radford Architectural Company, Chicago, Illinois.

this case a cord is a stack 4 by 8 feet but whose width is that of the given product (§ 99).

Different customs prevail in different industries. Shingle bolts (split or sawed billets) are sold in lengths which allow three cuts. For 16-inch shingles, with 4 inches for trimming, the piece is 52 inches long. For 18-inch shingles, a length of 58 inches is required. The cord is 4 by 8 feet by the indicated width.

Spoke manufacturers dealing in standard 30-inch spoke billets compute a cord as 4 by 8 by $2\frac{1}{2}$ feet, or 80 cubic feet. Others measure the cubic contents, using 128 feet for a cord. In the stave industry a cord measuring 4 by 11 feet by the length of the stave bolts is quite common. For 36-inch billets this gives 132 cubic stacked feet, but the rule is applied to billets of other lengths.

Billets and bolts for tool handles are always measured by the rank, in cords measuring 4 by 8 feet by the required width.

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CHAPTER III

THE MEASUREMENT OF LOGS. CUBIC CONTENTS

23. Total versus Merchantable Contents. Logs are measured to determine their total cubic contents with or without bark, or they are scaled for merchantable contents only. The total cubic contents is required in scientific studies of volume and growth and for such commercial purposes as make use of the entire volume of the log. The cubic contents is found by measuring the length and the diameter at one or more cross sections and computing the volume of the log as a whole, or by sections, from these measurements. Where the thickness of bark is measured, the difference in volume of the log measured outside and inside the bark gives the volume of bark.

24. Log Lengths. Softwood or coniferous logs are usually cut into even lengths, or multiples of 2 feet, and may be any length from 8 feet to over 60 feet, being limited only by the height and upper merchantable diameter of the tree, the length of material demanded for manufacture, or the convenience of transporting long versus short logs. Logs, especially hardwoods, are sometimes cut to odd lengths or multiples of 1 foot. The standard commercial lengths for softwood logs vary from 10 to 22 feet, and average 16 feet. In hardwoods, log lengths average somewhat shorter, since utilization of shorter lengths is more common. Log lengths are marked off on the felled tree by notching with an axe. It is customary to use a wooden measuring stick 8 feet long, and divided into 2-foot lengths.[1]

For exact measurement of length, the steel tape, graduated to feet, and tenths instead of inches, is used. The log length is measured along the surface, which is assumed to equal the length of the axis. For commercial uses, an excess length of from 2 to 6 inches is required as a margin for trimming. For total cubic contents the logs or sections are measured to their actual lengths.

[1] The accidental chopping off of the top of the measuring stick sometimes results in short measurements. In some regions, notably in Southern pine, careless measurement of log lengths resulting in excess trimming allowance and odd lengths causes a waste in woods and mill, in trimming to standard sizes, of from 3 to 5 per cent of the total cut. This statement is based on careful measurements covering 14 years' experience in six states with eight different companies.

25. Diameters and Areas of Cross sections. Cross sectional areas are assumed to be circular in form, and were this assumption correct the measurement of any average diameter would give the cross section.

If B = "basal" area, or area of circle,
D = Diameter of circle,
π = Ratio, or 3.1416.
Then

$$B = \frac{\pi D^2}{4} = .7854D^2.$$

But practically every cross section departs slightly from a true circle, and a large proportion are very eccentric, some showing a difference of several inches between their longest and shortest diameters, and having an elliptical or oval form.[1]

No attempt is ever made to compute the actual cross sectional area of such eccentric sections. Instead, two diameter measurements are taken at right angles and the average of these is assumed to be the average diameter. A circle with corresponding diameter is assumed to have the same cross sectional area as that of the actual section. Usually the longest diameter is taken, and one at right angles to it, through the geometric center of the section.[2]

Abnormal cross sections are occasionally encountered in which the average diameter of the section and its area are either too large or too small to give the volume accurately owing to some distortion in form of the log as a whole or of the portion

[1] The area of an ellipse is

$$B = \frac{\pi Dd}{4},$$

when D and d represent the long and short axes.

The area of a circle whose diameter is calculated as $\frac{D+d}{2}$ is

$$B = \frac{\pi (D+d)^2}{4(2)}.$$

Then

$$\frac{\pi (D+d)^2}{4(2)} - \frac{\pi Dd}{4} = \frac{\pi}{4} \frac{(D-d)^2}{(2)},$$

which is equal to the area of a circle whose diameter equals one-half the difference between D and d. This correction which is always minus, is ignored in measuring cross-sections.

[2] In determining the average diameter, no attention is paid to the growth rings or the position of the pith or growth center of the section. In eccentric cross sections the pith is always found some distance to one side of the geometric center, which is the point through which the diameter measurement must fall.

measured. Abnormally large sections are found at forks or at the base of limbs or are caused by swellings. Stumps cut low give a section averaging much too large to indicate the true volume of the log, due to the rapid flare of the butt.

Abnormally large diameters at the top end of logs should be measured by reducing the diameter to what the log would have if it held its regular form. Where flaring butts are measured, the errors incurred may be serious. It is preferable to adopt a method which does not require this butt measurement, or else to subdivide the log by caliper measurements into shorter sections. Abnormal cross sections caused by limb swellings, or knots, should be measured, if possible, by taking the diameters at equal distances above and below the swelling. When logs are cut to small diameters in the top, the log may taper rapidly in the last few feet, and the disproportionally small diameter at the top will reduce the computed volume of the log as a whole. This problem may be solved by measuring the tapering portion separately as a short piece. In commercial scaling of logs which have abnormal diameters, the scaler should apply a measurement which in his judgment will give the correct contents of the log.

In ordinary scaling, the diameter of logs is expressed in the nearest inch with fractions entirely dropped or rounded off (§ 83). For accurate volume measurements, each diameter is secured to the nearest tenth of an inch, for which purpose the rule or calipers used must be graduated to tenths. In commercial practice, thickness of bark is never included in measuring the diameter of a log except when the bark is to be utilized, as for fuel or tannin,[1] in which case the diameter is measured outside the bark.

When the diameter of the log is taken in the middle, the thickness of bark must be ascertained and deducted. For accurate volume measurements, thickness of bark on one side may be determined by notching and measuring to the nearest tenth of an inch. Double this thickness when deducted gives diameter inside bark. Or the bark may be stripped from opposite faces in order to apply the calipers directly to the wood. This latter method is laborious and is seldom used even in scientific volume determination.

26. The Form of Logs. Logs diminish in diameter from butt to top, corresponding to the form and growth of trees. This *difference or loss in diameter* at successive distances from the butt, is termed *taper*. The taper of logs gives them their characteristic forms. On account of this taper, logs are never truly cylindrical no matter how closely they may approach the cylinder in form.

The geometrical forms to which logs can be compared must therefore be circular in cross section and tapering. The forms suitable for this purpose are the paraboloid, cone, and neiloid.

[1] Exceptions to this practice may be found in some regions, in scaling, when the log rule in use gives a large over-run which is offset by including width of one bark (§ 83).

These three solids form a series of successively diminishing percentages of the volume of a cylinder of equal basal area and height.[1] Each tapers to zero at the tip. But logs are cut with two parallel faces at the two ends. The corresponding solids are the truncated forms of these bodies, termed *frustums,* as shown in Fig. 3.

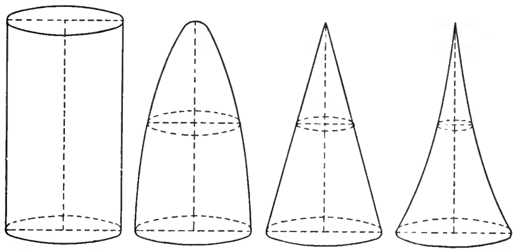


FIG. 3.—Forms of the cylinder, paraboloid, cone and neiloid, and truncated forms or frustums of the last three solids.

27. Formulæ for Solid Contents of Logs. The comparative volumes of these four solids are stated by formulæ below; when

B = Area of base, square feet,

$b\frac{1}{2}$ = Area of cross-section, at $\frac{1}{2}$ height,

b = Area of top,

h = Height or length, in feet.

[1] Each of these solids is formed by the revolution of a curve about a central axis. A true Appolonian paraboloid is derived from that form of a conic section (a symmetrical curve formed by the intersection of a plane with a cone) in which the plane is parallel with the side of the cone. For the conoid formed by the revolution of this curve about its axis, the ratio between a cross section taken at right angles with the axis at any point, and the height above this point to the apex, is constant for all points on the axis. This gives a volume equal to $\frac{Bh}{2}$. Logs which taper regularly will have straight sides, and resemble a *truncated cone.* Logs whose taper is most rapid near the butt, *diminishing* towards the top, will have concave sides and resemble a *truncated neiloid.* The form and volume of such logs will usually fall somewhere between a neiloid and a cone. Most logs taper more rapidly at the top than at the butt and will have convex sides, and resemble in form a *truncated paraboloid*—their volume usually falls between that of a paraboloid and a cone. Where most of the taper occurs close to the top, the log may exceed the paraboloid in volume, falling between it and the volume of the cylinder.

Form	Volume of perfect solid	Volume of Frustum
Cylinder	Bh	Bh
Paraboloid	$\frac{Bh}{2}$	$\frac{(B+b)}{2}h$, or $(B+b)\frac{h}{2}$. *Smalian's Formula*
		$b\frac{1}{2}h$. *Huber's Formula*
Cone	$\frac{Bh}{3}$	$(B+b+\sqrt{B\cdot b})\frac{h}{3}$
Neiloid	$\frac{Bh}{4}$	$(B+4b\frac{1}{2}+b)\frac{h}{6}$. *Newton's Formula*

Newton's formula will also give the volume of the cone, paraboloid and cylinder.

The per cent of the volume of the cylinder which is contained in the other three forms, when of equal diameter at base and equal height, is

Paraboloid.................................. 50 per cent
Cone...................................... 33⅓ per cent
Neiloid.................................... 25 per cent

But each of these three solids decreases in cross section from base to tip, while that of a cylinder remains the same. The frustum of a cylinder is always a cylinder, while the frustum of a paraboloid, cone or neiloid with equal basal area tends to more nearly resemble a cylinder as the area of its top section approaches that of its base, which results when the relative height of the frustum is shortened. The per cent of the cubic contents of a cylinder of equal base and height, which is contained in these frustums increases in the same manner, and the possible limits of variation in form and volume between the cylinder and each of the other three frustums correspondingly diminishes.

E.g., when the height of the frustum is one-fourth that of the perfect solid, the per cent of cylindrical volume is, for

Frustum of paraboloid........................ 87 per cent
Frustum of cone.............................. 77 per cent
Frustum of neiloid........................... 61 per cent

When the height is one-eighth of a perfect solid, these per cents are:

Frustum of paraboloid........................ 94 per cent
Frustum of cone.............................. 88 per cent
Frustum of neiloid........................... 77.5 per cent

A rapidly tapering log forms a truncated section of a relatively shorter completed paraboloid or cone than a log with gradual taper. The greater the height of a complete paraboloid with a given basal area, the less it will taper for a given length, as 16 feet. Whether the taper is rapid or gradual, a log may exactly resemble the frustum of a paraboloid, cone, or neiloid.

Provided it has the true form of one of these solids, its volume can be exactly determined by employing the corresponding formula. But the true form of the log may fall anywhere between the fixed points or forms in the series, which are marked successively by paraboloid, cone and neiloid, and in this case the volume even when calculated by the formula which corresponds most nearly to its true form, will still be in error by the amount of this divergence. This error may be excessive for long logs.

But by taking advantage of the effect of reducing the proportional height of the frustum, the probable error from this source may be reduced to any desired limit of accuracy. This is done simply by shortening the length of the logs, or by dividing each log into several shorter sections, measured separately. It is then no longer necessary to employ two or more forms arbitrarily according to the variations in the form of the logs, but a single standard geometric form may be chosen, which most nearly resembles the average form of logs, and the same formulæ applied to all logs measured.

The paraboloid comes nearest to answering this requirement, and for this reason the Smalian formula and the Huber formula have been generally adopted for both scientific and practical measurements of cubic volume of logs, to the exclusion of the formulæ for cone and neiloid.

28. Relative Accuracy of the Smalian and the Huber Formulæ. Logs having the form of a truncated paraboloid are measured with absolute accuracy regardless of their taper by either Huber's or Smalian's formula. But if the form of the log is more convex and lies between that of the paraboloid and the cylinder, the Smalian formula, measuring the two ends, gives too small a result, while the Huber formula will give too large a volume. Nearly all logs lie between the frustum of a paraboloid and the frustum of a cone in form, having slightly convex sides, but not the full form of the paraboloid, so the end area formula (Smalian's) shows an excess, while the middle area measurement (Huber's) gives too small a result. In either of the above cases, the error by Huber's formula is one-half that of Smalian's and opposite in character.

Newton's or Prismoidal Formula. To check the accuracy of measurements made on sections of given length and to determine the maximum length of section which will secure the desired degree of accuracy, the prismoidal formula may be applied. This formula is correct for cylinder, paraboloid, cone or neiloid, and consequently for logs of regular form whose volume lies within these extremes. It will not measure accurately eccentric or distorted forms resembling none of the above solids. The formula requires the measurement of both ends and the middle section, and is known as Newton's formula,

$$V=(B+4b_{\frac{1}{2}}+b)\frac{h}{6}.$$

When the form of logs resembles more closely the cylinder, cone or neiloid than the paraboloid, the errors in the use of the Huber or the Smalian formula may easily be checked by the above formula.[1]

29. The Technic of Measuring Logs. By either of the two paraboloidal formulæ, Huber's or Smalian's, the area of a single average cross-section is obtained which, multiplied by the length of log, gives the cubic contents. By the Smalian method, this area is the average of two cross-sections, while by the Huber method it is obtained directly. The volume of the frustum, or log, is thus equal to that of a cylinder of equal height, with a base equal in diameter to the average cross-section.

Diameters Measured at Ends of Log. Diameter inside the bark is usually required, and is best obtained at the exposed ends of the log. But if only the small end is measured, the corresponding cylinder does not give the cubic contents of the log on account of neglect of its taper (§ 26). Although almost universally practiced in scaling for board feet, this single measurement is never used to scale cubic contents. The choice lies, therefore, between the single measurement at middle of log, or the averaging of two end areas.

The volumes of cylinders vary directly as their basal areas, or as D^2, and not as their diameters. Hence an accurate procedure would require first, measurement of each diameter; second, determination of each corresponding area; third, averaging these areas; fourth, computing the corresponding diameter. The volume of a cylinder of this diameter and length is required. Such a procedure is practical only in scientific studies; in scaling, the two end-diameters are averaged directly. The assumption is that,

$$V = .7854\left(\frac{D+d}{2}\right)^2 h.$$

[1] The following formulæ are cited by Guttenberg, in Lorey's Handbuch der Forstwissenschaft, 3d Ed., Chapter XII, 1913.

Breymann, $V = \frac{h}{8}(B + b + 3b_{\frac{1}{3}} + b_{\frac{2}{3}}).$

Hossfeld, $V = \frac{h}{4}(3b_{\frac{1}{3}} + b).$

Simoney, $V = \frac{h}{3}(2(b_{\frac{1}{4}} + b_{\frac{3}{4}}) - b_{\frac{1}{2}}).$

While the substitution of the Hossfeld formulæ for that of Smalian on butt logs would give far more accurate results, and would be closer than the Huber formula, the point one-third from butt is not ordinarily measured in the field and is troublesome to ascertain. Hence this formula is impractical. The same objection applies to Breymann's. Simoney's formula has no advantage over either Huber's or Smalian's, since by using the small lengths, one-fourth log, the latter formulæ will secure results within 1 per cent of the true volume for the standard 16-feet length.

This gives a slightly smaller volume than by the correct method. The error increases as the square of the difference between the top and the bottom diameters.[1]

This error, expressed in per cent of total contents, falls below 1 per cent for logs not over 16 feet long with a taper of 2 inches or less. It also tends to offset the plus error caused by the use of the Smalian method as a whole (§ 28). The error increases with length of log scaled as one piece.

A far more serious source of error by this method is that due to the flare of butt logs. Due to the excessively large cross-section thus obtained at the butt, this error may give an excess cubic volume for the log of from 10 to 20 per cent. Chiefly for this reason, the end area method is confined in practice to scientific studies of volume, in which the length of the sections can be regulated to reduce this error, and time is not the determining factor. For such studies, the computation of average basal areas is no drawback. The volumes of the lengths into which the log is to be divided are more conveniently computed by the Smalian formula than by the Huber formula, which requires the middle diameter of each short section. Smalian's mean end formula is therefore universally adopted in these studies.

Diameter Measured at Middle of Log. Since it is impossible to measure the diameter at the middle of a log unless the log is exposed, logs cannot be scaled by this method if they lie in large rollways or piled one on another. The scaling for cubic contents therefore requires a time and place for the work where each log is exposed for its entire length and is less convenient than scaling for board feet (§ 83).

By measuring the middle diameter, the error due to flaring butts is avoided. But this practice requires, in addition to total length, the determination of this middle point. The use of calipers is required, since it is impossible to obtain consistent accuracy by placing a scale stick across a log and judging the diameter; the error thus incurred is always minus. This method is therefore termed a *caliper scale.*

In applying a caliper scale, the double width of bark is subtracted either by taking off a fixed average thickness or by adjusting the calipers

[1] The error in use of mean diameters is shown as follows:
Volume of truncated cone may be expressed as,

$$V=\frac{\pi}{12}h(D^2+Dd+d^2).$$

Volume of cylinder having a basal area equal to the mean diameter of the log is,

$$V=\frac{\pi}{4}h\frac{(D+d)^2}{2}.$$

Then,

$$\frac{\pi}{12}h(D^2+Dd+d^2)-\frac{\pi}{4}h\frac{(D-d)^2}{2}=\frac{\pi}{12}h\frac{(D-d)^2}{2}.$$

The minus error thus shown is equivalent to the volume of a cone having a basal area equal to the difference between the mean end diameters of the log. For the paraboloid, this error equals the contents of a cylinder with a basal area equal to that of the above cone. The error thus increases with the total taper of the log.

to read that much less in diameter for all logs alike. For more accurate scaling the width of bark is deducted separately for each log.

The caliper scale is the more accurate of the two methods for commercial use. The volumes by this formula, in average logs, are slightly below the actual contents.[1]

Where the length of a log exceeds that which can be accurately measured as one log by the above methods, the practice is to consider it as composed of two or more shorter sections. By Smalian's method, the intermediate points measured are taken as the ends of these sections. By Huber's method, the middle point of each section is found. In either case, calipers should be used. The length of section which can be measured without subdivision depends primarily on the rapidity of taper. Logs or sections whose total taper does not exceed 2 inches may be scaled or measured as one piece regardless of length. In commercial scaling logs less than 18 feet long are seldom subdivided. In scientific studies 8 feet is usually the maximum length between measurements of diameter, and 4 feet is often required for the first or butt sections.

30. Girth as a Substitute for Diameter in Log Measurements. The circumference of the circle, corresponding to the girth of the log, may be used to determine the area of the cross-section.[2] In this case, if G = girth, and B = Basal or end area,

$$B=\frac{G^2}{4\pi}=.0796\,G^2.$$

A tape is used in which the results are read directly in inches of diameter, each inch being equal to 3.1416 inches on the tape. A pin in the end of the tape enables one man to encircle the log.

The ratio between diameter and circumference, π, holds good only for the circle. The more eccentric the cross-section, the greater this ratio becomes, and the smaller the actual area in proportion to girth. Hence, whatever error occurs by this method tends to give a cross-sectional area greater than the actual area.[3]

[1] Tests of 4398 spruce and fir logs measured in lengths up to 40 feet by this method in Maine indicated that the scale required a correction factor of 1.049 or 4.9 per cent over-run. The Measurement of Logs, Halbert S. Robinson, Bangor, Me., 1909.

[2] Girth measurements are commonly used in India, and in commercial measurement of imported logs in England. In the United States, the girth of large logs is sometimes taken, when more convenient than the measurement of diameter, but the result is reduced to diameter by the formula $D=\frac{G}{\pi}=.3183G$.

[3] Mensuration of Timber and Timber Crops, P. J. Carter, Office of Supt. of Gov't. Printing, Calcutta, 1893, p. 2.

One advantage of girth measurements over diameter is that two measurements taken at the same point give consistent results, while in determining the average diameter of large and irregular or eccentric logs, considerable differences may occur in two separate measurements. Owing to the difficulty of measuring the girth of a log at its middle point, the mean of the two ends may be taken. This incurs an error identical with that by the mean diameter method (§ 29). This error is offset by the tendency of girth measurement to over-run.

The volume of the cylinder whose basal area is obtained from girth may be found by the method of the *Fifth Girth* in which

$$V=\left(\frac{G}{5}\right)^2 2h.$$

G is here expressed in feet. If measured in inches, divide the result by 144. Another method, known as the *Quarter Girth*, is expressed as

$$V=\left(\frac{G}{4}\right)^2 h \div 113.$$

In this formula G is expressed in inches.[1]

[1] The Fifth Girth method will give a result which is only approximately correct.

$$G=\pi D,$$

therefore,

$$\frac{\pi D^2}{4}h \text{ should equal } \left(\frac{\pi D}{5}\right)^2 2h,$$

and

$$\frac{\pi}{4} \text{ should equal } \left(\frac{\pi}{5}\right)^2 \times 2,$$

$$.7854 \text{ should equal } .6283^2 \times 2,$$

$$.7854 \text{ should equal } .7895,$$

an error of less than 1 per cent.

The Quarter Girth formula is of no particular value as it is merely a means of correcting a commercial standard (§ 35 Hoppus or Quarter Girth Log Rule) to obtain the full volume of the cylinder.

CHAPTER IV

LOG RULES BASED ON CUBIC CONTENTS

31. Comparison of Log Rules Based on Diameter at Middle and at Small End of Log. Log rules giving the contents of logs in cubic feet should be based on the diameter inside bark at middle of log. If, instead, the diameter is measured at the small end of the log, the indicated contents falls short of the true cubic volume (§ 29).

But the measurement of diameters at the small end of logs rather than at the middle point is so great a convenience in log scaling (§ 83) that efforts have been made to find a converting factor, or ratio, by which the true contents of logs may be correlated with diameters at the small end, and expressed directly in a log rule based on these diameters. Since the true contents is assumed to be equal to the cylinder whose diameter is that of the log at its middle point, the ratio or factor desired is the multiple required for converting the volume of the smaller cylinder whose diameter is measured at the small end of the log into the true cubic volume of the log taken as equaling this large cylinder. This ratio is influenced by three factors—namely, rate of taper, length, and diameter of the log.

A log rule, if based on the same conversion factor for logs of all sizes and tapers, will give correct volumes only for a log of a given diameter, length and taper and will be in error for logs of all other dimensions.

A log rule based on separate conversion factors for logs of each diameter but making no further distinction for different lengths or tapers will give correct volumes only for logs of a specific length and rate of taper in each diameter class, and will be in error for all other lengths and tapers.

A log rule based on separate conversion factors for each different diameter and length, can be applied accurately to obtain the average scale of logs of all diameters and lengths only in case the average taper of the logs scaled agrees with that of the logs measured in determining the factor used, and is in error when the average taper of the logs scaled is greater or less than this.

While these conditions apply to log rules based on measurement at the small end of log, a log rule based on measurement at middle of log is correct for all the above conditions, incurring only the errors due to divergence in shape of log from that of a paraboloid.

The ratio of volumes, and the loss in scaling logs by a rule based on the cylinder measured at small end, are illustrated in Table I. The figures in the last column represent the loss in scale expressed in per cent of the volume scaled, e.g., a 16-foot log 6 inches at the small end with 2-inch taper contains 36 per cent greater volume than shown by the scale.

TABLE I

Comparison of Results Obtained by Scaling the Cubic Contents of Logs, at Small End and at Middle of Log, Inside Bark

Length of log.	Taper per 16-foot length.	Total taper.	Diameter at small end.	Diameter at middle of log.	Cubic Contents Scaled at: Small end.	Cubic Contents Scaled at: Middle.	When Scaled at Small End: Loss in cubic contents.		When Scaled at Small End: Proportion of total contents scaled.	When Scaled at Small End: Over-run.
Feet	Inches	Inches	Inches	Inches	Cubic feet	Cubic feet	Cubic feet	Per cent	Per cent	Per cent
16	2	2	6	7	3.14	4.28	1.14	26.6	73.4	36.2
			12	13	12.57	14.75	2.18	14.8	85.2	17.3
			18	19	28.27	31.50	3.23	10.3	89.7	11.4
			24	25	50.27	54.54	4.27	7.8	92.2	8.4
			30	31	78.54	83.86	5.32	6.3	93.7	6.7
32	2	4	6	8	6.28	11.17	4.89	43.7	56.3	77.6
			12	14	25.13	34.21	9.08	26.5	73.5	36.1
			18	20	56.55	69.81	13.26	18.9	81.1	23.3
			24	26	100.53	117.98	17.45	14.7	85.3	17.2
			30	32	157.08	178.72	21.64	12.1	87.9	13.7
16	4	4	6	8	3.14	5.59	2.45	43.7	56.3	77.6
			12	14	12.57	17.10	4.53	26.5	73.5	36.1
			18	20	28.27	34.91	6.64	18.9	81.1	23.3
			24	26	50.27	58.99	8.72	14.7	85.3	17.2
			30	32	78.54	89.36	10.82	12.1	87.9	13.7
32	4	8	6	10	6.28	17.45	11.17	64.0	36.0	177.7
			12	16	25.13	44.68	19.53	43.7	56.3	77.6
			18	22	56.55	84.47	27.92	33.0	67.0	49.2
			24	28	100.53	136.83	36.30	26.5	73.5	36.0
			30	34	157.08	201.76	44.68	22.1	77.9	28.4

Table I indicates that the per cent of error resulting from assuming that the total contents of a log is equal to that of the cylinder measured at the small end decreases with increased diameter, increases with the total number of inches of taper in the log but for logs with a given diameter and the same number of inches of *total taper*, the per cent of error is the same regardless of the rate of taper or length of log, and is determined by the difference in volume of the cylinders based respectively on diameter at small end and middle of log.

32. Log Rules in Use, Based on Cubic Volume. There are two classes of log rules in use, based on cubic volume. The first class gives the actual or total cubic contents of the log. The second class gives the volume of sawed lumber expressed in board feet, but these rules are based upon the use of a fixed ratio of conversion from cubic volume and not upon the volume of sawed lumber which can actually be obtained from logs of different sizes (§ 39).

Cubic measure was early adopted in log measurements, but owing to the fact that logs are roughly cylindrical in shape, the custom grew up of using the contents of a cylinder of standard dimensions instead of the simpler standard of the cubic foot. There is no advantage in this substitution of new arbitrary cubic standards for the cubic foot.[1]

The principle used in the application of such a standard is that the volumes of cylinders of different sizes will vary as the square of the diameter multiplied by the length. The contents of all logs can then be expressed in a log rule in terms of the number of standards they contain.

The Adirondack Standard, or Market. In the Adirondack region of New York several such standards have been used but the only one of importance is the 19-inch or Glens Falls Standard, termed also the Market.[2] This is a cylinder 19 inches in diameter and 13 feet long,

[1] The cubic meter is the standard of volume used in the Philippine Islands. Logs less than 8 meters ($26\frac{1}{4}$ feet) long are measured as a cylinder whose diameter is the small end. The average diameter in centimeters is taken, the end area is obtained from tables and multiplied by the length of the log in meters to give the volume in cubic meters. For logs over 8 meters in length, the diameter at the middle is taken, or if this is impractical, the average of the diameters of the two ends is used.

[2] It is assumed that one market equals 200 board feet which is 65.1 per cent of its cubic contents regarding the log as a cylinder measured at the small end of log and neglecting taper. This gives 7.8 board feet per cubic foot.

Tests of actual output in board feet per market, sawed from 600 logs of each separate diameter, gave the results as shown in table on opposite page.

The saws used were a band and a band resaw, both cutting $\frac{3}{16}$-inch kerf. The lumber was 60 per cent 1-inch, the rest $1\frac{1}{4}$-inch and 2-inch thicknesses. These ratios are therefore higher than for inch lumber sawed with $\frac{1}{4}$-inch kerf. The ratio is still further increased by the fact that the cubic contents measured does not include the entire log but only the cylinder measured at small end while the sawed output is from the entire log. H. L. Churchill, Finch, Pruyn Co., Glens Falls, N. Y.

Twenty-two-inch Standard. A different unit is in use to a slight extent equivalent to 25.6 cubic feet. In application the log is measured at the small end and its contents are taken as that of the corresponding small cylinder. The taper is disregarded.

When D = diameter of standard log in feet or in inches;
L = length of standard log in feet.

The volume of the standard is .7854 D^2L.

Let d and l equal the diameter and length of any other log, whose volume will be .7854 d^2l.

The volume of any log is found in terms of standard units by the formula,

$$V = \frac{.7854 d^2 l}{.7854 D^2 L} = \frac{d^2 l}{D^2 L}.$$

The market is still a common standard of log measure on the Hudson River watershed in the Adirondack region.

Its neglect of the taper makes the Adirondack standard unsuitable for measurement of pulp wood, but were it applied at middle of log

on the Saranac river drainage in New York, termed the Twenty-Two-Inch Standard. The standard log is here 22 inches at small end, and 12 feet long, containing 31.68 cubic feet. It is assumed that one standard equals 250 board feet which equals 65.8 per cent of the cubic contents of the small cylinder. There have been still other log standards, which are now obsolete.

Diameter at small end inside bark. Inches	Board feet per market	Board feet per cubic foot	Diameter at small end inside bark. Inches	Board feet per market	Board feet per cubic foot
5	135	5.3	13	228	8.9
6	155	6.0	14	236	9.2
7	168	6.6	15	243	9.5
8	179	7.0	16	248	9.7
9	190	7.4	17	252	9.8
10	200	7.8	18	255	9.9
11	210	8 2	19	257	10.0
12	219	8.5	20	259	10.1

In principle and practice, these standards coincide closely with the use of the cubic meter, the only difference being in the size or cubic contents of the unit. The difference in shape, or use of a cylinder instead of a cubic foot, is of no significance. Since the cubic meter contains 35.3156 cubic feet, the market is a smaller standard. The cubic volumes are convertible from one of these standards to another by using the proper ratios; markets to cubic meters $\frac{25.6}{35.31} = .725$; markets to cubic feet 25.6.

it would give accurate contents. This standard, in common with all other cubic rules, is unsuited to the measurement of the board foot contents of logs.

33. The Blodgett or New Hampshire Cubic Foot. A cylindrical unit has been adopted as the legal standard of the state of New Hampshire. The statute reads, "All round timber shall be measured according to the following rule. A stick of timber 16 inches in diameter and 12 inches in length shall constitute 1 cubic foot; and in the same ratio for any other size and quantity." This arbitrary cubic foot contains 1.396 or approximately 1.4 cubic feet.

The contents of logs is computed in Blodgett feet by the formula,

$$V=\frac{D^2}{16^2}\times L.$$

This log rule is based on the middle diameter, and is therefore more accurate in application than the Adirondack standards. The diameter is measured by calipers and double width of bark is deducted (§ 84).

This rule is a rough attempt to use the cubic foot, with an allowance for waste in squaring round logs. But the per cent of waste by the rule is 28.4 per cent of the cylinder, utilizing 71.6 per cent, while the area of an inscribed square is 63.6 per cent of the circle with 36.4 per cent waste. The "squared" stick 1 foot long would therefore have considerable wane. The Blodgett Rule was an attempt to secure a standard which could be converted into board feet. The statute fixed the converting factor as,

100 Blodgett feet = 1000 board feet, or a ratio of 1 : 10

But in scaling practice it was concluded that this ratio was unsatisfactory, and gave too large a scale in board feet. So it was arbitrarily set in practice at

115 Blodgett feet = 1000 board feet, or a ratio of 1 : 8.7,

when the rule was applied, as intended, to the middle diameter inside bark. Though the scale in *Blodgett feet* in either case was the same, the converted result gave for the ratio of 1 : 10, 59.7 per cent of the contents of the log in *board feet*, and for the ratio 1 : 8.7, 51.9 per cent. Since 12 board feet = 1 cubic foot,

$$\frac{10}{12}=83\tfrac{1}{3} \text{ per cent of 1 cubic foot,}$$

and

$$\frac{.83\frac{1}{3}}{1.396}=.597.$$

Likewise,

$$\frac{8.7}{12}=72.5 \text{ per cent,}$$

and

$$\frac{.725}{1.396}=.519.$$

In order to permit measurement of diameter at the small end of log instead of the middle (§ 31), a further modification of the rule more radical in its character was now made. The loss in cubic contents by measuring the small cylinder was offset by arbitrarily increasing the ratio of board feet to each Blodgett foot. This new ratio was set for logs of all sizes at

106 Blodgett feet = 1000 board feet.

When compared with the cubic contents of the *small cylinder* this makes the ratio 1 : 9.44. For the ratio of 1 : 9.44 the per cent of the small cylinder scaled as boards is 56.2 per cent. But for the true cubic contents of the log the ratio would vary with length and taper of log (§ 31).

$$\frac{9.44}{12} = .78\tfrac{2}{3},$$

$$\frac{.78\tfrac{2}{3}}{1.396} = 56.2 \text{ per cent.}$$

From Table I, § 31, the following comparisons can be made between the volume thus expressed and the true volume. Taking 16-foot logs with 2-inch taper,

Diameter of log. Inches	Per cent of total contents of log in small cylinder	Per cent of total contents scaled as boards by above ratio of 56.2 per cent. Per cent
6	73.4	41.2
12	85.2	47.8
18	89.7	50.4
24	92.2	51.8
30	93.7	52.6

The attempt to convert this rule to apply at small end gives values which agree with the current ratio of 115 Blodgett feet to 1000 board feet in 16-foot only when these logs are 24 inches in diameter and with 2-inch total taper, while for 6-inch logs, tapering 2 inches the scale is $\frac{41.2}{51.9}$ or 79.3 per cent, incurring a loss of 20.7 per cent of the true cubic scale measured at the middle point.

Thus the change in point of measurement destroys the consistency of this log rule for cubic contents, while the conversion to board feet introduces still another error, discussed in § 42. The rule should either be used for Blodgett feet only, as a cubic measure, and applied only at middle diameter, or if the end diameter is used, the conversion factor should have been separately computed for logs of different diameters and lengths on basis of an average taper.

34. Use of Cubic Foot in Log Scaling. The cubic foot has been substituted for the Blodgett foot as the basis for measuring logs, by the U. S. Forest Service on the National Forests in Maine and New Hampshire.

A caliper with a long arm to the end of which is attached a measuring wheel, is used. The wheel consists of ten spokes, each tipped with a spike, and all painted black except one, which is yellow. The tips of the spokes are 6 inches apart. The yellow spoke is weighted. When the wheel is run along a log, each revolution as counted by the yellow spoke measures 5 feet, and the remaining spokes permit the length of log to be measured to the nearest 6 inches. The measuring wheel is run the length of the log, and then brought back to the center, at which point the caliper measurement is taken. Allowance for bark is made by moving the caliper jaw inward by a distance in inches equal to the estimated double width of bark on each log separately.

The diameter in inches is stamped on one edge of the arm, and around the base of the arm are placed standard lengths running from 8 to 34 feet. Opposite each length, and below each diameter, on the arm, is stamped the cubic volume of a log of these dimensions. The lengths are also stamped on the movable arm. When the log is calipered, the scaler reads the volume which lies opposite the proper length,

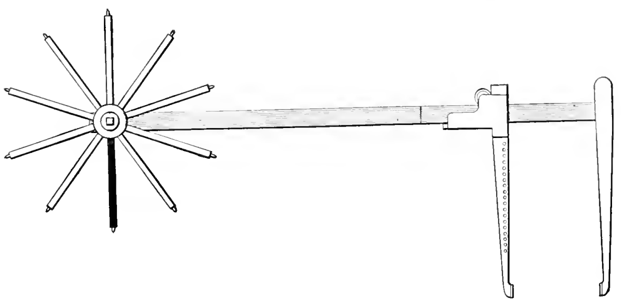


Fig. 4.—Caliper scale for measuring logs in middle, outside bark, with wheel for determining length of log.

the diameter being indicated by the position of the movable arm after calipering the log and taking off the bark correction. Defects are then deducted from the gross volume, either by measuring the defective portion or by ocular estimate of the volume of the defect. J. J. Fritz, Gorham, N. H., 1921.

Note. In 1909 a commission of investigation recommended to the Maine Legislature the adoption of the cubic foot as the statute rule of Maine. This was not done. One lumber company, Hollingsworth & Whitney, Waterville, Maine, has since 1904 used a cubic foot standard, measuring the middle diameter with calipers, outside bark. The rule then allows $12\frac{1}{2}$ per cent deduction for volume of bark, and gives the net cubic contents of solid wood. The per cent of volume of bark is not constant but varies with the size of tree and its age and exposure. The arbitrary figure chosen simply represented the approximate average volume for the species and region in question, namely, spruce and balsam in Maine.

A converting factor for this rule has been suggested, of 185 cubic feet to 1000 feet B. M. This gives 5.4 board feet per cubic foot, or 45 per cent of the cubic contents when measured at the middle. Reduced to diameter at small end, for a taper of 1 inch in 8 feet, logs 18 inches in diameter would give 50 per cent of the small cylinder in board feet. This suggested ratio is therefore lower than those adopted for the New Hampshire and most other converted cubic log rules.

NOTE. *Weight as a Basis for Measuring Cubic Contents.* Actual weight of logs is seldom used as a basis of measurement, as the variation in moisture contents caused by seasoning prevents standardization even for a given species. A few valuable timbers are imported by weight. The long ton of 2240 pounds is used.

The ton as ordinarily used in measuring timber is a cubic measure equivalent to either 40 or to 50 cubic feet and is usually applied to squared timbers. The unit of 50 cubic feet is also termed a "load" and is used in measuring teak.

Red cedar logs are sometimes purchased by weight, on account of their extreme irregularity and the difficulty of measuring them.

35. Log Rules for Cubic Contents of Squared Timbers. A definite departure from the use of total cubic contents is found in log rules giving the cubic contents of the squared timbers which may be hewn or sawed from round logs. The waste constitutes the portion hewn or slabbed off. A square inscribed in a circle occupies 63.6 per cent of its area. Rules based on this principle would give a waste factor of 36.4 per cent of the cylinder scaled.

Inscribed Square Rule. The width of a square inscribed in a 24-inch circle is 17 inches.[1] The width of any other inscribed square is seventeen twenty-fourths of the diameter of the log. The cubic contents of the log is that of the square so determined, *measured at the small end of log.*

The width of a square inscribed in a 17-inch circle is 12 inches, each foot of log containing 1 cubic foot of squared timber. The cubic contents of any log is $\frac{D^2}{17^2}L$. By either of these rules of thumb, the so-called Inscribed Square Rule is obtained. The latter method is termed the *Seventeen-Inch Rule.* The rule gives 63.4 per cent of the cubic contents of the small cylinder, and proportionately less of the entire log depending on taper, length and diameter (§ 31).

Big Sandy Cube Rule. Synonyms: Cube Rule, Goble Rule. This Cube Rule, used on the Ohio River, assumes that it requires a log 18 inches in diameter at small end to give a timber 1 foot square. This rule scales 56.6 per cent of the small cylinder. The volume of logs of other sizes is found by the formula,

$$V = \frac{D^2}{18^2}L.$$

This rule is sometimes expressed in board feet by multiplying the cubic contents by 12.

[1] The side of the inscribed square is found by squaring the diameter of the log, dividing by 2 and extracting the square root.

Two-thirds Rule. By this rule, the diameter of the log is reduced one-third, the remainder squared, and multiplied by the length of the log. As diameters are in inches the formula is $V = (\frac{2}{3}D)^2\ L \div 144$. This is a caliper rule applied to the middle area, and gives 56.5 per cent of the full cubic contents of the log. It is sometimes erroneously applied to the small end.

Quarter Girth or Hoppus Rule. This rule depends upon the direct use of the girth, rather than diameter. The average girth is taken in inches at middle point, or by averaging both ends. Then $V = \left(\frac{G}{4}\right)^2 L$. This formula gives 78.5 per cent of the actual total cubic contents of the log. It is a commonly used standard for measuring round logs in England and India. To express the contents in cubic feet the result is divided by 144.

36. Log Rules Expressed in Board Feet but Based Directly upon Cubic Contents. The Blodgett or New Hampshire rule is not the only log rule based on cubic contents, which attempted to express the results in terms of board feet. Any cubic rule can be converted into board-foot form, in theory, by the use of a ratio similar to those used for the Blodgett Rule. The ratio for board-foot contents of one cubic foot is 12. Twelve 1-inch boards cannot be sawed from 1 cubic foot, but a squared timber 12 by 12 inches contains 12 board feet per linear foot. For converting the entire log directly into board-foot contents of squared timbers, it is evident that the ratio will be less than 12 board feet per cubic foot, due to waste in squaring the log, while the conversion into contents in inch lumber requires a still lower ratio.

The characteristic of all converted rules is that a fixed multiple or converting factor is used, regardless of the diameter or taper of the log. The rules differ only in the converting factor used, and in the method of measuring the log, whether at middle, or end.

Constantine Log Rule. This rule is merely the expression of the cubic contents of a log regarded as a cylinder, in terms of board feet, by multiplying the cubic contents by 12. The diameter is measured at the small end of log. The formula is

$$V = \frac{\pi D^2}{4 \times 144} L.$$

The rule is used to measure the contents of logs used for veneers.

Cuban One-fifth Rule. This Rule is based on the square of one-fifth of the girth taken in middle of log. The formula when G is in inches is

$$V = \left(\frac{G}{5}\right)^2 L \div 12.$$

The rule gives just 50 per cent of the total cubic contents of logs in board feet. This is equivalent to 6 board feet per cubic foot. This rule is extensively used for imported hardwood logs. The contents of logs in cubic feet is found by dividing by 144 instead of 12.

In practice, fractional inches resulting from the fifth girth are dropped as follows, e.g.,

Girth, 50, 51 or 52 inches	Square, 10 by 10 inches
53, 54 inches	11 by 10 inches
55, 56, 57 inches	11 by 11 inches
58, 59 inches	12 by 11 inches, etc.

Square of Two-thirds Rule. Synonyms: St. Louis Hardwood, Two-Thirds, Tennessee River, Lehigh, Miner. This rule is derived from the Two-thirds Rule by multiplying the cubic scale by 12. The rule is used for hardwood logs in the Middle States, and for pine to some extent in the South Atlantic States, and is frequently erroneously applied to the small-end diameter of the log.

Cumberland River Rule. Synonyms: Evansville, Third and Fifth. This rule resembles the Square of Two-Thirds Rule, in that one-third of the diameter is deducted and the remainder squared. But it differs, in that one-fifth of the volume of the squared stick is then subtracted for saw kerf, and the remainder converted into board feet. The rule is always applied to the small end of the log except for long logs, when the diameter at middle point is taken. This rule is used on the Mississippi Valley and its tributaries, for hardwood logs.

Square of Three-fourths Rule. Synonyms: Portland, Noble & Cooley, Cook, Crooked River, Lumberman's. In this rule, one-fourth is deducted from the diameter at small end, and the squared timber expressed in board feet. The rule was formerly used in New England but is now obsolete.

Vermont Rule. This rule is derived from the Inscribed Square Rule by multiplying the values by 12. It is the legal standard of the State of Vermont. The contents of a 12-foot log may be calculated by a rule of thumb, by multiplying the average diameter of the top of the log inside bark, in inches, by half such diameter in inches. The rule is not extensively used even in Vermont, being supplanted by others, notably the New Hampshire or Blodgett Rule.

37. Formula for Board-foot Rules Based on Cubic Contents. Any board-foot log rule the values for which are obtained by deducting the same per cent from the cubic contents of logs of all sizes, may be expressed by the formula

$$\text{Board feet} = (1-C)\frac{\pi D^2}{4}\times\frac{12}{144}\times L,$$

in which C = total per cent of waste deducted from the cylinder,

$1-C$ = per cent of cubic contents utilized,

$\frac{1}{144}$ reduces D^2 from inches to square feet, and

12 converts cubic feet to board measure.

The formula, simplified, becomes

$$\text{Board feet} = (1-C)\frac{\pi D^2}{48}L.$$

But the important distinction remains, that some of these log rules are meant to apply to the middle diameter and others to the small end, and while the per cent subtracted from the *cylinder measured* is uniform for the rule, the per cent actually subtracted from the log is uniform only for those rules using middle diameter, and varies over a wide range for rules based on diameter at small end of log.

NOTE. Obsolete Rules. The following log rules, obsolete or unused, are based on the above formula and principles: Saco River (Maine), Derby (Mass.), Partridge (Mass.), Stillwell's Vade Mecum (Ga.), Ake (Pa.), Orange River or Ochultree (Texas). A new rule, the Calcasieu (La.), deserves the same fate. The Tatarian rule (Wis.), which is based on this principle, gives approximately correct board-foot contents for a log of a given size. It has never been adopted in practice.

38. Comparison of Scaled Cubic Contents by Different Log Rules. In Table II is shown the comparative volumes, in per cent of total cubic contents, which are scaled by different log rules based upon cubic volume. These per cents represent the converting factor used to obtain the values given in the rule from the volumes of cylinders.

NOTE. The values in this table were obtained by applying the ratio between the volume of two cylinders 16 feet long, 18 inches and 19 inches in diameter respectively. This ratio is 28.27 : 31.50. Log rules based on cylinder at small end then scale but $\frac{28.27}{31.50}$ or 89.7 per cent of their volume, to which the reduction per cent for waste is applied; e.g., the Vermont rule wastes 36.6 per cent by the inscribed square method. Then, based on the small end, the per cent scaled is 63.4, but based on middle diameter for the above size, it is $89.7 \times 63.4 = 56.9$ per cent. The table gives a correct comparison of the different log rules which are constructed by using a fixed per cent of cubic volume. The per cents given for the rule under the first column, based on the point at which the rule is applied, are consistent for all logs. But the equivalent per cents obtained by converting the scaled contents into terms of the cylinder based on the other diameter—as middle, for logs measured at the end and vice versa, will vary as the relative contents of these two cylinders varies (§ 31). This will not change the rank or order in which the rules fall. The rules are tabulated in order of the relative per cent of total contents which they scale.

There is no common standard for measuring the cubic contents of squared timbers. The Quarter Girth method gives the fullest measurements, while the others more closely approximate the net contents as given by board-foot rules.

TABLE II

COMPARISON OF PER CENTS OF CUBIC CONTENTS OF CYLINDERS SCALED BY VARIOUS LOG RULES, FOR LOGS 18 INCHES IN DIAMETER AT SMALL END, WITH 2-INCH TOTAL TAPER

Cylindrical contents measured inside bark

Log rule	Basis of measurement of cylinder, in application of rule		Per cent of scale if measured at other point		Per cent deducted from contents of cylinder to obtain contents given in rule—For rules applied	
	at small end. Per cent	at middle. Per cent	at middle	at small end	at small end	at middle
Cubic Standards						
Market or Glens Falls standard	100	.....	89.7	.....	0	10.3
22-inch standard	100	.....	89.7	.....	0	10.3
Blodgett or New Hampshire	.....	100	.....	111.4	11.4*	0
Cubic foot—Maine	.....	100	.....	111.4	11.4*	0
Cubic meter—Philippines:						
Short logs	100	.....	89.7	.....	0	10.3
Long logs	.....	100	.....	111.4	11.4*	0
Cubic Log Rules for Squared Timbers						
Quarter girth or Hoppus	.....	78.5	.....	87.5	12.5	21.5
Inscribed square	63.4	.....	56.9	.....	36.6	43.1
Two-thirds	.....	56.5	.....	62.9	37.1	43.4
Cube rule, or Big Sandy	56.6	.....	50.8	....	43.4	49.2
Log Rules Expressed in Board Feet but Based on Cubic Contents						
Constantine	100	.....	89.7	.....	0	10.3
Tatarian	84.0	.....	75.4	.....	16.0	24.6
Saco River	72.4	.....	65.0	.....	27.6	35.0
Derby	72.1	.....	64.7	.....	27.9	35.3
Square of Three-Fourths	71.7	.....	64.3	.....	28.3	35.7
Partridge	68.8	.....	61.8	.....	31.2	38.2
Blodgett, converted, ratio 100 to 1000 ft. B.M.	.....	59.7	.....	66.5	33.5	40.3

* Added.

TABLE II—*Continued*

Log rule	Basis of measurement of cylinder, in application of rule		Per cent of scale if measured at other point		Per cent deducted from contents of cylinder to obtain contents given in rule—For rules applied	
	at small end. Per cent	at middle. Per cent	at middle	at small end	at small end	at middle
Log Rules.—Continued						
22-inch standard, converted, ratio 1 to 250 ft. B.M.	65.6	.....	58.9	.....	34.4	41.1
Market, or 19-inch standard, converted, ratio 1 to 200 ft. B.M.	65.1	.....	58.4	.....	34.9	41.6
Vermont	63.4	.....	56.9	.....	36.6	43.1
Vade Mecum (Stillwell's)	63.2	.....	56.7	.....	36.8	43.3
Square of Two-thirds	.....	56.5	.....	62.9	37.1	43.5
Ake	62.4	.....	56.0	.....	37.6	44.0
French's (Los Angeles)	.....	52.2	.....	58.2	41.8	47.8
Calcasieu	57.8	.....	51.9	.....	42.2	48.1
Blodgett, converted, ratio 115 to 1000 ft. B.M.	.....	51.9	.....	57.8	42.2	48.1
Blodgett, converted, ratio 106 to 100 ft. B.M.	56.2	.....	50.4	.....	43.8	49.6
Cuban One-Fifth	.....	50.1	.....	55.9	44.1	49.9
Orange River	50.9	.....	45.7	.....	49.1	54.3
Maine cubic rule, converted 185 cu. ft. per 1000 ft. B.M.	.....	45.0	.....	50.1	49.9	55.0
Cumberland River	45.2	.....	40.6	.....	54.8	59.4
Delaware or Eastern Shore	42.4	.....	38.1	.....	57.6	61.9

Of the cubic log rules expressed in board feet, the Constantine is frankly a cubic rule, converted from the cubic foot, but based on the small end of log. The rest are suitable neither for cubic contents nor for board feet, since they do not express the former nor do they measure the latter correctly (Chapter V).

These rules are all convertible into cubic units or from one to the other, when based on cylinders measured *at the same point*.

The formula, Board feet $= (1-C)\frac{\pi D^2}{48}L$, can be used to obtain the values for any of these rules, by substituting for C the per cent given in the last two columns of Table II, e.g.

To derive the Inscribed Square rule, the cubic contents of cylinders from Table II are multiplied by 1 − 36.6, or 63.4 per cent.

To convert the Inscribed Square rule into terms of the Cumberland River rule; since 1 − 54.8 = 45.2 per cent, the volumes of the two rules are as 45.2 to 63.4. The Cumberland River rule gives $\frac{45.2}{63.4}$ of the Inscribed Square rule, or 71.3 per cent. But the Hoppus Rule cannot be converted into terms of either of the above rules, since it is measured at the middle point, unless a log of a given diameter and average taper is assumed.

39. Relation between Cubic Measure and True Board-foot Log Rules. The conversion of these log rules from cubic to board feet is based on the erroneous assumption that logs of all dimensions when sawed into lumber will yield the same ratio of board-foot contents to cubic contents. In practice, the larger the log, the greater will be the ratio or per cent of its contents which makes lumber and the less the per cent wasted. For this reason it is not possible to use the same standard for scaling both the cubic- and board-foot contents of logs, no matter what converting factor is chosen.

Cubic rules, converted to board-foot contents by a fixed ratio, tend to scale small logs too high and large logs too low, as compared to the actual sawed contents. The common mistake of the authors of these rules is to assume that once the sawed contents of a log of given diameter and length is found, the ratio obtained will apply unchanged to logs of all other sizes. These rules have therefore fallen into disrepute in the scaling of board feet, because of their inconsistencies for this purpose.

For products such as pulpwood, which utilizes the entire contents of the log, these so-called board-foot rules give consistent results for logs of all sizes, but do not possess any advantage over the direct use of the cubic standard upon which they are based. On the other hand, if log rules are intended for the measurement of the actual output of 1-inch lumber, they must be based on other principles (§ 54).

The two quantities of measurement, cubic volume, and squared board feet obtainable, are incommensurable unless the diameter and also the taper of each log is known. The lump sum of a lot of logs measured in cubic volume therefore, cannot be converted into board-foot measure except by readjusting each individual value by the diameter of each individual log. The use of these hybrid rules should be discontinued in favor of cubic standards on the one hand, and board-foot log rules based on correct principles on the other.

CHAPTER V

THE MEASUREMENT OF LOGS—BOARD-FOOT CONTENTS

40. Necessity for Board-foot Log Rules. In other lines of industry it is not customary to measure raw materials in terms of the quantity of finished product contained therein. The volume or weight of the raw product is the basis of sale. On this basis logs would be sold for their cubic contents.

But the purchaser of raw material must know approximately the quantity of finished product he can obtain from it before he can estimate its value. If the product is to be lumber, the possible yield of boards of certain qualities and grades determines for him the value of the logs.

If it had been found by experience that all logs regardless of size would yield the same per cent of their contents in lumber, if sawed by the same methods, the cubic standard might have been universally accepted, as it was in the Adirondack region. But when it developed that there was no consistent ratio of cubic to board feet the only alternative was to measure the product directly as boards.

That the board-foot log rule was needed is shown by the fact that such rules were originated independently in practically every lumbering region. The contents of the log in sawed 1-inch boards was placed on the scale stick, separately for each inch-class and each standard length. These board-foot rules soon became practically the universal standard of log measure, and are only recently being superseded where the logs are used for other purposes than lumber; they will continue to be a generally accepted commercial standard of log measure for the lumber industry as a whole, until such time as the original stands of timber of the country give way to smaller second-growth and closer utilization and probably as long as a large percentage of logs are sawed into lumber.

41. Relation of Diameter of Log to Per Cent of Utilization in Sawed Lumber. The sawed output from logs in board feet shows an increasing per cent of utilization with increasing diameter of the logs. This result may be expressed by the ratio of board feet produced from each cubic foot of total volume. This tendency is illustrated in Table III.

The per cent of utilization in this table is based on the total cubic contents of the log as measured by Huber's formula at middle diameter inside bark. But practically all log rules for board feet base the contents upon the cylinder whose diameter is taken at the small end, in which case the volume of the log lying outside the cylinder is neglected. On this basis, the apparent per cent of utilization would be considerably increased over the figures given in the table.[1]

TABLE III

RELATION OF CUBIC AND BOARD-FOOT CONTENTS OF 16-FOOT LOGS WITH A TAPER OF 1 INCH IN 8 FEET, BASED ON TIEMANN'S LOG RULE, $\frac{3}{16}$-INCH SAW KERF. (§ 63)

Diameter inside bark at middle of log. Inches	Cubic contents. Cubic feet	Sawed contents, Tiemann Log Rule. Feet B.M.	Ratio feet B.M. to 1 cubic foot	Volume utilized Per cent
3	0.79	1	1.27	10.5
4	1.40	4	2.85	23.8
5	2.18	9	4.13	34.4
6	3.14	15	4.77	39.5
7	4.28	23	5.37	44.8
8	5.59	32	5.71	47.7
9	7.07	43	6.08	50.7
10	8.73	55	6.30	52.5
11	10.56	69	6.53	54.4
12	12.57	84	6.68	55.7
13	14.75	101	6.85	57.0
14	17.10	119	6.96	57.9
15	19.63	139	7.08	59.0
16	22.34	160	7.16	59.7
17	25.22	183	7.26	60.5
18	28.27	207	7.32	61.0
19	31.50	233	7.39	61.6
25	54.54	419	7.68	64.0
31	83.86	659	7.86	65.5
37	119.47	954	7.99	66.5
43	161.36	1301	8.06	67.2
49	209.52	1703	8.13	67.7
55	263.98	2159	8.18	68.2
61	324.96	2669	8.22	68.5

[1] For a 16-foot log 12 inches at middle, with 2-inch taper, and scaling diameter at end of 11 inches, the cubic contents are 10.56 cubic feet, the ratio of board feet to cubic feet is 7.95, and the apparent per cent of utilization is $66\frac{1}{4}$ per cent as against an actual 55.7 per cent when the entire volume including taper is taken as the basis. For logs with considerable taper, which permits more lumber to be cut from the slabs lying outside the cylinder, the apparent per cent of utilization would be still greater, while the actual per cent utilized would in reality be lower for such rapidly tapering logs than for more cylindrical forms.

It is practically impossible to secure closer utilization than 70 per cent of actual total cubic contents of logs in the form of sawed inch lumber exclusive of the utilization of slabs, edgings and sawdust when circular saws whose kerf is $\frac{1}{4}$ inch or more are used. By using band saws which cut a $\frac{1}{8}$-inch kerf and by producing a large per cent of timbers and boards thicker than 1 inch, thus reducing the waste from saw kerf, the utilization may rise as high as 80 per cent for the larger logs.

42. Errors in Use of Cubic Rules for Board Feet. By comparing the per cent of possible utilization in Table III (§ 41) with the per cents given for cubic log rules in Table II (§ 38) the character and relative accuracy of these log rules can be judged. For the Blodgett Rule, with a ratio of 115 units to 1000 board feet measured at middle diameter, the ratio or per cent scaled is 51.9 for all classes and sizes of logs. By comparison with Tiemann's Rule this rule is shown to be correct for logs between 9 and 10 inches in diameter, but over-scales smaller logs, and under-scales larger logs. The original Blodgett ratio of 100 : 1000 gives a per cent of 59.7. This is correct for 16-inch logs, too high for all logs of smaller diameter and too low for larger logs.

When the point of measurement is shifted to the small end of log, the diameter measurement is correspondingly reduced. When the scale of board-foot contents thus determined is compared with this smaller cylinder, the per cent of utilization can be expressed for such log rules and applies uniformly to logs of all sizes, but only to the small cylinder thus measured (§ 81).

A comparison of the Blodgett Rule applied at the small end of log, with the Tiemann rule applied at the middle of log, is shown below. The per cents will apply to logs of all lengths whose total taper is but 2 inches.

TABLE IV

COMPARISON OF BLODGETT AND TIEMANN LOG RULES FOR CERTAIN LOGS

Diameter log. Inches	Total taper. Inches	Per cent of small cylinder scaled by Blodgett Rule	Per cent of total log in small cylinder	Per cent of total log scaled by Blodgett Rule	Per cent of total log scaled by Tiemann Rule	Error in Blodgett Rule
6	2	56.2	73.4	41.2	44.8	− 2.6
12	2	56.2	85.2	47.9	57.0	− 9.1
18	2	56.2	89.7	50.4	61.6	−11.2
24	2	56.2	92.2	51.8	64.0	−12.2
30	2	56.2	93.7	52.6	65.5	−12.9

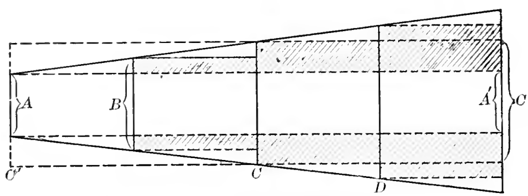
Cubic rules, as a class, when converted to read in terms of board feet, thus tend to over-scale small logs and under-scale large logs, whether they are applied at the middle point, or at the small end. Of the two methods the *small end gives the most consistent results in board measure*, since both the actual per cent utilized and the per cent of total contents scaled decrease with diameter of log. But the decrease in scaled contents is always at a lesser rate than that of actual sawed contents, hence the tendency to over-scale small logs remains though the size of the error is reduced.

43. Taper as a Factor in Limiting the Scaling Length of Logs for Board-foot Contents. Since board-foot contents of logs is equal to cubic contents minus waste in sawing, the character and amount of this waste determines the net scale of the log. This waste consists of sawdust, slabs and edgings. As lumber is commonly manufactured with parallel edges, in even widths, the custom of sawing boards whose length equals that of the log and rejecting all shorter pieces would cause a waste not only of the slabs sawed from the cross section at the small end but of the entire taper of the log, which would be discarded as edgings and slabs. When board-foot rules were first brought into use close utilization of short lengths and of wedge-shaped pieces was not practiced, and this total waste actually occurred. Under these conditions the correct point of diameter measurement was not the middle, but the small end of the log. Owing to their early origin, the commercial board-foot log rules now in use are nearly all based on measurement at the latter point.

This waste, as measured in cubic volume, increases rapidly with increasing length of log. The shorter the logs cut from a given tree, the less will be the apparent waste from taper. Long logs, the scaled contents of which are based on cylinders measured at their small end, would give an entirely different and much smaller scale than if the same logs were cut instead into two or more shorter sections and sawed into correspondingly shorter lumber. Instead of scaling one log of a given top diameter sometimes extending the entire length of the bole, we would then have to scale a series of shorter logs, each of which has a top diameter larger than the preceding one by the amount of the taper between the points measured. The sum of volumes of these short logs would always exceed that of the single log measured at small end. These long logs are usually cut into two or more sections at the mill. For these reasons, logs, if their length exceeds a definite maximum are scaled as the sum of two or more shorter logs, by taking caliper measurements at arbitrary points of division; e.g., a 26-foot log scaled as two pieces would be measured at its small end, and at a point 12 feet from the end, thus scaling as a 12-foot and a 14-foot log. The scaling diameter of the larger or butt section exceeds that of the top end by the amount of the taper between the points measured. Each section is thus scaled as a cylinder, and measured at its upper or small diameter, and the sum of volumes of these cylinders gives the scale of the long log.

The shorter these scaling lengths are made, the larger the total scale of the log, but the maximum scaling length must not be shorter than the average length of the lumber sawed. In log rules, figures for lengths up to 40 feet may be given, and scaling practice often corresponds, but in selling logs the U. S. Forest Service limits the scaling length to 16 feet, which is a standard commonly accepted by timber owners.

44. The Introduction of Taper into Log Rules. With the increase in utilization, much of the lumber formerly wasted in slabs is now secured as short lengths. All log rules in commercial use ignore this product and treat the logs as if cylindrical, up to the maximum scaling length. To overcome this drawback and include the products from slabs or taper without requiring the measurement of logs in separate very short sections, the International log rule was constructed,[1] based on the principle



Taper, 2 inches in 16 feet. Vertical scale exaggerated.

FIG. 5.—Short versus long sections in measuring log contents and in constructing a log rule.

of building up the scaled volume of a log from shorter cylindrical sections. These short cylinders are 4 feet long and each successive cylinder is increased by ½-inch in diameter. The scaled contents of each short section is determined, and the sum of these sections gives the scale of the log as given in the log rule. The soundness of this method depends upon demonstrating that the average taper of most logs is not less than that used in the rule, namely, 2 inches in 16 feet. This holds good for most Northern and Western species, but for Southern pines the taper does not always equal this figure. To guard against excessive error from tapers differing from the rate used in the rule, the maximum scaling length is limited to 20 feet.

If the log in Fig. 5 is regarded as a 64-foot log, scaled in four 16-foot lengths by any commercial log rule, the scaling diameters are taken at *A*, *B*, *C* and *D*. The gain in scale is caused by inclusion of the shaded portions.

[1] The Measurement of Saw Logs, Judson F. Clark, Forestry Quarterly, Vol. IV, 1906, p. 79.

Regarded as a 64-foot log scaled by middle diameter the scaling diameter is C, and the log content is that of a cylinder 64 feet long and of size indicated by $C\ C''$.

Regarded as a 64-foot log scaled by end diameter, the scaling diameter is A and the log content is that of a cylinder 64 feet long and of size indicated by $A\ A'$.

Regarded as a 16-foot log scaled at small end, and not in middle, the loss in scale is indicated by the shaded portions. This loss is common to all commercial log scales based on small end of log.

But if the contents of the 16-foot log as given in the scale when measured at A is built up by measuring the log as four 4-foot cylinders whose scaling diameters are A, B, C and D, this loss from taper common to all the commercial log rules, except when applied at middle diameter, is avoided and practically full scale secured.

A comparison of the results of these three methods of treating taper is brought out in Table V.

TABLE V

Effect of Different Methods of Scaling a Log

Length of log. Feet (1)	Diameter inside bark. Inches (2)	Scaling diameter rounded off. Inches (3)	Scaled as one log based on small diameter. Board feet (4)	Scaled as 16-foot logs each regarded as a cylinder. Board feet (5)	Scaled as 16-foot logs allowing ½-inch taper every 4 feet. Board feet (6)
0	24.5	....	....	....	....
16	20.6	21.0	328	328	355
32	19.6	20.0	590	623	675
48	17.3	17.0	618	829	900
64	14.0	14.0	531	962	1050

The final column in each of the above examples is the contents of a log 4 feet long as scaled by the International log rule. The difference in scale by the other methods is due entirely to the length of section scaled as one piece. In column 4, this cylinder, with top diameter indicated, extends the full length of the log. In column 5, a new diameter measurement is made every 16 feet, but the cylinder of this diameter is 16 feet long. In column 6, the diameter is taken at 16-foot intervals, but the cylinder from which this 16-foot log is scaled is built up from four cylinders each 4 feet long, and each ½-inch greater in diameter than the one preceding it.

If the average taper of logs is ½-inch for 4 feet, and pieces 4 feet long are merchantable, then the scale in column 6 is correct. Based on this conclusion the loss in scale through neglect of taper is as follows:

Length of log. Feet	Scaled as one log. Per cent loss	Scaled as 16-foot logs. Per cent loss
16	8	8
32	13	8
48	31	8
64	51	8

Thus the loss in scale is proportional to the length and total taper of the log.

45. Middle Diameter as a Basis for Board-foot Contents. In some regions no attempt is made to divide long logs in scaling. While short logs are scaled at the end, logs over a given length are measured once at the middle and the scale applied to the entire log. In cypress this measurement is sometimes taken at a point distant from the small end by one-third of the total length. This practice of substituting middle for end diameters on long logs and scaling the log as one long cylinder whose diameter is thus obtained assumes that the loss in sawing the smaller top section will be offset by gain from taper in the butt portion. The total scale by this method exceeds that obtained by scaling the log as the sum of separate cylinders.

In theory this measurement of logs for board-foot contents at the middle diameter should possess the same advantage over measurement at the small end as for cubic contents. But for the former purpose, the factor of waste exercises a definite influence on the method of scaling adopted, where for cubic contents it does not.

With very close utilization of short lengths, it may be assumed that the sawed output of two logs of the same middle diameter, one of which tapers rapidly, the other gradually, would be nearly equal, since what is lost at the small end of the rapidly tapering log would be saved at the larger end. That this is approximately true is the premise on which Tiemann based his board-foot log rule (§ 63) on middle diameter.

If, on the other hand, the minimum length of board corresponds with the ordinary length of log sawed, the log with rapid taper loses a far greater percent than that with small taper, and two logs whose diameters at their small end are the same would give equal sawed contents regardless of differences in taper. Since the latter condition held when the log rules in common use were invented, this fact, and not the difficulty of scaling logs at the middle point, explains the general adoption of the custom of basing the contents upon the diameter at the small end.

46. Definition and Basis of Over-run. The purpose of all log rules is to furnish a standard of measurement for logs, fair alike to buyer and seller. For board-foot log rules this is best accomplished when the rule measures accurately the amount of lumber that may be sawed from straight, sound logs. It was the intention and the claim that each of the fifty or more log rules extant should perform this service under the conditions for which it was made; yet in spite of this fact, the contents of sound logs of the same dimensions, as measured by different rules, may differ more than 100 per cent.

While some rules based on incorrect premises never were accurate, most of the rules as checked by actual mill tests were probably satisfactory when first employed. But these rules were not changed to keep pace with the closer utilization brought about by the improvements in machinery, methods and markets. Although obsolete as a measure of actual product, they have been retained through custom. It is difficult to supplant or alter a commonly accepted standard of measure, even if grossly inconsistent and inaccurate.

Antiquated log rules thus cease to perform the true function for which they were intended, of measuring in the log the possible output of lumber. The sawed product tends to over-run the scale of contents shown by the log rule.

An excess of sawed over scaled contents of logs is termed the *over-run*. The over-run is always stated as a per cent of the log scale. The log rule, whether accurate or defective, is accepted as the fixed standard, giving the same contents for all straight and sound logs of the same dimensions. Over-run, on the contrary, will vary with several factors. A knowledge of the average per cent of over-run which may be expected over the scale enables both buyer and seller of logs to gage their value more accurately. As value is dependent on the price of lumber, the dealer in logs must know whether for every 1000 board feet of lumber scaled by the log rule, there will be obtained say 1250 board feet of sawed lumber, or only the 1000 board feet scaled, for in the former case the logs are worth 25 per cent more per 1000 board feet of scaled contents than in the latter.

47. Influences Affecting Over-run. The Log Rule Itself. Two log rules giving different scaled contents for logs of the same sizes will yield correspondingly different per cents of over-run. Each rule is arbitrarily assumed to represent a standard of 100 per cent, the over-run being computed in terms of the rule employed.

For instance, a given quantity of logs when scaled by the Doyle rule may measure 67,000, and saw out 100,000 board feet. Instead of stating that the log scale gives 67 per cent of the actual product, with an "over-run" of 33 per cent, the scale is taken as the standard or 100 per cent, and the correct over-run in this case is 49 per cent. When scaled by the Scribner rule, these same logs may give 85,000 board feet. In this case the over-run will be 17.6 per cent since 15,000 board feet is 17.6 per cent of 85,000 board feet scaled in the log.

Since the quantity of sound lumber contained in logs can be measured with only approximate accuracy, due to hidden defects and other factors, the buyer demands a certain margin of safety. A reasonable over-run of from 5 to 10 per cent is usually expected. With a properly constructed log rule, the over-run should be about the same for large as for small logs. The worst defect which a log rule can possess is inconsistency in scale between logs of different sizes (§ 39). Slight irregularities in scale of individual diameter classes may average out in the general run of logs. But when the per cent of board-foot contents scaled by a log rule increases or decreases in proportion to size of log, there is no way of adjusting it. The over-run will then vary with the average size of the logs scaled. Such a rule can never give permanent satisfaction to both the buyer and the seller of logs.

48. Influences Affecting Over-run. Methods of Manufacture. With a fixed standard set by a log rule, the greater the economy of manufacture, the greater will be the over-run. Any factor which reduces the waste in manufacture increases the output. The waste in straight, sound logs consists of slabs, edgings, trimmings and sawdust. In addition, there may be a loss or gain in the scale of lumber due to fractional thicknesses not measured in board feet (§ 20).

Saw Kerf. The fewer the number of saw cuts required, the less the waste. Lumber sawed and measured to standard thicknesses greater than 1 inch therefore increases the total output in board feet. A diminished thickness of the saw has a similar influence. Log rules, correct when adapted to a $\frac{1}{4}$-inch saw kerf, give an over-run of more than 10 per cent when a $\frac{1}{8}$-inch saw kerf is cut. The use of circular saws cutting a $\frac{5}{16}$-inch kerf partially accounts for the small scaled contents given by some of the old log rules.

Slabs. Waste in slabs is reduced by sawing narrow and thin boards and short lengths. The short lengths serve to fully utilize the taper in long logs, increasing the over-run on this class of material. The method of sawing a log also affects the per cent of utilization of slabs. Slash sawing, or sawing alive, as practiced for round-edged boards (§ 21) would result in waste where the boards are to be used in their full length, and trimmed to square parallel edges. By this method, short boards would be secured from but two sides of the log. The usual custom in manufacturing lumber of standard lengths is to turn and square the log, slabbing all four sides.

The gain in sawed product, by sawing around, in comparison with slash sawing, for square-edged boards, was shown to equal the following per cents, as determined by H. D. Tiemann.

TABLE VI

GAIN IN OUTPUT SECURED BY SAWING AROUND, COMPARED WITH SLASH SAWING, IN PER CENT OF LATTER OUTPUT

Diameter of log. Inches	Length 10 feet. Per cent saved	Length 20 feet. Per cent saved
6	15	22
7	14	18
8	13	15
9	12	13
10	11	11
11	9	10
12	6	7
13	4	6

Above 13 inches the difference is less perceptible. Where round-edged boards are fully utilized and not reduced to square parallel edges, not only does sawing around give place to slash sawing, but the per cent of utilization is much greater than by either method of sawing for square-edged lumber, due to the shorter lengths utilized in working up the round-edged lumber in the factory.

Full and Scant Thicknesses of Boards. Boards not cut to exact dimensions, if cut full lose the excess when measured, and if too scant are either rejected, or reduced in grade. If cut scant but within prescribed limits, they are scaled by superficial measure, and increase the over-run (§ 20).

In either case the sawyer to secure full scale of lumber must produce boards measuring within $\frac{1}{32}$-inch of the required thickness. This is impossible without good machinery. In local custom mills, much lumber is manufactured in uneven thicknesses causing a loss in scale and reducing the over-run.

49. Standardization of Variables in Construction of a Log Rule. The over-run in sawing logs will depend for a given log rule upon thickness of saw kerf, average dimensions of lumber, closeness of utilization of slabs and of taper, and the exactness of manufactured dimensions. All four of these factors are variables.

For a given mill, the saw kerf alone is constant and even then the waste will vary if two or more saws of different kerfs are used. The other factors are variable. For different mills, one or more conditions are certain to differ radically, giving a corresponding increase or decrease in over-run. Standardization of output and methods, possible in mills of the same class serving the same markets, may secure a similar degree of slab utilization and of efficiency in sawing to exact dimensions, but this still leaves the fourth variable, differences in thickness of lumber sawed, to affect the over-run.

Where the sawed output is in thicknesses less than 1 inch, and expressed in superficial feet, the product is not comparable with 1-inch lumber and must be reduced to terms of 1-inch boards for a true comparison with the log scale.

Arbitrary Standards. The essentials of any standard of measure are fixed qualities and common acceptance. Even a poor or faulty standard which is universally used would be better than a number of different rules, or a rule which may be changed to suit conditions or the preference of the user. These four variables must therefore be arbitrarily fixed in adopting values for a standard or common log rule, and in the case of most rules which have found wide use this was done. The thickness of lumber was fixed at 1 inch, permitting an over-run whenever thicker dimensions are sawed. The width of saw kerf adopted by the rule was that used at the time and place of constructing the rule, and was usually $\frac{1}{4}$-inch or larger. Local custom determined the width of the narrowest 1-inch board sawed and this fixed the amount of waste allowed for slabbing and edging. Taper was disregarded. Boards were usually measured only to the nearest full inch of width and fractional inches disregarded. Skill in manufacture was considered by checking the results of the rule with the actual sawed output, by means of mill tallies.

Variable Standards. As contrasted with these fixed standard rules, comes the suggestion [1] for a log rule in which average thickness of lumber, saw kerf and degree of utilization of slabs and taper shall be represented by variable quantities, and adjusted by each mill owner to suit the conditions of manufacture prevailing at the time or for the past few months. Such a rule, when adjusted, would eliminate over-run as long as the variables in manufacture on which it was computed remained unchanged. But as a standard of measurement it could never have any general or legal status unless its values were fixed, when it would at once be open to the same objections which by its flexibility it sought to avoid.

50. The Need for More Accurate Log Rules. The great question with log rules is whether conditions have changed so permanently that new rules adjusted to these factors should replace those now in use. The $\frac{1}{4}$-inch circular saw is still retained in small custom mills, and there is a tendency, in regions that have been cut over by big operators, to revert to these primitive methods. The operator of a band saw mill is probably entitled to the over-run resulting from the use of thinner saws and closer utilization. A log rule made to scale closely the output of such up-to-date plants would exceed the product of the small mill. Provided the rule is consistent, a conservative log rule which will give an over-run varying in per cent with closeness of utilization is probably better for commercial uses than one which aims at securing the maximum product from modern mills.

Log rules based on correct mathematical principles are the only rules from which consistent and satisfactory results can be expected, and this is a far more important factor than the elimination of over-run. If, in addition, such log rules conform to the present conditions of manufacture, they have a use in scientific measurements of logs and standing timber, as a basis for estimates of volume and growth expressed in the board-foot unit. This use of such a rule would justify its existence, entirely aside from the question of its possible universal adoption as a legal standard of log measure.

51. The Waste from Slabs and Edgings. The total waste in sawing straight sound logs is the sum of the two factors, sawdust, and slabs plus edgings. For lumber of a given thickness, such as 1-inch boards, the portion of the cross section of the log wasted in slabs and edgings may be shown graphically by plotting on diagrams, allowing the proper space between each board for saw kerf. From these diagrams it is possible to compute the area of this waste, in square inches, and the thickness of a ring or collar which will have the same area and thus represent the waste from slabbing and edging.

[1] H. E. McKenzie, Bul. 5, California State Board of Forestry, 1915.

When this is done for logs of all sizes it is found that except for the smaller logs the width of these collars is practically the same regardless of diameter. This law does not hold for small logs, because the width of the minimum boards remains the same for all logs and as the diameter of the log approaches this minimum width of board, the proportional waste in slabs and edgings rapidly increases until utilization becomes zero and waste 100 per cent for a diameter of log just too small to saw out the smallest board or piece that is merchantable.

The waste in slabbing and edging varies, for any log, with the average thickness of the lumber sawed. Logs sawed entirely into $2\frac{1}{4}$-inch plank would show considerably greater waste in edging than where 1-inch boards are sawed (§ 21). The results shown by diagram are confirmed by tests in the mill.

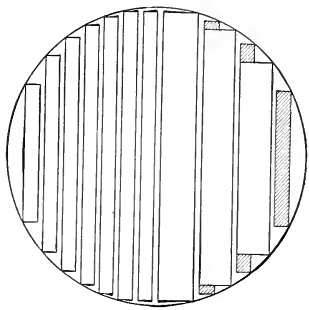


Fig. 6.—Relative waste in slabs and edgings from sawing $2\frac{1}{4}$-inch plank and 1-inch boards. If 1-inch boards are sawed, the waste is reduced by the amount of the shaded portion. The greater proportion of waste in sawing thick boards comes from the side cuts, hence the practice is to cut 1-inch lumber from the sides.

From these investigations it is evident that the waste from slabs and edgings is proportional, approximately, to the surface of the log inside the bark. The surface of a log is equal to the circumference or girth, multiplied by the length. As circumference equals πD for all logs, the *waste from slabs and edging is then proportional to the diameter of the log* multiplied by its length.

But the volume of the log increases as the cross sectional area, which is *proportional to the square of the diameter* (§ 27). The *amount* of waste in slabs and edgings from a log 20 inches in diameter is just twice that for a 10-inch log, since the diameter and the surface are doubled. But the 20-inch log contains four times the volume of the smaller piece, and this reduces the *per cent* of waste from slabs and edgings based on the volume of the larger log to one-half that for the 10-inch log.

52. The Waste from Crook or Sweep. Log rules apply only to straight logs. But the standard as to what constitutes straight logs requires definition. For all commercial log rules, this standard permits of " normal " crook (§ 93). This is best defined as crook averaging not over $1\frac{1}{2}$ inches in 12 feet, and including no log which crooks more than 4 inches in 12 feet. Crook or sweep in long logs is reduced by cutting them into two or more short sections before sawing. Where very short material such as box boards is used, crook does not cause abnormal waste in logs. Care in laying off log lengths in the woods to secure the maximum length of straight sections by dividing the tree at the points of greatest crook reduces this source of waste to small proportions.

Waste from crook is deducted in scaling on the assumption that the merchantable portion of the log must cut boards extending its whole length. The influence of length of log upon the waste due to crook is very pronounced, and where long logs are divided into shorter lengths in the mill they should never be discounted for crook except to the extent that this crook will affect the sawed contents of the shorter pieces. For lumber longer than 12 feet the influence of crook rapidly increases.

The relation of normal crook to taper is shown in Fig. 7 in which the line DE is the axis of the cylinder corresponding to a straight log. The line AB is parallel to this axis and tangent to the margin at the small

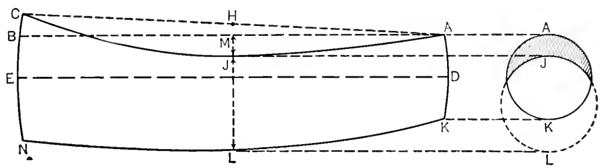


FIG. 7.—Method of measuring amount of crook in a log, in inches. The line JM represents the proper measurement, coinciding with the shaded portion JA or waste in the circle representing small end of log.

end. The line AC is a straight line connecting the margins of both ends of the log. Were the log cylindrical, the line HJ under these circumstances would represent the amount of crook. But the taper gives a larger cross-section at JL than at AK. *Unless crook exceeds the taper for half the log,* the cross-section JL when projected upon AK would completely cover it, permitting as much lumber to be sawed as if the log were straight. In the diagram the crook exceeds this taper and the upper shaded portion of the cross section which represents the small end must be wasted in slabs, in addition to the normal slabbing of a round log.

But this waste is incorrectly measured by any other method than that shown by the line JM, which is the distance to the surface of the log from a line parallel to the axis, and tangent to the margin of the small end. This distance gives the crook in inches.

For a 16-foot log tapering 2 inches, a crook of 1 to $1\frac{1}{2}$ inches at the middle point has no appreciable effect on the output.

By slabbing in the direction of KN this waste may be still further reduced, since the cylinder sawed is not parallel with the axis but follows the crook at the small end, and takes maximum advantage of taper at butt. Logs so crooked that their sawed contents is materially reduced are not scaled " straight and sound " or full. Deductions for crook are discussed in § 93. The waste from normal crook is included with that for slabbing and edging and is in proportion to surface, and hence to diameter.

53. The Waste from Saw Kerf. The total waste in sawdust, unlike that in slabs and edgings, takes approximately the same per cent of the cubic volume of all logs, regardless of their size. If a log is sawed by the method called slash sawing, in parallel saw cuts without squaring it, then, after the first slab is removed, there will be one saw kerf to each

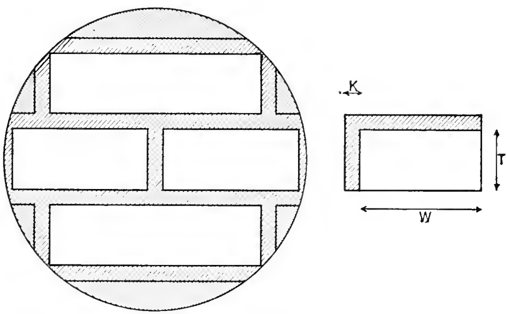


FIG. 8.—Waste incurred as slabs and sawdust in sawing round, straight logs.

board. The initial saw kerf, and the sawdust wasted in edging, and in ripping wide boards into narrower boards, forms an additional percentage of waste not exactly proportional to volume. Disregarding this discrepancy, the fixed per cent of waste from saw kerf for the log is the same as the per cent wasted in sawing one board. If the thickness of board plus that of the saw is taken as 100 per cent, this waste, for a 1-inch board with $\frac{1}{4}$-inch saw kerf is as $\frac{1}{4}$ to $1\frac{1}{4}$ or 20 per cent, while for a $\frac{1}{8}$-inch saw kerf the proportion is $\frac{1}{8}$ to $1\frac{1}{8}$ or 11.1 per cent. A general formula applicable to saws of all thicknesses is as follows:

Let K = width of saw kerf;

T = thickness of lumber.

Then

$T+K$ = total volume of board plus kerf,

$$\frac{K}{T+K} = \text{per cent deduction for saw kerf,}$$

$$\frac{T}{T+K} = \text{per cent of log utilized as lumber.}$$

Efforts to account for the exact per cent of waste in sawdust have been made, by including, first the saw kerf required for ripping or edging one edge, as shown in Fig. 8,[1] and second, the additional saw kerf for the first slab. But neither method is complete, since boards are edged when necessary on both edges. The best method is probably to include this extra saw kerf, together with the edgings, in the waste due to slabbing, leaving the sawdust as a straight per cent of volume.

Shrinkage. Where shrinkage is considered, or where lumber must be sawed a trifle full, the extra thickness which is not measured in the green lumber constitutes a waste exactly similar to saw kerf, and can be added to the latter factor in the formula before calculating the per cent of reduction.

For instance, if a log rule is intended to measure the output of 1-inch lumber after seasoning, and the average shrinkage on inch boards is $\frac{1}{16}$-inch, and saw kerf $\frac{1}{8}$-inch, the per cent of waste in small logs is

$$\frac{\frac{1}{8}+\frac{1}{16}}{1+\frac{1}{8}+\frac{1}{16}} = \frac{.1875}{1.1875} = 15.8 \text{ per cent.}$$

[1] By the inclusion of one edge, the formula for sawdust would be:

Volume of unit $(W+K)(T+K)$,

Saw kerf $K(W+T+K)$,

Per cent of waste $\frac{K(W+T+K)}{(W+K)(T+K)}$.

H. E. McKenzie, Bul. 5, California State Board of Forestry, Sacramento, Cal., 1915.

By inclusion of the extra saw kerf but not of the cut for edging.

Number of cuts $=N$,

Average saw kerf per board $=K+\frac{K}{N}$,

Volume of unit $=T+K+\frac{K}{N}$,

Per cent of waste $=\frac{K+\frac{K}{N}}{T+K+\frac{K}{N}}$.

C. M. Hilton, Bangor, Me., 1920.

Corrections for Saw Kerfs of Different Widths. Since the per cent of waste caused by saw kerf applies directly to the residual volume of logs after subtracting the waste for slabbing and edging, the effect of using a saw of greater or lesser width than that used in constructing the rule can be found in terms of a per cent of the values of the log rule. This flat correction can then be applied if desired, to correct timber estimates, convert the log rule into one which eliminates over-run from saw kerf, or correct the scale of logs to coincide more closely with sawed output.

For instance, the above rule would utilize $1-.158$ or 84.2 per cent of the net cubic contents of the cylinder. A saw cutting a $\frac{1}{4}$-inch kerf, with the same allowance for shrinkage, calls for the formula,

$$\frac{\frac{1}{4}+\frac{1}{16}}{1+\frac{1}{4}+\frac{1}{16}}=\frac{.3125}{1.3125}=23.8 \text{ per cent,}$$

giving 72.6 per cent utilized. The values expressed by the log rule made for the $\frac{1}{8}$-inch kerf must now be taken as 100 per cent to which the correction will apply. Then $\frac{76.2}{84.2}$ gives 90.5 per cent. The second rule requires values equaling 90.5 per cent of the first, or a straight reduction of 9.5 per cent.

That this conversion can be accurately made was demonstrated on diagrams by H. D. Tiemann, who found that the possible error was less than one-half of one per cent.[1]

54. Total Per Cent of Waste in a Log. The total per cent of waste in a log is the sum of the waste from slabbing and edging, or surface waste, and from saw kerf. The proportion of this total waste represented respectively by slabbing and by sawdust will depend upon which of these deductions is made first, and whether the sawdust made in slabbing and edging is included as part of the waste in slabs and edgings, or is counted as part of the waste in sawdust. If the deduction for sawdust is made first, it will include a fixed per cent of the cubic volume of the log. If on the other hand, the slab waste is first deducted as a ring or collar of a given thickness, the subsequent deduction for saw kerf, although the per cent is the same, applies only to the residual volume of the log.

The total per cent of waste, and its distribution between these two factors is illustrated in table VII. Let slab waste equal a ring $\frac{3}{4}$-inch in thickness or a reduction of 1.5 inches in diameter. Sawdust, for $\frac{1}{4}$-inch kerf, equals 20 per cent. The per cent of waste will vary with diameter of logs, as shown:

In column 2 the per cent of waste is seen to be approximately one-half as great for 20-inch logs as for 10-inch logs.

[1] Proc. Soc. of Am. Foresters, Vol. V, 1909, p. 29.

TABLE VII

Distribution of Waste between Slabbing and Sawdust

1	2	3	4	5	6	7	8
Diameter at small end of log.	Waste in slabbing.	Waste in sawdust 20 per cent of remainder of log.	Total waste Columns 2+3.	Waste saw kerf in slabs.	Total waste saw kerf, Columns 3+5.	Waste in slabs less saw kerf in slabs.	Utilization.*
Inches	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
10	27.75	14.45	42.20	5.55	20	22.20	57.80
20	14.44	17.11	31.55	2.89	20	11.55	68.45
40	7.27	18.54	25.81	1.45	20	5.82	74.19

* Of the small cylinder not including taper.

The waste in slabbing would be exactly proportional to diameter except for the fact that the volume of the hollow cylinders representing the collar deducted for slabs is not directly proportional to the *outer* surface of the respective cylinders in logs of different sizes. The same relation is seen to hold whether or not the slab waste is deducted before or after the sawdust. (Columns 2 and 7.)

Since the per cent of slab waste is roughly proportional to D, while that from sawdust is as D^2, the sum of these two factors causes the *total per cent* of waste to decrease as shown in column 4, instead of remaining constant as in column 6. The rate of decrease is less rapid than in columns 2 or 7 since *only a portion* of the waste decreases in per cent with increasing diameter of log.

Were the total waste in logs proportional to D^2 as is the waste from saw kerf, log rules could be converted from cubic to board feet by a single ratio. But since the part of this waste due to slabbing is proportional to D, *the per cent of total waste decreases with increasing diameter* by a rate which is the sum of these two factors and is therefore directly proportional to neither D nor D^2. This explains the increasing per cent of utilization secured in sawing larger logs and the need for log rules based directly upon the board-foot unit and not derived by conversion of cubic units.

To derive an accurate log rule, not only must the waste from slabs and edgings be deducted separately from the waste from saw kerf, but the correct amount must be deducted for each source of waste. A rule which deducts too much for slabs and too little for saw kerf will deduct too much on small logs, where the slab waste is normally high, and too little on large logs, where the greater portion of the deduction is for saw kerf. Such a rule can be correct only for a single diameter class where the two errors happen to balance.

On the other hand, if too small a deduction is made for slabs, and too large for sawdust, small logs may be overscaled, while the increasing per cent of utilization possible in larger logs will not be shown in the scale (Column 8), and the rule therefore tends to under-scale large sizes.

CHAPTER VI

THE CONSTRUCTION OF LOG RULES FOR BOARD-FOOT CONTENTS

55. Methods Used in Constructing Log Rules for Board Feet. The great variation in the contents of different log rules for board feet, and the variation in accuracy and consistency of these rules is due to the methods used in their construction as well as to the factor of over-run resulting from closer utilization.

Four general methods have been used in constructing such rules. These are:

1. By mathematical formulæ. A formula is used, which derives the board-foot contents of the log directly from its diameter and length, by allowing for reductions from $D^2 \times L$ for cubic volume, waste in saw kerf, waste in slabs, and reduction of residual volume to board feet. If the principles used in making these reductions (§ 54) are correct and the amounts used are also correct, such log rules are superior to diagram rules, but if errors in either principles or amounts of deduction are introduced into the formula, the rule is worse than useless.

2. By diagrams. Full-sized circles of all diameters are drawn on large sheets of paper, representing the top ends of the logs. On these cross sections of the log the ends or cross sections of the boards which could be sawed from these logs are drawn, leaving between each board a space equal to the width of the saw kerf. The area of boards in square inches is then reduced to board feet by the factor $\frac{1}{12} \times$length in feet, for logs of a standard length, and from this, for logs of all lengths.

3. By tallying the actual sawed contents of logs at the mill for different diameters and lengths. Owing to the variables introduced by the thickness of lumber sawed, and by taper, this method has seldom been accepted as the sole basis for a log rule, but has been extensively used to check the accuracy of rules made by the preceding two methods.

4. By conversion of the cubic contents of logs into board feet, after deducting a fixed per cent of this total cubic contents for waste in sawing and slabbing. As shown in Chapter V, all board-foot log rules constructed on this basis are fundamentally wrong.

A fifth method has been used, which is a combination of methods 1 and 2 or 3, namely, to alter or correct the values of an existing log rule, by means of mill tallies obtained in sawing. The author of such corrections may give a new name to such a rule, or may state that it is an old rule corrected. Such corrected rules while undoubtedly better than the originals have so far failed of adoption in place of the rules from which they were made, owing to the force of custom in perpetuating established standards even if in error.

56. The Construction of Rules Based on Mathematical Formulæ. Many efforts have been made to evolve a formula which will give an accurate basis for a board-foot log rule. Of these the erroneous formulæ, or rules of thumb, based on a fixed conversion factor are most common. Of those which recognize the fundamental difference between waste from slabs, and waste from saw kerf, we have two groups, distinguished not by principle, but by the method of procedure dependent on whether the deduction for saw kerf is made first, from the total contents of the log, or whether that for slabs and edgings is first deducted, and the waste from saw kerf then taken from the residual volume.

Method of Deducting Slabs First. When the first plan is used, a constant, a, representing in inches the double width or thickness of the hollow cylinder or surface layer wasted in slabs, edgings and crook, is first deducted from the diameter of the log at small end. From the area of the smaller circle thus obtained, the required per cent is subtracted for saw kerf, shrinkage or surplus thickness of board required in sawing.

The residual area of the circle in square inches is converted into board feet for logs 1 foot long, by dividing by the factor 12. Disregarding the taper, the volume of a log of any length is found by multiplying the contents by length in feet.

D = diameter of log in inches;

a = inches subtracted from diameter, a constant;

$D-a$ = reduced diameter of log after subtracting waste from slabs and edgings;

$\frac{\pi(D-a)^2}{4}$ = reduced area of small end of log in square inches;

b = per cent of volume deducted for saw kerf;

$1-b$ = per cent remaining after deduction for saw kerf;

L = length of log in feet;

B.M. = volume of log in board feet;

then

$$\text{B.M.} = (1-b)\frac{\pi(D-\text{a})^2}{4}\,\frac{L}{12}$$

$$= (1-b)\frac{\pi(D-a)^2}{48}.$$

Illustration

Let $a = 1.5$ inches, representing a collar of .75 inch thickness deducted for slabs, etc.

$b = 20$ per cent representing a $\frac{1}{4}$-inch saw kerf.

Then for any log,

$$B.M. = (1-.20)\frac{\pi(D-1.5)^2}{48}L.$$

For a 12-inch log 16 feet long,

$$B.M. = .80\left(\frac{3.1416(12-1.5)^2}{48}\right)16$$
$$=92 \text{ board feet.}$$

Method of Deducting Sawdust First.—By the second method, the per cent of waste in saw kerf is first deducted from the entire volume of the log. From the residual volume the amount to be further subtracted for slabs, edging and crook is taken. This is a smaller per cent than by the first method, as shown in Table VII, column 7 since the sawdust used in slabbing is not included, and it is for convenience computed in the form of a plank of width and length equal to the log, and whose thickness is varied to give the required volume of waste.

Let A equal the width of this plank in inches. This is taken as a constant.

Then,

$$B.M. = \left((1-b)\frac{\pi D^2}{4} - AD\right)\frac{L}{12}.$$

ILLUSTRATION

Let $b = 20$ per cent—sawdust allowance,

$A = 1.767$ inches, the thickness of a plank whose width is equal to D, and length to L—for slabbing allowance.

Then for any log,

$$B.M. = \left[.80\left(\frac{\pi D^2}{4}\right) - 1.767D\right]\frac{L}{12}.$$

For a 12-inch log 16 feet long,

$$B.M. = [.80(.7854\times 12^2) - 1.767\times 12]\tfrac{16}{12},$$

$$B.M. = 92 \text{ board feet.}$$

This result shows that for 12-inch logs, after subtracting 20 per cent from log for sawdust, a plank 1.767 inches by 12 inches gives a deduction from the *net* volume, equal to method 1 when a collar .75 inch thick is first deducted and 20 per cent for sawdust taken from the remainder.

The two methods are not absolutely interchangeable. Their relation may be shown by algebraical means.

Substitute C for $(1-b)$.

Then C = per cent left after subtracting saw kerf.

Since D is in inches, and L exerts no influence on the relative values, the areas of the small end of log, left after subtracting *total* waste, should be equal, and can be expressed in square inches for each formula as:

$$\frac{C\pi(D-a)^2}{4} = \frac{C\pi D^2}{4} - AD.$$

Then,

$$A = \frac{C(1.5708aD - .7854a^2)}{D}.$$

The results, for certain diameters are shown below:

TABLE VIII

THICKNESS OF PLANK TO BE DEDUCTED FOR SLAB WASTE TO COINCIDE WITH A COLLAR 1.5 INCHES THICK. SAWDUST ALLOWANCE 20 PER CENT

Diameter of log. Inches	Double thickness of collar deducted for slab waste previous to deducting sawdust. Inches	Corresponding thickness of plank to be deducted after deducting sawdust. Inches	Ratio of thickness of of plank to collar
3	1.5	1.414	0.940
6	1.5	1.649	1.099
9	1.5	1.728	1.152
12	1.5	1.767	1.178
18	1.5	1.800	1.200
40	1.5	1.849	1.233

The use of these ratios would give identical results by both methods. But in application the second method usually stipulates that the thickness of plank shall be constant for all logs. This results in a greater proportionate deduction for slabs on small logs than by the first method. This deduction is more in accordance with the actual results of sawing, owing to the increasing effect of minimum widths of board on per cent of loss in slabbing (§ 51). The best application is to adopt a ratio which applies to medium-sized logs, and use this for all logs, large and small.

If a log rule is constructed to deduct the waste which actually occurs in sawing, it must be based on one or the other of these two formulæ. If the waste allowances are correct for *the conditions assumed*, there will still be over-run when other conditions apply, but the per cent of over-run will be practically the same for all sizes, the rule is consistent, and the results are subject to correction by a fixed ratio or per cent.

If the waste allowance for either slabbing or sawing, or both, are incorrect for the conditions assumed, the rule will not only give over- or under-run, but will also be *inconsistent*, the per cent will differ with diameter, and the rule will not be subject to correction by a fixed ratio, and will lack the basic requirements of a standard of measure.

57. Comparison of Log Rules Based on Formulæ. In constructing a formula log rule, the correct application of the deduction for saw kerf presents no great difficulty. In the International rule, an extra deduction of $\frac{1}{16}$-inch was made for shrinkage. Other rules neglect all factors but the actual width of saw kerf (§ 53).

The deduction for slabs, edging and normal crook requires determination not only from diagrams but from practical tests. The following amounts are deducted by the log rules given below, expressed both as a "collar" deduction from diameter, (a), and as a thickness of plank (A), to correspond with the two methods described (§ 56).

TABLE IX

Deductions for Slabbing and for Saw Kerf, for 12-inch Logs, in Ten Log Rules Based on Formulæ. The Basis Used in the Rule is Shown in Heavy Type.

Log Rule.	Deduction from diameter for slabbing. Inches	Equivalent deduction in form of a plank thickness. Inches	Saw kerf plus shrinkage. Inches	Deduction for saw kerf. Per cent
International	1.73	**2.12**	$\frac{1}{8}+\frac{1}{16}$	15.8
Universal	1.66	**2.00**	$\frac{1}{4}$	20.0
Preston: Large logs	**1.75**	2.04	$\frac{1}{4}$	20.0
Small logs	**1.50**	1.77	$\frac{1}{4}$	20.0
British Columbia	**1.50**	1.77	$\frac{3}{8}$	27.3
Click	**1.25**	1.42	$\frac{1}{4}$	23.6
Clement	**1.18**	1.32	$\frac{1}{4}$	25.0
Wilson	**1.00**	1.17	$\frac{1}{4}$	22.2
Thomas	**1.00**	1.17	$\frac{1}{4}$	22.0
Baughman *	0.87	1.05	$\frac{1}{4}$	20.0
Champlain	0.83	**1.00**	$\frac{1}{4}$	20.0
Doyle	**4.00**	5.00	$\frac{1}{4}$	4.5
Baxter	**1.00**	1.00	$\frac{1}{4}$	33.8

* Diagram rule.

Of the rules above cited, the British Columbia and Doyle are the only ones used extensively at present. The table is instructive as an indication of the proper allowances to make for slabbing. The test of a formula is actual comparison with sawed output. The deductions in the International rule were determined by careful measurement on logs actually sawed. The Champlain rule is known to be too close a rule, with too small an allowance for slabs. The British Columbia rule neglects shrinkage and is a good standard. The Click rule was carefully checked by sawed output. These results indicate that for 1-inch lumber sawed to exact dimensions, an allowance for slabbing of 1.5 to 1.75 inches subtracted from diameter, or one-half this deduction as the single thickness of the collar, is a fair allowance for slabbing. This allowance would be too small for lumber of greater average thickness than 1 inch or for very small logs.

When the deduction is made in the form of a plank whose width equals the diameter, D, of the log, the thickness of plank required to make it equivalent to the collar deduction is from 1.75 to 2 inches for 12-inch logs, slightly more for larger logs, and decreasing in thickness for smaller logs. But where the deduction is made in this form, as in the International and Champlain rules, it is used as a constant for all dimensions (§ 59 and § 62) with results corresponding more closely to actual waste than by the first method.

The allowance for saw kerf, on all log rules in commercial use, is $\frac{1}{4}$-inch or over. The International rule in its original form gives values for a $\frac{1}{8}$-inch saw kerf, which, with the other allowances, gives a rule intended to measure the output of modern band mills.

58. McKenzie Log Rule, 1915. This log rule is a universal formula and not a commercial standard or true log rule. It is intended to reduce all the variable factors in the production of sawed lumber to elements in a formula, which will permit the determination of a local rule that will accurately measure the sawed output in the log for any condition, and eliminate over-run.

The factor of taper is treated by building up the log in 8-foot sections, permitting the use of whatever actual average taper coincides with that of the logs sawed. The allowance for slabs, edging and crook is made by the first method, that of deduction from the diameter previous to subtracting saw kerf. Shrinkage could be included with saw kerf, if necessary, but the author does not mention it.

The formula is the one already shown to be correct and universal for board-foot log rules,

$$\text{B.M.} = (1-b).7854(D-a)^2\frac{L}{12}.$$

The saw kerf allowance, b, is computed to include width as well as thickness of lumber sawed (§ 53). To this general formula the author adds a constant, c, to offset excessive taper on small logs.

The principal utility of this log rule will be found in determining, in advance of sawing, the amount of over-run which may be obtained from logs scaled by a commercial rule, or to test the results in over-run to be expected by the use of different log rules and different methods of manufacture. The objections to adopting it as a standard of measure are stated in § 49.

Reference

Bul. 5, California State Board of Forestry, by H. E. McKenzie.

59. International Log Rule for $\frac{1}{8}$-inch Kerf, Judson F. Clark, 1900. In constructing this rule, modern conditions of manufacture in large mills were presupposed. The values of the rule as published are for a band saw cutting a $\frac{1}{8}$-inch kerf and are rounded off to 5 and 10 board feet, thus approaching the principle of a decimal rule. Saw kerf is first subtracted, allowing $\frac{1}{16}$-inch for shrinkage, or a total of $\frac{3}{16}$ inch. The deduction for slabs and edging, including a normal crook of from 1 to $1\frac{1}{2}$ inches is then made in the form of a plank measuring $2.12D$.

The formula reads:

$$\text{B.M.} = (.66D^2 - 2.12D)\frac{L}{12}.$$

The rule was constructed as follows: Since the per cent of waste in saw kerf plus shrinkage is $\frac{K}{1+K}$ this becomes for inch boards $\frac{3}{16+3}$ or 3 parts in 19, which gives .158, and the factor for residual volume is .842. Then,

$$.842(.7854D^2) = .66D^2.$$

The deduction 2.12*D* was determined from tests of sawed logs, including all crook of 4 inches or less.

Since the log is divided into 4-foot lengths, the sum of which gives the scale, the formula reads for each length,

$$\text{B.M.} = (.66D^2 - 2.12D)\tfrac{4}{12}$$

$$= .22D^2 - .71D.$$

A taper of ½-inch in 4 feet is allowed. *D* is thus increased by ½-inch for each successive section and the sum of the scale of the separate 4-foot cylinders gives the scale of the log (§ 43). On account of the allowance for shrinkage the rule is based in reality on the production of $1\frac{1}{16}$-inch boards measured as inch boards. A minimum width of 3 inches, and a minimum length of 2 feet are adopted as standard, no piece to contain less than 2 board feet. Standard values were published, it being the intention of the author to furnish a commercial log rule that could be accepted as a common standard for the measurement of logs as sawed in modern mills using a band saw cutting a ⅛-inch kerf.

60. International Log Rule for ¼-inch Kerf, Judson F. Clark, 1917. For general adoption as a standard commercial log rule, the ⅛-inch rule is open to the objection that it over-scales the product of most small mills, since it is seldom that such mills use saws cutting less than ¼-inch kerf, or make close use of the taper of the log. A log rule which gives a safe margin, and which permits mills using thin band saws and up-to-date equipment to secure an over-run of about 10 per cent is more acceptable as a commercial standard than one which scales for the closest possible standard of utilization. For this reason, Mr. Clark has computed values for the International rule, for ¼-inch saw kerf. This form of the rule is here published for the first time from values furnished by its author (Appendix C, Table LXXX). To obtain this rule, the original values for the ⅛-inch rule were reduced by 9.5 per cent and then rounded off to the nearest 5 or 10 board feet. The rule is recommended as a standard for scientific measurements of volume and growth in terms of board feet, for regions where the product is manufactured by small mills using circular saws cutting a ¼-inch kerf.

61. British Columbia Log Rule, 1902. This is the only case of the legal adoption and application in commercial scaling of a new log rule based on sound scientific principles, as the direct result of a thorough investigation. In 1902 a commission of three men prepared from diagrams a rule to suceed the Doyle Rule for the province, which was adopted in 1909 as the Statute rule.

Their results were embodied in a formula reading:

"For logs up to 40 feet in length deduct 1½ inches from the diameter of the small end inside the bark; square the result and multiply by the decimal .7854; from the product deduct three-elevenths; multiply the remainder by the length of the log and divide by twelve." Or,

$$B.M. = (1 - \tfrac{3}{11}).7854(D-1.5)^2\frac{L}{12}$$

$$= .727\frac{\pi(D-1.5)^2}{4}\frac{L}{12}.$$

The minimum width of board used was 3 inches.

For logs over 40 feet in length, an increase in diameter is allowed on half the length of the log amounting to 1 inch on the diameter at the small end, for each 10 feet in length over 40 feet. Thus for logs from 41 to 50 feet long the contents of the butt cylinder is scaled by a diameter 1 inch larger than the top end; for logs from 51 to 60 feet long, the rise allowed is 2 inches, etc.

This allowance for taper is absurdly small and constitutes the only weak point in the rule. It is a concession to the low standards of utilization practiced in the province at the time.

62. Other Formula Rules, Approximately Accurate, Both in Principles and Quantities. When a log rule is constructed by using the principles embodied in the standard formula, and when in addition, the amount of deduction for both saw kerf and slabbing is approximately correct, the resultant log rule will be far more accurate and consistent than any of the commercial rules in common use except the last mentioned. Several rules have been constructed, whose values differ only because of slightly different allowances for waste, as shown in Table IX. Seven such rules are given below. This completes the list of log rules known to the author, and based on diameter at small end of log, which deserve to be classed as fundamentally correct standards for board-foot contents of saw logs.

Champlain Log Rule, A. L. Daniels, 1902. This log rule, intended as a perfect rule for 1-inch boards, is based on ¼-inch saw kerf and neglects taper. It is for perfect logs. The deduction for slabs and edging, without normal crook, is made equal to a 1-inch plank or $1D$. No shrinkage is considered. The diameter is taken at small end. Were it not for an over-run secured from taper or the methods of sawing used, logs would never saw out what this rule calls for. The quantities given are above normal in cylindrical contents for short logs. This error is offset by neglect of taper, so that in long logs the rule falls below the International.

This rule has not been used commercially, except in a few instances in Vermont. The formula is:

$$B.M. = (.62832D - D)^2\frac{L}{12}.$$

The author of the Champlain log rule realized that the slab allowance was too small for actual conditions. By increasing the width of plank deducted for slabbing to $2D$, a modification, termed the Universal log rule was computed, using the formula,

$$B.\ M. = (.62832D^2 - 2D)\frac{L}{12}.$$

This rule compares favorably with other theoretically accurate rules except that it shares the common fault of neglecting taper. Mr. Daniels states (1917), that he favors the use of the Champlain rule as the more accurate of the two.

Wilson Log Rule, 1825.

$$\text{B.M.} = .807\frac{\pi(D-1)^2}{4}\frac{L}{12}.$$

By Clark Wilson, Swanzey, N. H. Originated in 1825, and computed for $\frac{7}{8}$-inch boards. Now obsolete. This was unquestionably the first formula rule. The author was a mathematician, and "estimated the difference in yield in gain of the large logs over the small ones, and then calculated the intermediate spaces by nearly regular integral differences as logs increase in size. The author intended it for $\frac{7}{8}$-inch boards. It is recorded that E. A. Parks later used it for 1-inch boards, which use resulted in a lawsuit." (John Humphrey, Keene, N. H.)

Preston Log Rule, An Old Rule.

$$\text{Large logs,}\quad \text{B.M.} = .80\frac{\pi(D-1.75)^2}{4}\frac{L}{12}.$$

$$\text{Small logs:}\quad \text{B.M.} = .80\frac{\pi(D-1.5)^2}{4}\frac{L}{12}.$$

Still used in Florida. Known locally as a seller's rule. Sold in Jacksonville, Fla., by H. & W. B. Drew Co.

Thomas' Accurate Log Rule.

$$\text{B.M.} = .78\frac{\pi(D-1)^2}{4}\frac{L}{12}.$$

For $\frac{1}{4}$-inch saw kerf. Also computed for $\frac{1}{8}$-inch kerf.

Click's Log Rule, 1909.

$$\text{B.M.} = .764\frac{\pi(D-1.25)^2}{4}\frac{L}{12}.$$

By A. C. Click, Elkin, N. C., 1909. This rule was based on 1-inch boards averaging 6 inches in width and makes reduction for saw kerf of $\frac{1}{4}$-inch as per the formula (§ 58), used by McKenzie. Other rules for different widths of saw kerf were worked out by the author. (Forestry Quarterly, Vol. VII, 1909, p. 145.)

Carey Rule, Date Unknown. This was a caliper rule to be applied to middle diameter, and was used for round edge boards 1-inch thick. The values given are almost identical with the Wilson rule. Formerly used in Massachusetts.

Clement's Log Rule, 1904.

$$\text{B.M.} = \left[\left(.75\frac{\pi D^2}{4}\right) - 1.18D\right]\frac{L}{12}.$$

This log rule illustrates the use of a rule of thumb, based on correct mathematics. The above formula is expressed thus: Multiply half the diameter by half the circumference, then subtract half the circumference. The remainder will be the total amount of feet board measure, in a 16-foot log.

This becomes:

$$\text{B.M.} = (.7854D^2 - 1.57D)\frac{L}{16},$$

from which the above formula is derived.

With the exception of the Preston, none of these rules is in commercial use.

63. Tiemann Log Rule, H. D. Tiemann, 1910. All of the commercial log rules in use are open to the criticism that the taper is disregarded, thus causing the over-run to vary according to the length and amount of total taper of the log. The International rule, in which taper is included, is not in commercial use to any extent. But one attempt has been made to take proper cognizance of taper by the method of applying a log rule for board feet to the middle diameter instead of the small end. Most rules employing this method are cubic-foot rules or based on cubic contents. The Tiemann log rule on the other hand is a true board-foot rule based on a $\frac{3}{16}$-inch saw kerf. The rule was made from actual mill tallies accurately adjusted for saw kerf and for exact thicknesses and the results worked out graphically by curves. Quite remarkably the curves were found to correspond very closely to the exceedingly simple formula

$$\text{B.M.} = (.75D^2 - 2D)\frac{L}{16},$$

which equals $\left(.716\frac{\pi D^2}{4} - 1.5D\right)\frac{L}{12}$.

The application of the rule is limited by its author to lengths not exceeding 24 feet.

This log rule applies to logs scaled in the middle. When this is possible, the rule is more accurate than any other board foot log rule, since neither the variation in taper nor length of log affects it. It can be adjusted to apply to the small end just as well as any other rule can, but it is intended primarily for middle diameter as this largely eliminates errors in estimates of taper. For scientific records it is of distinct value. It is superior to the International rule as it eliminates taper as a variable instead of averaging it. The obstacles to converting this rule or any other rule into equivalent values at small end are discussed in § 31. The rule is given in Appendix C, Table LXXXIV.

64. Formula Rules Inaccurately Constructed. Baxter Rule. If the allowance for slabbing in a formula rule is excessive, and that for sawdust too small, the resultant volumes will be too small for logs of small diameters and too large for large logs, thus giving not only an inaccurate but an inconsistent rule. If these errors in deducting waste are reversed, slabbing allowance being too small, and that for sawdust too large, the reverse is true, and the large logs will be under-scaled.

Baxter Log Rule. In adopting a rule of thumb for the construction of a log rule, the author may have in mind a certain result, but the rule when expressed in a formula may give quite a different result.

The Baxter Log Rule was constructed by the rule "Subtract 1 from the diameter inside bark at the small end, square the remainder, and multiply by .52. The result is the contents of a 12-foot log" (hence $\frac{L}{12}$ gives the contents of any log). This squaring and subsequent subtraction of one-half the square was intended to give sufficient deduction for both slabs and saw kerf. But it actually gives,

$$B.M. = .662\frac{\pi(D-1)}{4}\frac{L}{12}.$$

The factor 1, for A, is insufficient for slabs and the factor .338 for C is far too great for sawdust, corresponding in fact to a kerf of $\frac{1}{2}$ inch. The rule therefore greatly underscales large logs. Its inconsistency makes it worthless.

65. Doyle Log Rule. Synonyms: Connecticut River, St. Croix, Thurber, Vannoy, Moore-Beeman (in part), Ontario, Scribner (erroneously).

This rule is used almost to the exclusion of all other rules for hardwoods in parts of the Ohio Valley, and for Southern yellow pine. Its use is extensive in every eastern state outside of New England and Minnesota. In the West, it is not used to any extent.

The Doyle rule reverses the error of the Baxter rule by deducting too large a per cent for slabbing and not enough for sawdust. The wide use of this rule has caused losses of millions of dollars to owners selling logs and standing timber, by improper and defective measurement of contents. The prevalence of its use is due first to the simplicity of its application as a rule of thumb. The rule reads: Deduct 4 inches from the diameter of the log as an allowance for slab. Square one-quarter of the remainder and multiply the result by the length of the log in feet. The result is the contents in board feet. Timber cruisers estimate logs in 16-foot lengths. For this length of log the rule would read: Deduct 4 inches from the diameter of the log inside bark, and square the remainder. The result is the contents of the log in board feet, by the Doyle rule. A rule as easily applied as this was sure to be popular.

The second reason for its wide use was its substitution for the old Scribner rule in Scribner's Log and Lumber Book, after this publication had already attained a large circulation. As this book was widely accepted as a standard and almost the only publication on log rules, the impetus given to the use of this inaccurate rule by this substitution was tremendous.

The third reason for the continued use of the Doyle rule is the same which operates to prevent reform in the use of log rules in general. Custom, or habit of using it, is fixed. So far has this gone that the States of Arkansas, Florida and Mississippi prescribe its use by statute. Added to this is the fact that a rule favoring the buyer will be advocated by this class to its own advantage.

The seller can defend himself against the use of a short measure if the latter is consistent and its per cent of error is known. But with a log rule like the Doyle, the per cent of error differs with every scale of logs or stand of timber and it is practically impossible to determine the actual loss without remeasuring the logs by a correct log rule or tallying the sawed contents.

Since it will be impossible to displace this log rule by better standards unless its vicious character is fully understood, the exact nature of the error should be made clear. The original form of this rule read "Deduct 4 inches from the diameter for slabs, then squaring the remainder, subtract one-fourth *for saw kerf* and the balance will be the contents of a log 12 feet long." The sawdust allowance *as intended*, would have corresponded to a $\frac{5}{16}$-inch saw kerf. The author evidently figured that 4 inches of slab would square the log sufficiently so that the sawdust

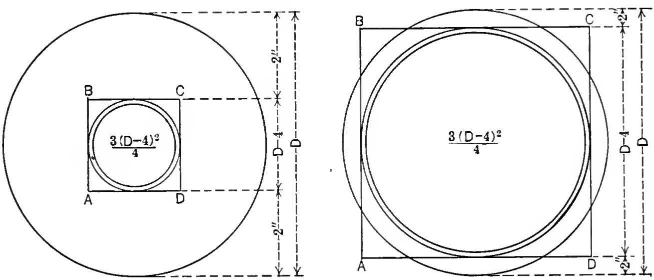


Fig. 9.—Actual deductions for slabs and for saw kerf made by the formula of the Doyle rule, for logs 6 inches, and 28 inches in diameter respectively.

The square *ABCD* is the supposed residue after deduction for slabs, while the outer inscribed circle represents the actual residue. The inner inscribed circle represents the residual percentage shown as board feet by the rule. The sawdust allowance is, therefore, the difference between the outer and inner inscribed circles, whose area is but 4.5 per cent of the contents of the cylinder.

allowance could be applied in this manner to the squared or partially squared stick. His fundamental error lay in his method of deducting for slabbing and edging. As shown, the waste from slabs and edging does not amount to a reduction of 4 inches in the diameter, but to about 1.75 inches, and instead of being slabbed from four sides, it is distributed evenly over the entire surface as a collar. The assumption made resulted in an *actual* deduction for slab far in excess of what was intended, this excess in turn reducing the sawdust allowance from an assumed 25 per cent to negligible proportions.

The above diagrams (Fig. 9) will explain the reason for this inconsistency.

The diagram for the larger log shows that the squaring of the timber would not require a 4-inch slab allowance. The standard formula $\frac{\pi}{4}(D-4)^2$ gives the volume $.7854(D-4)^2$ as the actual net result of deducting 4 inches from the diameter of the log. This was the point overlooked in constructing the rule. The deduction so made is in its effect a deduction for slabbing and edging although not so intended.

That it was not intended is shown by the insructions for next deducting one-fourth of $(D-4)^2$ "for saw kerf." But this leaves $.75(D-4)^2$ for all logs instead of $.7854(D-4)^2$, which is a further reduction of but $.0354(D-4)^2$, the actual reduction for saw kerf $\frac{.0354}{.7854}=.045$ or 4.5 per cent of the cylindrical contents for saw kerf instead of the 20 per cent of the same cylinder required by a $\frac{1}{4}$-inch saw kerf. The remaining 21.5 per cent of the supposed saw kerf is a true slab deduction of 4 inches from diameter. Thus the amounts and proportions of slab deductions are grossly out of balance and this ruins the rule.

This early form was not known as the Doyle rule. The present form, first published in the decade 1870–80 was advertised as a new rule. The scale is identical with the older form but the change in the wording of the rule to its present form still further concealed the flaw in its construction.

The formula for the Doyle rule is:

$$\text{B.M.}=\left(\frac{D-4}{4}\right)^2 L,$$

corresponding to the standard formula:

$$\text{B.M.}=.955\frac{\pi(D-4)^2}{4}\frac{L}{12}.$$

The true sawdust allowance can be shown by the following comparison:

$$\left(\frac{D-4}{4}\right)^2 L=.0625(D-4)^2 L.$$

The area contents of the cylinder $D-4$,

$$\frac{\pi}{4}(D-4)^2\frac{L}{12}=.06547(D-4)^2 L.$$

Since the cylinder $D-4$ represents the log minus true slab deduction, $\frac{.0625}{.06547}=$ 95.5 per cent or the log minus both slabs and sawdust.[1]

66. Effect of Errors in Doyle Rule upon Scaling and Over-run.

The effect of this overbalancing of the respective allowances is to cause this rule to give zero for the contents of logs 5 inches in diameter while for logs above 47 inches, the scale yields more than 80 per cent of the cubic contents, thus, for $\frac{1}{4}$-inch kerf, eliminating slab waste altogether. The over-run would thus vary with increasing diameter, from infinity to zero.

When the Doyle rule is applied to long logs, with a small top or scaling diameter, the over-run becomes proportionally greater. A careful test, under direction of the courts in Texas where logs of given sizes were actually sawed (Extending a Log Rule, E. A. Braniff, Forestry Quarterly, Vol. VI, 1908, p. 47), showed that for 24-foot logs sawed by circular saw the Doyle rule gave an over-run for different diameters, as shown in Table X.

[1] The author is indebted to material published by H. E. McKenzie in Bul. 5, California State Board of Forestry, for this discussion of the error in the Doyle rule.

TABLE X

OVER-RUN, DOYLE RULE. TEXAS

Diameter at small end. Inches	Sawed product. Board feet	Scale Doyle Rule	Per cent of over-run
6– 6¾	35	6	483
7– 7¾	49	14	250
8– 8¾	61	24	150
9– 9¾	76	37	105
10–10¾	95	54	76
11–11¾	112	74	51

The over-run steadily diminishes with increasing diameter until at from 36 to 40 inches the rule gives practically full scale for ¼-inch kerf and normal allowance for slab, disregarding taper.

An investigation made in 1904 for the Province of Ontario by Judson F. Clark, showed that the volume of the average log cut in the Province had decreased in 25 years by 63 per cent and at that time averaged 61 board feet and 12 inches in diameter. From mill tests of pine logs sawed with $\frac{3}{16}$-inch kerf, the per cent of over-run was as follows, for 12-foot logs:

TABLE XI

OVER-RUN, DOYLE RULE. ONTARIO

Diameter of log at small end. Inches	Scale by Doyle rule. Board feet	Actual output of inch lumber. Board feet	Per cent of over-run
6	3	14	366
8	12	30	150
10	27	50	85
12	48	76	58
14	75	108	44
16	108	144	33
18	147	186	26
20	192	234	22

When the average log ran between 18 and 31 inches, the defects of this rule were not so apparent, and the over-run was not excessive. But as the size of the logs cut grows less with the advent of second-growth and closer utilization, the rule becomes impossible. Its continued use in many regions is due largely to the fact that logs are not often bought and sold, but the timber is purchased on the stump and the owner is unaware of his losses. This rule must eventually be superseded either by a more consistent standard or by the rejection of board-foot measure altogether. No owner of small logs or of young standing timber can afford to sell on the basis of a scale or estimate made by the Doyle rule. As it stands, this rule is a serious obstacle to the profitable marketing of second-growth timber, hence to the practice of forestry.

67. The Construction of Log Rules Based on Diagrams. In constructing log rules based on diagrams (§ 55), the quantity of 1-inch boards contained within a given diagram may vary, due to four different factors. The first is whether a 1-inch board or a saw kerf is placed on the center line. For some diameters the one method gives the most lumber, for others the alternate plan, depending upon the relation of the total diameter to the sum of the diameters of boards plus saw kerf. The second factor is the minimum width of the boards to be sawed. The narrower the board, the greater will be the product from circles of a given diameter. The third source of variation lies in the choice of plotting all boards as if slash sawed, or else arbitrarily choosing a given method of sawing around or squaring the log on the diagram, with boards taken from the slabs. The fourth factor is the acceptance or rejection of fractional inches in the boards inscribed in the circle. When all boards are read to the nearest full inch in width, dropping all fractions, some diagrams will lose a much larger per cent than others—while in actual sawing, these variations tend to even up.

For circles of the same diameter and with the same minimum width of board and saw kerf, the board-foot contents will evidently vary considerably according to the treatment of these four factors in construction of the diagram. In a well-constructed consistent set of diagrams, the values in board feet should increase by a regular progression. This can be shown by plotting the original quantities on cross-section paper and connecting the consecutive points by straight lines. Irregularities are revealed by sharp angles in this continuous line. Most diagram log rules show considerable irregularity, which the authors made no attempt to smooth out, as could have been done by means of this graphic plotting. A wholly inexcusable variation of such rules is caused by increasing the average width of slab allowed on large logs. This increase does not conform to the actual practice in sawing and results in a larger over-run on large logs. It is the principal defect in both the Scribner and the Spaulding diagram log rules. The Maine or Holland rule, by avoiding this error, secured a more consistent result.

Diagram log rules tend to give the scale of perfect logs under a given standard for saw kerf and width of slab. The waste for normal crook and irregular form cannot be shown. Since the commercial rules have ordinarily allowed too thick a slab or too wide a minimum board or have rejected fractions, this loss is compensated, but formula rules if accurate are more practical and convenient.

Baughman Log Rules. As an example of a diagram rule which is too perfect for commercial use, since it neglects shrinkage and normal crook and includes fractional inches, can be cited the Baughman log rules for $\frac{1}{4}$-inch and $\frac{1}{8}$-inch saw kerfs respectively. The results obtained from these diagrams are so consistent that they conform to the typical formula for a perfect log rule.

$$B.M. = .81\frac{\pi(D-.87)^2}{4}\frac{L}{12} \text{ for } \tfrac{1}{4}\text{-inch kerf,}$$

and

$$B.M. = .90\frac{\pi(D-1)^2}{4}\frac{L}{12} \text{ for } \tfrac{1}{8}\text{-inch kerf.}$$

In practice the use of these rules would give an under-run: i.e., the logs would not saw out the scale.

In these diagrams the minimum board was 4 inches, the lumber exactly 1 inch. The 1-inch board was always placed in middle of diagram. Taper was neglected. H. R. A. Baughman, Indianapolis, Ind.

68. Scribner Log Rule, 1846. Synonym: Old Scribner. The Scribner log rule is the oldest diagram rule now in general use. But for the unfortunate substitution of the Doyle rule for this rule in Scribner's Log and Lumber Book, its use would now be practically universal. The rule held its own in the North and West, and is the legal standard for Minnesota, Wisconsin, West Virginia, Oregon, Idaho, and Nevada. It is the standard prescribed in timber sales on National Forests throughout the West and by the Dominion Forestry Branch of Canada.

The rule was published previous to 1846. The diagrams are for 1-inch lumber, and $\frac{1}{4}$ inch saw kerf. The width of the minimum board was not stated but the author modified an earlier edition of his rule by increasing the allowance for slab on larger logs. As a result of this unfortunate error, the rule gives a larger over-run on logs above 28 inches than on smaller logs. The products of the diagrams were evidently not evened off. The values, when plotted, show great irregularities, but except for the factor just noted, the general tendency of the rule is consistent.

The original values were for logs from 12 to 44 inches in diameter in sections 15 feet long, "the fractions of an inch inside the bark not taken into the measurement." Taper is not considered on logs of the lengths used. These factors the author intended to offset normal crook and concealed defects. Values were then given for logs from 10 to 24 feet in length.

Modification to a Decimal Rule. Two important changes in this rule have been made to meet the demands for a universal log rule. It has been changed to a decimal rule, and values for logs below 12 inches, and above 44 inches have been added. The practice of modifying a log rule in scaling by reducing it to even tens, in order to eliminate the column of unit feet in adding, is found in connection with several rules. With the Scribner, instead of dropping odd feet, thus reducing the scale, the odd feet were rounded off to the nearest ten, values over 5 feet being raised, while 5 feet and under are dropped. The average scale of even a few logs by this method is practically identical with that obtained by the original rule as the errors are compensating. This modified rule is known as the Scribner decimal rule.

Extension below 12 Inches. For values below 12 inches, the original rule provided no figures. The lack of a formula permitted individuals to supply their own values for these sizes. As early as 1900, the Lufkin Rule Company tabulated the decimal values then in use, under three schedules, termed A, B and C, shown below. To read in board feet, add a cipher to each figure.

TABLE XII

DECIMAL VALUES BELOW 12 INCHES FOR SCRIBNER LOG RULE

Length.	Decimal A						Decimal B						Decimal C					
	Diameter—inches																	
	6	7	8	9	10	11	6	7	8	9	10	11	6	7	8	9	10	11
Feet	Board feet, in tens																	
12	1	1	2	3	4	5	1	2	2	3	4	4	1	2	2	3	3	4
14	1	1	2	3	4	6	1	2	3	3	4	6	1	2	2	3	4	5
16	1	2	3	4	5	6	2	3	3	4	5	7	2	3	3	4	6	7
18	1	2	3	4	5	7	2	3	4	5	6	8	2	3	3	4	6	8
20	1	2	3	4	6	8	2	3	4	6	7	8	2	3	3	4	7	8
22	1	2	3	5	7	9	3	4	5	7	8	9	3	4	4	5	8	9
24	1	3	4	5	7	10	4	5	6	7	9	10	3	4	4	6	9	10

Still other values resulted from the use of the full scale, rather than the decimal form. In the Woodsman's Handbook, (1910 Forest Service), values for 16-foot logs used by a company in New York (Santa Clara Lumber Co.) were published. These values were adopted by the Canadian Forestry Branch in 1914. The State of Minnesota adopted standard values differing slightly from these figures. Wisconsin adopted definite values by law for these sizes, conforming exactly to the Decimal "C" scale given above. Idaho prescribes that the Scribner Decimal Scale be used without specifying values and both "A" and "C" scales are in use in the state. In Oregon and West Virginia the "Scribner Scale" is called for by statute, leaving the question open for values below 12 inches.

The weight of custom is at present in favor of the use of the Decimal "C" values for this rule, and the utility of the Scribner Decimal Rule would be improved by a universal adoption of this standard.

Extension above 44 Inches. With the adoption of the rule by the Forest Service, its use on the Pacific coast required an extension from 44 to 120 inches. In this instance a similar but worse confusion might have resulted, but was avoided by the adoption of a single standard of values prepared by the U. S. Forest Service about 1905, and published in the Woodsman's Handbook, 1910 edition. The extension (made by E. A. Ziegler) was based on a comparison of the curve formed by the plotted values of the rule with similar curves for the formula rules such as the International, and for the Spaulding rule. Ziegler states, "It might be described as an extension built on an old rule by graphic methods checked with the correct mathematical formula in which the slab waste varies with D and the kerf with D^2, and compared with the accepted rules in the Northwest, notably the Spaulding." The extension was built up on a 12-foot log, and applied to lengths of from 8 to 16 feet. As a concession to logging methods in the Northwest, logs up to 32 feet were scaled without taper by this rule.

No such difficulties in extension are encountered with rules constructed by the use of correct formulæ, since the values of logs of all sizes are in this way determined.

Attempt to Improve the Rule. Further efforts to modify this log rule have been made in order to even off the irregularities of value between contiguous sizes. Examples of this are the Hanna log rule, 1885 (John S. Hanna, Lock Haven, Pa.), the White rule, 1898 (J. A. White, Augusta, Mont.) and a local rule used by M. E. Ballou & Son, Becket, Mass., 1888, adopted from Scribner rule, for small logs. Such modifications unquestionably improve the rule, but the minor irregularities do not appreciably modify the scale of a large number of logs of different sizes. The confusion which would result in attempting to secure universal agreement on any change in accepted values for this rule has prevented their adoption, and the values still stand as they were originally determined, subject only to the conversion to decimal form.

The Scribner Decimal "C" log rule in spite of its imperfections comes the nearest at present to fulfilling the demand for a universal commercial log rule, because of its present wide acceptance and use (§ 13), and reasonable consistency in over-run. The latter reason alone makes it preferable to the Doyle rule. Not even this rule, however, does justice to logs below 12 inches in diameter; and in regions of second growth and small logs, a closer and more accurate rule is preferable.

69. Spaulding Log Rule, 1868. Synonym: California Rule. The Spaulding Log Rule was adopted by statute in 1878 as the standard for California, and the values were given. It was constructed by N. W. Spaulding of San Francisco in 1868 from diagrams of logs from 10 to 96 inches in diameter, using an $\frac{11}{32}$-inch saw kerf, and 1-inch lumber, and afterwards tested by sawing logs of each size in two mills. The size of the slab (width of minimum board) was varied according to the size of the log. This error of construction tends to increase the over-run in large logs. The values were given for lengths from 12 to 24 feet. The author directed that longer logs be scaled by doubling the values in the table, and this practice was incorporated in the statute. Thus the rule neglects taper altogether. In scaling, this principle is not applied to logs longer than 40 feet. It constitutes the most serious defect of the rule at present. Owing to the large saw kerf considerable over-run is secured by modern band saws but the rule is fairly consistent, as are all well-constructed diagram rules.

70. Maine or Holland Rule, 1856. Synonym: Fabian's. This is the most accurate and consistent diagram rule in common use (§ 55). It was constructed in 1856 by Chas. T. Holland for 1-inch boards, allowing for a $\frac{1}{4}$-inch saw kerf and for a minimum width of board of 6 inches. Fractional parts of a foot amounting to over .5 are reckoned as a whole foot, those less than .5 are rejected. This resulted in a more consistent rule from the diagrams. The rule is applied at the small end of log and disregards taper, so cannot be applied to the scaling of long logs without considering them as sections. The best practice now limits the length of these sections to 16 feet (§ 43).

71. Canadian Log Rules. The practice of adopting standard log rules by statute has been followed by New Brunswick, Quebec, Ontario and British Columbia. Their use is practically universal in the provinces.

The New Brunswick Rule, 1854. This rule is the statute rule of the Province and is probably based on diagrams. Values for from 5 to 10 inches were added by later regulations. Logs 26 feet and over are measured in two lengths. The small end is used and the rule is based on 1-inch lumber.

Quebec Log Rule, 1889. To construct this rule, diagrams of logs from 6 to 40 inches in diameter were divided into 1-inch boards. A second set was divided into 3-inch deals, using $\frac{1}{4}$-inch kerf. The mean of the two resultant contents was taken, and from this an arbitrary deduction was made, ranging from 0 to 17 feet. Taper was neglected. This scale is applied at the small end for logs up to 18 feet in length, above which the average diameter of the two ends is taken. The rule is the statute rule of the Province.[1]

The British Columbia Rule is discussed in § 61.

72. Hybrid or Combination Log Rules. The inconsistency of the Doyle rule by which small logs are under-scaled and large logs over-scaled has led to its combination with the Scribner rule. The values of the latter rule drop below the Doyle rule at 28 inches.

Low values in the log rule favor the buyer of logs. In purchasing large logs, especially hardwoods, the Doyle rule was considered unsafe. The combined rule, termed the Doyle-Scribner, retains the low values of

[1] The statute rule of the province of Ontario is the Doyle Rule which was adopted in 1879. In spite of the facts brought out in an investigation in 1904, that in that one year the Province lost 134 million board feet on the scale, equivalent to 23 per cent of the contents of the logs cut, by reason of this rule, the influences in favor of its retention were too strong to be overcome and it is still the standard rule of the Province.

the Doyle rule up to 28 inches, and substitutes the low values of the Scribner rule above that point.

The reverse of this process was adopted by the State of Louisiana in 1914. The values of the Scribner rule below 28 inches were combined with those of the Doyle rule for 29 inches and over, and the resultant hybrid rule, known as the Scribner-Doyle rule is the official rule of the state.

The Doyle and Baxter rules were also combined, using the Doyle values up to 19 inches, with those of the Baxter rule for the remaining diameters. Both the Doyle-Scribner and the Doyle-Baxter are cut-throat rules calculated to give the buyer the maximum advantage of the defects of both rules. The Scribner-Doyle rule has no advantage over the straight Scribner rule since most logs are below 28 inches in diameter.

73. General Formulæ for All Log Rules. When log rules have not been constructed by a formula, but from diagrams or mill tallies, no formula can be found which will give the exact values of the rule. But, consciously or not, the authors of log rules have attempted to deduct the waste from saw kerf and from slabbing and edging and the average results which they obtained, or the actual treatment of these two factors is revealed by reducing these rules to the nearest approximate formula.

The general form of such a formula is:

$$\text{B.M.} = (aD^2 + bD + C)\frac{L}{12}$$

in which aD^2 covers the per cent reduction of volume for sawdust after reducing the square to a circle, bD gives the reduction of diameter or surface for slabbing and edging, while C is a constant added in an effort to correct irregularities in the rule itself. The factor $\frac{L}{12}$ reduces square inches to board feet.

Cubic rules converted to board feet correspond exactly to the formula,

$$\text{B.M.} = (aD^2)\frac{L}{12}$$

or to

$$\text{B.M.} = (1-b)\frac{\pi D^2}{4 \times 12}L.$$

Perfect formula rules correspond to the formula,

$$\text{B.M.} = (aD^2 + bD)\frac{L}{12}$$

or to

$$\text{B.M.} = (1-b)\frac{\pi (D-a)^2}{4 \times 12}L.$$

But imperfect or irregular diagram or formula rules require the formula,

$$\text{B.M.} = (aD^2 + bD + C)\frac{L}{12}$$

or

$$\text{B.M.} = \left((1-b)\frac{\pi D^2}{4 \times 12} - C\right)L.$$

The first of these sets of formulæ was originated by A. L. Daniels, the second by H. E. McKenzie. By Daniels' formula, the values of logs of three sizes will give the formula. For the following rules, the formulæ read:

Doyle, $\text{B.M.} = (.75D^2 - 6D + 12)\frac{L}{12}$,

Scribner, $\text{B.M.} = (.555D^2 - .55D - 23)\frac{L}{12}$;

Maine, $\text{B.M.} = (.635D^2 - 1.45D + 2)\frac{L}{12}$;

Champlain, $\text{B.M.} = (.62832D^2 - D)\frac{L}{12}$;

Vermont, $\text{B.M.} = (.50D^2)\frac{L}{12}$.

By the McKenzie formula, adding the constant C gives the following for:

Spaulding, $\text{B.M.} = \left((1 - .266)\frac{\pi D^2}{4 \times 12} - 2\right)L$;

Scribner, $\text{B.M.} = \left((1 - .266)\frac{\pi D^2}{4 \times 12} - 3\right)L$;

Maine, $\text{B.M.} = \left((1 - .222)\frac{\pi D^2}{4 \times 12} - .67\right)L$.

These formulæ permit of analysis and comparison of different log rules.

74. The Construction of Log Rules from Mill Tallies. Graded Log Rules. A log rule based directly on mill tallies or the measured product of sawing logs into lumber will have no over-run provided the variable conditions of manufacture coincide with those which determined the contents of the logs from which the rule was made. But this is never the case. Standard log rules made for 1-inch boards do not conform to mill tally of lumber sawed partly into 2-inch plank, or even if sawed full or $1\frac{1}{16}$-inch in thickness. Standard rules for square-edged lumber fall far short of measuring the product of small logs sawed and tallied as round-edged boards. The board foot as a cubic measure will not indicate the quantity of surface or superficial feet of lumber produced in sawing $\frac{5}{8}$-inch boards.

Where it is desired to obtain, in the log, the probable actual contents in boards, and existing rules are unsatisfactory, a new rule may be worked out based directly on mill tallies. Unfortunately, most of the rules so obtained are not standardized for lumber of a given width, as 1-inch boards, but include the mill run, with varying per cents of thicker plank. This requires a statement as to the basis of the rule. Even when based on arbitrary per cents of 1-inch and thicker lumber such a rule may be superior, for local use, to one of the older commercial rules.

A mill tally, upon which a local log rule can be based, will also serve two other purposes if rightly conducted, namely, a check on the amount of over-run to be obtained from logs of different sizes if scaled by an existing log rule (Doyle rule, § 65), and an analysis of the product of the log by grades of lumber, leading to the construction of graded log rules.

For the single purpose of constructing a log rule for sound logs with normal crook (§ 52) but two operations are required. Each log is measured, preferably at both the small end, inside bark, and the middle diameter outside bark, and its length recorded. The contents of each board sawed from the log is then tallied, and the total found, from which, by averaging for logs of the same dimensions, and the use of graphic plotting (§ 138) the log rule may be obtained.

When mill-scale studies are made to check a given log rule, and to determine contents of logs by grades, from which a *graded log rule* is constructed (§ 87), the work is planned as follows: Each log is given a number, and is scaled as it enters the mill. A second man stationed at the edger places this number on the first and last board sawed from the log. A lumber grader at the grading table indicates the grade of each board, while a fourth man tallies the board-foot contents of the piece on a ruled blank which contains columns for each standard grade. As the scaler and grader are usually employees of the mill the work requires two extra men in the mill.

The study is usually extended to include defective logs, which are kept separate in the final averages, since the original scale of such logs is a matter of judgment subject to wide errors. (Appendix A, § 361.)

By a proper system of numbering the logs in the woods, a mill scale study may be applied to determine the graded contents of entire trees for the construction of graded volume tables (§ 165).

Reference

A Mill-scale Study of Western Yellow Pine, H. E. McKenzie, Bul. 6, California State Board of Forestry, Sacramento, Cal., 1915.

75. The Massachusetts Log Rule for Round-edged Lumber. This log rule is constructed for round-edged and square-edged boards as sawed from small logs for close utilization of second-growth timber.

The per cent of square-edged lumber sawed varies from 0 to 50 per cent, increasing with diameter of log. The rest of the cut was round-edged. The rule is for $\frac{1}{4}$-inch saw kerf, varying in the per cent of round- or square-edged boards included. It is based on mill tallies of 1200 logs down to 4 inches at small end. The rule is expressed in two forms, one for application to diameter at small end, inside bark, the other to diameter outside bark at middle of log. The latter form would apply only to species with bark of similar average thickness to the second-growth white pine on which the latter is based. The utility of this rule as a standard is interfered with by the fact that a certain per cent, not stated, of $1\frac{1}{4}$-inch and $2\frac{1}{8}$-inch lumber was included with 1-inch boards in its construction. The results are therefore somewhat too high for 1-inch lumber.

This log rule indicates that the contents of logs measuring from 4 to 10 inches in diameter at small end are from 20 to 50 per cent greater when scaled by this rule than by the International $\frac{1}{8}$-inch rule. Above 12 inches, the excess is not over 10 per cent. Since these boards are measured at their average face, taper is fully utilized, while waste from slabs and edging is reduced to a minimum. The resultant per cent of utilization is very consistent for logs of all sizes; hence it shows a marked gain in the small sizes over the per cents utilized in square-edged boards as shown in Table III.

The importance of a log rule of this character in scaling the board-foot contents of second-growth timber in regions utilizing round-edged boards is obvious. Rules of this character are nearly as satisfactory as the cubic foot in measuring small timber. For complete accuracy in applying this rule to other species, the average taper must be known, or the average thickness of bark. Similar local log rules have been made for loblolly or old field pine in the Atlantic Coast States.

76. Conversion of Values of a Standard Rule to Apply to Different Widths of Saw Kerf and Thickness of Lumber. Where over-run or under-run is caused by a difference in the width of saw kerf used, or in the thickness of lumber sawed, from the standards used in the log rule, the per cent of this difference between scaled and sawed contents due to these factors may be easily determined, and applied, if desired, to the scale; or it may be incorporated in a new set of values or local log rule similar to those made from mill tallies.

For saws of different widths.

Let K = width of saw kerf in standard rule;

K' = width of saw kerf used in sawing.

Then

$\frac{1}{1+K}$ = per cent of lumber, minus saw kerf by standard rule;

$\frac{1}{1+K'}$ = per cent of lumber using different saw kerf.

The correction to apply to the standard rule in terms of per cent is:

$$\text{Per cent correction} = 100 \times \frac{\frac{1}{1+K'}}{\frac{1}{1+K}},$$

e.g., the International rule, $\frac{1}{4}$-inch kerf plus $\frac{1}{16}$-inch shrinkage $= \frac{5}{16}$-inch $= .3125$, .

$$100 \times \frac{1}{1.3125} = 76.3 \text{ per cent.}$$

For a $\frac{3}{16}$-inch saw kerf plus $\frac{1}{16}$-inch shrinkage $= \frac{4}{16} = .25$,

$$100 \times \frac{1}{1.25} = 80 \text{ per cent.}$$

Then,

$$100 \times \frac{80}{76.3} = 104.8 = +4.8 \text{ per cent.}$$

The following table will convert values for the International $\frac{1}{4}$-inch log rule to products of saw kerfs of other widths, allowing $\frac{1}{16}$-inch shrinkage in each case as for the original rule.

TABLE XIII

Conversion of International Rule $\frac{1}{4}$-inch Saw Kerf for Other Widths of Kerf

Width of saw kerf. Inches	Per cent utilized*	Per cent correction to obtain product for desired kerf
$\frac{7}{64}$	85.4	+11.9
$\frac{1}{8}$	84.3	+10.5
$\frac{3}{16}$	80.0	+ 4.8
$\frac{1}{4}$	76.3	0
$\frac{5}{16}$	72.7	− 4.7
$\frac{3}{8}$	69.6	− 8.8
$\frac{7}{16}$	66.7	−12.6

* This per cent applies only to the residual portion of the log after deducting the waste for slabbing and edging. The ratio between the per cents utilized is the basis for correcting for saw kerf.

Log rules which make no allowance for shrinkage may be adjusted in the same manner by omitting this factor. Table XIV, Page 82.

Correction for lumber thicker than the standard. For this purpose the same formula as for saw kerf is used, substituting the actual thickness of lumber (t) for 1 inch, and using K as a constant representing saw kerf.

Let 1 = standard thickness of lumber;
t = actual thickness of lumber.

Then,

$\frac{1}{1+K}$ = per cent of lumber, minus saw kerf by standard rule;

$\frac{t}{t+K}$ = per cent of lumber, with thickness of t;

and

$$\frac{\frac{1}{1+K}}{\frac{t}{t+K}} = \text{per cent correction.}$$

For $\frac{1}{4}$-inch saw kerf the results obtained are given in Table XV, Page 82 (§ 48):

TABLE XIV

CONVERSION OF LOG RULES WITH $\frac{1}{4}$-INCH SAW KERF AND NO SHRINKAGE ALLOWANCE TO OTHER WIDTHS OF SAW KERF

Width of saw kerf. Inches *	Per cent Utilized	Per cent correction to obtain product for desired saw kerf
$\frac{7}{64}$	90.2	+12.7
$\frac{1}{8}$	88.8	+11.1
$\frac{3}{16}$	84.3	+ 5.4
$\frac{1}{4}$	80.0	0
$\frac{5}{16}$	76.2	− 4.8
$\frac{3}{8}$	72.7	− 9.1
$\frac{7}{16}$	69.6	−13.0

* Rules made by first subtracting slabbing and edging may evidently be altered for different widths of saw kerf, as these deductions are directly proportional to volume, and are applied to the reduced cylinder only. Where, as with the International rule, the deduction for saw kerf is made *before* subtracting *AD* for slabs and edging, this rule still holds good, since the per cent of correction is not applied to the entire log, but to the values in the rule, which already exclude *AD*. If worked out for the log, independent of the rule, the sawdust in the slabs is deducted before the factor *AD* is found, and for larger saw kerfs this factor *AD* would be proportionally smaller, so that the total net product in lumber is the same as if computed by the above correction.

TABLE XV

PER CENT OF INCREASE IN SAWED LUMBER CAUSED BY SAWING LUMBER OF DIFFERENT THICKNESSES †

Thickness of lumber. Inches	Increase in sawed product over 1 inch lumber. Per cent
$1\frac{1}{4}$	4.1
$1\frac{1}{2}$	7.1
$1\frac{3}{4}$	9.4
2	11.1
$2\frac{1}{8}$	12.5
3	13.6

† In preparing tables of volume for Connecticut hardwoods (Bul. 96, Forest Service), Frothingham used the International rule, reduced for a $\frac{1}{4}$-inch saw kerf by subtracting the required 9.5 per cent of volume from-values for $\frac{1}{8}$-inch saw kerf. Complaint was later made that in applying these tables to logs sawed in mills using $\frac{1}{4}$-inch saw kerf, the output over-ran the tables. This was due not to error in the tables, but to the production of a large proportion of thick planks, thus reducing the sawdust waste.

These per cents are applied to the scale of 1-inch lumber. When 50 per cent of the output is in 2-inch plank, the correction would be 50 per cent of 11.1 per cent, or 5.55 per cent. As the increase in per cent of correction in the total scale becomes less with increasing thickness of boards sawed, this method is more accurate than that of computing the average dimensions of the products sawed. In the above case the latter would have been $1\frac{1}{2}$ inches, calling for a correction of 7.1 per cent instead of 5.55 per cent.

Correction for thin lumber based on superficial contents. In a similar way, log rules for 1-inch lumber may be corrected to give the product in superficial board feet for lumber sawed to thicknesses less than 1 inch. Since the board, of whatever thickness, measures 1 superficial foot, the "per cent of utilization" will be $\frac{1}{t+K}$, t being thickness of board, K, saw kerf. For $\frac{1}{4}$-inch kerf and 1-inch lumber, the standard per cent is $\frac{1}{1+K}=80$ per cent. Then the correction per cent is $\dfrac{\frac{1}{t+K}}{\frac{1}{1+K}}$.

TABLE XVI

CORRECTION PER CENTS FOR CONTENTS OF LOGS IN SUPERFICIAL BOARD FEET FOR LUMBER SAWED LESS THAN 1 INCH IN THICKNESS

Thickness of lumber. Inches	Saw kerf. Inches	Per cent of utilization	Per cent for inch lumber	Correction per cent to add to log rule for 1-inch boards Per cent
$\frac{1}{2}$	$\frac{1}{4}$	133.3	80	66.6
$\frac{5}{8}$	$\frac{1}{4}$	114.3	80	42.9
$\frac{3}{4}$	$\frac{1}{4}$	100.0	80	25.0
$\frac{7}{8}$	$\frac{1}{4}$	88.8	80	11.1

77. Limitations to Conversion of Board-foot Log Rules. It is thus seen that a correction of the total scale of logs regardless of diameter or length can be made whenever this correction takes the form of a straight per cent of the volume of the scale. In addition to the effect of saw kerf and thickness of boards, this principle applies to cubic rules erroneously used for board feet (§ 38). But no true board-foot log rule can be converted by a constant or flat per cent into the values of any other log rule, unless the deduction for waste from slabs and edgings is identical for both rules, and the difference is wholly due to the use of different per cents of waste for saw kerf. Otherwise, the conversion factor will vary with diameter of log. Since tables of tree volumes and the scale of a number of logs include logs of different sizes, such volume tables or scale totals must be remeasured in the log in order to determine the values for any other than the log rule originally used.

78. Choice of a Board-foot Log Rule for a Universal Standard. As long as opinions and customs differ with regard to the measurement of taper, scaling length, saw-kerf allowance and amount of waste in slabbing which should be expressed in log rules, it will be impossible to reach an agreement on a common standard. Meanwhile, custom is working towards the elimination of rules which have not found favor and all but about ten log rules in the United States can already be classed as obsolete.

A log rule becomes obsolete when it ceases to be used, regardless of the reasons for its disuse. Poor rules should, and sometimes do, become obsolete because they do not give satisfaction. But good and consistent rules may also become obsolete or may never be taken up, because the use of other and inferior rules is so firmly intrenched that a substitution is impractical. Rules which scale so closely as to permit no overrun will be very difficult to bring into common use, owing to the opposition of buyers who prefer lower standards even if inaccurate.

The log rules whose use is sufficiently extensive to justify their consideration, on this basis alone, for universal adoption include only the foilowing:

Basis of Rule	United States	Canada
Formula	Doyle	Doyle British Columbia
Diagram	Scribner Scribner Decimal C Spaulding Maine	Quebec New Brunswick
Hybrid	Doyle-Scribner	
Mill Tallies	Massachusetts	

Of these, the Doyle must be rejected because of its glaring inconsistencies and the Doyle-Scribner because it combines the worst features of both rules. The use of the Maine and the Spaulding rules is confined to single states, and the Massachusetts rule is for a special form of product; i.e., round-edged timber.

This leaves the Scribner, preferably in Decimal C form, as the only logical rule now in wide use, which is applicable to the measurement of square-edged lumber.

If the admitted irregularities of the Scribner rule are deemed so serious as to justify its rejection, its successor should not be chosen from among the other rules in common use, but should rather be a rule based on a formula and tested to conform to actual conditions of sawing. For such a purpose, the International $\frac{1}{4}$-inch Rule is probably as perfect a rule as will ever be required in commerce. This rule is especially valuable for logs below 12 inches and above 28 inches, in which classes the Scribner rule is defective. There is nothing to be gained by further efforts to construct new " perfect " log rules.

79. Unused and Obsolete Log Rules. In addition to the rules described in this chapter we may mention the following rules, all of which are now obsolete.

Bangor Rule. Synonyms: Miller, Penobscot. The Bangor Rule was constructed from diagrams, and gives slightly higher and more consistent values than the Maine rule. It shows more care in construction and is probably the best of the diagram rules. Owing to the more extensive use of the Maine rule, this rule is almost obsolete.

Parson's Rule. This rule is of similar construction to the Bangor and Maine rules and its values are almost identical but a little below the Maine rule. The difference is about 2 per cent. It is a local rule, still used to some extent.

Boynton Rule, 1899 (Vermont, local). Made up from values taken from Scribner and Vermont rules checked by mill tallies. A fair rule but of no general value. D. J. Boynton, of Springfield, Vermont.

Brubaker Rule. No detailed knowledge.

Chapin Rule, 1883. The most erratic of all log rules, made up apparently by selecting values from existing rules to suit the author.

Drew Rule, 1896. The Drew rule has been the statute log rule of the State of Washington since 1898 but is used practically nowhere in the state. Instead, the Scribner rule is universally used, except along the Columbia River, where the Spaulding rule is in use.

This rule (by Fred Drew, Port Gamble, Wash.) was made from diagrams checked by tallies of logs as sawed. The values are given for diameters from 12 to 60 inches and lengths of from 20 to 48 feet. Taper is not considered. The values are said to have been reduced to allow for hidden defects. The rule is inconsistent in scale, resembling the Doyle in tendency on large logs. Its use is practically discontinued.

Dusenberry Rule, 1835. This rule was made in 1835 by a Mr. May, and adopted by Dusenberry-Wheeler Co., of Portville, N. Y. It was probably constructed from mill tallies, and was intended to measure the output of pine sawed $1\frac{1}{8}$ inches thick with some $1\frac{1}{2}$- and 2-inch pieces. The saw kerf was $\frac{7}{16}$ inch. The rule is very consistent and was generally adopted in the Alleghany Waters in Pennsylvania. It is still used in that and adjoining states. Owing to the wide saw kerf used, this rule under-scales Scribner from 15 to 20 per cent and is not suited to present conditions.

Favorite Rule. Synonym: Lumberman's Favorite. A diagram rule, made by W. B. Judson in 1877 and published in Lumberman's Handbook, 1880. The values for small logs are lower by 15 per cent than Scribner's. The rule is now practically obsolete.

Finch and Apgar Rule. Date unknown. A diagram rule, erratic, for $\frac{5}{16}$-inch saw kerf. Gives low values.

Forty Five Rule. About 1870. Based on an inaccurate rule of thumb formula which gives high values for small and large logs and low values between these extremes.

Herring Rule, 1871. Synonym: Beaumont. The values in the Herring rule as originally made, to include from 12- to 44-inch logs, are practically identical with the Dusenberry rule. The rule was applied at the small end to logs up to 20 feet in length. Above 20 feet a rise of 1 inch was added, and was applied at middle point of logs up to 40 feet in length. Here another inch was added, and the scale carried to 60-foot logs. The taper allowed in this was is about half of the average taper.

The rule is used extensively in the pine regions of Texas and gives a large over-run.

The same trouble was experienced with this rule as with the Scribner, in agreeing upon an extension of values to cover logs less than 12 inches in diameter. The values most commonly used are the so-called Devant extension, based upon the Orange River rule, and agreeing closely with the Scribner extension.

Licking River Rule. No detailed knowledge.

Northwestern Rule. A diagram rule for $\frac{3}{8}$-inch saw kerf. Erratic, and similar to Scribner's.

Ropp's Rule. A rule published by C. Ropp & Sons, Chicago. Based originally on diagrams of 1-inch lumber for a $\frac{1}{4}$-inch saw kerf, it was reduced to a rule of thumb which gives erroneous results especially for small logs, which are severely under-scaled. The rule is therefore of no value.

Warner Rule. A diagram rule with excessive allowance of $\frac{3}{4}$ inch for saw kerf. Worthless.

Wheeler Rule. No detailed knowledge.

Wilcox Rule. A diagram rule for $\frac{3}{8}$-inch saw kerf. Irregular. Low values.

Younglove Rule.[1] Fitchburg, Mass., 1840. A caliper rule resembling the Baxter in values.

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CHAPTER VII

LOG SCALING FOR BOARD MEASURE

80. The Log Scale. The scale of a given quantity of logs is their total contents expressed in the unit of measurement employed. The term "scale" also refers to the general rules or customs of scaling adopted in a given region or locality, upon which depend the liberality or closeness of the measurement (§ 83). Differences in the method of scaling may make from 5 to 50 per cent difference in the scaled contents of the same logs (Table XVII).

To determine the contents of logs in board feet, the diameter of the log is measured with a stick marked in inches, the length in feet is determined by measuring it with the above stick or by a tape or wheel (§ 34), and the volume corresponding to these dimensions looked up in the log rule.[1] This process is simplified by placing upon the sides and edges of this stick, opposite each diameter, rows of figures giving the values of the rule for each of several standard lengths. The volume in board feet is then read directly from the stick, and recorded. A stick so graduated is termed a *scale stick* or *scale rule*.

Scale sticks are made of hickory or maple about 1 by $\frac{1}{4}$ inch in cross section, graduated in inches, with the figures burnt into the wood (Fig. 10). Metal sticks are also in use and in some regions caliper rules are used. The inch scale is on one or both edges and the stick easily accommodates six or seven other rows of figures corresponding to the contents in board feet of logs of as many different standard 2-foot lengths. A metal tip aids in measuring the diameter inside the bark. Other forms are made for scaling logs in water, or logs with ends rounded or sniped. Lengths of scale sticks in inches correspond to the maximum diameters of the logs to be scaled. Hexagonal scale sticks are sometimes used. Scale sticks have been made which are graduated at points giving volumes to exact tens or hundreds of units, but these rules have never become popular as the basis of the rule is not indicated (§ 111).

The purpose of a log scale depends upon the ownership of the timber or logs. Where the logs are to be sold the scale is the basis of settlement and must be far more carefully made than when the timber is

[1] Experienced scalers sometimes substitute ocular or paced lengths on short logs. The scale of logs shorter than the minimum length given in the rule is taken as equaling one-half the scale of a log twice as long as the one in question, *i.e.*, when the shortest length given on the scale is 10 feet, an 8-foot log is scaled as one-half of a 16-foot log.

owned, logged and manufactured by the same firm. In the latter case, the purpose of the scale is merely to provide a basis for the payment of contractors for logging or sawyers for felling, or for checking the com-

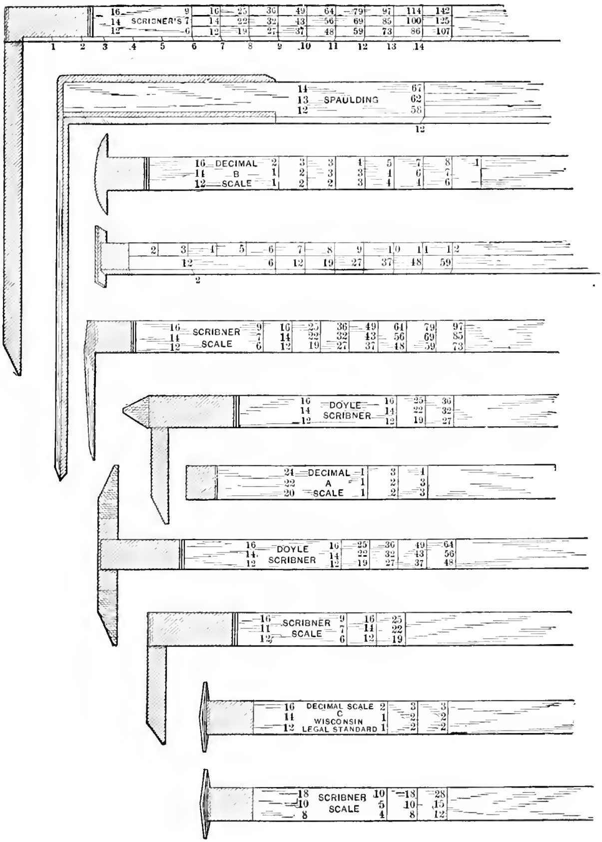

Fig. 10.—Forms of scale sticks in use.

parative efficiency of crews or camps. Finally, the woods scale determines the quantity of timber felled, thus keeping track of the operation, while a re-scale at the mill permits the keeping of costs and credits separately, on the basis of the volume of logs delivered, between the logging and milling ends of the business, as if they were under separate management. Woods scaling also checks the accuracy of timber estimates, whenever the timber from given areas is scaled separately in logging.

When the purpose is to determine the basis for paying saw crews, logs are scaled in the woods before skidding. When standing timber is sold on the basis of the log scale, the scaling is done at the skidways or landings before removal from the tract or vicinity. The mixing of logs cut from two or more tracts must be avoided by any necessary measure such as sawyers' marks, or scaling in the woods. Where no question of sale is involved, the logs are scaled wherever it is most convenient. Logs are usually re-scaled on the log deck. Where logs are rafted and sold, they usually are scaled in the water.

81. The Cylinder as the Standard of Scaling. A log rule does not give an exact scale of lumber which will be or can be sawed from logs (§ 46). The log rule is an arbitrary standard fixing the quantity of 1-inch lumber said to be contained in logs of given diameters and lengths. When the top or small end of the log inside the bark determines the diameter, as it does for all board-foot log rules in common use, these rules do not include any boards or pieces sawed from the taper or swell of the log. The scaler must therefore pay no attention to that portion of the contents of the log which lies outside of this cylinder, no matter whether this portion be sound or defective. On the butt end of a log, the contents to be scaled lies within a smaller circle representing the area of the top end of the log, or the cross-section of the cylinder whose diameter is this top end. This cylinder must coincide in position with the axis of the log, so that the center of the cross-section or area to be scaled coincides with the center of the butt or larger end of the log. Common errors in scaling are the shifting of the scaled cylinder towards one side to avoid defects, and the offsetting of defects within the cylinder against sound short lumber which may be scaled from the taper.

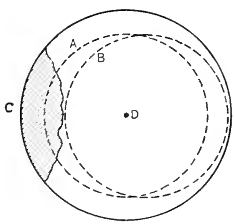

FIG. 11.—Projection of area of top end of log on butt section, showing portion of butt to be scaled. The circle *A* represents the area to be scaled. The presence of defect in area *C* does not justify the shifting of this circle to position *B* but deductions for defect must be made from *A*. *D* is the geometric center of the log and of the scaled area *A*.

82. Deductions from Sound Scale versus Over-run. Log rules give the scale of this cylinder in sound lumber and do not allow for defects. The standard scaling practice is to make deductions from the scale for all *visible* defects which lie within the cylinder in each log separately, of the amount of lumber which would be lost because of the defect.

This rule is not always observed. In many species, certain defects may exist without visible external indications either on the surface or at the exposed ends. When the logs are in water it is difficult to detect defects. There has been a tendency on the part of makers of log rules to reduce the standard volumes of the log rule in order to offset these invisible defects (Scribner rule, § 68). Log rules, like the Cumberland River rule which gives but 45 per cent of the cubic contents, permit the buyer to ignore most defects with perfect safety.

The use of a log rule which is known to give a large over-run (§ 47) usually gives rise to the practice of scaling "sound" and ignoring defects. The buyer can afford to be lenient, and the seller objects to any further discounts than those inherent in the rule itself.

Except for a few species and regions, defects may usually be seen and deducted. Where the opposite is true, custom sometimes permits a reduction of the final scale by a straight per cent to allow for such invisible defects.

Over-run (§ 46) is therefore an element which should not influence in any way the practice of log scaling. Where an admittedly defective rule is offset by lenient but inaccurate scaling practice, the entire technique and standard of scaling suffers, and such conditions should sooner or later yield to accurate standards, both in the rule used and in its application.

83. Scaling Practice, Based on Measurement of Diameter at Small End of Log. The advantages of measurement of the log at the small end, which have made this custom practically universal in scaling, are that the scaling diameter inside the bark can be directly measured without guessing at bark thickness, and no matter how high a skidway or rollway is piled, the ends of the logs are usually visible for scaling. By contrast, logs to be calipered at the middle point can be measured only when lying separately or before being placed on rollways, and the bark thickness is usually guessed at.

The per cent of over-run on the log scale is affected by three main factors. Two of these, namely, the elements affecting manufacture of lumber and the character of the log rule itself, have been discussed in Chapter V. The third is the practice of scaling, and the customs which govern it, collectively termed the "scale." This practice affects, first, the method of determining scaling diameters and lengths, for when these are once ascertained the rule permits no variation in contents for sound logs; and second, the deductions from this scale for defects, as interpreted by the scaler.

Scaling Lengths. The total length of a log must be accurately determined. For log rules which are based on diameter at the small end, logs whose length exceeds a given maximum are scaled as two or more sections or shorter logs (§ 43). Custom or "scale" determines the maximum length to be scaled as one section and the method of determining the taper or diameter of the second or remaining sections to be scaled. Short sections scaled to full or actual top diameter give the maximum scale, while the loss from scaling long logs as one piece based on diameter at top end may be very large, due to the increasing per cent of volume in long logs which lies outside the cylinder and is thrown into the over-run.

The standard lengths of softwood or coniferous logs are multiples of 2 feet, to which is added an allowance for trimming. Where long logs are divided into two or more lengths for scaling, this rule is still adhered to; e.g., a 26-foot log is scaled as a 14- and a 12-foot. Usually the longer length is scaled as the butt log.

The tremendous variations in scale which may result from different treatment of scaling lengths and taper in long logs is illustrated in Table V (§ 44). In order to secure a consistent scale between long and short logs, the scaling length should be limited to not over 16 feet, and the actual diameter of each section taken as the scaling diameter.

Trimming Allowance. The trimming allowance varies according to the method of transportation used. For logs hauled by rail or driven down sluggish streams, from 2 to 3 inches is allowed for each 16 feet of length. Large logs require the greater allowance, to guard against slanting cross cuts which might give a short length on one side. Where logs are driven down swift rocky streams the trimming length must be sufficient to allow for the brooming of the ends. In very bad waters, the exact length of a log is immaterial and the loss from brooming a heavy item. Odd lengths, *i.e.*, lengths measured in odd feet as 13 feet, are permitted in hardwoods and to a limited extent in softwoods.

In ordinary scaling, trimming lengths in excess of standard 2-foot gradations are not scaled. But sellers of logs, to reduce loss from careless cutting of log lengths, may stipulate that when trimming lengths are in excess of the margin agreed upon, the log shall be scaled as if cut from 1 to 2 feet longer. The U. S. Forest Service adopts this practice as a penalty scale.

Scaling Diameters. In the apparently simple process of measuring the diameter inside the bark at the top end of the log, there are two ways in which the buyer may be given the advantage of a smaller scale. Owing to the irregular cross sections of logs, an average diameter should be found by taking two measurements at right angles. Instead, the practice of scaling the smallest diameter is common. The difference, in large logs, sometimes amounts to 2 or 3 inches. The second choice lies in the treatment of fractional inches. These fractions should be rounded off to the nearest inch; e.g., the 18-inch log class should include diameters from 17.6 inches to 18.5 inches. Instead, all fractions may be dropped, throwing logs from 17.6 inches to 17.9 inches into the 17-inch instead of the 18-inch class.[1]

The variations in scaling practice or local "scale" for the different regions in the United States and Canada are shown in Table XVII, p. 94.

It is seen that the standard set by the U. S. Forest Service is almost nowhere complied with in private operations, and that the departures from this standard work uniformly in favor of the buyer. Except for hardwoods, there is no valid reason for rejecting fractional inches, since these are in most instances already rejected in the construction of the log rule itself (Scribner, § 68), and in any case, the contents of logs of exact inch diameters represent a fair average for logs varying up to $\frac{1}{2}$ inch larger or smaller. In the same way, it is unfair to measure the smallest diameter instead of the average, for the sawed contents of logs with eccentric cross-sections is little if any less than for round logs, and certainly does not diminish in proportion to the ratio between smallest and average diameter.[2]

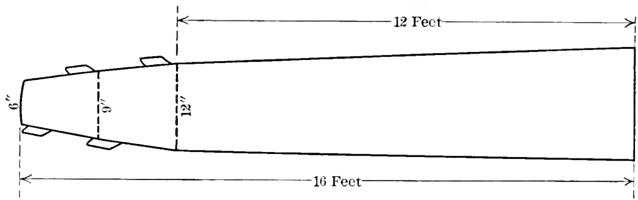

Fig. 12.—Effect of rapid taper at small end upon scaling diameter and scaled contents of a log.

[1] The adoption of these two buyers' practices in the scale will result in a loss to the seller which, by the Scribner log rule, amounts to from 5 to 15 per cent, averaging 8 per cent for logs running 10 to the thousand board feet, and 13 per cent for logs running 20 per thousand. The use of the average diameter, and the rounding off of fractional inches are practices fair alike to buyer and seller, and are required by the U. S. Forest Service in selling public timber.

The practice of reducing unit feet in a log rule to tens, or converting the rule into a "decimal" rule gives a third opportunity for discrimination in favor of the buyer. The correct method is that employed in the Scribner Decimal rule where all fractions above 5 feet are thrown to the 10-foot value above, while those less than 5 feet are dropped. But in one section of Maine it is the custom to drop all unit feet scaled by the Maine rule. Thus a log scaling 19 feet would be entered as 10 feet. The effect of such a custom on the scale is self evident.

[2] In a contract for sale of logs, the log rule to be used must be mentioned. The practice regarding scaling length, trimming allowance, method of measuring taper or rise on logs of greater than scaling lengths, measurement of diameter and treatment fractional inches should be specified. Otherwise, common custom or scale in the locality will determine what constitutes a proper method. The method of deducting for defects whether by each log separately or by a straight per cent should be agreed upon, and if possible, standard instructions adopted for culling defects. The minimum dimensions of a merchantable log should be defined, both as to length and diameter, and as to per cent of total scale which must be obtained after deducting for defects.

TABLE XVII

Scaling Practice or "Scale" in Different Logging Regions

Region	Log rule	Log lengths scaled as one log	Taper on long logs, how measured	Trimming allowance	Diameter at small end, how measured	Fractional inches	Cull deductions, how made	Remarks
United States Forest Service	Scribner Decimal C	Pacific coast 32 feet. Elsewhere 16 feet	As 2 or more logs. Actual taper	3 to 6 inches	Average, inside bark	Averaged to nearest inch	On each log By diagrams of lumber lost	Logs numbered for check scaling
New Brunswick	New Brunswick	16 to 48 feet	None	8 inches	Average, *outside* bark	Dropped	On each log. For cedar, 12 to 30 per cent from scale for hidden defects	Often counted, with a percentage scaled to get average
Maine Penobscot "Sound" scale	Maine	34 feet 34 to 40 feet as 2 logs	 1 inch	Fractions of feet rejected	Smallest, inside bark	Dropped	A per cent of total scale, where required by presence of defect	In addition, the odd feet in the scale may be dropped. A buyer's scale
		Over 40 feet as 2 logs To odd feet	Actual taper					
Kennebec "Sound" scale	Maine	26 feet 26 to 30 feet as 2 logs	 1 inch	Fractions of feet rejected	Average, inside bark On tapering top measure back to point allowing fair scale	Averaged to nearest inch	A per cent of total scale, where required by presence of defect	The over-run of the Penobscot scale compared with this scale is, for diameter alone, 2 to 17 per cent, average 8 per cent; for taper and scaling length combined, 5 to 35 per cent average 22 per cent; for total scale 16 to 17 per cent. But neither scale gives full value due to excessive log lengths and treatment of taper
		30 to 34 feet as 2 logs	2 inches					
		Over 34 feet as 2 logs	Actual taper					

Androscoggin and elsewhere	Maine	16 feet	Actual taper	Fractions of feet rejected	Average, inside bark	Averaged to nearest inch	A per cent of total scale where required by presence of defect	Owners of timberland usually prescribe proper scaling rules as basis of sale
Lake States and Inland Empire (Idaho)	Scribner Scribner Decimal A or C	22 to 24 feet	Actual taper	2 to 3 inches	Inside bark, either average or smallest	1. Averaged to nearest inch 2. Drop fractions below $\frac{3}{4}$ inches 3. Drop all fractions	On each log Judgment of scaler	A fair and full scale. Inland Empire, taper on long logs becomes standardized in practice instead of actual.
Central hardwood region	Doyle Doyle-Scribner Cube. Two-thirds	16 to 20 feet	Seldom cut long	2 to 3 inches	1. Smallest, inside bark 2. On rafted logs, in middle, allowing 2 inches for bark	Dropped	On each log Usually by reducing grade of log	The custom of sawing hardwood lumber $\frac{1}{8}$ inch full is offset in scaling by the method of measuring the diameter
Southern pine, Gulf Region	Doyle Doyle-Scribner Herring (Texas) Scribner-Doyle (La.)	16 to 32 feet 70 ft. (Texas)	1 inch for each 24 to 32 feet of length for logs longer than standard	Log lengths carelessly cut and scaled to nearest 2-foot lengths. 3 to 5 per cent waste in trimming	Smallest, 1—inside bark 2—including one bark 3—(Texas) including both barks	1. Dropped 2. Averaged to nearest inch	Usually not culled Occasionally, on each log	Both the log rules and the scale combine to give a low scale and large overrun (20 to 30 per cent) which is greatly increased for small logs and close utilization
Cypress	Doyle Doyle-Scribner Scribner-Doyle	22 to over 60 ft.	None in most cases in spite of actual taper of 3 to 10 ins. per 16 feet	Log lengths carelessly cut and scaled to nearest 2-foot lengths. 3 to 5 per cent waste in trimming	1. Smallest 2. Average, inside bark, or including one or both barks 3. On long logs, sometimes $\frac{1}{3}$ from small end	Usually averaged to nearest inch	Usually not culled Hollow logs butted Sometimes a cull per cent from total scale	Concealed defect, or peck, accounts for conservatism of scale. Lack of uniformity in method. Most firms own their timber and scale not important as basis of sales

TABLE XVII—*Continued*

Region	Log rule	Log lengths scaled as one log	Taper on long logs, how measured	Trimming allowance	Diameter at small end, how measured	Fractional inches	Cull deductions, how made	Remarks
Pacific Northwest	Spaulding	40 to 50 feet	1 inch for butt log for each 10 feet of total length above 40 feet	Logs under 36 inches allow 4 inches Logs over 36 inches allow 6 inches	Smallest, inside bark	Dropped	On each log Judgment of scaler	Chief defect is log length and taper Tolerated because of incomplete utilization Tendency (Scribner) to correct, as utilization becomes closer
		British Columbia, 40 to 50 feet	Ditto		Average, inside bark	British Columbia; dropped	Ditto	
	Scribner	40 to 50 feet	Various customs		Either method, inside bark	Dropped	Ditto	
Redwoods California	Spaulding	40 feet	As in Pacific Northwest	4 to 6 inches, 6 inches on all large logs	Average, inside bark, and sometimes inside sap as well	1. Dropped 2. Sometimes averaged to nearest inch	1. 25 to 30 per cent cull deducted from total scale 2. On each log, plus 8 to 10 per cent cull for unseen defects	Concealed defects demand a conservative scale. Incomplete utilization tolerates neglect of taper

Abnormal Diameters. The practice of basing the scaling diameter on that of the small end of the log, with its consequent disregard of taper, gives rise to difficulties on logs which taper rapidly at the small end, as for instance, rough or limby logs on the basis of their top diameters may result in loss of scale when in reality a greater volume of the tree has been utilized, Fig. 12, p. 93.

By the International $\frac{1}{4}$-inch rule this log would scale, in actual diameter

Length. Feet	Scaling diameter. Inches	Scale. Feet B.M.
12	12	70
14	9	45
16	6	20

Rigid adherence to the scaling practice on such logs results in the refusal of contractors to cut them. There are two possible modifications of the end diameter rule which will meet this condition: First, to scale the log as a shorter log, at the point which will give the largest total scale, in the above instance at 12 feet giving a scale of 70 board feet; second, to scale it as two logs, including the short tapering portion as a separate piece from the main portion. In the above case, the 6-inch top, with a length of 4 feet would add one-fourth of the scale of a 16-foot log of that diameter, or 5 board feet, giving a total scale of 75 board feet. The latter method is the most equitable, otherwise there is no object to the contractor in going into the top to secure closer utilization.

Abnormally large diameters, occurring at the small ends of logs are the result of cross cutting through crotches or swellings caused by limbs, or by defects or cankers. Such diameters must always be reduced to a size representing the normal diameter of the cross section as determined by average taper. For slight swellings this is judged by eye. For crotches, the diameter at butt end is sometimes taken and average taper deducted.[1]

84. Scaling Practice Based on Measurement of Diameter at Middle of Log or Caliper Scale. None of the true board-foot log rules in common use are applied at the middle of the log. By the Blodgett Rule, a cubic rule expressed in board feet (§ 33) the log is usually measured in the middle, outside the bark. When taper is taken on long logs by the ordinary rules, the scaler depends upon his scale stick and ocular judgment for the measurement of the upper diameters. But if logs are customarily cut long, and must be scaled by getting actual taper rather than assumed

[1] The following court decisions are important as defining the bearing of the "scale" on agreements:

"In the absence of any agreed standard of measure in a contract, that of the place where a commodity is purchased will govern the contract." Supreme Court of New York, Dunberic *vs.* Spaubenberg, 121 N. Y. 299.

"Where a contract involves the measurement of logs by specified rule, but does not indicate the manner of measuring whether by end, average or middle diameter, local custom shall determine such manner." Supreme Court of Louisiana, 13 So. 230.

standard tapers, calipers must be brought into use in scaling. The calipers employed in scaling logs by the Blodgett rule are equipped with a wheel of 10 spokes, one revolution measuring 5 feet in length (§ 34).

The greatest drawback to a caliper scale is the necessity of determining the width of bark, doubling this, and subtracting to get the scaling diameter of the log. When all logs are calipered, it is a common practice to determine the average width of bark of the species and region, and deduct twice this fixed amount on all logs regardless of variations in actual bark thickness, relying on the law of averages to secure a true scale. For the Blodgett rule, $\frac{3}{4}$-inch for each bark is allowed and the calipers are adjusted to read the diameter inside bark direct. On the Big Sandy River in Kentucky (Big Sandy Cube Rule) the allowance is 1 inch for each bark.[1]

85. Scale Records. The tally is the record kept of the logs by the scaler or his assistant, the tally man.[2] The tally may consist merely of a record of diameter and length of each log. From this the full scale is easily computed at camp. But the system prevents deductions for defects from each log separately, and is used only where such discounts are not made, or are made either as a per cent of total scale, or by reducing the length or diameter of the log. This primitive method of scaling has been largely replaced by the plan of recording the board-foot contents of each log when scaled. From the full scale, deduction is made for defect, and the net or sound scale recorded. For long logs scaled in two or more sections, only the sum of these volumes is set down, giving the total scale for the log as one piece and thus keeping the count intact. The purpose in this is to obtain a tally of the exact number of pieces scaled as well as their total contents.

To still further insure an accurate record, logs are numbered serially, with crayon, coinciding with printed numbers in the scale-book. This enables a check scaler to re-scale and compare individual logs, or any number of logs, with the original scale to determine the per cent of error and the specific faults in practice. Without such enumeration, the entire number must be re-scaled to obtain a check, and specific errors are not shown. The method of numbering is cumbersome where large quantities of very small logs are handled, but it is the only plan by which a uniform standard of scaling may be attained by a force of several scalers.

[1] A second method, employed in Maine in scaling cubic contents, is to assume that the volume of bark is $12\frac{1}{2}$ per cent of the total volume of the tree with bark. The diameter outside bark is measured direct, and the volumes given on the rule are computed to express the contents of wood alone.

Bark is never removed, in scaling, to permit the calipering of the direct measurement inside bark, as this process is too time consuming. The Tiemann log rule (§ 63) which applies to middle diameter inside bark, if used commercially, would probably be applied by the common method of deducting fixed widths of bark, to be regulated by measurements taken of the species and locality. This practice permits of an additional source of variation in measuring diameters (§ 29) through the bark on individual logs being thicker or thinner than the arbitrary measurement.

[2] Scalers usually work alone, preferring the extra labor to the risk of errors made in the record by incompetent tally men.

The scaler marks the logs with crayon as he scales them. If not numbered, they are check marked.

Where logs are piled in rollways, unevenly, and cut different lengths, the count must be checked carefully to see that none is missed. This is best done by making a recount after scaling a rollway, and check marking the butts of the logs, the tops having been marked in the scaling. Logs piled in high rollways can best be scaled by two men, one working at each side of the rollway.

Cull logs which are not scaled are given a distinguishing mark. If already skidded, they should be counted and recorded as culls. The scaling of logs in the woods eliminates the culls from the scale altogether and saves the expense of logging them.

Log Brands, Termed Stamps and Bark Marks. When the practice is necessary the scaler must see that the logs have been properly stamped and bark marked. A stamp is a pattern or die stamped into the end of a log with a marking hammer. A bark mark is a pattern cut into the bark, usually near an end, with an axe. Stamps and bark marks are used to distinguish logs when driven with those of other owners down a common stream. These marks are recorded by scalers and determine the ownership of the logs.

The Scale Book. A form of scale book is shown on p. 100 containing 100 printed numbers on a page with spaces for entering the contents of logs, and for totaling each column separately and adding these totals for the page.

The scale record shown in this sample page is for the Scribner Decimal C Scale. The original records give the scale in tens of feet. At the foot of each column, the total is entered parallel to the base, and the zero added to obtain full scale.

Logs whose scale has been culled show the net scale, and also the amount culled enclosed in a circle as, ⑥, which permits checking the cull.

Other forms of scale records are in use following these general principles.[1]

86. The Determination of What Constitutes a Merchantable Log. A merchantable log is one which it is profitable to log. Logs whose contents will not return the cost of logging and manufacture are unmerchantable. This may be due either to small size, to defects which reduce the scaled contents of the log, or to high cost of logging.

Minimum Size. The costs of producing lumber are separated into logging cost and milling cost. Both depend on the cubic volume of the log. But both are modified by the time required in handling separate pieces. This causes the cost per cubic foot to increase for small logs. In logging, and in small mills, the cost also increases per cubic foot when logs reach large sizes difficult to handle.

The value of the product depends not upon the cubic contents of the log, but on the quantity of sawed lumber which it contains, and

[1] The following court decisions are of interest: "When record of scale is kept on temporary paper and transferred every evening to permanent record, this record holds in court as original evidence." Court of Appeals, Alabama, 68 South. 698.

The U. S. Forest Service instructs its scalers to make the original and final record of scale in the field because of the liability of error in copying figures.

"Parties must abide by the official scaler's report except that fraud or gross mistake can be shown." Supreme Court, Michigan, Brook *vs.* Bellows, 146 N. W. 311.

Purchaser, John Smith Where Scaled, At railroad landing No. 3. 6

Timber, Sale, 5-20-12 End Mark, None Compartment 2; Sec. 25; T. 5; R. 4E; Date 9-15 1902

SPECIES 8-380 Western Yellow Pine SPECIES 8-380

Log No.	Length.	Ft. B.M.	Log No.	Length	Ft. B.M.	Log No.	Length.	Ft. B.M.	Log No.	Length.	Ft. B.M.	Log No.	Length.	Ft. B.M.	Remarks.
50 1	16	40	5 21	12	35	5 41	14	60	5 61	16	37	5 81	12	15	Other Species
2	14	57	22	16	43	42	12	75	62	16	59	82	14	18	are recorded
3	12	53	23	16	24	43	16	53	63	12	21	83	18	(7) 46	on other pages
4	20	36	24	18	60	44	16	20	64	16	16	84	16	78	or in other
5	16	(6) 12	25	14	cull	45	14	8	65	14	35	85	16	39	books.
6	14	cull	26	12	15	46	14	13	66	18	(5) 67	86	14	cull	
7	16	6	27	16	(3) 37	47	12	cull	67	18	95	87	20	105	
8	16	(2) 9	28	14	54	48	20	98	68	12	41	88	12	27	
9	12	25	29	16	75	49	16	(12) 100	69	12	9	89	12	50	
10	14	57	30	16	87	50	18	49	70	14	10	90	16	cull	
11	16	(11) 60	31	14	18	51	14	57	71	16	cull	91	16	53	
12	16	92	32	14	10	52	12	23	72	16	74	92	16	10	
13	14	10	33	12	10	53	16	10	73	14	49	93	14	17	
14	14	12	34	10	cull	54	16	12	74	14	(9) 57	94	16	29	
15	12	10	35	16	28	55	16	55	75	20	24	95	12	8	
16	14	(4) 20	36	20	30	56	16	30	76	16	6	96	16	(10) 56	
17	16	18	37	14	(7) 50	57	10	65	77	16	30	97	14	49	
18	16	21	38	12	42	58	14	46	78	14	89	98	16	60	
19	16	24	39	16	64	59	12	25	79	12	57	99	16	cull	
20	18	cull	40	16	75	60	14	18	80	12	(4) 36	100	14	36	
		562			757			817			812			696	
		5620			7570			8170			8120			6960	

TOTAL, THIS PAGE. 36440

BROUGHT FORWARD. 110750

TOTAL SINCE LAST REPORT. 147190

REPORTED TO 9/1/12. 560420

TOTAL TO 9/15/12. 707610

Scaled by Chas Brown F.R.

FIG. 13.—Sample page of scale book.

finally, upon the qualities or grades, and price of this lumber. The ratio of board feet per cubic foot (§ 41), the quality and value, all increase with increasing size of log. Due to these factors, logs below a given diameter and length, or total scale, even if sound, become unprofitable or unmerchantable. This minimum diameter and length, when specified, relieves the logger or purchaser of the requirement of removing such logs from the woods, cutting them from tops, or felling trees which will not yield larger sizes. If he chooses to take these sizes, especially from the tops, the logs are customarily scaled and paid for.

Defective Logs. Defective logs, which will produce only a portion of the normal contents of sound logs of the same size, cost just as much to log and saw as if sound. But the ratio of lumber secured per cubic foot is reduced in proportion to the amount of cull, and the margin between cost and value shrinks accordingly, until it disappears and the log is classed as a cull and not scaled even if taken by the logger. Defects occur most frequently in large logs, whose quality and value are high.

A defective log which produces a small per cent of its contents but of clear lumber or high grades may be merchantable, while a rough log with a much smaller per cent of defect may not show a profit in handling. Millmen who log their own timber can base their standard for culls directly upon this margin of profit, and can afford to accept very defective logs for a few high-grade boards. Value or margin of profit, if applied as a standard in selecting or rejecting logs, means an elastic per cent of cull dependent on the character of the log itself. But the logger or logging contractor is paid not by value or grade of sawed lumber, but by the scale. Since his costs are determined by cubic volume and size, he would prefer a cubic log scale, but in accepting payment on the basis of board-foot contents, his profit in logging depends instead on the ratio of board feet to cubic feet independent of quality, and is diminished by reduction in scale caused by cull. On the other hand the loggers' costs vary with the distance which the log must be skidded or hauled. A log with a given per cent of sound scale if near the point of delivery will show a profit, while the same log is unmerchantable if located at a greater distance from the track. For defective logs, then, the merchantability is determined, for the millman, by comparing the combined cost of logging and milling with the value of the product, but for the logger it is determined by comparing the price per thousand board feet secured for the scaled contents of the log with the cost of delivering it to the point agreed upon.

Where firms are doing their own logging, sawyers and loggers are frequently paid on basis of full scale disregarding cull. But in contract logging, the scaler usually rejects cull, thus requiring an agreement on the per cent of sound contents which constitutes a merchantable log.

This per cent cannot be varied from log to log according to value of contents to favor the millman, or to location of log to favor the logger, but is arbitrarily set at an average figure applicable to all logs of a given species. Different per cents are permitted for species having different average values, the greater the value the lower the per cent of sound lumber accepted. As between the logger and the millman, the use of the board-foot scale favors the latter, but its application regardless of grades of lumber in the log is a concession to the logger. The rejection of cull logs is a concession to the millman but the adoption of a fixed percentage for each species simplifies administration and aids the logger, who does not have to determine the profit in a log but only the cost of logging. Contract loggers are favored, then, by a cubic basis, no deductions for cull, and reduction of logging costs by leaving inaccessible logs in the woods. The manufacturer considers the additional factor of profit or value of the log, which the logger himself would have to consider if he were selling his logs. Only by determining average total costs and average values for a given logging operation can the actual specifications of a merchantable log be determined, and the average agreed upon. In the U. S. Forest Service the custom is quite widely adopted that logs of the more valuable species must scale $33\frac{1}{3}$ per cent of their sound contents, and those of inferior species, 50 per cent to be merchantable.

The limits of merchantability will vary widely in every region, unless standardized as is the case in the Pacific Northwest. The average conditions for different regions for the year 1917 are indicated below:

Region	Smallest diameter. Inches	Per cent of sound scale accepted
Central, hardwoods	8 to 12	40 to 70, average 60
Southern pine	7 to 8	25 to 75, average 50
White pine, Lake States	4 to 5	10 to 25, average 20
Idaho	5 to 8	20 to 33, average 25
Pacific Northwest	12	$33\frac{1}{3}$
Southwest	6 to 9	30 to 40, average 33

These limits apply to saw logs. For pulpwood, bolts are taken down to between 3 and 4 inches.

Tests on spruce logs in the Adirondacks showed that 5-inch logs had a relative value per board foot of 56 per cent compared with 11-inch logs at 100 per cent, while the relative value of 20-inch logs was 126 per cent.[1]

[1] The following legal decision is interesting:
"A merchantable log is one that contains sufficient lumber to make it profitable

87. Grades of Lumber and Log Grades.[1] In the scaling of logs the primary object is to determine the contents in board feet of sound lumber as fixed by the arbitrary standard of the log rule, based solely on dimensions of the log, and modified only by deductions for unsound lumber (Chapter VIII).

But as shown in § 86, the purchaser of logs, or millman, is even more concerned with the value per 1000 board feet of the scaled contents. This value will depend directly upon the amount, by per cent of the total scale, of each of several standard or recognized grades of lumber which the logs will yield when sawed, and the resultant weighted average value which this gives to the logs as a whole.

When the value of logs must be determined before sawing, as is required when logs are purchased, and in the sale of standing timber, the relative percentages of these standard grades which will *probably* be produced from these logs or the stands in question must be estimated. It is evident that this can only be done with approximate accuracy, since a mere inspection of the surface and ends of logs will not reveal exactly the condition of the interior as to texture, extent of defects and per cent of better and poorer grades present.

In scaling, no attempt is ever made to divide or separate the total scale of a log as indicated by the log rule, into the amounts or per cents of different grades of lumber in the log. Not only would such a process be too expensive and time consuming, but it would not be sufficiently exact to pay for the effort of calculating the results separately log by log to get the total scale for each grade of lumber.

Instead, a system has been substituted of establishing so-called log grades, usually three in number, based on the average value of the contents of logs as determined by the grades of lumber which they contain. This classification permits of the fixing of separate prices for each log grade. The total scale of each log is thrown to the log grade in which it is classed.

Defects in lumber (§ 352-353) may be separated into two classes, unsound defects which reduce the scale of the log as described above, and sound defects which reduce the grades of sound lumber but do not reduce the scale of the log. The effect of the first class is to render the log unmerchantable if in excess of the determined limit; the effect of the second class is to lower the value and consequently the grade of the

to take it to a mill and have it sawed." Gordon *vs.* Cleveland Sawmill Co., 82 N. W. Rep. 230, Supreme Court, Michigan.

This ruling is based on the millman's point of view, which, in the absence of contract specifications protecting the logger, will always determine the standard of merchantability.

[1] Ref. Appendix A.

log. The fact that, with increasing prices unsound lumber is sold and is graded does not change the standard scaling practice, which takes no account of these unsound grades and excludes them from the scale. Such lumber merely increases the amount of the over-run.

The characteristic sound defects are tight or sound knots, pitch and stain. Sound tight knots never reduce the scale unless present in such size and quantity as to cause the lumber to fall apart or to be rejected. Stained sap, which is still firm, or red heart, the precursor of red rot, are scaled. Pitch is usually classed as a sound defect for which no deduction in scale is made. But these defects, especially knots, and others such as twisted grain and wide rings do serve to reduce the grade of the log. The presence of unsound defects, such as rot, shake and break, does not reduce the grade of a log, provided there is sufficient sound lumber remaining to permit the log to meet the minimum requirements of the grade. Since the purpose of log grades is to establish value, log grading specifications are drawn so as to permit logs of the same average value to be placed in the same grade, and too detailed specifications are avoided.

By thus simplifying the classification of logs by grade, the total log scale is easily separated into log grades, and any variation in the average quality of logs within the grade can be adjusted in the price of the grade (§ 359).

For any given region, and class of timber, the actual average per cents of different standard grades of lumber contained in log grades can then be determined by mill-grade or mill-scale studies (§ 361). These per cents can then be applied to the total scale for each log grade with far greater accuracy than could be attained by attempting to analyze the scale of each log.

Log grades, as analyzed by such mill-grade studies, have become the basis of determining the stumpage value of standing timber in appraisals as conducted by the U. S. Forest Service (§ 234).

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CHAPTER VIII

THE SCALING OF DEFECTIVE LOGS

88. Deductions from Scale for Unsound Defects. No deduction will be made from the scale of a log unless there is some visible indication of unsound defect such as will reduce the quantity of sound lumber that can be sawed from the log. The character and extent of the deduction to be made for the indicated defect is judged by the scaler based on his knowledge of the given species and region and his experience in observing the way such logs open up in sawing. Defects visible at the ends of the log give a basis for judging the remaining contents. When logs must be scaled as they lie after bucking, with ends still in contact, as sometimes happens with overhead skidder operations, it is difficult to make correct deductions for defects.

The surface of the log offers additional evidence of unsound defects, especially the character of the knots. Sound knots from live limbs do not affect the scale, but the knots of dead stubs, if they show rot, and especially the presence of rotten knot holes, with exudations of pitch, indicate the presence of advanced stages of rot, which a little experience in the mill will teach the scaler to allow for in full measure. The mere suspicion that logs may be rotten does not justify deductions. When timber is full of concealed defects with no surface indications, the method of deducting a given per cent of the total scale may be adopted instead of attempting to reduce the scale of each log separately.

89. Methods of Making Deductions. There are four methods of reducing the scale of a log; by length, by diameter, by diagram or specific quantity of lumber and by a per cent of the gross scale. The reduction in either length or diameter enables the scaler to read the reduced scale from his stick as for a log of smaller dimensions and is the simplest form of discount, but least accurate except for certain forms of defect.

Reduction in Length. A reduction in length gives a proportionate reduction in per cent of total contents. The per cent taken depends on the relation between the lengths of the log before and after reduction. For a 16-foot log, $12\frac{1}{2}$ per cent of the total scale is deducted for each 2-foot reduction. This deduction becomes 10 per cent for a 20-foot log or $16\frac{2}{3}$ per cent for a 12-foot log.

Reduction in Diameter. Reduction in diameter is not a satisfactory method of making deductions except for rotten sap found on logs cut from dead trees, or for surface checking. The per cent of the scale thus deducted varies for every diameter of log, and for each difference in the number of inches subtracted. This method of deduction should not be used to offset some interior defect. By this method, a 20-inch log by Scribner's Rule would give the following deductions from scale in per cents. For other diameters, the per cents would differ:

Reduction of diameter. Inches	Per cent deduction in diameter	Per cent loss in scale
1	5	14.2
2	10	25.0
3	15	36.7
4	20	42.8

This method should usually be rejected in favor of one of the other three, since it substitutes a guess for an accurate deduction.

Use of Diagrams. The diagram method is the most accurate way of computing the actual number of board feet to deduct from a log for a given defect. The cross section of the defective area is blocked out as a square or rectangle, and its length decided upon, whether running completely through the log or only part way through. For rules based on $\frac{1}{4}$-inch saw kerf, 20 per cent of the cross section of this area must be deducted to get the net volume of 1-inch boards to be deducted from the scale.

This is expressed by formula when

$a \cdot b$ = cross sectional area in inches,

l = length of defective section in feet,

y = cubic contents of the section in board feet,

x = volume of section, sawed into 1-in. boards, $\frac{1}{4}$-in. saw kerf.

$$y=\frac{a \cdot b \cdot l}{12}.$$

Then

$$x=y-.20y=.80y,$$

or

$$x=\frac{a \cdot b \cdot l}{15}.$$

In using a decimal rule, the resultant volume is rounded off to the nearest 10 or "decimal value" before subtracting it from the log scale.

As a substitute for this calculation and to save time, scalers frequently approximate the amount of deduction by guess, based on experience.

Deducting a Per Cent of Total Scale. The method of deducting a per cent of the total scale, as distinguished from the above methods is chiefly applied to logs containing defects within the log, evidenced by rotten knots, punk, conks, or other indications and whose amount can only be guessed at on the basis of experience obtained by observing such logs as they are sawed in a mill.

Influence of Log Rule on Deductions for Defects. A log rule based either upon diagrams of 1-inch boards and definite saw kerf, or upon a formula in which the proper deductions are made both for saw kerf and slabbing, permits the scaler to make deductions from the scale of each log separately on the basis of the actual loss in 1-inch boards from that portion of the log included in the scale or log rule. But when a log rule is inaccurate, either because of excessively low valuations, false basis as in converted cubic rules, or erroneous values in formulæ as in Doyle or Baxter rules, such deductions when applied to logs already scaled too low would take from the scale more than the proper per cent of defect, as the following comparison will show.

A log 10 inches in diameter and 16 feet long, which will saw out but one-half of its scaled contents due to defect (and omitting boards sawed from outside the cylinder), if scaled by the Scribner and Doyle rules respectively will give:

Log rule	Sound scale. Feet B.M.	If actual loss in sawed content is Feet B.M.	Net scale deducting actual loss. Feet B.M.	Net scale deducting 50 per cent of sound scale. Feet B.M.
Scribner.....	54	27	27	27
Doyle.......	36	27	9	18

If the log is sawed by a mill whose output coincides with the Scribner rule, the over-run on a sound log by the Doyle rule will be 50 per cent. The defective log will give no over-run of sound lumber by Scribner. But if 27 feet, or one-half of the actual sawed contents, is deducted from the scale by Doyle rule the over-run will be 18 feet, which is 200 per cent of the residual scale of 9 feet, on this scale, or four times as great on the defective as on the sound log. By deducting 50 per cent of the Doyle scale for the log, the over-run remains at 50 per cent of the scale as for sound logs.

Although the method last mentioned gives a consistent basis for making deductions in rules like the Doyle, while the deduction of actual loss in lumber gives far too great an over-run, it is evident that when log rules are used capable of giving a scale equaling but two-thirds of the actual contents, the tendency will be to overlook the defects in scaling unless very serious and numerous.

90. Effect of Minimum Dimensions of Merchantable Boards upon these Deductions. Log rules made from diagrams, such as the Scribner and Spaulding Rules, were based on a minimum width of board of not less than 6 inches. Present practice permits the sawing of 4-inch strips. In deducting for defects by diagram, the latter practice is used, and portions of the log which will yield 4-inch strips are scaled, provided these dimensions lie within the cylinder and do not include taper. A rotten butt with 6 inches of sound wood will be a total cull unless the inscribed area of the top or small end of the log contains within it at least 4 inches of sound wood.

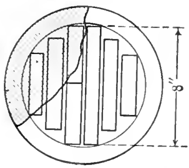

FIG. 14.—The boards lost are measured inside the smaller inscribed circle representing the top diameter. Three boards are affected, 4 inches, 6 inches, and 8 inches. The 6-inch board is deducted. If the minimum width of board utilized is 4 inches, a 4-inch strip is deducted from the 8-inch board. But the 4-inch strip on the margin was not scaled in the original diagram and should be omitted, as constituting over-run by this log rule. In ordinary scaling practice this distinction would probably be overlooked as too great a refinement.

In theory, this rule must be modified for deductions which take the form of slabs, since the original diagram or scale rejected all boards below 6 inches in width. This case is illustrated in Fig. 14.

The minimum length of merchantable board should first be standardized or agreed on in scaling. Formerly a defect at one end of a standard log, say 16 feet long, would cull the boards affected for their whole length. But where boards of 6- or 8-foot length are merchantable, defects which leave a sound length equal to these minimum boards will be scaled only for the actual length of the part affected. This rule affects the results for nearly all forms of defect. Standard minimum lengths are important in scaling crooked logs. The standards now in use for saw timber vary from 6 to 10 feet with a tendency to become shorter.

91. Interior Defects. Unsound defects may be classed as interior, causing waste in the interior of log; side or exterior defects, causing waste at the surface or outside; and defects in form, i.e., crook, in otherwise sound logs, causing waste in sawing straight lumber. Interior defects are due to rot, shake, seams or checks, and worm-holes. The defect may extend through the entire log, or be present only at one end. It may be circular, and regular in form, or irregular in form and extent.

Center Rot. Circular defects in the form of either rotten or hollow logs, or ring shake, if they extend through the log, will be measured not at the small but at the large end, provided the log is not over 16 feet long. For longer logs the average of the dimensions at butt and top is taken. If only one end is affected, the diameter of the defective portion is scaled at that point and its length judged by experience gained in the locality by the butting off of defective logs; e.g., a log 20 inches in diameter at the top end, 16 feet long, with a center rot measuring 3 inches at top and 15 inches at butt, will lose the equivalent of a 15-inch butt rot, and not a 3-inch piece. Should the log be 20 feet long, the average

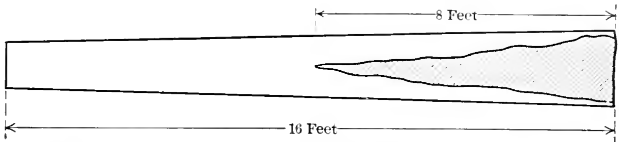

Fig. 15.—When the minimum length of board is 8 feet this log will scale one-half of the contents of a 16-foot log. But with a minimum length board of 10 feet the log according to common practice will scale nothing and be culled.

dimension of this rot, or 9 inches, would be taken, according to the above arbitrary rule of scaling. But if the rot is present only in the butt, the 15-inch measurement would apply to that portion of the log which was judged to be affected, provided the length of the remaining sound portion equaled the minimum length of board prescribed.

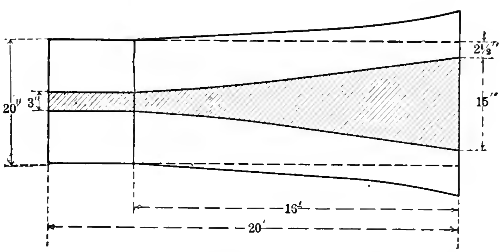

Fig. 16.—Center rot extending through log. Effect of length of log in determining the diameter of the portion to be culled.

The scale of this log, if sound, would be 280 board feet, Scribner Decimal C rule. The deduction for a rotten butt 15 inches in diameter and 16 feet long is 228 board feet, residue 52 board feet or 18.2 per cent of sound scale. The log is a cull. The average w dth of rim left to be scaled after projecting the area of the rotten butt upon the top end, is 2½ inches, or less than minimum width of board, and not the actual measurement of sound wood at either the top or the butt.

If this log is 20 feet long, i.e., longer than a prescribed maximum length of 16 feet, the diameter of this rot is averaged at 9 inches. The 20-foot log, 20 inches in diameter scales 350 board feet. The 9-inch measurement is applied to the entire length of log, and the deduction is 111 board feet. The net scale is 240 board feet, or 68.6 per cent of total sound scale. Such a log is merchantable.

It is evident that such rules for deductions are arbitrary. The 16-foot log would yield considerable short lumber and is under-scaled by the rule. Where short-length boards are commonly used, logs over 12 feet long might be scaled on the basis of average diameter of rot, to correct this tendency. But it is better to adopt arbitrary rules than to have no methodical plan for scaling defects.

The cull required by the presence of an unsound or hollow circular core is proportional to the diameter of the core, and independent of that of the log. By the diagram method, the deduction for center rot would be found by determining the board-foot contents of a square with the diameter of the rotten core and of the length indicated as above. This method when checked against actual sawed contents gives too smal a deduction for cores up to 9 inches, and above that, too large, the relation varying from 87 per cent for a 6-inch core to 110 per cent for one 24 inches in width. The actual amounts of sawed lumber lost for cores of each diameter are accurately expressed by a formula developed by H. D. Tiemann, which reads,

$$\text{Contents of core} = \tfrac{2}{3}(D+1)^2\frac{L}{12},$$

i.e., add 1 inch to diameter of core, square, and deduct $\frac{1}{3}$, converting the remainder into board feet by the factor

$$\frac{\text{Length in feet}}{12}.$$

This formula calls for four-fifths of the sawed board-foot contents of a square 1 inch larger than the core ($0.66D^2 = 82.5$ per cent or $\frac{5}{6}$ of $0.80D^2$) instead of the full sawed board-foot contents of a square of the same size as the core.

Several rules of thumb exist for determining the deduction for center rot, none of which are absolutely correct, and some very inaccurate.

Example. In a 12-foot log 20 inches in diameter with a rotten center 6 inches in diameter at large end and running through the log and a sound scale of 210 board feet, the correct deduction is 33 board feet which is $\frac{2}{3}(7^2)\frac{12}{12}$. The following rules of thumb can be cited, using Scribner Decimal C rule.

1. Deduct the diameter of core from that of log, and scale as a log. This gives a cull of 90 board feet.

2 Deduct the scale of a log of same diameter as the core. This gives a cull of 10 board feet.

3. Scale out a log with diameter 3 inches larger than the core. This would give 30 board feet, but the rule gives inconsistent results for larger and smaller cores.

4. Scale out the contents of a square timber whose side is the diagonal of the square of the diameter of the core. This would be $1.4D^2$ and gives 70 board feet. If reduced by 20 per cent for saw kerf, and applied to small end of core, it would come closer by balancing errors. None of these rules is accurate or consistent.

Butt Rot, Termed also Ground or Stump Rot. Butt rot enters the butt log from the ground, and usually extends but a short distance into the log. Its full diameter should seldom be applied to the entire log, even if rot appears at the top end.

The diameter of the rotten butt must first be compared with the scaling diameter as determined by the top end of log (§ 81). If the rim of sound wood lying within this inscribed circle is wide enough for boards, or if the volume of the rotten core, $\frac{a.b.l}{15}$ shows a smaller cull than the sound scale of that part of the log, deduction by diagram of the squared core is made (preferably by Tiemann's formula) to a length judged to include the rotten portion.

Example. A log 12 feet long and 20 inches in diameter at top end has a rotten butt 6 feet long, the rotten core measuring 17 inches across. Although the butt measures 25 inches, leaving a 4-inch rim of sound wood, the inscribed circle representing the top of the log is only 20 inches, and the butt is a cull. This observation is borne out by applying Tiemann's formula:

Scale of 12-foot log, 210 board feet,

Scale of 6-foot length, 105 board feet,

Cull for butt rot, $\frac{2}{3}(18^2)\frac{6}{12} = 108$ board feet,

or more than the sound scale of butt. This deduction is not applied to the whole log but only to the butt.

The scale of the log is then 105 board feet on the basis that the upper half is sound.

If this core should measure 13 inches,

Cull for butt rot $\frac{2}{3}(14^2)\frac{6}{12} = 65$ board feet.

The scale of the log is then $210 - 65 = 145$ board feet.

But if the minimum board length should be over 6 feet, the first log will be culled entirely, and from the second log, a cull of $\frac{2}{3}(14^2)\frac{12}{12}$ or 131 board feet Scribner Decimal C is deducted, leaving a scale of but 79 board feet, or 37.6 per cent of the merchantable contents.

Shake. Shake is a mechanical defect caused by wind. The annual rings have separated at one or more points, giving a circular or ring crack, and the board falls to pieces when sawed. This flaw is found at the butts of such species as hemlock, and is seldom more than a few feet in length although entire logs may be shaky. Lumber sawed from shaky portions of logs is often worthless.

A single circular shake is scaled out in the same manner as butt rot except that the contents of a smaller sound core lying within the shake may be added or restored to the scale. The diameter of this interior core should be measured at the small end of the culled section if it extends through the log, while the diameter of the culled portion is measured at the butt or large end. In short sections whose length is guessed at, a proportionate reduction from butt diameter is made in scaling the sound core. This same method is used to scale out pitch rings, where this is deemed necessary. In most cases pitch is considered a sound defect (§ 82). Where shake shows in several rings, the entire shaky portion of the log is butted, by shortening its length.

Seams, Heart Checks, Frost Cracks or Pitch Seams. Seams are cracks penetrating the log from the surface. They have the same effect as shake, in causing boards to fall apart, and the deduction is made by enclosing the seam in a timber of required dimensions to remove it. Twisted grain, causing seams to take a spiral form, results in ruining either the entire log or a large per cent of its volume. The deduction must include the entire seam in a squared timber. The width of the plank deducted should not include the portion which would be slabbed in sawing.

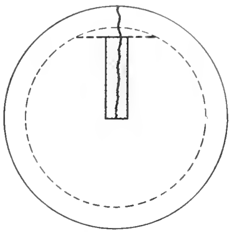

Fig. 17.—Method of deduction for a seam, or a heart check. The width of plank should exclude both the taper of log and the slab, on the small end.

Method of deducting for a twisted seam or check: The wedge enclosing the seam is scaled as a per cent of total scale of cylinder proportional to areas of cross sections. But on long logs, of larger diameters, the entire segment shown in Fig. 18 is not lost, if short boards of scaling length can be sawed from the butt and top portions of the segment respectively. This saving will not amount to more than one-third of the total deduction.

Worm Holes. If the size and extent of worm holes is not sufficient to cull the boards, their presence will not cause a loss in scaling. It is difficult to judge the extent of damage from worm holes, except by local experience in observing the sawing of logs.

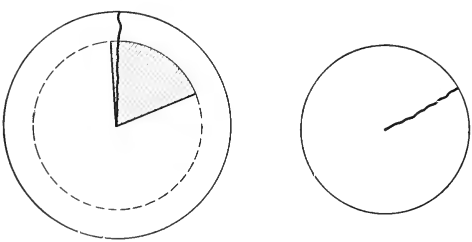

Fig. 18.—Position of twisted seam at butt, and at top of same log, and resultant sector deducted in scaling.

Rot Entering from Knots. The most common forms of rot enter the tree through dead limbs, stubs or knots, or through wounds or abrasions, which by penetrating or interrupting the layer of bark and live sapwood, expose the heartwood to infection. From these points of infection the fungus spreads through the heartwood both upwards and downwards. The form which it takes depends upon the species of fungus, and of trees attacked. The unsound portion is surrounded by a stained portion which is yet sound. The area of the rot increases with age of tree and time elapsing since the infection took place.

In deducting for rot, the amount of the loss depends upon the location of the point of infection, usually a rotten knot. Stain which shows at one end of a log requires no deduction if the rot of which it is an evidence lies in the adjoining log as cut from the bole. On the other hand, two or more rotten knots in a log, with stain showing, means a heavy discount and a possible cull. Sawyers are accustomed to leave such logs in the woods and even in the tree without sawing them. Rot from a single point of infection will extend from 2 feet to as much as 10 or 15 feet in either direction. It is deepest and most complete at the point of entry, tapering out with increasing distance from this point. Rot of this character is so irregular that experience is required in observing such logs sawed before proper deductions can be made by scalers.

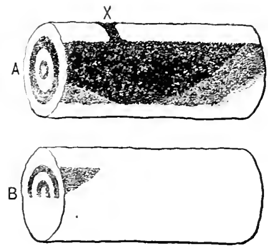

FIG. 19.—Log *A* is infected at the point *X* and is a cull. At the lower end no rot shows, but stain only. This stain therefore shows at the upper end of log *B*, but causes no deduction for cull.

In deducting for interior rot, the probable extent and shape of the unsound portion therefore depends upon the appearance of the ends taken in connection with unsound knots. The only portions of the log which can be scaled are those which will produce sound boards having the minimum length and width prescribed in the rules for scaling. The deduction will take the form of a per cent of the sound scale. Diagrams are sometimes of assistance, but in logs containing rotten knots the extent of rot is usually greater than revealed at the cross section. The apparent cull must ordinarily be increased, from 25 to 100 per cent. Since deduction of length is equivalent to a percentage reduction of scale, this method is frequently used.

Peck in cypress, and the rot found in Incense cedar gives no external indications, and is not always revealed on the cut ends of logs. This condition tends to the substitution of a straight percentage deduction from the total scale instead of reducing the scale of individual logs for defects.

92. Exterior Defects. Exterior defects, on the sides of logs, include unsound sap, surface checks, cat faces, fire scars, and scars caused by mechanical injuries such as lightning or falling timber. Irregular butt rot, appearing as a small patch on one side, or rot from knots which is local in extent, can sometimes be scaled by the methods used to scale side defects.

Exterior defects, especially at the butts of logs, may fall entirely outside the inscribed circle representing the top or scaling diameter, in which case they cause no deduction in scale. With defects which penetrate deeper a further portion is included in the slab allowed in sawing, within this circle.

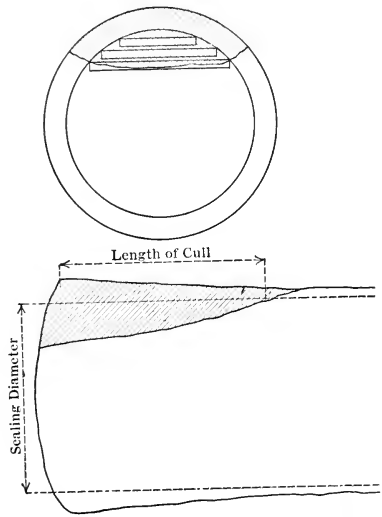

FIG. 20.—Effect of fire scar at butt, on deductions from scale.

Where the defect extends but a few feet in length, as for instance a fire scar at the butt of a log, the deduction is confined to that portion of the length of the small cylinder whose contents is scaled, which is affected by the defect. The amount to subtract may be found in one of two ways; by diagram of the slab affected by the defect, or by culling a per cent of the volume of the log.

Deductions by Slabs. The dimensions of the portion to be deducted as a slab are not those of the piece actually slabbed from the butt, but only the depth of the portion lying within the inscribed circle of the small end of log. From this again there is subtracted an additional amount for slabbing, shown in Fig. 20. The remaining depth, multiplied by the average width of the inscribed slab, gives the area of the cross-section whose length will be that of the defect, and volume, $\frac{a \cdot b \cdot l}{15}$.

In the above figure, the fire scar on the butt log is 8 inches deep, but only 5 inches of this is within the inscribed scaling dimensions. Of this $1\frac{1}{4}$ inches is slab, giving $3\frac{3}{4}$ inches for lumber. The widths of the boards lost are 10 inches, 14 inches and 18 inches. The average width of the rectangle is 14 inches. A diagram measuring 4 by 14 inches, whose length equals that of the fire scar lying within the inscribed cylinder, gives the deductions. As the scar gets shallower, the length lying within this cylinder is less than its total length. Tables could be worked up by a scaler to express the board-foot contents that could be cut out of slabs of given thickness on circles (inscribed) of given diameter for a standard length of log, allowing a minimum width of board equivalent to that used by the log rule (§ 67) But ocular methods are almost equally efficient after practice.

Deduction by Sectors. Side defects extending deeply into the log (Fig. 21) cannot be slabbed off and are not easy to express by diagrams. By enclosing them in V-shaped areas representing sectors of a circle, an idea may be obtained of their extent. This method may be used for any defect occurring wholly on one side of the geometric center of a log and which is more accurately enclosed by a sector than a slab.

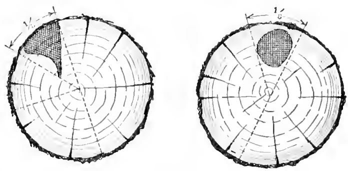

FIG. 21.—Method of deducting from scale by means of sectors enclosing defective portion of log.

The cull per cent for the portion of the log affected is roughly equal to the ratio between the area of the circle and of the sector. This rule is exact for the ratio $\frac{1}{2}$, and nearly so for smaller or larger sectors. The error in applying the rule will average less than 3 per cent of the volume of the log, and if the defect is confined to a short length, this error is proportionately less for the whole log (from investigations of H. D. Tiemann); e.g., a sector equaling one-fourth of a circle calls for 25 per cent cull. Cull tables may be made for this deduction, but it is equally convenient to apply the percentage directly to the scale. This latter method adjusts the cull factor to any log rule (§ 89).

Other Surface Defects. Stained sap is scaled as sound. When unsound or decayed, the scaling diameter is taken inside the sap. Surface checks caused by prolonged weathering as in the case of dead timber, or by neglect or exposure of logs, must be scaled out in the same manner as sap. Cat faces, as defined for cedar poles in the Lake States, are defects on the sides of logs caused by some mechanical injury to the bark which has caused a wound. A cat face may be accompanied by rot, or be merely a dry face, not healed over and forming an indentation in the bole. According to its shape and depth, a cat face is deducted either as a slab or a segment, of proper length. The term cat face is also applied to a fire scar at the butt of a tree, usually partly healed over, which may be sound, rotten or wormy. Any surface defect partly healed over, on the bole, caused by either fire or mechanical injury, whether at the butt or on the bole, may properly be called a cat face. Lightning scars, even when the tree is not shattered or killed, usually form a dead streak causing a surface defect, sometimes of considerable proportions.

Breakage. The deduction for splits and breakage caused by felling is made either by slabbing or by shortening the log length, to remove the portion ruined by the breakage. Where this waste is avoidable, owners stipulate that it shall be scaled as sound, but purchasers of logs insist on the deduction. In the Pacific Coast States, breakage may exceed 25 per cent of the scale.

93. Crook or Sweep. Crook may be defined as a rather abrupt bend in the log at a given point, while sweep is a more gradual bend extending over a considerable length. Crooks occurring near the ends of a log may be allowed for in scaling by shortening the scaling length. With gradual sweep affecting the form of the log as a whole, a different deduction is necessary. The effect of sweep or crook upon the scaled contents of the log (§ 52) depends directly upon the minimum length of boards utilized and scaled, or upon the acceptance of fixed minimum scaling lengths for the logs. If it is assumed that the minimum board governs the scale, deductions for crook or sweep will seldom be made, since almost complete utilization can be obtained of sound crooked logs by the box factory. But if the scale of a log is based on the output of boards of the standard scaling lengths into which the logs are cut, and short lengths cannot be utilized, crook or sweep will cause deductions in scale when it exceeds the normal minimum permitted.

When logs crook in but one plane, the loss in sawed lumber is proportional to the relation which the total deflection or crook bears to the diameter of the log, and does not depend on the number of inches of crook independent of size of log; e.g., for a 12-inch log a 6-inch crook is 50 per cent of the diameter but for a 24-inch log, a 6-inch crook is but 25 per cent of the diameter, and a 50 per cent crook indicates a crook of 12 inches.

By diagram checks, and sawing, the per cent of waste due to sweep for a given total number of inches of crook per log is found to be independent of the length of log, and to show the following results:

TABLE XVIII

DEDUCTIONS FOR CROOK AND SWEEP

Sweep in terms of diameter of log. Per cent	Waste in terms of scale of log. Scribner rule
$8\frac{1}{3}$ (or $\frac{1}{12}$)	$11\frac{1}{4}$
$16\frac{2}{3}$ (or $\frac{1}{6}$)	$22\frac{1}{2}$
25 (or $\frac{1}{4}$)	$33\frac{1}{3}$
50 (or $\frac{1}{2}$)	$66\frac{2}{3}$

From these results a rule of thumb may be suggested as follows: Add one-third to the per cent of sweep as expressed in terms of diameter of log to obtain the per cent of cull; e.g., a log 16 feet long and 16 inches in diameter scales 159 board feet. With a sweep of 4 inches or 25 per cent, deduct $\frac{4}{3}\times25=33\frac{1}{3}$ per cent or 53 board feet; scale, 106 board feet. With a sweep of 8 inches, deduct $\frac{4}{3}\times50=66\frac{2}{3}$ per cent, or 106 board feet; scale 53 board feet. With a sweep of 2 inches no deduction would be made, since this is merely the normal crook.

Logs which crook in two or more planes must be culled far more heavily than when the axis lies in a single plane. For a given per cent of crook the scale is roughly proportional to the square of the per cent scaled by the deductions set forth above; e.g., a log which scales 50 per cent or one-half if crooked in one plane will, if crooked in two planes, scale $(\frac{1}{2})^2$ or 25 per cent of its contents.

94. Check-scaling. By check-scaling is meant the re-scaling of selected logs or of a portion of a total run of logs, in order to determine the relative accuracy of the original scale, check the methods used by the scaler and detect and correct errors in these methods. A *re-scale* requires the remeasurement of all of the logs. The necessity for a re-scale is usually revealed by a check-scale.

Where a number of scalers are employed, check scaling becomes necessary in order to maintain uniformity in scaling practice. No matter how carefully the standard of scaling practice is set forth in printed instructions which cover not only the " scale " with respect to diameters, length, taper and trimming allowance, but rules for deductions for defects, individual scalers tend to vary from this standard through habit or carelessness and inexperienced men are slow to acquire accuracy, especially in scaling defective logs.

A check scale should be made by the most experienced man available as frequently as possible, but usually at from three to six months' intervals. Where logs are numbered, the original scale should show the deductions made from the full scale of each log (§ 85). The check scale can be made at random on as many logs as there is time for. The total scale for the logs checked is then compared with the original scale of the identical logs, keeping separate the sound and the defective logs. Using the check scale as 100 per cent, the per cent of error in scaling is computed according to the following plan:

	Sound logs		Defective logs		Total	
Scale by	No. of logs	Scale per cent + or −	No. of logs	Scale per cent + or −	No. of logs	Scale per cent + or −
JAMES SMITH Check scale by JOHN KIPP						

The standard of accuracy in the U. S. Forest Service for check scaling requires that the scale should not vary from the check scale by more than the following per cents:

For sound logs, within 1 per cent;
For logs up to 10 per cent defective, within 2 per cent;
On logs 11 to 20 per cent defective, within 3 per cent;
On logs over 20 per cent defective, within 5 per cent.

Check scales are made usually for the purpose of correcting the scaler, but not as a basis of altering the scale. Only where the original scale is shown to be decidedly in error so as to work an injustice on the purchaser (or seller) are logs ever re-scaled.

Personnel. Scalers should never be reprimanded in general terms for scaling too close or too high. The result is usually a worse error in the opposite direction. Instead, the scale should be checked by individual logs to discover the sources of error and the scaling practice corrected in detail. The fault may lie in some specific practice such as an erroneous method of obtaining diameters or in allowing for certain common defects.

Mill-scale studies do not furnish an adequate or satisfactory check on scaling, but serve merely to determine the over-run. The scale, if in error, must be corrected by re-scaling the logs, not by measuring the lumber (§ 74). Such studies do furnish an indication of the scale of defective logs, where the scaler's judgment may be in error, but an exact check is impossible, as it would require the rejection of boards sawed from the taper, which is not practicable.

95. Scaling from the Stump. Where timber has been cut in trespass and the logs removed, the evidence remaining is the stump, the indentation on the ground where the butt struck in falling, the sawdust where the cuts were made in sawing into log lengths, and the top, giving the upper diameter. The length of the tree can then be measured, and occasionally, that of each log sawed. The total difference in diameter between top and butt is distributed according to the accepted local customs for scaling long logs. This gives the scaling diameter and length of each log in the tree. Specific deduction for defect can be made only for stump rot, since this is revealed by the stump and the average deduction for rot having the character and extent of that shown can be made from the butt log. Further deductions if made must be based on the average per cent of cull for timber of the given species and character.

When tops are removed, burned or otherwise rendered indistinguishable, neither the top diameter nor the length of the tree can be judged. Merchantable length must then be based upon the heights of trees in the vicinity, and volumes taken from volume tables (§ 121) for trees of given diameter and height. A table of stump tapers (§ 168) must be used to express the diameter of the stump in terms of diameter $4\frac{1}{2}$ feet from ground (§ 134).

96. The Scaler. A scaler with no other duties can number and scale 500 logs per day, running 10 logs per 1000 board feet or 50,000 board feet at a cost of about 10 cents per 1000 board feet, based on wages and subsistence of $125.00 per month. This average can be exceeded but is apt to be reduced in quantity by time lost in travel to and from the logs, scaling in the woods, or an insufficient number of logs on hand daily to occupy the full time of the scaler. Often these logs must be scaled daily and cannot accumulate, because of insufficient room on the skids, thus keeping a scaler in constant attendance. A scaler thus employed is often given other duties such as inspecting the work of the saw crews. National Forest Scalers supervise the disposal of brush, closeness of utilization and the marking of timber for felling. This reduces the average cost of scaling to approximately the basis mentioned.

Commercial scaling by private companies is done far more rapidly and cheaply because of the elimination of numbering, and by careless or indifferent methods of measuring lengths and deducting for defects. A scale of 1000 to 1500 pieces, and 100,000 board feet per day and a cost of 5 cents per 1000 board feet or less is not unusual on large operations.

So important is an accurate scale that the scaler must be given every facility to obtain the measurement with the least trouble and greatest certainty. This usually means providing a sufficient force of scalers so that they may be on hand at the most favorable time, or constantly. When on account of small or scattered operations the logs must accumulate the scaler is handicapped in various ways. Large and high rollways require two men, one on each side, to get the length, even approximately, and to distinguish top from butt, of each log. Logs landed on ice will in time by their weight cause cracks and flooding, and small logs are frozen in. Whole rollways may break through the ice and become partially submerged. Snow covers and buries the piles, and logs are overlooked. Logs may be rolled down steep banks and lie in such confusion that scaling is difficult and dangerous. Steam skidders pile logs in huge heaps impossible to scale at all until loaded on cars. The inability of the scaler to cover his route at frequent intervals encourages careless sawing, timber stealing and poor scaling. Contracts should specify that logs must be piled or skidded in such a manner that accurate scaling is possible.

Legal Status of Scaler. "A scaler whose services are agreed upon by both parties to a contract or sale, is the sole arbiter between these parties in determining the amount of the scale. But if one party furnishes the scaler without the expressed consent or agreement of the other, his scale may be appealed from." Frisco Lumber Co. *vs.* Hodge, U. S. Circuit Court of Appeals, 218 Fed. Rep. 778.

"A scaler furnished by the defendant and boarded by plaintiff would be one mutually agreed upon, and they must abide by his decisions." Connecticut Valley Lumber Co. *vs.* Stone, U. S. Circuit Court of Appeals, 212 Fed. Rep. 713.

"Binding in the absence of fraud or mathematical mistakes." Hutchins *vs.* Merrill, Supreme Court Maine, 84 Atlantic 412.

"Scale made by scaler appointed by defendant not binding in absence of some stipulation to that effect in contract." Owen *vs.* J. Neils Lumber Co., Supreme Court of Minnesota, 145 Northwestern 402 (1914).

"Scaler who performed his duty fairly and honestly, though negligently, could-not be held liable for discrepancy between the amount he scaled and the amount of logs delivered, as permitting such action would destroy independence of arbitration." Hutchins *vs.* Merrill, Supreme Court Maine, 84 Atlantic 412.

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CHAPTER IX

STACKED OR CORD MEASURE

97. Stacked Measure as a Substitute for Cubic Measure. Stacked or cord measure is the cubic space occupied by stacked wood when the exterior dimensions of the stacks are measured. This is expressed in terms of standard units termed cords. Wood in the form of round bolts or split bolts, which are termed billets (§ 9) is usually intended either for use as bulk products such as firewood, pulpwood or acid wood, or for manufactured articles whose dimensions conform to those of the bolts or billets.

For the former uses, the total cubic contents of the wood, or of wood and bark, is desired. This could be obtained as with logs, by measuring the dimensions of each separate bolt and totaling their contents. On account of the smaller sizes, greater number, and irregularity of form, especially of billets, such a method would be time consuming, inaccurate and impossible to check as to results without complete measurement. Yet it is quite extensively employed to obtain actual cubic contents of logs and bolts for commercial purposes, when the material is fairly large and of regular shape (§ 29).

Where the pieces are short, small, split, or irregular in form, the more convenient and simple method is to stack the wood in ranks and measure the surface dimensions to get stacked cubic contents including both solid wood and air space.

98. The Standard Cord versus Short Cords and Long Cords. A standard stacked cord is a pile, 4 feet high, 8 feet long, of pieces 4 feet long, and contains 128 stacked cubic feet. For bulk products, the net cubic contents of wood, either with or without bark is desired. The use of wood with bark for fuel for domestic purposes utilizes by far the greater portion of all wood sold in bulk. For this purpose the standard cord is the basis of delivery in the rough, to wood dealers.

But the domestic consumer seldom burns 4-foot wood, and usually requires short wood of varying sizes commonly between 12 and 24 inches in length and making 4, 3 or 2 cuts to a 4-foot stick. Other special lengths may be specified when the wood is cut direct from the tree. This demand gives rise to the *short cord*. A short cord is a pile measuring 4 by 8 feet on the side or face and one rank deep. The depth and cubic contents depends on the length of the pieces. Since this substitution of surface measure reduces the cubic volume of short cords, either the price must be reduced, or the full cubic contents of a standard cord secured by requiring the cord to be two, three or four ranks deep, or to have an additional length sufficient to make up 128 stacked cubic feet. A standard cord of 4-foot wood when cut into stove lengths is considered a full cord, although in repiling it shrinks from 8 to 13 per cent in stacked volume (§ 108). When the cord of short wood is measured on this basis, the full dimensions of a standard cord cannot be required on repiling.

Wood is also cut longer than 4 feet. The term *long cord* usually refers to a cord 4 by 8 feet in surface by 5 feet in depth and containing 160 cubic feet. The standard length of stick for hardwoods for distillation or acid wood is 50 inches, giving a cubic contents of $133\frac{1}{2}$ cubic feet. Unless long cords are accepted by custom, stacks measuring more than 4 feet in length of stack are reduced to their equivalent volume in standard cords. When pulp wood bolts, ordinarily cut 4 feet long, are cut 8, 12 or 16 feet long, they are measured as standard cords, a stack 4 by 8 by 8 feet containing 2 cords.

99. Measurement of Stacked Wood Cut for Special Purposes. Stacked cubic measure is commonly employed in measuring bolts or split billets intended for manufacture into spokes, handles, staves for slack and tight cooperage, shingles and similar piece products. Bolts measuring over 12 inches in diameter are usually scaled in board feet. Billets, if split or rived into pieces each of which is to be shaped into one finished article such a split staves, may be counted.

Bolts intended for sawing are usually measured by stacked contents. The lengths of the bolts sawed from the tree must correspond to the required length of the product plus a small margin for trimming, or must be a multiple of this length, to avoid waste. For spokes, 30 inches is a common length. Handles require lengths of from 12 to 60 inches. Common lengths for staves for tight cooperage are 19 inches and 38 inches. The demands of the market or purchaser determine the length in every case.

The measurement of shingle bolts is frequently by double cords, in lengths of 8 feet. On the West Coast, the bolts are cut in lengths equal to 3 shingles. For 16-inch shingles the cord is 4 feet 4 inches in depth, while for 18-inch shingles, the length of bolt required is 4 feet 8 or 10 inches. Shingle bolts illustrate the tendency to simplify and standardize measurements of products to save expense. The bolts are not uniform in size, and one cord may contain from 16 to 40 bolts. But it is common practice to first determine the average number of bolts in a cord, and then measure the remainder by counting the bolts to avoid stacking. The number agreed upon is used as a divisor to obtain the quantity in cords.

Stacks measuring more or less than 4 feet in length of stick can thus be measured in either of the two ways described above (§ 98). Surface feet or 32 square feet equivalent to 4 by 8 feet may be taken as a short cord. But stacked contents based on the standard cord of 128 cubic feet is just as commonly employed. For instance, in cooperage it is a common custom to measure 36-inch stave bolts in ranks 4 by 11 feet for one cord, giving 132 cubic feet or approximately a standard cord.

100. Effect of Seasoning on Volume of Stacked Wood. Green hardwoods shrink on seasoning, decreasing from 9 to 14 per cent in volume. Conifers shrink from 9 to 10 per cent. Contractors sometimes stipulate an extra height of 3 to 4 inches on the stack to offset this loss. Where such extra allowance for shrinkage, or for any other reason, is required, it must be specified by contract unless generally accepted in the locality.

101. Methods of Measurement of Cordwood. Stacked cordwood is measured by a stick usually 8 feet long, marked off in feet and tenths. Choppers prefer to pile each cord separately, since the division into a number of smaller piles reduces the cubic contents required for one cord (§ 103). When surface measure, 32 square feet, is accepted for short or long cords, their measurement is identical with that of standard cords, the length of piece being measured only to insure conformity with specifications. Stacks piled to more or less than standard height and length are reduced to cords by dividing the surface feet by 32; e.g., a stack measuring 12.7 feet by 6.4 feet contains 81.28 surface feet, or 2.54 cords.

When standard stacked contents is used as a basis, the length of piece is also measured, the cubic contents of stacked wood obtained and divided by 128; e.g., a stack of 30-inch bolts with the above surface dimensions gives 81.28 by 2.5 = 203.2 stacked cubic feet; $\frac{203.2}{128} = 1.5875$ standard cords, while a similar stack of 5-foot wood gives 81.28 by 5 = 406.4 stacked cubic feet. $\frac{406.4}{128} = 3.175$ standard cords, instead of the 2.54 cords based on surface standard.

A *cord foot* is a pile measuring 1 by 4 by 4 feet or containing one-eighth of a standard cord. It is also termed a foot of cordwood, being equal to 1 foot in length in a stack of cordwood of standard dimensions. The unit applies to short or long cords when surface only is measured and not cubic contents.

The chopper is required to pile the rank to an even height, preferably the standard of 4 feet. Unless otherwise specified, the height of the pile is to be the average height of the tops of the sticks in the top layer. With uneven, crooked or poorly piled stacks a point 1 or 2 inches below this is taken. From this height is subtracted whatever allowance is required for shrinkage, when so specified.

If the ends of the stacks are not vertical the length is measured at one-half the height of the pile. If wood is piled in irregular stacks the average of both height and length is obtained, if necessary from several equally spaced measurements.

Wood piled on inclined surfaces is measured incorrectly if the length of the pile is taken parallel with the surface of the ground or top of stack, while height is taken vertically. The true contents of a stack with the dimensions shown in Fig. 22 is 87.5 per cent of a cord. The correct measurement is secured if length and height are taken at right angles whether or not the length is taken horizontally or along the surface.

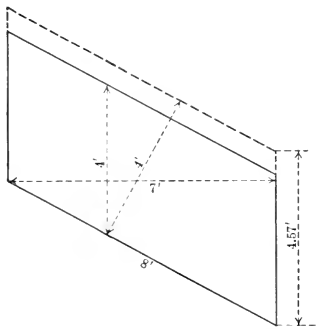

FIG. 22.—In the example given, the vertical height of the pile must be 4.57 feet to give 128 cubic feet. The actual pile measures 112 cubic feet by either method.

102. Solid Cubic Contents of Stacked Wood. The stacked cord is a measure purely of convenience. The purchaser is interested not in the cord, but in its solid cubic contents of wood. Stacked round bolts can never give 128 cubic feet of wood to a cord. The highest possible contents would be obtained from bolts which were perfectly cylindrical and of uniform diameter. These, if stacked in hexagonal formation, or alternating, and with one end bolt in each tier split in half to fill out the tier, would give 116.07 cubic feet, or 90.68 per cent of 128 cubic feet, which is the relation of the area of an inscribed circle to that of a hexagon. *This relation holds true for bolts of any length or diameter.*

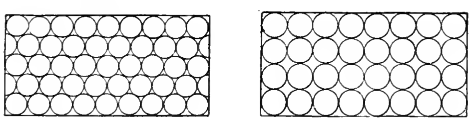

FIG. 23.—Hexagonal piling—116.07 cubic feet per cord or 90.68 per cent solid wood. Square piling—100.53 cubic feet per cord or 78.54 per cent solid wood. It is evident that neither the diameter nor the length of sticks would in any way influence the solid cubic contents of a cord unless taken in conjunction with some other factor whose effect varies with the dimensions of the piece.

When these cylinders are piled directly above one another in square formation, the cubic contents of a cord becomes 100.53 cubic feet, or 78.54 per cent of 128 cubic feet, which is the relation of the area of an inscribed circle to that of square.

103. Effect of Irregular Piling on Solid Contents. In actual practice, the solid contents of a cord seldom exceeds 100 cubic feet. Straight smooth sticks of uniform sizes, carefully piled, may yield from 105 to 107 cubic feet, but never as much as the 116 cubic feet theoretically possible. This loss is due first to irregular piling, and second, to variation of the bolts or sticks from uniform cylindrical form.

Piling exercises an enormous influence, which increases in direct proportion to the irregularities of form. When to extreme crookedness and surface irregularities is added dishonest piling, including the laying of sticks at angles with each other, or even piling over stumps and other trade practices, the purchaser may incur a loss of from 20 to 30 per cent from piling alone. Choppers are always paid by stacked measure and close supervision is required to secure a full cord. The factor of piling may cause more variation in the solid contents of a cord than that of form of sticks. Since this factor depends upon the laborer, the contents of a cord of wood, as a commercial standard, is based on what can be expected of choppers rather than a theoretical maximum. Conversion factors for obtaining cubic contents of wood are based on average conditions of piling. The cord can never be satisfactorily used as a basis of scientific measurements of volume produced by trees and stands, or of growth, though for convenience, cubic contents is often converted into cords to express the results of these investigations.

104. Effect of Variation in Form of Sticks on Solid Contents. Variation in the form of sticks is caused by taper, eccentric cross sections, crook, and irregularities or roughness of surface. All departures from cylindrical form increase the air space in a stacked cord.

The effect of taper can be partially overcome by piling bolts with large and small ends alternating. But this is never done in practice. Sticks split from bolts which include stump taper are apt to be somewhat curved as well as tapering. Sticks with eccentric cross-sections do not pack as closely as round sticks and give a smaller per cent of solid contents.

Crook is one of the most important factors in reducing the cubic contents of a cord. The slightest departure from a straight axis exerts a corresponding influence in increasing the air space in stacking. Very crooked sticks may reduce the contents of a cord by 50 per cent.

Irregularities of surface in round sticks are caused by bark, knots, stubs and swellings. Every such protuberance, by contact with adjoining sticks, decreases the solid contents of the stack. Split sticks are irregular in both form and surface and always take up more room than the round bolts from which they were split or round bolts of equal diameter and straightness.

Since sticks with the smoothest surface and least taper will pack the closest, and the removal of bark affects both factors favorably, the cubic contents of a cord of peeled wood is always greater than the cubic contents of a cord of wood with bark, for the same species and sizes of sticks. The shrinkage in stacked contents after peeling exceeds that caused by loss of bark because of this closer piling. Bark is a waste product for pulpwood or excelsior and purchasers prefer to buy peeled wood.

The thinner the bark on a tree the smoother it is apt to be. Species with smooth bark yield appreciably more solid contents in stacks than thick-barked trees, because in the latter case the bark is usually irregular and fissured. Hence conifers such as spruce and balsam, and hardwoods like white birch and poplar give the highest contents per cord, while hardwoods such as oak and maple yield considerably less per cord than conifers.

The same difference holds for branch wood as contrasted with body wood, open-grown and limby trees compared with those grown free from branches in close stands, and split wood with twisted grain compared to straight grain.

While the splitting of sticks decreases the solid contents, by increasing the irregularities of surface and the effect of crook through reduced diameters, split cordwood is usually cut from much larger bolts than round sticks, and hence a cord of split wood may contain a greater solid content than one of round sticks, especially if the round pieces are below 3 inches and cut from limbs.

105. Effect of Dimensions of Stick on Solid Contents. The effect of a given amount or rate of crook, or of given irregularities of surface, in diminishing the solid contents of a stack, increases with increased length of stick, but this effect is more nearly proportional to the square of the length than to the length. Hence the longer the sticks in a stacked cord, the less its net cubic contents, other factors being equal.

This explains the shrinkage in cubic volume when 4-foot wood is cut into shorter lengths and restacked. In sticks longer than 6 feet this becomes a serious factor and pulpwood from fairly straight logs when sold in from 8- to 12-foot lengths gives about 12 per cent less cubic contents than for 4-foot bolts (Table XXI, p. 130).

Conversely, the cubic volume of sticks increases as their cross-sectional area, which is as the square of the diameter, while the effect of both crook and surface irregularities increases in porportion to the surface of the stick, which is directly in proportion to diameter and consequently less than cross-sectional area or volume. A crook of 2 inches in a stick with 3-inch diameter has twice the effect that a 2-inch crook would have on a 6-inch stick. Due to these relations, the solid contents of a cord of wood always increases with the increased average diameter of the sticks, but diminishes with increased length.

106. The Basis for Cordwood Converting Factors. The value of stacked wood depends upon the quantity of wood contained in the stacked cord as well as upon its quality. It is just as consistent to require a knowledge of the solid cubic contents of stacked cords as it is to measure sawlogs for board-foot contents by a log rule. For this purpose, converting factors are required, and these factors are determined by actual measurement of the solid wood in cords composed of sticks of different diameters and degrees of straightness.

Since a cord contains 128 cubic feet of space, the solid contents in cubic feet may be expressed in terms of per cent; e.g., a cord containing 90 cubic feet of wood gives 70 per cent of stacked contents in wood. A cord of theoretically perfect cylindrical sticks piled square gives 100.5 cubic feet, or 79 per cent (§ 102). This in actual practice is about the maximum contents of stacked cord, no matter how the piling is done, for losses caused by taper, crook and surface compensate for any gain by hexagonal over square arrangement of sticks. Smooth pine or white birch may give 102 to 107 cubic feet for large sticks, but the attainable maximum solid cubic contents of cords can for commercial purposes be set at 100 cubic feet.

TABLE XIX

SOLID CONTENTS OF STACKED WOOD *

Class of product	Per cent solid contents in stack	Cubic feet solid wood in one cord or per cent of standard contents of 100 cubic feet per cord
Large smooth logs or bolts	75–80	96.0–102.4
Average split firewood	60–75	76.8– 96.0
Top and branch wood	50–65	64.0– 83.2
Fagot material (small branches and twigs)	30–45	38.4– 57.6
Stumps and roots	30–40	28.4– 51.2

* Adolph R. von Guttenberg, in Lorey's Handbuch der Forstwissenschaft, Vol. III, 1903, Chap. XII, p. 179, Tübingen.

There is thus a choice of two methods of expressing converting factors for indicating the solid or cubic contents of wood in a cord; first, the number of feet of solid wood in a cord of 128 stacked feet; second, the per cent of a stacked cord which this cubic contents represents. Of the two, the former is preferable for two reasons; first, it is directly applicable to cubic contents of trees as a divisor or converting factor to obtain cords; second, it indicates the comparative solid volume in cords of different cubic contents on a basis which practically amounts to a 100 per cent commercial standard. For if 100 cubic feet, as indicated above, is the practical maximum solid cubic contents of a cord of stacked wood, a cord containing 70 solid cubic feet bears a 70 per cent relation to this maximum, regardless of the fact that 70 feet is but 54 per cent of the space in a stacked cord of 128 feet. This accidental relation holds good only for standard cords. To apply this same basis of comparison, instead of the per cent of stacked contents, to long or short cords, the solid contents would have to be compared to 78.12 per cent or $\frac{100}{128}$ of the stacked contents. Average cordwood worked up from hardwoods, either split or round, is often reckoned at 90 cubic feet or 90 per cent of a maximum cord, which is 70 per cent of stacked contents.

107. Standard Cordwood Converting Factors. The cubic contents of stacked wood has been thoroughly investigated by European authorities on the basis of the stacked cubic meter, of length equal to 39.37 inches or 8.63 inches short of a 4-foot standard. According to the per cents given in Table XXI (p. 130) these results should give about 1 per cent more than the contents of similar sticks 4 feet long.

The following Table XX is adopted from the results of an investigation conducted by Prof. F. Baur, and published in a pamphlet entitled "Untersuchungen über die Festgeholt und das Gewicht des Schichtholzes und der Rinde," Augsburg 1879, pp. 97–99. These factors may be regarded as standard for 4-foot lengths, after subtracting 1 per cent.

The difference in per cents between hardwoods and conifers in this table is seen to fall largely in the smaller sizes. Where branch wood is mixed in the cord the per cent of difference between hardwood and conifers, usually about 6 per cent, may be increased to 12 or 15 per cent, since many conifers lack merchantable branches, while hardwood branches are usually crooked.

108. Converting Factors for Sticks of Different Lengths. The influence of length on per cent of solid contents is fairly constant for sticks of all diameters, but differs tremendously according to the amount of crook in the average stick. Table XXII gives average results for *conifers*, which as a rule are much straighter than hardwoods. It is seen in the table that the per cents when standardized for sticks of the same diameter do not differ much, whether the sticks average over 5.5 inches or are between 1 inch and 2.5 inches in diameter.

The differences in contents caused by crook and surface irregularities is well shown in Table XXIII, prepared for hardwoods by König, p. 131. In this table the values for straight sticks 4 feet long slightly exceed the values in Table XXI since these sticks are selected. But for other lengths even in this class the percentages increase more rapidly than for conifers; while for crooked and knotty sticks the differences caused by length are excessive, when added to those caused by diameter.

TABLE XX

STANDARD CONVERTING FACTORS FOR CORDWOOD

Species	Diameter	Class of material	Character of piece	Per cent solid wood in a cord	Cubic feet solid wood in a cord or per cent of standard contents of 100 cubic feet per cord
Conifers	Large	Round logs	Straight	80	102.4
	Medium	Split firewood	Straight, smooth	75	96.0
	Medium	Split firewood	Crooked, knotty	70	89.6
	Small	Firewood	Round bolts	70	89.6
	Small	Firewood	Top wood	60	76.8
	Small	Strips	Hewn from bole	50	64.0
	Small	Chips	Hewn from bole	45	57.6
Hardwoods	Large	Sawlogs	Straight	80	102.4
	Medium	Split firewood	Straight, smooth	70	89.6
	Large	Split firewood	Knotty, crooked	65	83.2
	Small	Firewood	Round bolts	65	83.2
	Small	Firewood	Knotty, crooked	55	70.4
	Small	Firewood	Top wood	55	70.4
	Small	Firewood	Branch wood	45	57.6
	Small	Strips	Hewn from bole	35	44.8
	Small	Chips	Hewn from bole	25	32.0
	Small	Brush	Long branches	15	19.2

109. Converting Factors for Sticks of Different Diameters. The figures in table XXIV indicate the influence of diameter of stick upon solid contents of stacked cords, for various species. The differences in contents for species is due entirely to differences in form and smoothness of sticks.

Second-growth white pine and Norway or red pine give results approximating white birch. Old growth, knotty twisted grain and limby northern hardwoods give 60 cubic feet per cord, as against 90 cubic feet for tall slender straight clear second-growth. A cord of average hardwoods does not contain more than 70 cubic feet. A cord of second-growth hickory spoke bolts contains 95 cubic feet. Chestnut acid wood on the Pisgah National Forest, N. C., is scaled as 110 cubic feet of wood per cord of 160 stacked cubic feet, or 87 cubic feet per standard cord. In California, a cord of red and white fir, averaging 60 sticks, contains 81 cubic feet. Western juniper in Arizona averages 62 cubic feet of solid wood per cord.

TABLE XXI

CONIFERS *

Influence of Length of Stick upon the Solid Cubic Contents of a Cord

Length of stick. Feet	Solid contents per cord. Sticks over 5.5 inches in diameter at small end. Cubic feet	Per cent in terms of 4-foot sticks	Solid contents per cord. Sticks from 2.5 to 5.5 inches in diameter at small end. Cubic feet	Per cent in terms of 4-foot sticks	Solid contents per cord. Sticks from 1 to 2.5 inches in diameter at small end. Cubic feet	Per cent in terms of 4-foot sticks
1	91.80	+ 3.2	85.25	+ 3.4	65.69	+ 3.2
2	90.90	+ 2.2	84.35	+ 2.3	65.32	+ 2.7
3	89.98	+ 1.2	83.40	+ 1.6	64.60	+ 1.5
4	88.92	0	82.42	0	63.62	0
5	87.75	− 1.3	81.30	− 1.3	62.60	− 1.6
6	86.45	− 2.8	80.00	− 3.0	61.60	− 3.2
8	83.75	− 5.8	77.20	− 6.3	59.40	− 6.6
10	81.00	− 8.9	74.30	− 9.9	56.90	−10.5
12	78.05	−12.2	71.20	−13.6	54.25	−14.7
14	74.85	−15.8	67.95	−17.5	51.50	−19.0

* Raphael Zon, Forestry Quarterly, Vol I, 1903, p. 132.

These results were verified by test on balsam fir in the Adirondack region of New York

TABLE XXII

INFLUENCE OF LENGTH OF STICK ON SOLID CUBIC CONTENTS OF A STANDARD CORD, BALSAM FIR

Length. Feet	Volume			
	Diameter of sticks, small end, 7 inches and over. Cubic feet	Loss in long sticks. Per cent	Diameter of sticks, small end, 4 to 7 inches. Cubic feet	Loss in long sticks. Per cent
4	96.7	....	92.4	....
8	91.6	− 5.3	87.4	− 5.4
12	86.2	−10.8	81.6	−11.6
16	80.2	−17.1	75.5	−18.3

This table was based on 56 cords by R. Zon, Bul. 55, U. S. Dept. of Agriculture, p. 52.

TABLE XXIII

INTERDEPENDENCE OF THE STICK LENGTH AND THE VOLUME OF SOLID WOOD PER CORD *

Length of stick.	Straight Sticks		Crooked Sticks		Knotty Sticks	
Feet	Volume. Cubic feet	Difference. Per cent	Volume. Cubic feet	Difference. Per cent	Volume. Cubic feet	Difference. Per cent
1	99.81	+8.3	93.47	+14.1	89.60	+20.7
2	97.28	+5.5	89.60	+ 9.4	84.48	+13.8
3	94.72	+2.8	85.76	+ 4.7	79.36	+ 6.9
4	92.16	0.0	81.92	0.0	74.24	0.0
5	89.60	−2.8	78.08	− 4.7	69.12	− 6.9
6	87.04	−5.5	74.24	− 9.4	64.00	−13.8

* Cited in Dr. Müller's Lehrbuch der Holzmesskunde, Graves Mensuration, p. 104.

TABLE XXIV

SOLID CONTENTS OF A STANDARD CORD BASED ON DIAMETER OF STICK

Average, 4-foot wood

Average diameter at middle of sticks. Inches	Paper birch.* Cu. ft.	Balsam fir.† Cu. ft.	Spruce.‡ Cu. ft.	Aspen.§ Cu. ft.	Beech.§ Cu. ft.	Red maple.‖ Cu. ft.	Mixed hard-woods.§ Cu. ft.
3	64	76	75	49	....	67	60
4	72	82	80	57	....	69	65
5	82	86	84	64	54	70	69
6	87	88	86	71	62	72	73
7	91	90	88	77	70	74	77
·8	96	91	90	83	77	77	80
9·	100	92	91	88	83	80	83
10	103	93	92	92	88	84	85
11	105	94	92	96	93	87	88
12	105	....	93	....	....	90	90
13	105	....	94	....	....	92	92
14	....	....	95	....	....	93	95
15	....	....	96	....	....	95	97
16	....	....	96	....	....	96	99
17	....	....	97	....	....	96	....
18	....	....	97	....	....	....	....

* S. T. Dana. † R. Zon. ‡ H. L. Churchill. § E. H. Frothingham.
‖ E. E. Carter.

110. The Measurement of Solid Contents of Stacked Cords—Xylometers. The solid or cubic contents of stacked cords must be actually measured in order to determine the converting factors for wood as influenced by any of the above conditions. The purpose may be to obtain either an average factor for commercial use, or to further test the effect of crook, diameter or length of sticks specially selected.

Two methods of measurement are available, actual calipering or stereometric[1] calculation, and xylometric[2] measurement. By the first method, the diameter of each bolt is measured in the middle (Huber's method) taking two measurements at right angles to obtain the average. The length is measured if necessary, but the sticks are usually cut to a standard length. Split billets cannot be measured by this means, and in this case, the round bolt must first be measured before splitting. The measured wood is piled and the contents of the sticks required to make a stacked cord are totaled for as many cords as possible, to obtain average factors.

Wood after splitting, or very small crooked or irregular pieces such as branches or root wood, is best measured by a xylometer.[2] The displacement of water when wood is submerged in a tank is exactly equal to the cubic volume of the wood. The only question is the fo m of the tank and method of measuring the cubic volume of water displaced.

One plan (invented by Karl Heyer, Giessen, 1846) is to have an overflow spout flush with the water level and to catch and measure water which overflows.

But this is found to take seven times as long as Reisig's method (Darmstadt, 1837) which employes a tank about $5\frac{1}{2}$ feet high and about twice as wide as the diameters of the largest sticks. The cross-section must be uniform at all points. The scale is worked out for cubic feet and decimals, corresponding to the inch scale in height of water in the tank and is either marked on the inside of the tank, or better on a stand pipe of glass outside the tank, with proper connection, and carefully plumbed. This gives instant readings when a piece is submerged. The endwise position favors complete submersion.

111. Cordwood Log Rules. The Humphrey Caliper Rule, 1882. Cordwood log rules are in use in Southern New Hampshire and in Massachusetts for measuring the cubic contents of white pine logs in terms of stacked cords and stacked cubic feet. These rules are based upon the principle of the circle inscribed in a square (§ 102). It is assumed that a cord, no matter what the diameter, length or character of the timber, contains 100.5 cubic feet of solid wood. The diameter is calipered in the middle of the log outside the bark, but the rule could be

[1] Stereometry, the art of measuring solid bodies. Stereos (Gr.) = solid.

[2] Xylos (Gr.) = water.

applied to peeled wood by subtracting diameter of bark. The old *Partridge rule* used at Winchendon, Mass., computes the stacked volume of the log as $(D^2)\frac{L}{12}$ with D = diameter in feet. Each " cubic foot " by this rule is $\frac{1}{128}$ cord. The rule is thus based on stacked contents, and fractional cords are reduced to decimals by the divisor 128; e.g., 64 " feet " would give .5 cord.

To simplify this process the cordwood caliper rule known as the *Humphrey Caliper*[1] *Rule*, was divided into $\frac{1}{100}$ of a cord; i.e., instead of measuring a stacked cubic foot the unit or $\frac{1}{100}$ cord equaled 1.28 stacked cubic feet. The scale stick for this rule was not marked off in inches, but for each standard length of stick the graduations representing diameter were placed at the points which gave logs measuring a certain even *volume* (§ 80). Hence no fractional stacked feet were shown.

Since by either rule, the cubic contents of a cord is given as 100.5 cubic feet, the Humphrey Rule by using the decimal system expressed the contents as $\frac{\text{cubic feet}}{100}$ within an error of but 0.5 per cent. The values of the rule thus correspond with those given for cubic contents of cylinders, but pointed off for two decimals.

If we accept the standard of 100 solid cubic feet of wood as the maximum contents of a cord, the Humphrey Caliper Rule measures wood of any character or degree of straightness, surface, roughness, length or diameter not only by a uniform standard of cubic contents (as does the Partridge Rule) but *directly in cubic feet, or in standard cubic contents.*

This rule therefore offers a double advantage. It is not only a cubic-foot standard, which is desirable for all scientific measurements of volume and growth, but it serves to standardize cord measure as well, on the basis of solid rather than stacked contents. The limitations in the use of the rule are the same as those of all caliper rules (§ 84). It cannot be applied to wood in the stack but only to pieces measured singly. Scale sticks made up for these values would enable measurements of cubic contents to be made directly for logs or trees to be used for volume tables or other scientific purposes and would do away with calculation of cubic contents. This rule is used as the principal commercial standard in the vicinity of Keene, New Hampshire. It can be made up by anyone on the basis of diameter by applying the cubic contents of cylinders given in Table LXXVII, Appendix C.

112. Discounting for Defect in Cord Measure. Pulpwood must be sound and free from rot or defective knots. Where logs of 8, 12 or 16 feet are measured by

[1] Invented by John Humphrey, Keene, N. H.

the cord, defective portions may be culled by subtracting from the total stacked volume, a piece whose volume is the square of the diameter in feet multiplied by length in feet. This deduction coincides with the basis of a standard cord of 100.5 solid cubic feet and is based on $\frac{1}{128}$ cord for each cubic foot subtracted. This method is the basis of the following table:

TABLE XXV*

MEASUREMENTS OF 4-FOOT ROUND SPRUCE PULPWOOD—WITH CULL FACTORS BASED ON SOLID CUBIC CONTENTS

Average diameter of stick. Inches	Solid contents of cord. Cubic feet	Sticks per cord. Number	Volume to be deducted for each stick culled. Cubic feet
3	75.0	375	0.34
4	79.8	228	.56
5	83.6	152	.84
6	86.1	109	1.16
7	87.7	82	1.56
8	89.6	64	2.00
9	90.3	51	2.51
10	91.6	42	3.08
11	92.4	35	3.66
12	93.3	29.7	4.27
13	94.1	25.5	5.02
14	95.0	22.1	5.87
15	95.8	19.6	6.67
16	96.5	17.1	7.71
17	97.0	15.4	8.59
18	97.4	13.7	9.70
19	97.9	12.4	10.76
20	98.3	11.3	12.06

* Prepared by H. L. Churchill for spruce in the Adirondack region, New York.

Where the contents of the cord are expressed directly in solid cubic feet, special tables can be worked up for deducting the actual cubic contents for sticks of given diameters.

The Humphrey Caliper Rule will serve to make deductions based on solid measure, by scaling the contents of the defective portion as a stick of a given length and diameter.

113. The Measurement of Bark. Bark, when used for tannin, is stripped off in sheets and piled in cords. At the factory a cord is measured by weight. Eastern hemlock bark must weigh 2240 pounds per cord, when dry.

The bark peelers are paid by the stacked cord measure, which is in some localities 4 by 4 by 8 feet but more often is required to be full in one or more dimensions, according to local specifications. In New York, the dimensions are

4 by 4 by 8 feet. In Upper Michigan, 4⅓ by 4⅓ by 8⅔ feet is sometimes required, in order that the cord shall check out in weight. Others stipulate 4⅓ by 4⅓ by 8 feet. In the West, hemlock bark is usually bought and sold by the standard cord, although weight per cord (2240 pounds) is sometimes used. Tan-bark oak is sold by weight.[1]

Bark forms the largest per cent of total volume in young, small and rapidly growing trees, exposed to light and growing on dry exposed sites. It gives the smallest per cent of total volume on old, large trees, grown in dense stands, and on slow growing or suppressed trees.

Measurement of bark in per cent of total volume of tree with bark, for the following species, show:

Species	Character	Per cent bark
Southern yellow pine species	2-inch trees	40
	Diminishing with increased diameter	30 to 15
Western yellow pine	12-inch trees	24
	Diminishing with increased diameter	24 to 12
Yellow poplar, or tulip	Diminishing with increased diameter	15 to 12
Ash	Diminishing with increased diameter	22.4 to 10.3
Hickory	Diminishing with increased diameter	22 to 12
Sugar maple	All diameters	Average 17
Cottonwood	All diameters	Average 22
Spruce, balsam, white pine, white birch	All diameters	Average 11 to 12½
Hemlock	All diameters	15 to 19
Lodgepole pine	All diameters	Average 6

The manufacturers of pulp, excelsior and products requiring peeled wood, when forced to purchase their raw material with bark on, soon determine the reduction factor required for their species and locality. The large and variable per cent of bark on loblolly pine in the South forces the purchaser of pulpwood stock to insist on peeling.

114. Factors for Converting Stacked Cords to Board Feet. Where the output of wood in a given region, or for a given tract or ownership is in the form of both cordwood and sawlogs, it is often desirable to reduce cordwood to terms of its equivalent in board feet, in order to express the total production in terms of a single standard. Less often, this conversion is desired as the basis of sale or contracts for logging. It is *not* the purpose of such conversion to determine the actual quantity of lumber which can be sawed from sticks of cordwood sizes and shapes.

[1] The standard cord in Oregon is 2300 pounds. The standard cord in California is 2400 pounds.

The board-foot contents of a stacked cord depends first on the solid cubic contents of the cord rather than its stacked measure, and second, on the diameter of the sticks which it contains (§ 54). Since solid contents *also* depends on diameter of stick, the ratio of board feet to *stacked* contents increases with diameter from both sources, or much faster for stacked than for cubic volume.

The diameter of the average stick is the determining factor in this ratio. The ratio itself will thus vary over a wide range depending on the class of wood handled. Crook and other irregularities of form have the same double effect as diameter, in reducing first the solid contents, and next, the board-foot contents per cubic foot of wood. The latter ratio can be determined for straight sticks by Table III (§ 41), Tiemann log rule, based on middle diameters, outside bark. For crooked sticks, a further reduction in ratio is required.

To obtain the true ratio for a given cord of straight wood, it is necessary to determine first, the converting factor for solid cubic contents, and second, the average diameter of the sticks, at middle point outside bark. By use of Table III the converting factor from cubic to board feet is found for logs or bolts of this average size, and this multiplied by solid cubic contents gives contents of the stacked cord in board feet.

But commercial log rules are based on diameter at small end and do not usually give actual sawed contents. For such rules the ratio can be approximated directly by determining the average diameter and number of sticks in a cord, and scaling their contents with a log rule.

The ratio for actual board-foot contents of cordwood diminishes to zero for sticks averaging from 3 to 4 inches in diameter, which is a common size for cordwood. If so determined, the converting factor is not an indication of the real volume or utility of the contents of a cord of wood. For a given species and class of cordwood an arbitrary converting factor can be obtained, based first on the per cent of solid cubic contents of a cord of sticks of average diameter and second, on an *average* or fair ratio between board feet and cubic feet, and *not* on the ratio for the actual small or irregular sizes. For instance, western juniper cordwood gives about 60 cubic feet per cord. Adopting a fairly low ratio of 46 per cent or 5.55 board feet per cubic foot of total solid contents, the board-foot converting factor is 60 times 5.55 or 333 board feet per cord, or 3 cords per 1000 board feet. For white pine, 100 cubic feet per cord, with nearly the same ratio, 5.5 board feet per cubic foot, gives 550 board feet per cord. The ratio of 500 board feet per cord adopted by the U. S. Forest Service for pulpwood gives 5.55 board feet per cubic foot for wood yielding 90 cubic feet per cord, which is a fair average for well-shaped sticks.

It would appear then that the factor 5.55 has some merits as a universal converting factor and that the variation of board-foot converting factors for entire cords should be based on the difference in *cubic contents* of the cord rather than by the adoption of variable ratios between board feet and cubic feet. This practice is sound. The factor 5.55 corresponds to the actual sawed contents of a log between 7 and 8 inches in diameter at middle of stick inside bark. The basis of this ratio is comparison between total cubic contents including taper, and actual sawed contents. Commercial log rules deal with reduced values for both cubic and sawed output, using the contents of the small cylinder for the one, and neglecting over-run in the other. These two reductions may not be of equal weight, but tend to give approximately equal ratios to those stated.

If the average diameter of logs exceed $7\frac{1}{2}$ inches at middle, inside bark, the actual ratio is correspondingly larger. Only in this way can ratios as high as 575 board feet per cord, used on the Pacific Coast, be obtained. The ratio in New England for pulp wood is 560 board feet.[1]

115. Weight as a Measure of Cordwood. For fuel, weight is a better measure of the value of cordwood than solid cubic volume, and of still greater utility for the measurement of stacked volume. Its merits increase with the increasing irregularity of form in sticks which render the determination of solid contents of stacks so uncertain. But one factor operates against the substitution of weight for stacked measure, for fuel wood, and that is the unfamiliarity of the public with the proper standard weights which should constitute a cord. This is due first to the great variation in weight between wood of different species, a variation which would be equalized as to *price* if equal weights regardless of bulk commanded approximately the same price, and second, to the great difference in weight between green and air-dried wood. If sold by weight, dealers would endeavor to sell the wood as green as possible. Green wood has less net fuel value per pound, not only because the purchaser pays for water instead of net dry weight, but also because each pound of dry wood has to generate heat enough to vaporize all the water in the wood and only the surplus heat is given off.

But for dead dry juniper or pinon or mesquite roots or for well-seasoned woods difficult to measure in bulk, weight is practically the universal standard. Dealers customarily deliver from 200 to 400 pounds less of weight per cord than the actual weight of an average cord of such wood. For instance, pinon should weigh 3000 pounds per cord, but it is often sold at 2000 pounds per cord. It would be better to substitute weight altogether and not maintain the pretense of delivering a cord by measure. This would place the dry wood on the same basis as coal.

Air-dried wood still contains from 15 to 20 per cent moisture. The variation in per cent of water in green wood compared with dry wood is extreme, as illustrated by Table LXXXIII (Appendix C).

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[1] In Forest Mensuration of White Pine in Massachusetts, p. 45, ratios for white pine 1-inch lumber are given, running from 488 board feet for 5-inch logs to 730 board feet for 24-inch logs, measured at middle of log *outside bark*.

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PART II

THE MEASUREMENT OF STANDING TIMBER

CHAPTER X

UNITS OF MEASUREMENT FOR STANDING TIMBER

116. Board Feet—Basis of Application. The value of standing timber must be determined as a basis for sale either of the timber alone, or of the land and the timber. This value depends upon the quantity of wood which may be cut from the tract, but still more upon its value per unit of volume. As set forth in Part I, the contents of logs and trees in North America are expressed, whenever possible, in terms of the final products instead of by cubic volume as in Europe. Standing timber, therefore, is commonly measured in terms of board feet, cords, or pieces such as poles, piles or railroad ties and is rarely expressed as cubic feet, since it is seldom sold on that basis. If estimated by cubic feet, the contents are usually converted into their equivalent in cords.

When the board-foot unit is used in timber estimating, the basis of determining the contents of the standing timber must be identical with that on which the timber is to be sold when cut.

If manufactured on the tract by small portable mills, the actual sawed output in lumber, the mill cut, furnishes this basis. When round-edged lumber is sawed and small trees utilized to a small top diameter (§ 21) the yield in board measure may be 100 per cent greater than when the "sawlog"-sized timber only is merchantable, as in large logging operations.

When scaled and sold in the log, the estimated contents of the stand, before cutting, should coincide, not with the sawed output, but with the log scale. Since different log rules give different scaled contents for the same logs, the estimate must be based upon the log rule which will be used to scale the logs. Hence an estimate made on the basis of the Doyle rule will differ from one based on the Scribner rule or the International rule. In all large logging operations where the logs are transported some distance to the mill, timber is estimated solely on the basis of the standard log rule in use.

Local log rules based on mill tallies may be substituted for the sawed product as the basis of estimating timber on small tracts.

No such difficulties affect the estimating of timber in terms of cubic units or cords, which include the entire contents of all trees within the merchantable limits of size, up to the merchantable limit in the tops.

117. The Piece. Poles or piling usually comprise the entire merchantable portion of the trees which produce them, but can only be cut from trees having the specified dimensions. Familiarity with these specifications enables the cruiser to count the number of pieces in the stand, and to tally them in separate classes. The same method may be used in estimating standard railroad ties, but in this case the number of ties in each tree must be counted separately in accordance with the five standard grades (Appendix B, § 369). Where the tree is large enough to produce more than one standard tie from a single 8- or $8\frac{1}{2}$-foot length, the cruiser must rely either on his knowledge of the contents of the bolt in ties, or refer to a volume table for piece products (§ 162). He gets the total tie count for the tree by adding the contents of each separate bolt, up to a point where the diameter is too small to produce another standard tie. Posts are counted in the same way but, owing to their smaller value and greater number, the count is usually more or less of an approximation. The same system may be used, if required, in estimating the quantity of mine timbers and mine ties in a stand. Products such as stave bolts, which demand a high quality of timber practically free from knots and all forms of defect, and are of small size, introduce two features common to estimating in board feet, namely, a table of volumes, and discounts for cull. Stave timber for staves of given sizes may be estimated by knowing how many staves may be cut from bolts of given dimensions. The number and size of the cuts in each tree will give their sound contents, from which are deducted all visible defects. A liberal allowance is also made for invisible defects in the interior of the tree.

Since only a portion of a stand is converted into these forms of product, the estimating of piece products may be only a part of a general estimate in which the remainder of the stand is measured either for logs or for cordwood.

118. Choice of Units in Estimating Timber. Methods of timber estimating are determined by the cruiser's choice as to whether he will deal directly with one of four units, namely, the stand as a whole, the individual tree, the individual log, or the piece (§ 117). Any one of the first three methods may be used when the volume of the stand is expressed in terms of cubic units, or in board feet. If the tree or log is not used, the stand is considered as a whole and a direct guess or estimate is made of its total contents (§ 206). If the tree or the log is used, the method requires a count and tally by different sizes, and gives rise to many systems of estimating, depending on whether the entire area or only a portion of it is to be counted.

119. The Log as the Unit in Estimating. When the product to be estimated in board feet is lumber, the log becomes a convenient and much used unit for estimating. Lumber is measured or scaled in the log by a given log rule. The contents is given for logs according to their diameter inside bark at small end, and length. Hence a tally of the top diameter inside bark and the length of each log in a tree, and the use of a log rule, will give the board-foot contents of the tree. If every log is so tallied the stand is measured by merely totaling the contents of the logs, without computing the volume of separate trees.

No further volume basis is needed in this method than the log rule or scale stick. But the cruiser must know the amount of taper in each log, the thickness of bark to be deducted, and the log length to use in estimating.

Log lengths as actually cut are determined by the crooks and other peculiarities of each tree. But in estimating timber, these variable log lengths are disregarded and a uniform or standard length is adopted which conforms within reasonable limits to the average log length most frequently used. For eastern conifers this is 16 feet, while hardwoods may require 12 feet. On the Pacific Coast, 32 feet is used by many cruisers. If logs when cut average shorter than the standard, the scaled contents of the logs will over-run the estimate, while if longer logs are cut, the scale will fall short (§ 83).

The method of tallying the logs in a tree is as follows:

1. Estimate or measure the diameter of the butt log either at the stump, at $4\frac{1}{2}$ feet from the ground, or at 1 foot above the butt swell, choosing one of these methods to the exclusion of the others. Foresters use $4\frac{1}{2}$ feet as the accepted standard.

2. Deduct the double thickness of bark to obtain the diameter, inside bark, at this point.

3. Estimate the number of inches to deduct from this diameter for taper, to obtain the diameter at the top of the first log of standard length. This and all upper estimates of diameter are inside the bark.

4. Estimate by eye the number of standard logs in the tree, to the limit of merchantable size. The top diameter at this point should be known or estimated, inside bark.

5. From the diameter of the top of the first log, inside bark, deduct successively the estimated taper, in inches, to obtain the diameter of each remaining log.

An alternate plan frequently used is to measure the diameter outside bark at the butt, or at $4\frac{1}{2}$ feet, subtract the taper outside bark for the first log, and then subtract the estimated thickness of bark at this point, or at the top of the first log instead of at the butt.

A third plan is to estimate directly the diameter, minus bark, at the top of the first log, without measuring the butt. Or, a table may be prepared showing diameter, inside bark, at the top of the first log, for trees of different diameters at $4\frac{1}{2}$ feet.

Each of these plans aims to secure the diameter, inside bark, at the top of the butt log as the basis from which to figure the top diameters of the remaining logs.

The eye may be trained to estimate log lengths and taper by the use of a pole with a cross-piece at the top, marked off in inches. The length of pole (about 12 feet) permits holding the cross-piece at the height of the top of the first log plus an allowance for height of stump. By comparison with this measured length, the number of logs in the upper bole may be estimated by eye. By measuring the tree at $4\frac{1}{2}$ feet, and reading the cross-arm, the taper, in inches, for the butt log is shown. Bark thickness is then subtracted as determined for the species by observation on felled trees or logs. This varies for the top of the butt log, from 2 inches to 1 inch for most species. The total number of logs, to the limit of merchantable diameter, gives the total taper to that point. If 6 inches is the merchantable limit, this diameter, subtracted from that of the top of the butt log inside bark, indicates the taper to be distributed between the upper logs. Bearing in mind the tendency to more rapid taper in the crown, the actual taper of each log can be approximated with reasonable accuracy and its diameter inside bark recorded. Two men usually work together in this practice, or in training. One man may use the method if the pole is made long enough to be leaned against the tree (17 to 18 feet), while he gets far enough off to judge its height.

This method assumes that the eye can be trained to judge diameters to an inch, at varying distances and heights above ground. But in timber estimating only the general character of the tree is noted, and its total height, or the number of standard-length logs. The taper of the successive logs is obtained from measuring the diameters of felled or wind-thrown trees of the same character as the standing timber. The taper for a 16-foot log may vary from 1 to 10 inches or even more, depending on site, density of stand, butt diameter, and position of the log in the tree.

Many cruisers assume that once the difference in diameter between the top of the second and the first log is ascertained or assumed, each successive upper log will have an equal taper, giving to the tree a uniform taper per log of 2, 3 or more inches. They know that the butt log will taper more rapidly than the second log, but the above practice ignores the taper of the butt log.

They also know that as soon as the green crown is encountered, the taper per log again increases. But in regions where rough logs in the crown are seldom utilized, this assumption of a uniform taper for the second and higher logs in the bole is approximately correct.

Where greater accuracy is sought, and especially, where the diameter of the tree is measured at $4\frac{1}{2}$ feet rather than guessed at, tables may be compiled from the actual measurement of the upper diameters of felled trees which show the average taper for each log, for trees of given diameter and height, and with the width of bark actually measured and deducted for the top of the butt log. These tables will enable the cruiser to tally the sizes of his logs without relying on his eye for more than the determination of total height or number of logs.

Log grades (§ 87), when used in timber estimating, require the tally of the top diameter of the logs, separated into grades. This permits of the separate totaling of volume in each log grade on the tract.

120. Log Run or Average Log Method. The tallying of the actual size of every log on a tract is so slow and expensive that it is possible only when the timber is large and scattered. Woodsmen, who use the log as the unit of estimating, do not usually tally any sizes but obtain the total number of logs on the area by five steps, namely:

1. A count of the trees.

2. Decision as to the average number of logs per tree. This may be in halves or even quarters, as $3\frac{1}{4}$ logs per tree, referring of course to the standard length adopted for estimating.

3. The board-foot contents of an average log.

The last point is based on familiarity with the results of scaling logs cut from similar timber, and the cruiser expresses it in terms of " log run " or number of logs required to scale 1000 board-feet of lumber, as illustrated by the following figures:

Log Run.	Contents of Average Log.
2 per 1000 board feet.	500 board feet.
5 per 1000 board feet.	200 board feet.
10 per 1000 board feet.	100 board feet.
20 per 1000 board feet.	50 board feet.
40 per 1000 board feet.	25 board feet.

The " log run " increases as the average log content diminishes. Knowing the log run, or guessing at it, the estimate in board feet is obtained by:

4. Multiplying the total number of trees by the number of logs per tree.

5. Dividing the total number of logs by the log run or number of logs in 1000 board feet of lumber.

This method was used by many old-time cruisers in the Lake States region to the exclusion of all others. When old and young, or large and small timber is found on the same tract, separate classes are usually made in the count.

121. The Tree as a Unit in Estimating. Volume Tables. The necessity for combined speed and accuracy to reduce the cost and increase the reliability of timber estimates has led to the almost universal substitution of the tree unit for the log unit. Instead of entering the size of each log separately, the dimensions of the entire tree are noted.

This requires that the volume of entire trees of the sizes tallied be previously known. The sum of the volume of the logs which they contain gives this information. A table, in which the *average* volume of trees of given sizes is shown, is termed a *volume table,* in contrast to a log rule or log table, which gives only the contents of single logs and never that of entire trees.

To avoid confusion in these terms, it should be noted that the standard definitions are:

For a log-volume table—the term, Log Rule.

For a tree-volume table—the term, Volume Table.

The latter term should never be used by foresters to mean the contents of logs, although the term log table may be used. The term " volume table " always refers to the volume of trees, being substituted for the longer descriptive term, Tree-volume Table.

Timber cruisers were slow to see the advantage of thus tabulating or summing up the total volumes of trees in systematic form. They either adhered to the log basis, or in the instances when they used the tree volume as a unit, merely calculated this for " average " trees by mentally summing up the contents of the logs in individual trees, and from the general knowledge thus obtained, assuming that trees in a given stand averaged or " ran " a certain volume per tree. This method was universally used in the South, where the Doyle rule readily lent itself to quick mental computations of the contents of 16-foot logs (subtract 4 inches from the diameter inside bark, and square the remainder for board-foot contents of log, § 65). The total count of trees, multiplied by the average contents per tree, gave the estimate.

122. Volume Tables Based on Standard Tapers per Log. " Universal " Volume Tables. In the Pacific Northwest, the great height of the trees and consequent large number of logs in each tree, and the relatively few trees per acre, each with a large volume, soon brought a realization of the need for substituting the tree unit for the log. The difficulty of mentally computing the contents of trees varying so widely in volume forced the use of the volume table, in which was recorded the total volumes of trees of all sizes. These cruisers' volume tables, of which several have been constructed, are, in most instances, based on the principle of uniform taper per log, varying from 2 to 10 inches. The contents of successive logs, as scaled by the accepted log rule, diminishing in top diameter by the indicated taper, are totaled, and the sum taken as the volume of the tree. These computations do not require the measurement of the tree but are performed in the office from the log rule.

The volumes in such a table are the scaled contents of logs by a given log rule, and will apply only to regions where this same log rule is used. But it is a simple matter to compute a new table for any other log rule, by the same method, since no field work is required. Wherever the log rule is the standard, such a table is applied to all species, types and character of trees, and in this sense is universal. The assumption underlying such a table is that the merchantable portion of all trees have the shape of the frustums of cones, hence the determination of the three factors, average taper per log, diameter at top of first log, and number of logs in the tree, determine the scaled contents of the tree as given in the table. As shown below, the assumption is not correct.

In applying this table, these cruisers seldom attempt to tally the dimensions of each tree. The trees are counted, separately by species, and also by classes, as large, medium or small. Then the *average* diameter, average number of logs per tree, and average taper per log is decided on usually by guess or by judgment. The volume table merely serves to give the assumed volume of a tree of this diameter, height and taper. The estimate or total for the species is obtained by multiplying this volume by the tree count.

The advantages of obtaining a universal and elastic volume table, applicable to any species, region and character of timbers are self-evident. The defects in uniform or universal volume tables based on the frustums of cones are:

1. The form of the average tree of any species, when the merchantable portion only is considered, resembles more nearly the frustum of a paraboloid than that of a cone (§ 26). While the merchantable portion may be treated as the frustum of a cone, yet investigation shows that the average volume of trees of different species and diameters is usually either less or greater than that assumed by the table. This possible error is consistently neglected.

2. For accurate application, the universal table requires the determination of three dimensions for every tree whose volume is to be ascertained, namely, diameter, height and taper. A tally of every tree by diameter and height is possible, but the separation of a third factor, tree by tree, makes the tally too complicated, and requires the substitution of average tapers for a species, or for groups of diameters as indicated above. But the trees in any given stand or area never taper uniformly. The larger trees have the greater taper. Those growing in dense stands have the least. No average can be found which will apply even to the trees of one diameter class, much less to trees of all classes. The assumption of a definite taper for the trees on a plot will tend to over-estimate the volume of trees larger than the selected average tree, and under-estimate those of small diameter. Whether these errors balance depends more on luck than on skill.

3. The use of such a table presupposes the system of counting rather than of tallying each tree, and assumes the risk of error in selecting, largely by eye, an average tree which, when multiplied by the count, will give the approximate estimate. It does not lend itself to an accurate inventory of the timber, tree by tree, in which the diameter and merchantable length of each tree is recorded.

4. Since such tables assume that upper diameters differ by gradations of 1 inch per log, a 4-log tree will show top diameters in the table differing by 4-inch classes,

while the average taper may be somewhere between these limits and the volume be given incorrectly by either the upper or lower class. A tree 20 inches at the top of the first log will be classed as having a taper per log of 1 inch, 2 inches or 3 inches. At the top of the fourth log, the first tree will measure 17 inches, the second tree, 14 inches, and the third, 11 inches. The actual average top diameter may fall at 12 inches or at 15 inches.

123. Substitution of Mill Factor for Log Rules in Universal Tables. In the above tables, the contents of the logs are determined by the standard log rule used in scaling. Dr. C. A. Schenck substituted what is termed the mill factor for the log rule, thus basing the volume of the tree upon the sawed output (§ 116). Assuming, as a basis, that the cubic contents of the cylinder measured at the small end of the log, when multiplied by 12, gives the maximum board-foot contents (§ 12), the waste for slabbing, edging and saw kerf, independent of taper, which is not considered, will reduce this output to from 8 to 5 board feet per cubic foot. The per cents of cubic contents of the cylinder based on small end of log, which these mill factors represent are:

Mill factor	Cubic contents. Per cent	Scaled contents of nearest equivalent log rule (Table II, § 38). Per cent
8	$66\frac{2}{3}$	Vermont (63.4)
7	$58\frac{1}{3}$	Calcasieu (57.8)
6	50	Orange River (50.9)
5	$41\frac{2}{3}$	Delaware (42.4)

An example of these mill-factor tables is given on page 147, for logs 16 feet long:

To determine these values the volume in cubic feet of the cylinder was multiplied by 5, 6, 7 and 8 respectively. These tables give the cruiser the opportunity to substitute a fixed per cent of utilization, as indicated above, for a log rule. The other three variables remain the same, namely, diameter, number of logs and rate of taper per log.

It is assumed that the mill factor can be chosen to suit the local conditions of milling, the factor 8 or $66\frac{2}{3}$ per cent representing the use of band saws in large mills, while the factor 5 approximates the conditions in small local circular-saw hardwood mills, thus making the cruiser independent of log rules. This apparent advantage is nullified by two serious defects: First, the taper of the log is neglected, and this frequently produces a mill factor of 10 for large logs. Second, the board-foot contents is assumed to vary directly as the cubic contents, so that the tables force the use of log rules based on cubic rather than sawed products and introduce the errors of this method. Mill factors increase directly with the average diameter of the log independent of mill practice. It is not sufficient merely to know the general character of the milling, but the sizes of the timber must also be known. An average mill factor based on both of these variables may be seriously in error and the use of different mill factors for logs or trees of different sizes is apparently necessary to secure accuracy. The use of these tables is therefore not as satisfactory as their apparent simplicity seems to indicate.

TABLE XXVI

A PORTION OF A VOLUME TABLE BASED ON MILL FACTORS

Trees measuring 9 inches at top of first 16-foot log, inside bark

16-foot logs	Mill factor	Taper per Log			
		1 inch	2 inches	3 inches	4 inches
		Board feet			
1	5	31	31	31	31
	6	37	37	37	37
	7	43	43	43	43
	8	57	57	57	57
2	5	55	49	45	40
	6	66	59	54	48
	7	77	69	62	57
	8	89	79	71	65
3	5	74	59	..	..
	6	89	71	..	..
	7	104	83	..	..
	8	118	95	..	..

124. Volume Tables Based on Actual Volumes of Trees. Volume tables as used by foresters are based on the measurement of the actual contents of entire trees, and not upon assumed regular taper or conical form. The tree contents or volume table may give,

- Entire cubic contents of stem, with bark, or without bark.
- Merchantable cubic contents of stem, or of stem and larger branches, with or without bark.
- Merchantable contents of stem in terms of
  - Board feet
    - By a given log rule.
    - By mill tally, under given conditions of sawing.
  - Other units, such as
    - Standard cross ties.
    - Poles, or posts.
    - Staves or headings.
  - Cords, usually converted from cubic feet.

Combination Volume Tables giving the merchantable volume in
Ties, and residual cords.
Board feet, and residual cords and other combinations.

Graded Volume Tables, giving the volume in
Board feet, by lumber grades.
Logs, by log grades.

The use of the last-named type has not yet been attempted.

Volume tables of this character make possible the tallying of every tree, eliminate the risk of averaging the dimensions or volume of trees counted, and require of the cruiser only the recording of diameters and of heights, and discounts for defect.

Since trees vary so widely in form, height and taper, and the table is implicitly relied on to give correctly the variable volumes caused by these factors, without measuring the taper, the use of such tables and their reliability or accuracy must be thoroughly understood, or it may easily lead to errors of greater magnitude than those incurred by an experienced cruiser using the universal "taper" table for volumes (§ 149).

The greatest drawback in the use of specific volume tables is the number of tables required, and the cost of their preparation. Species may differ from each other in form or bark thickness, so as to require separate volume tables. Substitution of a table made for one species for use with a different species is justifiable only when research has shown the two species to possess the same bark thickness and average form.

Tables made for one unit of measure, or even for a given log rule are not serviceable for a different unit or log rule. Tables of merchantable volume, accurate for a given standard of tree utilization, become obsolete when a closer standard is adopted. For these reasons, and owing to the great number of species, range of conditions, difference in log rules, and variety of products, the cruiser entering a new region is usually confronted with a lack of tables, and is driven to adopt either the universal taper system, or the log, as his means of estimating volumes. The adoption of a universal cubic-foot basis for volume would greatly simplify the problem of volume tables.

125. The Point of Measurement of Diameters in Volume Tables. Either of the above types of volume table shows volumes for trees of given diameters and heights. The diameter must be measured near the base of the tree, where it can be reached with calipers or tape. But there is no regularity about the flare of the butts of trees, for this is determined by exposure to wind strain, by the size of the bole, the site and the species. Butt swelling increases more rapidly with age than does the diameter of the bole, so that the older and larger the tree, the more pronounced this swelling, and the further it extends up the trunk. Tree volumes must be averaged on the basis of their diameter in inches. If this diameter is taken at some point on the butt swelling, a tree with a rapid butt swelling will have a far smaller volume than one of the same stump diameter and a gradual swelling, as is illustrated in Fig. 24 by trees A and B. But if these diameters were taken at a point above the butt swelling the two trees would properly fall into different classes. Since it is necessary to put in a single class trees whose volumes are as nearly similar as possible (trees A and C), the practice of classifying these trees by their diameter on the stump is inaccurate. The height of stump itself is also a variable. Tables

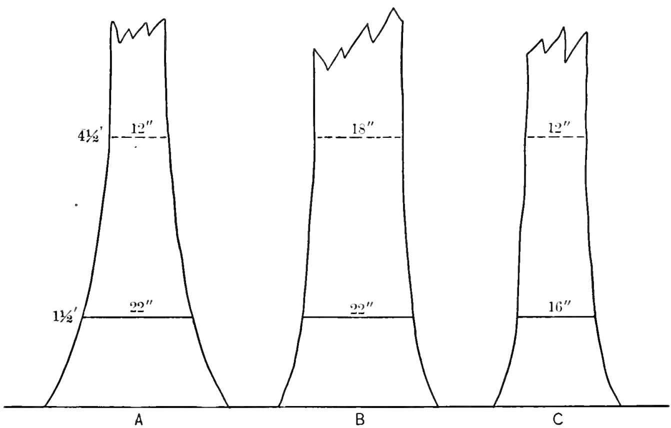

Fig. 24.—Comparison of stump height and breast height as points of measurement to determine the diameter of standing trees.

based upon "diameter at the stump," which do not indicate at what height this diameter is measured, are difficult to apply and unreliable.

For very large trees with excessive butt swelling such as cypress, or many West Coast species, the diameter classes should be based upon measurements taken above this swelling. A standard form of universal table used on the Pacific Coast is based on a butt measurement to be taken 1 foot above the point where the butt swelling ceases. The disadvantage of measuring at a variable height is considered as offset by the merit of avoiding this variable factor of butt swelling. In cypress, one typical table was based on diameter at 20 feet from the ground and cruisers customarily estimate cypress trees from the diameter obtained above the butt swelling.

For most species, the point $4\frac{1}{2}$ feet above ground has been accepted by foresters for measurement of diameter as it falls above the swelling and at a convenient height for use of calipers. This height is also used in England and India. In Continental Europe, 1.3 meters, or 4.3 feet, is the standard height.

This measurement at $4\frac{1}{2}$ feet is termed diameter breast high, and is abbreviated both in speech and record to *D.B.H.* Measurement outside bark is always indicated by the abbreviation.

In the Philippines and other tropical countries it will be impossible to use a similar height for many species owing to the development of buttresses on the trunks. Such species will probably have to be measured either above the flare, or at a height of 16 to 20 feet, by eye, using the $4\frac{1}{2}$ foot standard point only for species and types which permit it.

Where D.B.H. is adhered to for species like Western larch, red cedar or Douglas fir on the Pacific Coast, butt swelling greatly interferes with the uniformity of the volumes for these species for trees of given diameters when compared with other species like western yellow pine whose swelling seldom reaches this height. This apparent difference in volume may be from 20 to 40 per cent in favor of the pine.

126. Bark as Affecting Diameter in Volume Tables. For species whose bark is of uniform thickness for trees of the same D.B.H., the diameter taken outside the bark is preferable as a standard of classification to diameter inside the bark. The cruiser has no time to measure bark thickness except on occasional test trees. The width of bark, however, is seldom uniform. For trees of the same diameter, it is thickest on exposed and on rapidly growing trees, and thinnest on sheltered, crowded and slow-growing or suppressed trees (§ 113). The larger the trees, the greater the actual thickness of bark, and the wider the possible variation in thickness. This thickness may range from 2 to 5 inches and over, on West Coast species. Volume tables based on diameter *inside* bark, therefore, are more consistent and accurate as tables, than those based on outside bark measurement.

But this would require the tallyman to throw off the double width of bark from every tree tallied. The experienced cruiser, who deals with single average trees only, can from his experience throw off the proper average width of bark for the selected tree, increasing the deduction for open and exposed situations and vice versa. There is no such choice in the tally of every tree. The mistakes made in mental arithmetic and the errors in guessing the proper width of bark to allow would be more serious than discrepancies in the table. In practice, then, D.B.H. would have to be recorded and average bark thickness afterwards deducted previous to computing the volume.

Species with thick bark will show a smaller volume for the same diameters than those with thin bark, because of taking the diameter on the bark surface and not on the wood. Individual trees with thick bark will give correspondingly less volume than the average for the diameter class shown in the table. Timber on exposed sites will be over-estimated by tables based on diameter outside bark unless constructed locally for the same sites. Width of bark, therefore, is a cause of variation in the attempted standardization of volume by diameter classes, which is eliminated in the universal tables when these are based on diameter inside bark, at either top of log, D.B.H., or stump.

127. Classification of Trees by Diameter. Standard volume tables are commonly based on D.B.H. outside bark. The actual diameter of trees can be measured as closely as the nearest $\frac{1}{10}$-inch. The average of two measurements taken at right angles is considered the diameter of the tree.

For felled trees whose volume is to be measured in the construction of volume tables, the diameters are recorded to the nearest actual $\frac{1}{10}$-inch. But these volumes are classified later by 1-inch, or 2-inch classes. One-inch classes have been adopted as standard for Eastern species, while in the West, owing to the greater range of diameters encountered, 2-inch classes are deemed sufficient. Each 1-inch class includes all trees whose average D.B.H. is above .5 in the inch below, and .5 and under in the given inch class; e.g., the 9-inch class includes trees measuring 8.6 to 9.5 inches. In 2-inch classes, the even inch is used. A 10-inch class would include trees measuring 9.1 to 11.0 inches.

128. Classification of Trees by Height. Height is never used as the sole basis of tree classes; diameter is the fundamental basis of classification. But height exerts an enormous influence on the volumes of trees of the same D.B.H., the extreme difference in volumes for different heights being more than 100 per cent. These differences in height and volume for trees of the same diameters occur in stands of different density, growing on different qualities of site, or at different altitudes. They correspond with differences in the average taper per log, as distinguished in universal volume tables.

It follows that the separation of trees of a given diameter class into several height classes previous to averaging their volumes is another way of distinguishing between trees of gradual and of rapid taper, and that if enough of these height classes are made, the differences in volume due to more or less rapid taper are distinguished even more accurately than by introducing taper as a factor in the table. The height, rather than any arbitrary amount of taper, is the real basis of classification, and the actual average volume, rather than an assumed volume, is then expressed in the table. The rate of taper for trees in different height classes within any diameter class, as 20 inches D.B.H., need not be shown in such tables. If measured, it will be found to differ by arbitrary fractions of inches instead of by exact 1-inch classes per standard log.

Height classes may be based on total height, or on the length of the merchantable bole. In the former case, height classes are based on either 5- or 10-foot gradations, using the same system of rounding off as for diameters, e.g., the 70-foot height class with 10-foot gradations includes all trees 66 to 75 feet in height. With 5-foot gradations, it includes trees 68 to 72 feet in height. When merchantable heights are used, these lengths are commonly standardized to conform to a common log length such as 16 feet and expressed as 1, 2, 3 or more log trees. The log length used is always stated. Half-log lengths may be differentiated. With valuable hardwoods of variable merchantable length, there is some need for closer classification of merchantable lengths, but volume tables are seldom constructed for intervals of less than 8 feet.

129. Diameter Alone, Versus Diameter and Height, as Basis of Volume Tables. To separate or classify the volumes of trees of each given diameter class into from 4 to 10 height classes requires the measurement of from 250 to 1000 trees, in order that the average volume in each of these numerous classes may be found with some accuracy (§ 137). This makes it impossible to take the time to construct such tables for local or immediate use. Hence many volume tables have been based on diameter alone, averaging together trees of all heights. Sometimes the average heights of the trees of each diameter class are shown, often they are omitted.

For timber of uniform age and density of stand and growing on the same quality of site, individual trees of the same diameter will still differ considerably in height and volume; yet an average height for each diameter may be found, which will indicate quite closely the average volume for that particular stand or type and age class. But such a volume table is quite worthless for application to any other stand, age class or type, unless it can first be shown that the average heights based on diameter are the same in both cases. Lacking, first, the knowledge of the average heights used in the table, and second, the demonstration that these coincide with those of the stand to be estimated, the only possible procedure is the preparation of an entirely new volume table.

But with a table based on a classification of heights and corresponding volumes under each diameter class, stands of any degree of density or age, and growing on any site, may be estimated by use of this table, if the volumes taken from the table are those for heights corresponding to the trees in the stand.

130. Standard Versus Local Volume Tables. Volume Tables based on both diameter and height classes, in whose construction from 500 to several thousand trees have been used, selected from as wide a range of sites and locations as possible, are termed *Standard Volume Tables,* while those based on diameter, either alone or with the average height of trees of each diameter class stated, and applicable only to a given stand or site, are known as *Local Volume Tables.*

It follows that local volume tables applicable to any stand, age or site can be derived from the values given in a standard volume table and can be expressed on the basis of diameter alone by first determining, for the stand, the average height to use for each diameter class.

Classification by both diameter and by height is not sufficient to secure complete accuracy in volume tables because of differences in average form (§ 166). But such tables, well constructed, are vastly more accurate than any universal table based on uniform tapers, or frustums of cones, and are known to apply with almost the same degree of accuracy throughout the entire range of a species. Greater variation in form and volume of stand is caused by differences in soil, exposure and density in a restricted locality than by a thousand miles difference in location.

CHAPTER XI

THE CONSTRUCTION OF STANDARD VOLUME TABLES FOR TOTAL CUBIC CONTENTS

131. Steps in Construction of a Standard Volume Table. The steps in the construction of a standard volume table, whether for total cubic contents, or for any form of product, are practically the same. They are:

1. Selection of felled trees in sufficient number, and representing the complete range of diameter and height classes of the species or locality.
2. Measurement of each tree to secure all the data needed for the construction of the volume table.
3. Computation of volume of each tree.
4. Classification of tree volumes according to diameter and height classes.
5. Averaging the volumes of trees of each separate diameter and height class.
6. Elimination of irregularities in final table by graphic plotting and curves.

132. Selection of Trees for Measurement. As only felled trees can be measured with the accuracy needed for construction of volume tables, the choice is presented of utilizing timber already felled, either by wind, or by loggers, or of felling the trees for measurement. Windfallen trees are usually of the larger sizes, and scattered individually or in groups, and are measured more as a check on rough methods of estimating than in the systematic construction of tables. A logging job presents the opportunity to secure trees of all diameters except those below merchantable size. The operation may be too local in extent to embrace the extreme forms desired, and a standard table covering the extremes of diameters and complete range of heights should be based on trees cut from several different operations covering the range of altitude and soil qualities for the species or type.

The influence of soil, altitude, age and other factors upon the form of trees of the same diameter and height class is discussed in Chapter XVI. When it can be shown that differences in volume can be correlated with age, or site, separate standard tables may be constructed for trees of the specified classes or sites. In this case, the same principle of securing as wide a range of diameter and height classes as possible, by distributing the selection of the trees, applies within the limits of the predetermined region, type or age class.

The number of trees necessary to secure a good basis for a volume table increases with the range of diameter and height. Ten trees in each separate diameter and height class will suffice, and only in a few standard tables has this number been secured. This would call for a total of 500 to 2500 trees. Ordinarily, a sufficient number of trees is easily obtained for the smaller and more common diameter and height groups, but the material becomes scarce as the larger sizes are reached. The graphic methods of averaging are chiefly useful in overcoming this deficiency (§ 138). The use of form factors also facilitates the construction of tables from fewer trees (§ 175). Standard tables, computed by averaging the volumes of trees by the method given in this chapter should be based on at least 300 trees, and if used as a general reference table should never have less than 500 and preferably over 1000 trees. Local tables based on diameter alone can be made from 10 to 50 trees. It is desirable to tabulate the number of trees measured in each diameter and height class in the field as the work progresses, and to make a special effort to find trees of the less numerous sizes to fill out the table. On the other hand, the more common sizes should be represented by somewhat greater numbers of trees in the table than odd sizes, as errors in the table affect the results of estimating in proportion to the per cent of volume of the stand which falls in the specified classes.

To secure trees of smaller sizes than are considered merchantable by loggers, in order to show total cubic contents for these classes, or contents in terms of smaller products not being utilized in that locality, the trees may be felled by the mensuration crew. This must be done for all sizes in absence of logging, but it adds greatly to the time and cost of the work.

133. The Tree Record. The data for each tree must be entered on a separate blank, or printed form, and headed by the items,

Species,
Locality,
Date,
Name of investigator,
Number of analysis.

Records should be carefully filled in with legible figures, using a 4H or 6H pencil. They constitute permanent records of tree form and may be available for use in compiling data many years afterward.

Description of site factors are useful in determining their influence, if any, on the form and volume of trees of the same diameter and height.

These are,

Soil, origin, whether sedimentary or residual.

Depth, rock, physical character, sand, etc.

Exposure and slope.

Altitude.

Forest type.

Character and density of stand.

These items involve considerable repetition and are often omitted, or may be written up for groups of trees. But if the material is to be used for investigations, to determine the effect of site factors on form, each tree analysis should be associated with a complete description covering the points enumerated.

134. Measurements of the Tree Required for Classification. The measurements of the felled tree must be taken before the logs are removed by skidding. These may be divided according to their purpose into those needed to

1. Classify the tree by dimensions and character.
2. Obtain the volume of the stem and branches.

The first class of measurements consists of D.B.H., height of stump, total height, crown and bole. The D.B.H. (§ 125) is the most important measurement taken. This point must be located on the butt log of felled trees, unless the D.B.H. has been taken in advance of felling the tree. To the stump height is added the additional height needed to equal $4\frac{1}{2}$ feet, which is measured upon the butt log. If the butt cut is slanting, care is taken to measure from the same point on the log as on the stump, thus reproducing the measurement which would be taken on the standing tree—otherwise a slight error is incurred. The D.B.H. and all other measurements of diameter are taken in two directions, at right angles. This is always possible on the felled trees as shown in Fig. 25.

The average of these two diameters is obtained and recorded to the nearest $\frac{1}{10}$-inch, and is never rounded off to the nearest inch.

The *height of stump* is taken not only to obtain D.B.H. on felled trees, but as a basis from which merchantable length and contents is figured (Chapter XII). It is recorded in feet and tenths, or in feet and inches. Stump height is measured vertically from the root collar or point of contact with the ground, and at the average height of this collar. On side hills, this point occurs half way between the upper and lower sides of the stump.

The *total height* of every tree measured for volume should be recorded, whether or not it is to be used as a basis of height classification (§ 137). The most accurate method is to stretch a steel tape from the butt to tip of crown, along the stem, although a pole graduated in feet is sometimes substituted. To this height the stump height is added, and the total recorded to the nearest foot. The height of a rounded or irregular crown is measured to a line drawn at right angles to the bole, and tangent to the highest point of crown. Height may also be obtained by adding together the lengths of the separate sections of the bole, plus the distance from the top of last section to tip of trees.

Character of crown may or may not be required. It is useful in hardwoods where separate tree classes may be desired, and in any species where growth is being investigated and as the index of form, as indicated in Chapter XVI. On felled trees, two measurements are taken. Width of crown is measured as the tree lies, at widest point, at right angles to stem. Length of crown is the dis-

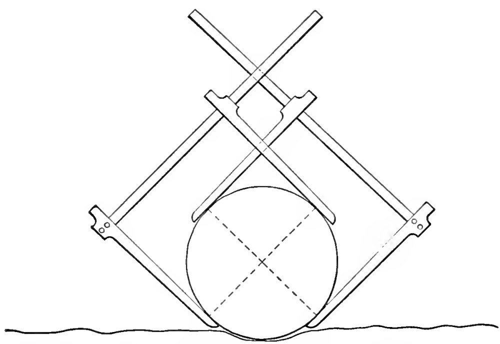

Fig. 25.—Method of measuring a log twice at right angles to obtain the average diameter.

tance from tip to the point where the lowest vigorous and well-shaped green branch joins the bole, or better still, at a point on the bole, opposite the lower limit of the green crown or foliage. Some judgment is required in excluding from crown-length small, feeble or straggling single live branches which may have survived by accident on one side but do not form part of the main crown of the tree. Dead branches or knots form no part of the crown.

The position or class of the crown in the stand may also be described, as open-grown, dominant, co-dominant, intermediate, or overtopped. This is best judged before felling.

The following definitions have been adopted as standard by the Society of American Foresters.

Crown Class. All trees in a stand occupying a similar position in the crown cover. The crown classes usually distinguished are:

Dominant. Trees with crowns extending above the general level of the forest canopy and receiving full light from above and partly from the side; larger than the average trees in the stand, and with crowns well developed but possibly somewhat crowded on the sides.

Co-dominant. Trees with crowns forming the general level of the forest canopy and receiving full light from above but comparatively little from the sides; usually with medium-sized crowns more or less crowded on the sides.

Intermediate. Trees with crowns below, but still extending into the general level of the forest canopy, receiving a little direct light from above, but none from the sides; usually with small crowns considerably crowded on the sides.

Overtopped. Trees with crowns entirely below the general forest canopy and receiving no direct light either from above or from the sides. These may be further divided into oppressed, usually with small, poorly developed crowns, still alive, and possibly able to recover; and suppressed or dying and dead.

As currently used, overtopped trees are now classed as suppressed; and an additional class, open-grown, is added, consisting of trees standing alone with crown free on all sides.

The *bole* is not described unless there is some marked peculiarity which may explain an abnormal shape or volume and enable the investigator later to decide whether to use or reject it in his tables. Such peculiarities include forks, dead tops, abnormal or swollen butts, especially if the D.B.H. is affected, or other deformities in shape. The presence of rot, shake, or other internal defects may be noted, but does not influence the subsequent measurements (§ 156) or volume of the tree, unless its form is affected abnormally, as sometimes happens when rot at the butt causes abnormal butt swelling extending beyond D.B.H.

135. Measurements Required to Obtain the Volume of the Tree. Systems Used. While the object of measurements of the stem is to obtain its volume, these also serve to record the form of the bole. The diameter is taken (§ 29) at definite points, dividing the bole into lengths which are recorded consecutively. The cubic volume of round logs of any length is easily computed from the end diameters (Smalian formula) if the proper precautions are taken to guard against the influence of butt swelling (§ 29). But if the recorded diameters or form of the trees are to be used to get average form or taper (§ 166) as well as merely for volume, these measurements should be taken at the same heights or intervals on all trees.

For cubic volume, the log lengths into which the bole is cut by the loggers may be disregarded. This factor would exert no appreciable influence on the tree contents when the full volume of each log is accurately obtained.

There are three systems of taking these upper diameter or taper measurements, as follows (Fig. 30, § 155):

System A. Disregard stump height. Take diameter at every 10 feet from ground to tip. Record length of tip above last 10-foot taper.

This method permits of accurate averaging of these diameters on different trees to obtain average form, and also gives the total cubic volume of the tree. But it is unsafe to rely solely upon these measurements for the volume of the first 10-foot log, which should be supplemented by stump taper measurements, taken at 1, 2, 3, 4 and $4\frac{1}{2}$ feet from the ground. This gives a complete record of form and an accurate basis for total volume.

By means of form or taper tables (§ 167) based on these measurements, the diameters at any other points may be obtained from diagrams, and the volume of the tree can then be calculated for any unit of product.

System B. This method is a compromise between measurements intended solely to secure form or total cubic volume, and those required for merchantable volume (§ 145). The height of stump is first recorded and the height of upper diameters is then taken from the stump as a base. As stump height tends to increase with diameter of tree, the upper measurements of larger trees fall at higher points on the bole, by just the difference in stump heights. This inaccuracy is usually accepted and the diameters which fall at equal height above the stump are averaged together.

The length of log or interval adopted for upper diameter or taper measurements by this method is a multiple of 4 feet. Four-foot intervals give closest results, and correspond to cordwood lengths. A more common interval is 8 feet, corresponding with the standard length of cross-ties. Greater lengths give less accurate permanent data. If only the 16-foot tapers are required for the immediate purpose of the table, it is comparatively little extra work to take the 8-foot points as well, for future use if needed.

System C. By this method the logs as cut by the sawyers are measured as they lie, for diameter and length. As these commercial lengths vary, the taper measurements for different trees will fall at several different points even for the first log, and require tabulation at 2-foot intervals. Except when measured for total cubic feet, the resultant volumes will vary according to the lengths cut (§ 43), and not solely according to the dimensions of the tree as by Systems A and B. No advantage is gained by the securing of volume corresponding to the used lengths of the tree measured, since in every logging job, the average of lengths used will differ. This method is therefore inadvisable. But a record can be made on the analysis blank of the log lengths actually cut, and their scaled contents, to determine the

FORM FOR TREE ANALYSES

No. 116 *Species* Pitch Pine *Locality* Milford, Pike Co., Pa. *Date*, July, 1916
D.B.H. 16.3″ *Ht. Stump* 1.0′ *Total Ht.* 68′ *Merch. Length* 58.7′ *Used Length*.
Width Crown 23′ *Length Crown* 22′ *Tree Class* Dominant *Log Rule*.

Sections	Stump	1	2	3	4	5	6	7	8	9	10	11
Height above stump		8.15	16.3	24.45	32.6	40.75	48.9	57.05	67			
Length of Section	1.0	8.15	8.15	8.15	8.15	8.15	8.15	8.15	10			
Diam. Outside Bark	19.9	15.7	13.6	12.6	11.5	10.6	8.4	5.4				
Width Bark (Single)	1.7	.7	.5	.45	.45	.4	.3	.25				
Diam. Inside Bark	16.5	14.2	12.6	11.7	10.6	9.8	7.8	4.9				
Volume of Section												

	Volume Used						Total
Actual Used Lengths	16	16	16				
Board Feet Scaled							
Ties							
Cubic Feet							
Notes Description of bole when necessary							

Section	Age	Distance on Average Radius from Center to Ring by Decades																					Sap. Age	Sap. Width
Stump																								
1																								
2						Growth	data to	be entered	in these spaces															
3																								
4																								
5																								
6																								
7																								
8																								
9																								
10																								
11																								

difference between volumes as cut and sealed, and volumes from regular tapers.

In case the study of the growth of trees at upper sections is required (§ 289) either the trees will have to be felled and bucked into sections of even lengths by System A or System B, or else the logs as cut by System C must be accepted as the basis of this growth study.

For total cubic volume, the taper measurements are continued to the tip in either system. With slight additional cost, these extra measurements taken above the merchantable top diameter limit complete a permanent record of tree form available for future computation of volume for any unit or limit of merchantable sizes.

A further modification is the addition of *trimming lengths*, usually standardized as $\frac{3}{10}$-feet in 16 feet, so that the points marked fall at 8.15 feet, 16.3 feet, 24.45 feet, etc. If this is done the fact should be be noted on the analysis. Total cubic volume is obtained as accurately by this method as by System A, and in addition, the data can be used directly to determine the volume in board feet. It is therefore preferable for most objects to System A.

The *width, single, of bark* is measured at each diameter (§ 29), and recorded as read. This width is then doubled and subtracted to obtain diameter inside bark.[1]

If the volume of sapwood is desired, this will require the sectioning of the tree, and measurement of width of sap. Sapwood volume is therefore most easily obtained by System C.

The measurements are entered on a blank, of which an example is shown on p. 160.

This completes the field record. The remainder of the work is performed at any time in the office.

The crew for field measurements of volume, when the trees are already felled, should consist of two to three men, one of whom records the data while the others measure the tree.

136. Computation of Volume of the Tree. For total cubic volume, each section is usually computed by the Smalian or mean end formula in which

B = area of large end of section in square feet;

b = area of small end of section in square feet;

l = length of section in feet;

V = cubic volume.

[1] Abbreviations are used, as follows:

Diameter outside bark, D.O.B.
Diameter inside bark, D.I.B.

Then

$$V=\left(\frac{B+b}{2}\right)l$$

$$=(B+b)\frac{l}{2}.$$

For the sum of the volumes of the sections each end area except the first and last is evidently used twice. A series of three such sections would total

$$V=\left(\frac{B+b}{2}\right)l+\left(\frac{b+b'}{2}\right)l+\left(\frac{b'+b''}{2}\right)l.$$

When, as in systems A and B, equal lengths of section (l) are used, the formula can be expressed

$$V=(B+2b+2b'+b'')\frac{l}{2}=\left(\frac{B+b''}{2}+b+b'\right)l,$$

i.e., average the first and last basal areas, and add the remaining areas. Then multiply by length of one section to obtain the sum of volumes of the sections.

The areas in square feet, corresponding to the diameters of each section are found in Table LXXVIII, Appendix C, p. 490.

Sections different in length from the standard must be computed separately.

The tip, beyond the last taper, is computed as a paraboloid, by the same formula,

$$V=\left(\frac{b+0}{2}\right)l=\frac{b}{2}l.$$

The volume of stump, needed to complete the tree when system B is used, is standardized by custom as a cylinder, whose diameter is that of the stump section, thus neglecting the variable factor of stump taper. Its volume is therefore

$$V=Bl.$$

System A permits the volume of the section up to 4 or 4½ feet to be computed accurately if desired.

Owing to the serious error incurred by measuring the butt section by the Smalian method, the use of Huber's formula for the first 8- or 16-foot log may give more consistent results. In this case, for a 16-foot log (l) the basal area at 8 feet (b') gives the log volume, or

$$V=b'l.$$

A check should be made by this method against the Smalian method for the butt section (§ 29).

The total cubic volume of branches and twigs is practically never computed. The measurement of merchantable volume of limbs and branches is discussed in § 146.

For obtaining the total volume of the tree bole exclusive of branches by regarding the bole as a complete paraboloid, the so-called Schiffel's Formula may be applied. For this purpose the area of the cross section at D.B.H., and one at one-half height above stump is obtained and applied, thus:

$$V=(.16\,B+.66\,b_{\frac{1}{2}})h \quad (\S\,177).$$

Volume of Bark. The volume of the tree may be computed from D.O.B. to give total cubic contents with bark. It is then computed, if necessary, from the D.I.B., to give the peeled contents or wood without bark. The volume of bark is obtained by subtraction of the second from the first result.

Volume tables give the volume with bark, or without bark, according to the use to which wood is put and the form in which it is sold. When the peeled volumes are given, the per cent of bark in terms of peeled volume may be shown for each diameter.

137. Classification and Averaging of Tree Volumes According to Diameter and Height Classes. 1. The separate sheets are now sorted first into diameter classes (§ 127).

2. The height classes, for tables giving total cubic volume, are based on total height of tree. Whether 10-foot, or 5-foot classes are used depends on the total height of the species. For second-growth hardwoods or small timber, 5-foot classes are preferred, while in the extremely tall timber of the West Coast, 20-foot classes are sometimes sufficient. For either standard, trees are placed nearest their actual height. The trees of each diameter class are now sorted into their respective height classes. The trees in each separate diameter and height class are then checked to see that no mistakes of classification have been made.

3. The average volume is found for the trees of each separate group or class comprising all trees falling in the same diameter and height class.

If trees having the same diameter and height had similar forms, the volumes of all trees in any one diameter and height class would be equal, except for the differences due to the fact that the actual diameter, or height, though falling within the size limits required, may be larger or smaller than the exact standard size of the class.

But variation in the form of the bole is a third factor which causes considerable variation in volume for trees of the same total height and diameter (§ 166). Trees whose form is full, lying between the paraboloid and the cylinder, have a correspondingly greater volume than trees with a form lying between the paraboloid and cone, or neiloid

(§ 26). The extreme range of volume caused by differences of form alone for trees of the same height and D.B.H. is as much as 40 per cent. Even the average volume of trees of the same ages or sites may differ by more than 20 per cent.

The volume of single trees follow the general law of averages. Those which depart most widely from this law are few in number, while a range of 5 per cent above or below the average would probably include by far the larger number of trees in fairly uniform stands.

When the exact volume of a specific tree is wanted it is unsafe to assume that this tree is an average specimen. It must be measured separately. But in estimating standing timber, the object sought is the total volume of the stand, or the sum of all trees. If the *average* volume of trees of each size class is correctly given in a volume table, the cruiser can assume that every tree tallied is an average tree, and the result or total will be the same as if the true volume of each separate tree were measured.

This averaging of the variable individual volumes of trees of each class to obtain a reliable average volume is the principal service rendered by volume tables. The timber cruiser stretches this same principle much farther when he attempts to average the volumes of trees of totally different diameters and heights, and the chances for error are much greater, especially as this is usually a mental process or guess, while the averaging of trees in a volume table is a calculation based on exact measurements.

The method of obtaining the average volume of trees for a given size is as follows. Enter on a sheet, labeled with the diameter and height class, the data for each tree, according to the illustration given below for four trees. Place at top of sheet the tree class, e.g.,

13 Inches—60 Feet		
Diameter. Inches	Height. Feet	Volume with bark. Cubic feet
12.7	56	59.0
13.1	58	63.2
13.4	61	66.0
13.4	62	68.2
4)52.6	257	256.4
13.15	59.25	64.1

TABLE XXVII

PRELIMINARY AVERAGES FOR PITCH PINE. VOLUME TABLE BASED ON DIAMETER AND TOTAL HEIGHT. 139 TREES

HEIGHT CLASSES—FEET

D.B.H. Inches	50	55	60	65	70	75	80
7		7.5 1 6.96 52.6					
8	8.0 1 8.73 52.0						
9				9.0 1 14.28 63.0			
10	10.2 1 12.51 50.0	9.75 4 14.88 53.4	10.0 1 17.37 58.1	10.5 2 19.05 65.8			
11	11.5 1 17.78 50.0	10.9 6 17.67 55.6	11.1 3 19.78 59.35	11.1 2 23.35 63.2			
12	12.3 1 17.93 52.0	12.3 6 24.18 55.1	12.2 8 24.27 59.6	12.0 1 26.09 63.0			
13	12.9 4 23.4 49.6	13.1 11 26.23 54.2	13.15 4 27.53 59.25	13.4 2 34.27 65.0			
14		13.9 6 31.8 56.6	14.0 9 31.61 60.3	14.1 5 34.05 64.1	14.1 2 42.32 68.5	13.6 1 38.92 73.4	14.3 1 46.1 78.0
15	14.7 2 32.9 51.5	15.1 1 36.1 57.0	15.1 3 39.44 60.2	15.2 4 39.96 64.2	15.1 2 45.3 68.8	15.0 1 43.55 77.0	
16		16.3 2 37.15 54.5	16.1 7 43.71 59.8	15.9 3 44.69 64.9	16.1 5 49.21 69.3		
17		16.9 3 44.67 54.8	16.7 2 47.26 60.0	16.8 2 47.82 64.8	17.1 1 51.3 68.0	17.1 2 55.57 73.45	17.0 1 65.14 78.0
18			18.0 1 54.82 60.0	18.0 4 61.57 64.25	18.3 2 59.25 68.1		
19				18.6 1 60.45 66.0	19.1 3 65.27 70.2	19.0 2 71.82 74.0	
20					20.0 1 69.56 67.8		

Legend

D.B.H. Inches	No. Trees
Cubic feet	
	Total Height Feet

The quotients represent respectively the actual average diameter, height and volume for the class. These data, together with the number of trees measured in each class, are entered on a large sheet in the form shown in Table XXVII, p. 165, and constitute the basic or rough table which is the first step in preparing a standard volume table. Thus 64.1 cubic feet is not the average volume for 13-inch trees 60 feet high but for trees averaging 13.15 inches and 59.25 feet in height.

138. The Graphic Plotting of Data—Its Advantages. The volumes shown in such a table should increase with both diameter and height. If sufficient basic data has been obtained, this rate of increase in the values of the table, both vertically and horizontally, will follow the law of averages which expresses the true relation of the two variables; for the vertical columns, volume and diameter; for the horizontal, volume and height. But where only a few trees are obtained in a class, these trees may not only be larger or smaller in diameter and height than the true average, but may have too full or too slender a form, and the average of their volumes will be correspondingly higher or lower than the regular progression to be expected. The form of this progression or increase will be determined by the character of the two variables. For cubic volume based on diameter, with trees of the same height and form, the increase in volume will be proportional to D^2. If these values are plotted on cross-section paper, the result will be a curve showing graphically to the eye the law of increase in volume based on diameter.

The increase in volume based on height can be shown in a similar manner by plotting the volumes and heights. This curve will differ in shape from the first, since volume tends to increase directly as height for trees of the same diameter, and the curve showing this approaches a straight line. When thus presented to the eye, any irregularities or inconsistencies in the average volumes obtained in Table XXVII become evident at once, while to detect them by mere examination or checking of the arithmetical table would be far from satisfactory.

Since such irregular values do not conform to the general law of increase in volume based on diameter and height, they cannot be depended upon to give the true average volume of all the trees of a size class. One of two things must now be done—either more data must be collected in the field in order to improve these averages, or the averages obtained must be harmonized, and these irregular values changed or corrected. The irregular volumes plotted would be based on sufficient field data to bring out the real tendency or character of the law of the relations sought. The minor irregularities in this case are not serious enough to prevent a fairly accurate approximation of this law and a drawing of the curve as indicated by the data.

The principles of graphic plotting are treated in analytical geometry, or graphic algebra. The relation of the two variable quantities is shown by a series of plotted points in which the horizontal and vertical lines each represent a scale of values corresponding to one of the quantities or variables. Both being positive quantities, the lower left-hand corner of the chart is taken as zero, or the origin. The horizontal line passing through this point along the base of the sheet is the axis of abscissæ or horizontal scale, and the abscissa or value of each point is measured parallel with this axis or along the scale thus indicated. The vertical line through the origin, forming the left margin of sheet is the axis of ordinates or vertical scale. The zero, or intersection of these two axes, is usually located to the right and above the extreme lower corner of the sheet to give a margin for entering the scales. The scale of diameters, by inches, is then placed along the horizontal scale while the volume scale is entered on the vertical scale. The whole forms a system of rectangular co-ordinates. Each point on the paper represents two quantities, a diameter, measured parallel with the base, and forming the abscissa of the point, and a volume, measured vertically, and forming an ordinate. This is illustrated by Fig. 26.

In this figure, the volumes of three average trees, or the averages volumes of three groups of trees have been plotted, namely, 10-inch, 13.15-inch and 16.1-inch trees. The horizontal and vertical values of each point are indicated by dotted lines. If the theoretical relation of volume, and diameter for all points is as y to px^2 we would not only expect y (volume) to increase faster than x (diameter), but this increase would be in the form of a regular curve, and once the position of this curve is indicated by a sufficient number of reliable points, all other values for x and y, representing the volumes for all diameters, would fall on the same curve. False or abnormal average volumes obtained from too few trees will not fall exactly on the curve, but above or below it. The greater the number of trees used in obtaining an average point, the more closely will the point representing this value approach or coincide with the curve.

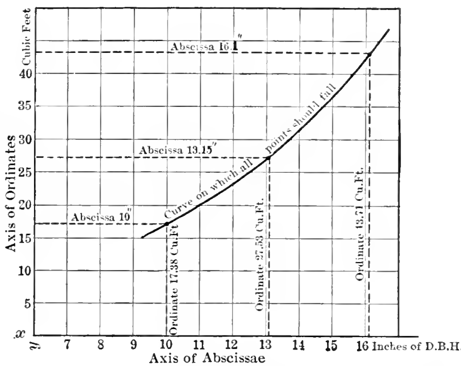

FIG. 26.—Rectangular coordinates, showing position of a curve of volume on diameter as determined by three points whose ordinates and abscissæ are known.

The actual shape of the curve will depend upon the relation arbitrarily established between the two scales. Doubling the values on the ordinates, for instance, reduces the ordinate distance one-half. The scale selected must bring all values within the boundaries of the sheet, which is usually accomplished if the largest ordinate is not less than one-half nor greater than one and one-half times the greatest abscissa.

The value of using this method is that each separate point or average aids in establishing the law, or fixing the values for all the others. If enough good or well-weighted points are obtained, they correct the abnormality of other points based on insufficient data and even show up arithmetical mistakes in obtaining these averages. The curve makes possible the interpretation of missing data, but it is considered unsafe to extend it to cover values beyond the limits of the original data.

Although from the standpoint of mathematics it makes no difference which variable is plotted on the horizontal and which on the vertical scale, yet as the purpose of this plotting is to convey to the eye the tendency or law of increase in one variable when based upon another definite variable, as for instance, the increase in volume due to increase in diameter by 1-inch classes, it is always preferable to plot the independent variables on the horizontal scale and the dependent variables on the vertical scale.

Neglect of this precaution not only conveys an ocular impression the reverse of the actual law, but tends to create the false notion that the two variables are interchangeable, whereas one must always be an independent or fixed base, on which

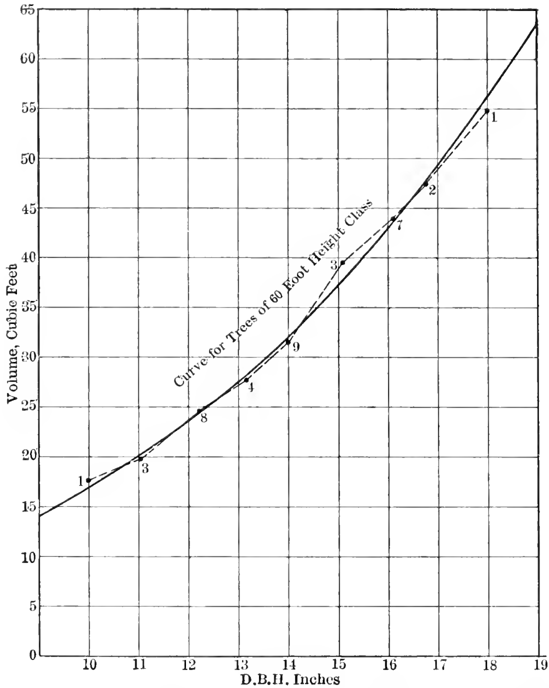

Fig. 27.—Curve of volume based on D.B.H. for trees of a single height class.

the required data are collected, classified and arranged. For instance, in determining the relation between D.B.H. and age of trees, absolutely different results are obtained if in the first instance, the average D.B.H. is found for all trees of given age classes, and in the second, the average age is determined for all trees of given D.B.H. classes (§ 275). The values of these tables or curves are not interchangeable. The dependent variable can always be identified as the one whose values are sought; the independent, the one whose values are already known.

The use of curves, or graphic plotting, enables the investigator to obtain a given degree of accuracy with a greatly reduced number of field measurements.

This saving in field work is from 100 to 500 per cent; in fact it would be impractical, though possible, to get the same degree of accuracy by the averaging of field data as in Table XXVII without using the graphic method. The application of these principles would have greatly improved the construction of certain log rules, notably the Scribner rule (§ 68).

139. Application of Graphic Method in Constructing Volume Tables.—In applying this method to the values in Table XXVII volume is evidently the variable whose value is sought, while diameter and height are the two independent variables. It is evident that not more than two values can be plotted in a single point, nor more than two variables, as for instance, diameters and volumes in a single curve. The volume of trees varies with both diameter and height, yet variations due to height cannot be shown in the same curve with those due to diameter. But if we select from the original table (XXVII) the volume of trees, all of which fall in the same height class, the factor of height, for these volumes, becomes a constant, except for deviations from the true average height of the class, which can be ignored in plotting this curve. The curve formed by the volumes of this group of selected trees will be designated as the volume curve based on diameters, for trees of the specified height. Such a curve is shown in Fig. 27, with the original average volumes plotted.

In determining just where the curve should fall, the weight of each point is influenced by the number of trees included in the average column for that diameter; the weight of a point varies with the square root of the number of entries and not directly with the number of entries. Thus an average of a point representing one tree and a point representing four trees would be on a straight line connecting them and *one-third* of the way from the "4" point to the "1" point. The number of trees in each class should therefore be entered on the sheets opposite the point representing the volume.

The original volume for the trees of a given diameter class may represent a diameter slightly larger or smaller than the exact inch. For instance, in Table XXVII, the average diameter for 17-inch trees, 55 feet high, was 16.7 inches. This volume should not be entered above 17 inches, but above its true average diameter.

When the curve is completed, the values are read from it for each exact inch of diameter.

A comparison of the original and harmonized values from the above curve is given in Table XXVIII, p. 171.

The averages for 33 out of 38 trees and 6 out of 9 diameter classes fall within 2 per cent of the curve.

140. Harmonized Curves for Standard Volume Tables Based on Diameter. So far, the volumes of trees of different diameters for but one height class have been shown. By the same method, a curve is constructed for each separate height class, based on the scale of diameters. If, instead of making each of these curves on separate sheets, they are all placed on the same sheet, their relation to each other is shown.[1] All curves should show the same general trend, in harmony with the law of variation between diameter and volume. The set

[1] Where insufficient data are available and height divisions are small, the values for different heights will frequently overlap. In such cases it is better to plot every alternate height class first, and draw the respective curves before plotting the intervening classes.

of harmonized curves of volume based on diameter is shown in Fig. 28 with height class of the trees in each curve indicated.

From this set of curves a table can be read, whose form is similar to that of Table XXVII, but whose volumes increase regularly with

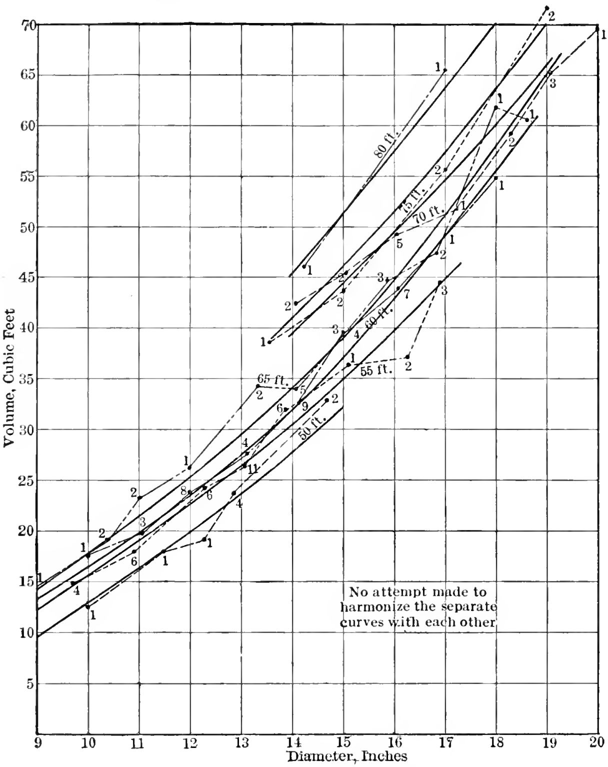

FIG. 28.—Curves of volume based on diameter for separate height classes, plotted from original averages in Table XXVII.

diameter, and whose values are interpolated to even inch classes from the averages of the original table.

141. Harmonized Curves Based on Heights. But this table is not necessarily in final form, for the variations caused by height must also be harmonized. The first set of values has been made regular

TABLE XXVIII

COMPARISON OF ORIGINAL AND HARMONIZED AVERAGE VOLUMES

D. B. H. Inches	Original volumes. Cubic feet	Harmonized volumes. Cubic feet	Remarks
9	.....	14.0	
10	17.38	16.5	One tree with full bole
11	19.78	19.75	
12	24.27	23.4	
13	27.53	27.4	
14	31.61	32.1	
15	39.44	37.3	Original volumes evidently too cylindrical for average
16	43.71	43.1	
17	47.26	49.5	Original diameter 16.7 inches, but average volume
18	54.82	56.2	One tree with poor form
19	.....	63.6	

TABLE XXIX

VOLUMES READ FROM CURVES OF VOLUME ON DIAMETER FOR DIFFERENT HEIGHT CLASSES

D. B. H.	Height Classes, Feet						
	50	55	60	65	70	75	80
Inches	Cubic Feet						
9	9.5	12.2	13.0	14.0			
10	12.9	15.4	16.5	17.6			
11	16.2	18.8	19.9	21.3			
12	19.7	22.4	23.2	25.1			
13	23.5	26.2	27.1	29.4			
14	27.8	30.6	31.8	34.1	39.3	41.0	45.7
15	32.3	35.0	37.1	39.0	44.0	46.0	51.4
16	....	40.0	43.0	44.7	49.0	51.5	57.2
17	....	45.0	49.2	51.3	54.4	57.4	63.6
18	....	....	55.5	58.0	60.0	63.8	70.2
19	....	....	....	65.0	66.0	70.2	
20							

within each height class separately, but this does not prevent the values of all the trees of a given height class from being too low or too high. In fact, if one of the volume curves representing a height class is incorrectly drawn lower or higher than it should be, this very result is produced.[1]

The law of variation of volume based on height may be expressed by the equation $y = px$, since volume (y) increases approximately in direct proportion to height (x). For trees of the same diameter, whose volumes lie on the same ordinate in Fig. 28, the curves of volumes for regular gradations of height should be spaced at about equal distances. This interval, of course, increases with each diameter class. Since this is known, the first set of curves based on diameter may be harmonized, not only in direction but in spacing, being placed at equal intervals on each successive ordinate. The resultant table will then show volumes increasing regularly by height.

A still better method of securing this regularity is to plot, from the values obtained from the first set of curves, a second set in which heights are the determinate variable, or basis plotted on the horizontal scale, and volumes are plotted vertically as before. Diameter must now be eliminated as a variable, by plotting all the volumes for trees of a single diameter class in the same curve. Beginning with the first diameter class in Fig. 28, which is intersected by two or more curves of volume representing different height classes, these volumes at the intersecting points are read, beginning with the lowest. The series of values thus obtained represents the volumes of successive height classes, and as such are plotted on the new sheet, and connected to form a new curve, which represents only trees of the diameter class so taken.

Each point so plotted should be placed above the actual average height for the class, as found in the original averages shown in Table XXVII, e.g., for the 15-inch curve, the 55-foot class must be plotted, not above 55 feet, but above 57 feet, which is the actual average height for this class.

Separate new curves are thus plotted for the trees in each diameter class. Instead of plotting these values direct from the first set of curves, a table may be made from the values read from these curves,

[1] The tendency to error may be greatly reduced in the original curves if the the square of the diameter is made the basis of the table, or abscissæ scale, in which case the curves take the form of straight lines characteristic of those based on height. The same result may be obtained by plotting on logarithmic cross-section paper. (Logarithmic Cross-section Paper in Forest Mensuration, Donald Bruce, Journal of Forestry, Vol. XV, 1917, p. 335.)

and the new values then replotted from this table. In this case, the values from each curve will be read horizontally from the table instead of from the vertical column as in the first instance.

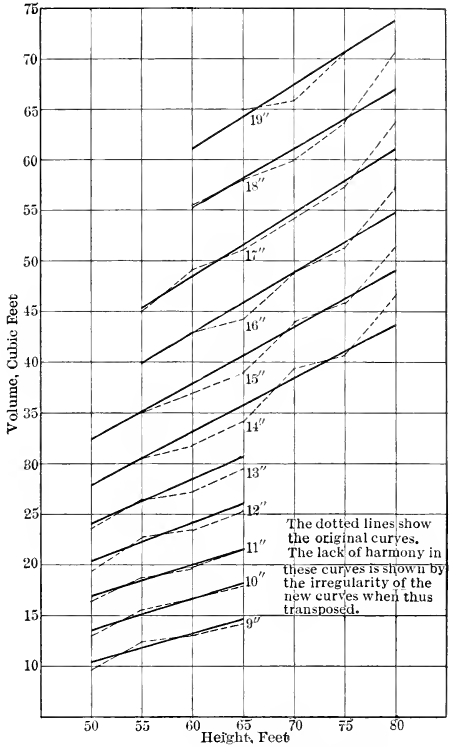

Fig. 29.—Curves of volume based on height. Original curves, dotted, from curves shown in Fig. 28, or values from Table XXIX. Harmonized curves drawn.

"Strip" Method of Replotting. A rapid method of replotting direct from the curve is by means of a strip of paper. The zero or end of strip is placed on the base or abscissa, and held in a vertical position, so that the edge lies on the ordinate representing the diameter class to be transferred; a mark is then made where the curve of volume for each successive height class intersects the strip. These marks may be numbered or otherwise designated, but their mere order is a sufficient identification. Transferring this paper to the second sheet, the vertical or ordinate distance (which represents volume in each set of curves) for the first height class, is plotted on the ordinate intersecting the abscissa representing that height. The strip is then moved to the right, to intersect the next height on the scale and the corresponding volume point transferred to the sheet. When plotted thus, these volumes indicate the position of the curve of volume for different heights, for trees of the given diameter class.[1]

[1] This method is described by W. B. Barrows, "Reading and Replotting Curves by the Strip Method," Proc. Soc. Am. Foresters, Vol. X, 1915, p. 65.

Irregularities in spacing the first set of curves are now shown by this second set as similar distortions of each curve where they intersect the same ordinate. This is shown in Fig. 29.[1]

Volumes read from this second and final set of curves increase with both diameter and height according to the true laws of variation applicable to each dimension. In this way *Standard Volume Tables* are secured, which may be applied to a species throughout its range, unless it is convincingly shown that there are consistent differences in form and volume not due to either height or diameter, which can be correlated with age or site, and call for separate standard table.

TABLE XXX

STANDARD VOLUME TABLE READ FROM CURVES OF VOLUME ON HEIGHT FOR DIFFERENT DIAMETER CLASSES

D. B. H.	Height Classes, Feet						
	50	55	60	65	70	75	80
Inches	Cubic Feet						
9	10.3	11.8	13.2	14.6			
10	13.6	15.1	16.6	18.1			
11	17.0	18.5	20.0	21.5			
12	20.2	22.1	24.0	26.0			
13	24.0	26.2	28.4	30.6			
14	28.0	30.6	33.2	35.9	38.5	41.2	43.8
15	32.4	35.2	38.0	40.8	43.6	46.4	49.2
16	....	40.0	43.0	46.0	49.0	52.0	55.0
17	....	45.4	48.6	51.8	54.9	58.0	61.1
18	....	....	55.3	58.3	61.2	64.2	67.1
19	....	....	61.2	64.4	67.6	70.8	74.0

142. Local Volume Tables—Their Construction and Use. In the absence of a standard table, or when for any reason the available tables are not reliable and there is no time to construct a table for all heights

[1] Based on the law of variation between volume and height, this set of curves (in rectangular co-ordinates the term "curve" applies to any line, curved or straight, which follows a regular law and can be expressed by a formula) consists of lines which are nearly straight, but not parallel, since the difference in volume increases with each diameter class representing a single curve.

and diameters, a local table based on diameter alone may be made directly, from whatever number of measurements can be secured. The volumes of all trees of the same diameter are averaged regardless of height. These averages must then be plotted, and a single curve drawn similar to that shown in Fig. 27 but containing trees of all heights. From this curve average volumes for each diameter class are read.

When diameter is shown in the table, such tables are useful only within the same stand, age class or site class in which they are constructed. Timber whose average height is greater or smaller, for any cause, for trees of the same diameter classes, cannot be measured by this local table but require a new basis of volumes. If it is found that the heights do average the same for each diameter the local table can be used unless it is known that other factors influence form sufficiently to require its correction. But where no record is made of heights of the trees used in constructing the table, as frequently happens, the cruiser has no way of knowing whether the table applies to any stand but that in which it was made. Where it is expected that such local tables may be used again, heights should be measured as well as diameter, and a curve of height on diameter drawn. The full data for such a local table, which is to be saved for possible future use, are:

TABLE XXXI

Local Volume Table, Form

D. B. H. Inches	Volume. Cubic feet	Height. Feet
12	20.2	50
13	25.3	53
14	32.1	58
15	39.1	62
16	46.0	65
etc.		

143. The Derivation of Local Volume Tables from Standard Tables. Where a reliable standard volume table is available, it is not necessary to construct a local volume table based solely on diameter. If the estimator does not need or desire to distinguish different heights in tallying trees, he may select the volumes from the standard table which represent trees of the average heights of the given stand, and tally diameter only.

The first step is to determine the average height of trees of each diameter class, by means of a few measurements, and the plotting of a curve to show the average height of trees of each diameter (§ 209). The volumes corresponding to these heights in the standard table are taken. When the height for a diameter class falls between the fixed heights given in the table, the volume for this class must be interpolated. For instance, a height of 54 feet in a table showing volumes for 50- and 60-foot trees, would require an addition to the 50-foot volume, of four-tenths of the difference between those of the 50- and 60-foot classes.

The standard volume table therefore permanently replaces all local tables, provided the average form, the unit of volume, and the merchantable units used correspond to the conditions for the timber to be measured (§ 205).

144. Volume Tables for Peeled or Solid-Wood Contents. To obtain volume tables for solid or peeled contents, the original tree volumes are computed from D.I.B. measurements taken at stump and at each section. The D.B.H. of each tree is based on the measurement outside bark just as for volume tables with bark. This permits the comparison of the volumes with and without bark for trees of the same size class.

References

Volume Tables and the Bases on Which They May Be Built, Judson F. Clark, Forestry Quarterly, Vol. I, 1903, p. 6 (Schiffel's formula).

Volume Tables, Henry S. Graves, Forestry Quarterly, Vol. III, 1905, p. 227.

CHAPTER XII

STANDARD VOLUME TABLES FOR MERCHANTABLE CUBIC VOLUME AND CORDS

145. Purpose and Derivation of Tables for Cubic Volume of Trees. Volume tables for merchantable cubic volume are intended to measure the merchantable portion of trees, thus excluding the stump, top and branches too small for use. In America these tables are used for the measurement of firewood, pulp or acid wood, or products to be totally consumed or disintegrated (§ 18). The volumes in this class of tables may be obtained from those for total cubic volume by subtracting the waste or unused portion of the stem represented by stump and top, or the merchantable portion of the bole may be computed directly. For board contents or other units, different tables are employed.

146. Branch-wood or Lapwood. Where branch-wood is of sufficient size for use, which occurs with many hardwoods used for firewood, its volume is computed separately from the stem, usually in 4-foot lengths, each of which is calipered at the center of the stick (by Huber's formula). The additional volume of branches is termed lapwood. The better method is to keep this volume separate from that of the main bole in the volume table, and express it by diameter classes as a per cent to be added to the volumes in the table. Lapwood is an exceedingly variable quantity, chiefly found in hardwoods, practically absent in conifers, and dependent entirely upon the degree of density of the stand, which also affects the form of the bole itself. Where lapwood is included with the volume of the bole, the trees should be separated not only by diameter but by crown classes, dependent on the degree of crowding and the relative spread of crowns. No more than three such classes would be practical, namely open-grown or large spreading crowns containing a large per cent of merchantable lapwood, medium crowns containing an appreciable quantity of lapwood, and trees without lapwood in quantity sufficient to affect the estimates.

Standard volume tables (§140) will seldom include lapwood but will be confined to the volume of the main stem. Where lapwood is included, the tables will usually be local in character, and based solely on diameter, with a separate table for each crown class.

147. Merchantable Limit in Tops and at D.B.H. Where cubic volume is utilized, the limit of merchantable size in the tops lies between

2 and 3 inches, outside bark. The same standard applies to branches. The "merchantable" top diameter for European conifers is about 7 centimeters or 3 inches outside bark, but this applies to wood for manufacture, and practically the whole tree may be taken by the use of fagots; i.e., brushwood, done up in bundles. There is considerable range in top diameters even for these purposes, the top diameter limit, and consequently the waste, increasing in regions of poor markets. The top diameters used in constructing tables of merchantable volume must be clearly stated. For peeled wood, diameter inside bark is given.

The minimum top diameter usually does not coincide with an exact merchantable length, but when a length of 4 feet is used, the practice may be adopted of accepting the last 4-foot stick which measures the minimum diameter at the middle of piece. The *average top* diameter will then coincide with the minimum established, half the sticks being slightly below this limit at the top end.

The merchantable top diameter, combined with the minimum length of a merchantable piece, indicates the smallest size of tree measured at B.H. which can be shown in the volume table. Ordinarily, the minimum commercial diameter limit will be somewhat larger than this, based on the inclusion of cost of logging as a factor preventing the marketing of trees with the minimum merchantable contents. Volumes of trees of still smaller sizes can be shown only in tables for total cubic volume. Since the merchantable limit of top diameters for cordwood is small, in constructing standard volume tables for cubic feet or cords the trees are classed by D.B.H. and total height, in 5- or 10-foot height classes, as for tables giving total volume.

148. Stump Heights. Stump height varies with local custom and with the scarcity and value of the wood. Stump heights, especially for large trees, are not uniform but increase with the diameter of the tree, and rules for cutting usually recognize this fact, specifying for instance that the height of stump shall not exceed one-half its diameter. For small timber, uniform stump heights may be specified, as low as from 1 foot to 6 inches. If the stump heights used in constructing the volume table are stated it enables the cruiser not only to know whether the table conforms to local usage, but to correct it for difference in practice.

The cutting of low stumps not only increases the merchantable contents of the tree but will greatly increase the possibility of error by use of Smalian formula for volume. This error is always plus and will require special measurement of short lengths in butt log.

149. Merchantable versus Used Length. Where the portion of the tree which is actually used falls short of the full possibility, due to careless supervision or to failure to appreciate the economic conditions, there arises a difference between the definition of merchantable length, and used length. Merchantable length is the total length of a stem which *can be used* under given conditions. Used length is the total length of a stem actually utilized in commercial operations. There is therefore no fixed or absolute merchantable length, since the very definition of the term "merchantable" indicates that the product must be salable. When an operator is actually utilizing all the material that he can manufacture or market at a profit used length and merchantable length coincide.

150. Waste, Definition and Measurement. Waste is therefore defined in two ways. First, there is the unavoidable waste in twigs, branches, stump and top, that cannot be used under existing economic conditions, logging costs, and markets. A better term for this material is refuse. This waste was large in earlier periods and tends constantly to diminish. Second, there is avoidable waste, caused by the fact that the markets and logging possibilities have changed faster than the logging practice. During the war this form of waste increased in certain sections due to the inefficiency, indifference and independence of woods labor. The amount of this avoidable waste is somewhat a matter of judgment. When waste is demonstrated, practice tends to take up the slack, and used lengths are readjusted to coincide with merchantable lengths.

The unavoidable waste is usually taken as the difference between the total and merchantable volumes of the bole, excluding branches. For tops, the paraboloidal formula $V=\frac{b}{2}l$ is used, while for stumps, the cylindrical contents of the stump based on its upper area is usually accepted in place of its actual total volume.

The avoidable waste represents the cubic volume of the top section between the upper limit of used length and the merchantable diameter limit, plus the cylinder representing the difference between actual height of stump and height to which it should have been cut.

A more complicated method applied to board-foot contents is to re-scale the contents of the tree, measuring the top diameter of each log at a point lower than the existing point by the difference in stump height. The difference in total tree scale so obtained is regarded as indicating the waste.

151. Defects or Cull. For pulpwood, defective or rotten pieces are not merchantable. This raises the question of cull or deductions from the cubic volume table. The question is far more serious for board-foot volume tables. No such deductions should be made for cull in the volume tables themselves, especially in standard tables. The cull per cent varies without any reference to tree form or total volume.

The deduction of a given per cent for cull would ruin the table, making of it a local table applicable only to timber which is assumed (one can never know certainly) to show the given per cent of defect. Even if the per cent of deduction is stated, the table would require complete recalculation for stands varying from this per cent of cull. By contrast, tables made for sound trees permit of the calculation of total volume for trees or stand, after which the estimated per cent of cull may be deducted from this total.

All volume tables should be constructed to show only the volume of trees as if sound. They are based on exterior measurements or form, without deduction for interior defects, which must always be made by the cruiser from observation of the character of each separate tree or stand.

152. Conversion of Volume Tables for Cubic Feet, to Cords. As seen in Chapter IX the ratio of cubic to stacked volume increases with the diameter, straightness and smoothness of the average stick and vice versa. Tables of cubic volume may be converted into cords by the use of ratios or converting factors, but if a constant ratio is used for trees of all sizes, the corded or stacked contents of small trees will overrun the values shown, while that of the larger trees will fall below it. Fixed ratios, of which 90 cubic feet per cord, or 70 per cent is an example, have the merit of standardizing the cubic or solid contents per stacked foot for trees of all sizes, regardless of their actual stacked volume. By mixing the cordwood from large and small trees, the average ratio might be attained in practice. The best example of this principle is the Humphrey caliper rule, which converts cubic to stacked measure by the ratio of 100.5 cubic feet per cord or 78.5 per cent. If this principle is adopted, the volume for each tree class is divided by the number of cubic feet per cord, which converts the table to the form desired.

Where actual stacked volume is desired for trees of each size, the ratio of conversion must be found separately for the different size classes. The tree, and not the bolt of cordwood, is the unit to be measured, hence the average size of the cordwood from trees of different sizes determines the converting factor. But few tables have been prepared on this basis. The most satisfactory method is to stack the cordwood from trees of different diameters separately and determine the factors directly. A simpler method is to determine the diameter of the average stick in the tree, and apply the ratio previously found to hold good for cordwood of this average size.

The ratio or ratios used for conversion should always be shown in connection with cordwood volume tables.

An example of the converting factors used in constructing cord wood volume tables for second-growth hardwoods is given in Table XXXII.

TABLE XXXII

Conversion Factors for Second-growth Hardwoods by D.B.H. Classes with Corresponding Diameters of the Average 4-foot Stick in the Tree or in the Stack *

Tree diameter breast-high. Inches	Chestnut		Black Oaks		White Oaks	
	Diameter average stick. Inches	Conversion factor per cord. Cubic feet	Diameter average stick. Inches	Conversion factor per cord. Cubic feet	Diameter average stick. Inches	Conversion factor per cord. Cubic feet
1	0.9					
2	1.8	63	1.8	63	1.8	63
3	2.6	70	2.5	69	2.5	69
4	3.3	75	3.1	74	3.1	74
5	4.0	79	3.6	77	3.5	76
6	4.7	83	4.1	80	3.9	79
7	5.2	85	4.5	82	4.2	81
8	5.8	88	4.8	84	4.5	82
9	6.2	89	5.0	85	4.7	83
10	6.7	91	5.3	86	4.9	84
11	7.0	92	5.4	86	5.0	85
12	7.4	93	5.6	87	5.1	85
13	7.7	94	5.7	88	5.2	85
14	7.9	94	5.7	88	5.2	85
15	8.2	95	5.8	88	5.3	86
16	8.4	95	5.9	88	5.4	86
17	8.5	95	5.9	88		
18	8.7	95	6.0	89		
19	8.9	96	6.0	89		
20	9.0	96				

* Second-Growth Hardwoods in Connecticut, E. H. Frothingham, U. S. Forest Service, Bul. 96, 1912, p. 64.

From a table showing the contents in cords, by either of the above standards, for trees of each size class, a second table can be constructed, giving the number of trees of each class required to produce one cord of wood. The cubic contents of a cord, according to the ratio adopted, is divided by that of the tree as shown in a volume table. This gives the number of trees required. These tables may be of value in estimating cordwood, by making rough counts. The principle involved is the same as that used in estimating board feet by log run (§ 120).

CHAPTER XIII

VOLUME TABLES FOR BOARD FEET

153. The Standard or Basis for Board-Foot Volume Tables. In Chapter X it was shown that the basis of measurement for standing timber intended for sale is either the possible sawed output for tracts that are cut by local mills, or the log scale for timber to be transported to mills at some distance from the area. Even in the first instance the measurement of tree volumes requires a local log rule based on mill tallies.

Volume tables for board feet must be based upon the contents of the logs which can be cut from sound trees, as measured by the standard or log rule which forms the basis of sale of the timber. For the purpose of timber estimating for which these tables are required, it is not permissible to substitute volumes representing a different standard even if a more accurate one.

But it is recognized that existing conditions requiring the scaling of logs by defective log rules may change and for purposes of stock taking or inventory of standing timber required by an owner for the management of forest property which he intends to retain, and for the prediction of growth, volumes of standing timber are preferably measured by tables based on log rules which give an accurate measurement of the board-foot contents of the trees.

This conflict between a temporary economic condition and a permanent basis of management may require a double standard of measurement, and two separate volume tables. The first step in the construction of volume tables for board feet is to decide upon the log rule to be used in obtaining the tree volumes.

For second-growth timber, and for the purpose of inventory and basis of growth studies, this should if possible be a rule such as the International, or one based on mill tallies of lumber such as the Massachusetts log rule.

For commercial timber estimating it must of necessity at present be the log rule in common use in the locality.

154. Adoption of a Standard Log Length. The standard practice, in measuring the contents of entire trees for the construction of board-foot volume tables is to disregard the actual log lengths as sawed, and to measure the diameter on the bole at fixed points corresponding to logs of a standard length, since this basis coincides with the application of the table by timber cruisers (§ 119). Sixteen feet is the standard most commonly adopted, to which is added a trimming allowance of .3 foot. Volume tables for hardwoods may, if advisable, be based on logs 12 feet long but this is the exception. The objections to the alternative method of scaling the contents of the logs as sawed are summed up in § 135, but this latter method has been extensively used in the past in volume-table construction. The base from which log lengths are measured is usually the actual height of the stump, as sawed. This introduces a variable factor dependent upon the standard of heights secured in felling.

155. Top Diameters, Fixed or Variable Limits. The field measurements of tree volumes are the same as for cubic contents of logs (§ 135). If 16 feet is the standard log length, the taper measurements are commonly recorded for each 8-foot point as well. The purpose of the work is to determine the merchantable contents. This evidently calls for the omission of the volume of the top portion of the bole, which is not merchantable. But shall the length of the rejected top be based upon the actual utilization of the specific tree? If so, the last saw cut will indicate the limit of merchantability, beyond which the contents of the top is classed as waste. By the method of measuring the volume of the logs as sawed, this top is rejected as it lies, regardless of whether the utilization of the tree has been close or wasteful. If on the other hand diameters are taken at fixed intervals, the point of measurement will seldom coincide with that of the last cut, but will fall above or below it.

If actual utilization practice is to be adopted as the basis of the table, while at the same time the fixed length of section is to be retained, the top diameter of the last " merchantable " log for the volume table should be taken at the point which falls the nearest to the last saw cut, whether this point is above or below the cut. When the saw cut is midway between two points, the lower measurement may be taken, or else the character of the bole may be made the basis of choice (p. 184, Fig. 30).

When, by method B, only the merchantable volume is desired, if last cut is at (1), the volume will be taken to the nearest 8-foot point B_6. If cut at (2), B_6 is still the nearest point. But if cut at (3) equidistant from B_6 and B_7, either the upper point B_7 would be chosen on alternate trees or the point best representing merchantable volume, in this case B_6.

Utilization, especially where sawlogs are cut from trees with limby tops, is seldom to a uniform diameter. The actual top diameter varies widely but the average increases with the D.B.H. of the tree. By the method outlined above, the contents of the volume table are made to coincide with the portion of the tree which is actually used, and the average top diameter with that which is actually cut.

But the variable practice of sawing and the arbitrary standards set by saw crews as to waste in the tops, differing with different crews, logging jobs, regions and seasons, is a strong argument for adopting a fixed standard for top diameters for saw timber. This standard may either conform to the average diameter utilized, or may depart from it and be smaller; e.g., as at B_7.

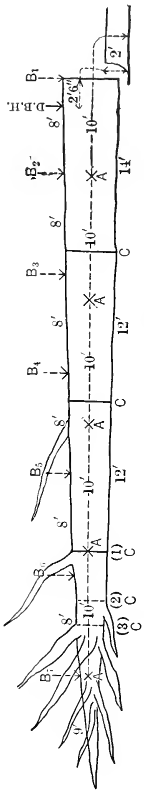

FIG. 30.—Three methods, A, B and C, for taking taper measurements of a felled tree. By method A the diameters are taken at every 10-foot distance from ground to tip. By method B the diameters are taken at every 8-foot distance from stump to tip. By method C the diameters are taken at the top of each log as actually cut. D.B.H. is recorded for all methods.

Where a fixed top diameter is chosen, instead of the variable one coinciding with utilization practice, the last taper measurement will usually fall above or below this diameter, as before. Here the same rule of give and take can be applied; but if the diameter limit is small the top tapers rapidly and it may be preferable to take no measurement of less than the minimum top diameter. The last top measurements will then fall always either at or below the point.

Where 16-foot measurements only are made, it is necessary to take an 8-foot length at the top whenever the last cut falls more than 4 feet distant from the last 16-foot taper. This is another reason for taking 8-foot tapers throughout.

156. Defective Trees, Measurement. Frequently one or two top logs in certain trees will not be utilized because of defects in the upper portion of the bole. Where the table is based on actual utilization, such trees should be rejected for measurement or else the defective logs should be measured, since the cull is not due to form but to defect. Where the top diameter is fixed independent of the last cut, these defective trees should be measured. All trees are suitable for volume measurements except forked-topped trees, those with abnormal D.B.H. dimensions due to butt swelling and frequently caused by fire scars, and trees deformed in such a manner that a series of normal taper measurements cannot be obtained. Abnormalities at a given taper point can be overcome by proper methods of measurement (§ 25). It is the purpose of volume tables to show average volumes for sound trees. Since defective logs or trees will be scaled as if sound in volume table construction, they are suitable for this purpose.

157. Total versus Merchantable Heights as a Basis for Tree Classes. Where cubic contents, either total or merchantable, are the basis of tree volumes, the total height of the tree to tip of crown is the only serviceable basis of classification by height (§137). Where the volume of the tree is desired in merchantable units of product, such as board feet, the height desired in practice is the merchantable length of the bole or height of the top of the last log. Timber cruisers commonly use the number of logs of given length in a tree, and not the total height in feet, to obtain the contents. The practice of basing height on the merchantable length of bole is most useful where the proportion of total length used is most variable, as in large hardwoods or heavy-limbed conifers, and where there is an evident variation between actual top diameters utilized. Total heights in dense stands of tall old trees are hard to see and measure while the top diameter limit is usually visible. This basis is used almost universally in the estimation of old-growth timber of all species.

The same height basis must be used in timber estimating as is used in the tables, if volume tables are to be employed. Hence the method of measuring heights in cruising will be either determined by the existing tables, or else the tables must be constructed on the basis desired for the estimating. The measurement of trees for the construction of volume tables should therefore include both the total and merchantable height, to permit of constructing tables on each basis for use as desired.

158. The Coördination of Merchantable Heights with Top Diameters. The use of volume tables to determine contents of standing trees requires the determination in the field of but two dimensions, namely D.B.H. and height, and is based on the assumption that the volume of an average tree of these dimensions gives the average volume of the trees of the same sizes in the stand to be estimated. Where total height is used as the basis, there is little opportunity for error in applying the volumes in the table, since but one point on the tree can be measured for height, namely the tip. But where merchantable height is the basis, a second variable is introduced, the top diameter. The volume now depends, not on one definite factor of height as before, but on securing coördination between these two variables, i.e., height of merchantable top, and diameter of merchantable top, in the application of the volume table.

The choice of top diameter limits has been discussed. But the effect of this choice upon the merchantable length (the height), in such tables, needs special emphasis. If a large top diameter is adopted, the merchantable height is correspondingly less for trees of the same total height and form. A tree 100 feet high may have five logs, 16 feet long, if cut to 10 inches, but if cut to 16 inches instead, it may be only a four-log tree. A 6-inch top may in turn give 88 feet or $5\frac{1}{2}$ logs from the same tree. Thus top diameter increases as merchantable length diminishes. Whatever coördination between these two variables is adopted in constructing the volume table will have to be used in applying it; i.e., the same top diameters used for the table must be used as the basis of merchantable heights in timber estimating. Failure to observe this rule may result in serious errors and has sometimes brought the use of such volume tables into disfavor among practical cruisers.

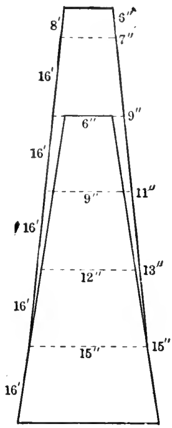

FIG. 31.— Cause of errors in use of volume tables, when based on merchantable heights and fixed top diameters.

The results of such lack of coördination are easily illustrated, by comparing the volumes of trees, when divided into 16-foot cylinders and scaled as logs. Since the frustum of a cone is a regular solid resembling the merchantable portion of the bole, it serves to illustrate the principle in question. Assume that a 6-inch top has been adopted as a standard, and all trees measured to that point.

A four-log tree, 15 inches at the top of the first log, inside bark, is assumed to have 3 inches taper per log. The volume of this tree, by the International log rule, will then be

Logs	First	Second	Third	Fourth	Total for four logs
Diameter, inches......	15	12	9	6	
Volume, board feet....	175	105	55	20	355

In estimating, if this table is to be used, the only 15-inch four-log tree whose volume can be correctly measured is one which tapers 3 inches per log, and hence has a 6-inch top diameter. But the cruiser may fail to observe the same coördination between merchantable length and top diameter, and may tally a 15-inch tree which tapers 2 inches per log, as a four-log tree. The dimensions of this tree up to the top of the fourth log are

Logs	First	Second	Third	Fourth	Total for four logs
Diameter, inches......	15	13	11	9	
Volume, board feet....	175	130	90	55	450

This tree, if measured to 6 inches, has the additional length of $1\frac{1}{2}$ logs, whose volume is

Logs	Fifth	Half of sixth	Total additional	Total for $5\frac{1}{2}$ logs
Diameter, inches	7	6	. .	
Volume, board feet	30	10	40	490

The recording of this tree as a four-log tree was probably based on the fact that it would actually be cut at 9 inches in the top instead of at 6 inches. But the cruiser, if he uses this volume table, does not obtain from it the volume of a tree with a 9-inch top, but of one with a 6-inch top. The initial error for this tree consists in not tallying it as a $5\frac{1}{2}$-log tree with a 6-inch top. If the full contents of the four actual logs which it contains could be obtained from the table, the error would be the loss of 40 feet in the $1\frac{1}{2}$ logs not measured. This is 8 per cent of the total tree volume. But instead, a much greater additional error is incurred. The volume given in the table is for a four-log tree with a 6-inch top containing 355 board feet instead of one measuring 9 inches at top. This error, due to difference in top diameter not only of the last log but of the remaining logs, is 95 board feet $(450-355)$ or 21 per cent.

If the purpose of the estimate is to obtain, not the volume of all trees to 6 inches, but the volume actually to be cut, the attempt to obtain this by dropping the merchantable length of this tree to the 9-inch point, $1\frac{1}{2}$ logs below the 6-inch point, has made the use of the above volume table impossible, for in place of a correct deduction of 8 per cent from the true volume of a $5\frac{1}{2}$-log tree, which would give the true volume merchantable, the use of the table has lowered the estimate by 27 per cent, which is $\frac{355}{450}$ of the desired estimate or 21 per cent too low. Errors of this magnitude and even greater may and have been made in use of volume tables, solely from this source.

The coördination evidently demands:

The estimation of height to the same point which has been used in constructing such a table.

The deduction of the requisite per cent, representing the small top log or logs, to obtain net merchantable volume, in case utilization falls short of this point.

Errors in estimating merchantable heights, if consistently too great or too small, incur both the above errors when the tally is applied to the volume table. Other methods of avoiding these errors are:

To use total height as a basis.

To measure a few heights carefully instead of guessing at many or all heights.

To construct the table so as to coincide with used top diameters, and then exercise care in employing this same standard in estimating.[1]

[1] The writer's initial experience in timber cruising was with W. R. Dedon, in Minnesota. Mr. Dedon did not believe in the use of volume tables, claiming that

159. Construction of Board-foot Volume Tables. The basis agreed upon as to the top diameter to use, if merchantable heights are utilized, will determine the height class into which each tree falls. The steps in construction are the same as for tables of total cubic volume (§ 131) with the following exceptions.

Compute the volume of each tree by means of the log rule chosen, by scaling each 16-foot log. In volume table work, this scale per log should preferably be interpolated to $\frac{1}{10}$-inch values, for which purpose the values of the log rule can be tabulated for the given interpolations. The last or top log if 8 feet long is scaled as one-half the volume of a 16-foot log of equal diameter. If the logs are not scaled to $\frac{1}{10}$-inch they are rounded off to nearest inch above or below (§ 137) but where but a few trees are measured in each size class, this incurs the risk of unnecessary variations in volume of the tree classes.

When merchantable heights are taken to fixed lengths, the variable at this point will be the top diameter. Therefore, the average top diameters should be shown for each diameter and height class. These tops may later be averaged solely on the basis of diameter at breast height.

160. Data Which Should Accompany a Volume Table. Because of the errors possible in misapplying tables for merchantable volumes, as set forth, the use of such volume tables presupposes knowledge of their reliability and applicability. For this purpose the following data should always accompany the tables:

Species.
Region or locality where measurements were taken.
Age of trees to which values apply, when distinguished.
Sites or quality to which values apply, when distinguished.
Unit of volume used.
Log rule if in board feet, or mill tallies specifying character and thickness of lumber included.
Specifications, if for piece products.
Number of trees measured as basis, by diameter classes.
Height of stumps.

on the only occasion on which he had attempted it, the table gave just half of the true estimate. This was unquestionably due to the cause explained above, that is, trying to coördinate large top diameters with a table made to smaller tops. The first impression, in using a table constructed to a small top diameter is that it "secures a greater volume per tree." The error is just the reverse of this—it under-estimates the timber. If, on the other hand, the top diameters in the table are larger than those applied in the field and the per cent of total contents less, the error in applying the table is an over-estimate equally great. These possibilities of error in the use of volume tables based on merchantable length have been commonly overlooked in practice.

Top diameters used—by diameter classes if variable.
Method used in constructing table,
a. Based on measurements at fixed intervals.
b. Based on measurements of logs as cut.
c. From tables of taper or form (Chapter XV).
d. From form factors (Chapter XVI)
Author, and year of preparation.

The basis of classification of volumes, as to height and diameter, is shown in the table itself. But tables based solely on diameter will have their value increased if the average heights used in constructing the table are also shown (§ 162).

161. Checking the Accuracy of Volume Tables. Volume tables make no pretense of giving accurately the volume of single trees (§ 121). If the average values given coincide with the average of the volumes of the trees to be measured, the table is accurate for the purpose in hand.

But, although applied correctly (§ 158) volume tables will give inaccurate results, first, if the table itself is inaccurately made and does not give correctly the volumes of the trees from which it was constructed, second, if the trees to be measured average greater or smaller volumes for given diameters and heights than those given in the table, on account of fuller form or vice versa.

Volume tables made in one locality may be serviceable in other regions, covering the entire range of a species. If the estimates are made to conform with the top diameters and log rules used in the table the only possible variation in volume from such tables is that of average form, and variations due to this factor can be determined without constructing an entirely new table (§ 171).

To check the accuracy of construction of a table, the basis in trees is first considered. Tables based on from 500 to 1000 trees or more are regarded as fairly reliable, while if fewer trees have been used the table is open to question. The total actual volume of the trees used in constructing the table can be checked against the total volume of the same trees figured from the table. This gives a basic check which may, however, conceal compensating errors. The average volume of the trees in each diameter and height group may then be checked against the tabular values in the same way, and the errors recorded in terms of per cent. These errors should compensate. A still more accurate check is to record the divergence in volume of each tree from the tabular volume and total the per cents of error plus and minus, which should compensate. Or, the plus and minus errors may be plotted to detect any trend towards high or low values at one end or the other of the curves.

To test the accuracy of a table of proved value, when applied to a specific stand or region, the volume of as many trees as convenient, preferably about 100 trees, is determined *by the same standards as used in the table.* The per cent of divergence of the actual volumes, one by one, from those of the table, is computed. These per cents may be tabulated and averaged by diameter and by height; if they reveal a consistent difference in volume, the values of the table can be raised or lowered by the average per cent indicated.

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CHAPTER XIV

VOLUME TABLES FOR PIECE PRODUCTS, COMBINATION AND GRADED VOLUME TABLES

162. Volume Tables for Piece Products. The purpose of volume tables for piece products is identical with that for board feet—to enable the timber estimator to dispense with the necessity of judging by eye the contents of separate trees, and substituting therefor merely the record of diameters and heights.

Volume tables for piece products are limited in scope. The specifications as to size of the product are the governing factor. For poles, no volume table is needed. For small products such as staves, it is almost impossible to make volume tables, on account of the effect of cull in reducing the output and the difficulty of judging this in the standing timber. Even here, tables showing the number of staves of given dimensions in perfect trees of different diameters, or in sections or bolts of different diameters may be of help in estimating. Here, as elsewhere, the cull factor cannot be introduced into volume tables but must be applied as a reduction factor to their contents.

To construct a volume table for any specific product, the same methods used in constructing log rules can be applied; first, the number of pieces of certain dimensions which can be cut from logs or bolts of given diameters can be found by plotting with cross-section of the standard piece upon the areas of circles. Second, these theoretical results can be checked against the actual number of pieces hewn or sawed from logs or bolts of the same diameter. The second check is to ascertain the effect of irregular shapes, and of methods of cutting or manufacture, as affected by the grain of the wood and tools used. In such a check, only sound logs are taken, but the factor of cull may be studied at the same time. The contents of these logs can then be combined into volume tables by the methods outlined in Chapter XI.

163. Volume Tables for Railroad Cross Ties. The most useful volume tables for such products are those for railroad cross ties. Just as for poles, the length of the ties, usually standardized at 8 feet, is a partial indication of the number of ties which can be cut from trees of given sizes. Hewn or pole ties, flattened on the faces only, are cut only from trees or the upper portion of boles which are too small to produce two or more ties from one bolt. Volume tables are needed:

1. For trees of larger diameter, to show the number of ties which can be obtained from each bolt, hence from the tree.

2. To show the number of ties of different grades as determined by size, which can be obtained from each bolt, and from the tree.

This latter requisite also applies to bolts from which but one tie can be cut.

A good example of a tie-volume table is that prepared[1] for western larch and Douglas fir, Kootenai National Forest, Idaho, in 1919, for the five standard grades of hewn railroad ties specified by the U. S. R. R. Administration. The dimensions called for are:

No. 1. 6 inches by 6 inches by 8 feet.
No. 2. 6 inches by 7 inches by 8 feet.
No. 3. 7 inches by 7 inches by 8 feet.
No. 4. 7 inches by 8 inches by 8 feet.
No. 5. 7 inches by 9 inches by 8 feet.

Each tree was measured at 8-foot intervals for diameter inside bark. The method was to construct a taper table (§ 167) from which the sizes of pole ties which could be cut from each bolt were determined. The steps were:

1. Determine the average top diameter inside bark required to produce a tie for each standard size. These were:

For No. 1. 8.5 inches.
No. 2. 9.2 inches.
No. 3. 9.9 inches.
No. 4. 10 6 inches.
No. 5. 11.4 inches.

2. Separate the trees measured into D.B.H. and height classes. The height classes used were the number of 8-foot lengths in the merchantable bole, to a top diameter of 8.5 inches.

3. Determine the average diameter at each 8-foot point, for the trees in each of these separate groups. This gives a series of taper measurements and an average form for the tree.

4. With distance above stump as the independent variable, on the horizontal scale, and top diameter of each tie (each 8-foot point) as the dependent variable on vertical scale, plot the average diameter at each 8-foot point. By connecting these points the form of the tree is shown. These curves are used to smooth out irregularities in values.

5. From the average upper diameter of each 8-foot bolt, for trees of each D.B.H. class, and separate height classes, as 5-tie trees, 6-tie trees, etc., the class of tie which can be cut from each bolt is indicated, and the number of ties of each grade in the tree is shown. This constitutes the tie-volume table. Instead of recording merely the total number of ties, regardless of grade, which could be done without the table, the estimator now has his products classified.

The same method can be used for trees whose dimensions permit of sawing or splitting two or more ties from one bolt, but usually trees of this diameter will be measured in part as sawlogs in board feet rather than as sawed or split ties.

[1] James W. Girard and W. S. Schwartz.

164. Combination Volume Tables for Two or More Products. Close utilization of tree volumes requires the measurement of two or more classes of products, such as saw timber and residual cordwood, saw timber and residual mine props, railroad ties and residual mine props.

In all tables of this class, the method of construction is to determine the diameter which limits the sizes used for the higher purpose, and then to measure the contents of the remainder of the bole to the smaller diameter which limits the sizes used for the residual product. The measurements must be taken on the felled tree before any portion is skidded off.

For example, in constructing a sawlog, tie, prop table for lodgepole pine, on the Arapahoe National Forest, Colorado, 6 inches was used as the top diameter for sawlogs, to be scaled by Scribner Decimal C log rule. Five inches was the top diameter for mine props. The number of feet remaining in the top, between 6 and 5 inches, was recorded as linear feet. In the same manner, 10 inches was fixed as the top diameter for the production of hewn ties (this has now been lowered to 8.5 inches by new specifications), and the number of ties in each tree, to this point, recorded. Above 10 inches, the 8-foot lengths are entered as prop material.[1]

The residual cordwood in the tops of trees cut for sawlogs or ties is measured as for cubic feet. Where the volumes for the more valuable product are measured to a fixed top diameter, the problem of residual volume is easily solved. Where top diameter varies with other factors, the amount of cordwood in the tops varies accordingly. This variation is further increased when branch-wood or lapwood is included. Tables usually express the volume of residual cordwood in terms of decimal fractions of cords per tree, and the data are frequently simplified by averaging the contents on basis of diameter.

165. Graded Volume Tables. A graded volume table is an attempt to show the amount of different standard grades of lumber which may be sawed from trees of different dimensions. Its purpose is to aid in estimating the value of standing timber. The preparation of graded volume tables is one of the objects of mill-scale studies (§ 74). The basis of these tables is the sawed lumber produced from logs. To coördinate these data with the volume of standing trees, the following points must be considered:

1. The logs sawed are usually cut into variable log lengths and cannot be standardized to a given length, such as 16 feet.

2. In sawing logs, especially hardwoods, the resultant output will

[1] Ref. Volume Table for Lodgepole Pine, A. T. Upson, Forestry Quarterly, Vol. XII, 1914, p. 319.

be determined by the amount of defect in the log as well as the grades of lumber—the net, not the gross scale will be obtained.

But the same objections hold against introducing into graded tables the variable factor of the cull due to a great range of defects as have operated to exclude such deductions from all standard tables. Hence the only safe standard on which to construct such tables is sound logs.

3. The grades of lumber are first determined in logs of given diameters and lengths, from which graded log rules may be constructed. Such rules are of course never used in scaling logs (§ 87) but solely to aid in the determination of the average price to be paid for the contents as scaled.

4. The grades of lumber in trees of different sizes must be obtained by correlating the sizes of the logs graded with the logs contained in the trees.

One standard method used in constructing such tables is to follow the logs from different trees through the mill, by numbering the logs in the woods, a process impossible without much delay except in small jobs.

Separation of butt logs and top logs is a less detailed method of classification of logs.

A third plan is to prepare separately the graded log table without reference to the trees, and then determine the sizes of logs in trees of different D.B.H. applying the grades to the given logs to get the grades for the tree. Of the three methods, this is the most practical and useful. In this the graded log table is the real basis, local graded volume tables being constructed from this table for use in each different stand of timber (§ 87).

5. To show the actual contents of trees of each separate diameter and height class, expressed in from four to eight standard grades would call for a table of considerable bulk, and when in addition to this drawback the actual volumes shown are based on an arbitrary net sawed output minus whatever cull happens to have been present in the logs measured, the advisability of using such a form of standard table is questionable.

6. Where graded volume tables of greater permanent value are desired the purpose of the tables will be accomplished by the following simplification:

a. Substitute per cents of sawed contents for actual sawed contents for each grade of lumber sealed.

b. Substitute D.B.H. alone for D.B.H. and height, as the basis of classification of the trees.

If these per cents apply to sound logs, they may require modification in the case of defective timber. Where heart rot is prevalent it causes a greater loss in the middle portions of logs which on account of the presence of knots are of lower grade than the sound outer portion. On the other hand, cat face and exterior defects reduce the amount of clear lumber of upper grades. Unless such factors can be judged correctly, the same per cents of grades must be accepted for defective logs as are shown in the table for sound logs.

It has been the common practice, in preparing graded volume tables for hardwoods, to base the table upon the net sound contents after deducting cull. Where sufficient typical sound logs of the larger sizes cannot be obtained, the drawbacks of a table based on a partial scale, i.e., culled, can be in a measure overcome by reducing this table to per cent form as indicated above. Such a table should include a statement of the basis on which it was made, the average per cent of cull deducted, and the general character of the defects and influence on the different grades. On this basis, its application to other timber is possible.[1]

Graded *log* tables are of permanent value, and the utility of these tables, if expressed in per cent, may be greater than is now imagined. The permanence of such a table depends entirely on the maintenance of the standard of grading, or grades of lumber on which the graded table is based, hence such tables cannot have the permanent scientific value of tables giving volume in standard units for sound trees.

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Graded Log Tables for Loblolly Pine, W. W. Ashe, Bul. 24, North Carolina Geological Survey, 1915.

[1] European investigations have shown that the per cent of total volumes which is obtained in the different grades of product varies with the diameter but does not differ appreciably with height. "In proportion as the shorter stem is less in volume than the longer, the assortment contents decreases but the per cent relation remains the same." Ref. Forestry Quarterly, Vol. XIV, 1916, p. 752.

CHAPTER XV

THE FORM OF TREES AND TAPER TABLES

166. Form as a Third Factor Affecting Volume. While standard volume tables (Chapter XI) differentiate the volumes of trees of different D.B.H. and heights, they make no distinction between trees having paraboloidal forms and those approaching the cone or neiloid (§ 26) in form, but seek to average the differences in volume caused by these variations. Occasionally two separate tables are made for a species, one for old trees, the other for young second-growth, since it has been found that the average volume of trees of these two age classes differed considerably. Any such difference, whatever its cause, is due to difference in form as indicated above, for trees which have the same D.B.H. and height.

Volume tables have come to stay, since they substitute accurate measurements of D.B.H. and of height, which may be checked by calipers or hypsometers (§ 193), for too exclusive a use of the eye, and for the very uncertain method of guessing at or figuring out the volume of an average tree whose dimensions are in turn arrived at by guess or judgment.

The difficulty of having to depend solely on volume tables of this character lies not in the tables themselves but,

(1) in their incorrect application (§ 124);

(2) in their not being based on the same factors of volume determination as are desired for the estimate;

(3) in the possibility of not having any tables and being forced to construct them. To summarize here the factors in which the tables must agree with the basis of estimating we find: (*a*) Choice of unit of measurement as board feet, specific log rules, cross-ties, cords. (*b*) Closeness of utilization in tops and stump. (*c*) Point of diameter and height measurement. (*d*) Thickness of bark. (*e*) Variations caused by form independent of diameter and height.

For these reasons the demand for some form of universal volume table in estimating is very strong.

The substitution of a fixed taper per log, and the use of tables showing volumes for trees of the same diameter and height but with different rates of taper (§ 122) is an attempt to differentiate between trees with different form, but, in effect, this plan assumes that all trees have the same form, that of the frustum of a cone and differ only in being tall or short, or tapering slowly or rapidly up to the top diameter.

The only satisfactory basis of a universal volume table is one in which all three of the variables, namely diameter, height, and form classes are distinguished. In tables based upon diameter and height only, no record of form is shown. The volumes as given in the table do not indicate whether the tree is full-boled or conical. This drawback is further aggravated by the use of board-foot log rules whose values are not interchangeable.

167. Taper Tables, Definition and Purpose. There are two methods for recording differences in the form of trees, form tables or taper tables, and form classes or form factors.

A table which does not show the volume of the tree, but shows the actual form by diameters at fixed points from base to tip, is commonly termed a *taper table.* From such a table, the volume of the average tree for each diameter and height class can be measured as readily in the office as from the felled tree. Tables of volume can thus be constructed from a taper table, using any desired unit of product, such as cubic feet, board feet or piece products. They therefore form the basis for any required future volume table. For this reason, if taper measurements are taken at regular intervals, preferably 8.15 feet, from stump to top of tree, they constitute a permanent scientific record of tree form which will make it unnecessary to measure felled trees again for new volume tables.

168. Methods of Constructing Taper Tables. Taper tables are based on total height and hence they should record the form of the entire bole.

A separate table is required for each height class showing the taper of trees of each diameter in this class; e.g., for white ash [1] tapers are shown for trees of 10-foot height classes from 30 to 120 feet.

For each height class, and D.B.H. class, the diameter of the tree inside bark must be given at each fixed point, 8.15 feet or multiples thereof above the stump.

The bole, below D.B.H., tapers much less regularly than above that point, but a complete taper table should give the average diameter inside bark preferably at 1, 2, 3 and 4 feet from the ground.

In Table XXXIII, p. 198, stump tapers are given, the diameter inside bark at B.H. and the upper diameters at 8.15-foot intervals from stumps taken as uniformly 1 foot high. But one class is shown, namely, 90-foot trees. A similar table is constructed for trees of each separate height class, such as 80-foot or 70-foot trees.

When the taper measurements have been taken at fixed points on all trees, the average diameters at these points may be obtained directly from the original data. The process is shown in Table XXXIV.

[1] Bul. 299 U.S. Dept. Agr., The Ashes, W. D. Sterrett.

TABLE XXXIII

FORM OR TAPER FOR WHITE ASH TREES OF DIFFERENT DIAMETERS UNDER 75 YEARS OF AGE, GIVING DIAMETERS INSIDE BARK AT DIFFERENT HEIGHTS ABOVE THE GROUND

90-foot Trees

Diameter breast-high.	Height above Ground—Feet													Basis Trees
	1	2	3	4.5	9.15	17.3	23.45	33.6	41.75	49.9	58.05	66.2	74.35	
Inches	Diameter inside Bark—Inches													
8	9.2	8.5	7.9	7.3	6.8	6.4	6.0	5.5	4.9	4.2	3.3	2.3	1.4	
9	10.4	9.5	8.9	8.2	7.6	7.2	6.8	6.2	5.5	4.8	3.8	2.7	1.7	
10	11.7	10.6	9.9	9.1	8.5	8.0	7.5	6.9	6.2	5.4	4.3	3.1	1.9	1
11	12.9	11.7	10.9	10.1	9.3	8.7	8.2	7.5	6.8	6.0	4.9	3.5	2.2	1
12	14.1	12.8	11.9	11.0	10.2	9.6	9.1	8.3	7.6	6.6	5.4	3.9	2.5	3
13	15.3	14.0	13.0	11.9	11.0	10.3	9.8	9.0	8.2	7.3	5.9	4.3	2.8	6
14	16.5	15.1	14.0	12.8	12.0	11.2	10.5	9.8	9.0	7.9	6.5	4.9	3.2	7
15	17.6	16.2	15.0	13.8	12.7	11.9	11.2	10.4	9.6	8.5	7.0	5.3	3.5	4
16	18.8	17.3	16.1	14.7	13.6	12.7	11.9	11.1	10.3	9.2	7.6	5.7	3.9	2
17	20.0	18.4	17.1	15.6	14.5	13.4	12.6	11.8	11.0	9.8	8.1	6.2	4.2	
18	21.2	19.7	18.2	16.5	15.3	14.2	13.3	12.5	11.7	10.4	8.6	6.2	4.6	1
19	22.3	20.6	19.2	17.4	16.1	14.8	14.0	13.2	12.3	11.0	9.2	6.7	4.9	1
20	23.5	21.7	20.2	18.4	17.0	15.7	14.7	13.9	13.0	11.5	9.7	7.2	5.3	
21	24.6	22.8	21.3	19.3	17.7	16.3	15.3	14.5	13.7	12.2	10.4	8.2	5.8	
22	25.8	23.9	22.3	20.2	18.6	17.1	16.1	15.3	14.5	12.9	10.9	8.6	6.1	
														26

Original Curves, Tapers Based on Heights above Stump.[1] In the form shown, these average tapers or upper diameters may be insufficient to bring out the true average form for large numbers of trees. The irregularities of form, occasioned by the variation in form of individual trees and lack of sufficient number of trees to secure a true average by arithmetical means, are best shown by plotting the forms of the resultant average trees. For this operation, height above stump is taken as the independent variable plotted on the horizontal scale while upper diameter is the dependent variable plotted on the vertical scale. A separate curve is required for trees in each D.B.H. class.

[1] The details of constructing taper curves are fully discussed by W. B. Barrows, Proc. Soc. Am. Foresters, Vol. X, 1915, p. 32.

TABLE XXXIV

TAPERS OF LOBLOLLY PINE, TWO TREES *

Tree Class, 15-inch, 80-foot

D. B. H.	Stump	Height above Stump—Feet									Total height.
	2	8	16	24	32	40	48	56	64	72	
		Diameter inside Bark—Inches									Feet
15.4	16.1	13.5	12.4	11.4	11.7	11.1	10.0	8.8	5.9	3.0	76
15.1	15.0	13.3	13.2	12.5	11.9	10.8	9.6	8.0	6.3	3.8	84
30.5	31.1	26.8	25.6	23.9	23.6	21.9	19.6	16.8	12.2	6.8	160
Average 15.2	15.5	13.4	12.8	11.9	11.8	10.9	9.8	8.4	6.1	3.4	80

* Data taken from loblolly pine tapers at 8-foot intervals, without stump tapers. Two trees.

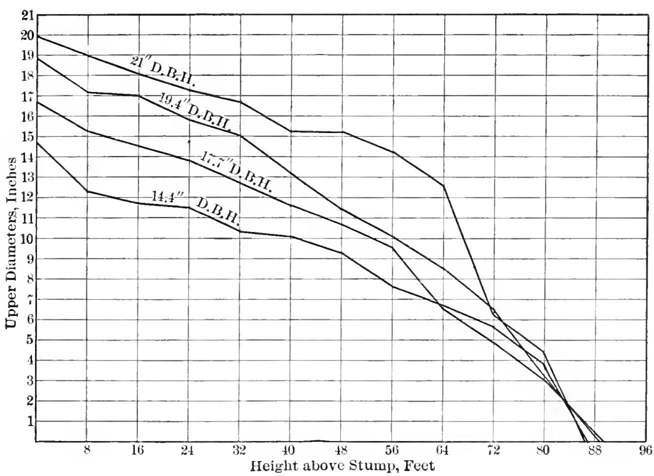

FIG. 32.—Actual upper diameters or tapers of four loblolly pine trees, inside bark, based on height above stump, plotted to show form of trees. 90-foot trees.

From these plotted forms of trees the diameters at any desired point or height on the boles can be read.

The nature of these original averages is shown in Fig. 32 in which four single trees of different D.B.H., 14.4 inches, 17.7 inches, 19.4 inches, and 21 inches, but falling in the same height class, 90 feet, are plotted. The eccentricities of form in this table are partly due to branches, partly to failure to obtain the true average diameter at each point, and partly to the natural variations in form for individual trees.

As in the preparation of volume tables, the averages obtained from a number of trees are more consistent than the forms of single trees. A graph plotted in this manner from averaged upper diameters instead of single trees, will be fairly regular in the relation of the curves for successive D.B.H. classes and will resemble Fig. 35, p. 204.

When, as is sometimes the case, the upper diameters are measured on logs as cut by the saw crews, in irregular lengths, and hence fall at different heights above the stump, only the measurements falling at the same height can be averaged, as at 12, 14, 16, 18 and 20 feet. This will be done, and all of the resultant upper diameters for trees of a given D.B.H. and height class will be plotted, to obtain the curve of average form. From this curve, the desired upper diameters at regular intervals of 8 or 10 feet can be read.

These curves of form are not in final shape for a standard table of form. Although the averages are improved by the use of larger numbers of trees, the values will be slightly irregular for two reasons. The average D.B.H. may be larger or smaller than the exact inch class desired, and the forms of the average trees of the consecutive D.B.H. classes may vary in fullness. These two sources of variation are well shown in Fig. 32. There is no reason why average 21-inch and 18-inch trees should have a fuller form than 19-inch trees.

Values required are based on exact D.B.H. classes, and vary regularly with D.B.H., as would be the case were sufficient trees included in the mechanical average.

Second Set of Curves, Tapers Based on D.B.H. For trees of each successive D.B.H. class which have the same total height and the same general form, the diameters at each given height on the boles will diminish in direct proportion with diminishing D.B.H. If D.B.H. is then taken as the independent variable in a second set of curves, and upper diameters plotted on D.B.H. as the dependent variable, the form of these new curves approaches straight lines as did those of volume based on height (§ 141), and the irregularities between the forms or upper diameters of different average trees are easily reduced. In this second operation as in the first, the trees of a given height class form the basis for a set of curves; e.g., 90-foot trees only are included in the one set of taper curves, separate sets being required for 70-foot or 80-foot trees. For this set of curves the same scale can be used for both variables, e.g., 2 inches = 1 inch.

To plot this second set of curves the values for a given tree, or set of tapers, are transferred to this new sheet, in which process the strip method described in § 141 is most convenient. The diameter of upper tapers diminishes with increasing height; each tree is plotted in a single vertical column, with the D.B.H. at the top.

The D.B.H. column must be that of the actual average D.B.H., e.g., 14.4 inches, not 14 inches. When each set of values has been transferred and plotted above its respective D.B.H., the points representing equal heights above stump are connected by lines. The guide line for this set of curves is a line drawn at 45° angle whose value would be D.I.B. = D.B.H. For any tree, the D.I.B. at D.B.H. is less than the D.O.B., and at upper points, D.I.B. is still less; hence all points above D.B.H. will fall below this line.

Regular forms such as are shown in Fig. 35 could be drawn directly on Fig. 32 guided by the original averages, which will usually be far more regular in themselves than those shown in the diagram. But the desired shifting of the basis to exact D.B.H., e.g., 14 inches instead of 14.4 inches, and the far greater accuracy in harmonizing tapers secured by plotting (Fig. 33) makes the method of plotting a second set of curves almost obligatory.

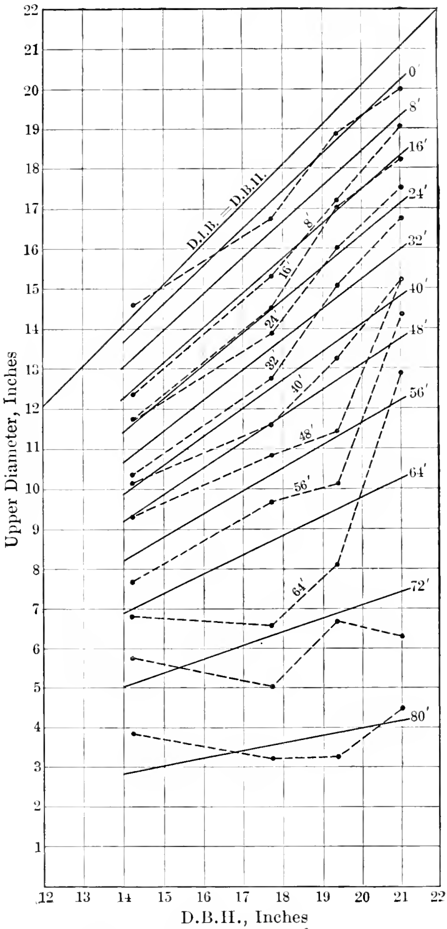

FIG. 33.—Tapers of the four trees shown in Fig. 32, plotted on basis of D.B.H. for each 8-foot point, and results evened off by curves. Separate curves are made for each height above stump. Effect is to reduce the irregularities of form in Fig. 32.

With more regular original averages, the curves will coincide very closely with the original data, instead of showing the wide variations indicated in this figure, caused by the great irregularity of the original unharmonized values of Fig. 32.

The effect of this second plotting upon the irregular forms shown in Fig. 32 is illustrated in Fig. 35, in which the curved or harmonized tapers from Fig. 33 are replotted in the original form.[1]

The values when read from the curves are taken from the ordinates representing exact diameter classes. This set of curves therefore is evened off for values of the diameter classes, and progresses regularly by 1-inch or 2-inch diameters.

Third Set of Curves, Tapers Based on Total Heights of Trees. We now have, first, true averages of the original form of each separate class, second, true averages for exact diameter classes instead of for average diameters larger or smaller than these exact classes. Both

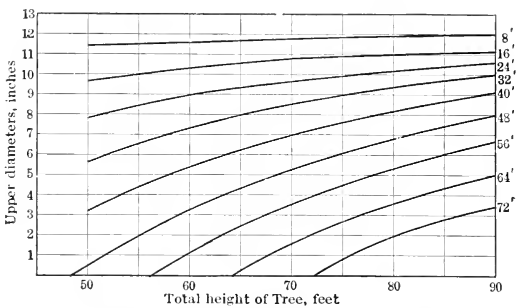

FIG. 34.—Tapers based on total heights of trees. For trees of the same D.B.H. class. 14-inch trees.

sets of curves deal, however, only with one separate height class. It may happen that the trees of the 80-foot class are all slender, tapering trees, while those of the 70-foot or 90-foot class are more cylindrical. There is no reason why in a general table which seeks average form, the accidental departure of form from the average, by a set of trees in one height class, should be accepted if this deviation can be easily shown and corrected.

To do this, it is necessary to compare the upper diameters of the trees of different height classes, at the same points on the stem. D.B.H. must therefore be eliminated as a variable and height substituted.

[1] Since height above stump is the basis of curves in Figs. 32 and 35, the tree form is shown as if lying on its side. The diameter, instead of being plotted symmetrically on both sides of an axis, is plotted on the vertical scale above the base of the figure. But by holding this figure at right angles, the form of the bole is suggested.

A set of curves (the third) will therefore be made from all trees of the same D.B.H., such as the 14-inch class. In this set the independent variable which is plotted on the horizontal scale is the total height of the tree in feet. The dependent variable is diameter or taper at upper points, as in all the graphs used in this method.

The set of points, which is transferred from curves in Fig. 33 and falls in the vertical column above the height of the tree, is the diameter of a 14-inch tree, 90 feet high, at each taper measurement, the larger diameters, beginning with D.B.H., falling highest in the column.

After each series of points for 14-inch trees, representing trees of different total heights as 80, 70, 60 and 50 feet, has been taken from the separate sets of curves prepared in step 2, for each of these height classes, and plotted successively on Fig. 34, the points representing diameters at the same height, e.g., at 8 feet from stump, are connected.

Irregularities in the resultant curves show departure in form for one height class as compared with others. By smoothing out these curves, the tapers of trees of different height classes are harmonized. The scale used in this set is 5 feet per inch for the horizontal scale, 2 inches per inch for the vertical scale. In Fig. 34 only the resultant harmonized values are shown

Fourth Set of Curves, Tapers Replotted on Basis of D.B.H. To utilize the data from Fig. 34 the values may be read off direct, forming tables, but it is customary to have these tables classified by height classes, as in Fig. 33 instead of by diameter classes. To bring together these values, the curved values for the separate diameters may again be assembled on one sheet as in Fig. 33 with a separate sheet for each height, diameters on the horizontal scale, upper diameters on the vertical scale, and a curve for each fixed height above the stump. This replotting should still further iron out any irregularities in taper values. The taper table can be read from this set direct, but only for the fixed heights given in the table, e.g., for 8, 16, 24 feet, etc.

Final Set of Curves, Tapers Replotted on Basis of Height above Stump. One further step completes the curves of form, by restoring them to the shape of the separate trees as shown in Fig. 32. In this final step the values are plotted as for Fig. 35, with separate graphs for height classes, height above ground on the horizontal scale, upper diameter or tapers on the vertical scale and a curve for each diameter class.

The form of such a set of tapers for universal use should be graphic, thus showing the upper diameter at every point on the stem. From this set of graphs, board-foot volume tables for any log rule, length of log, upper diameter limit or stump height, cubic volume, number and dimensions of ties, poles or other piece products, can be determined. It is apparently a universal basis for the construction of volume tables, and while the number and diversity of such tables would remain as great as ever, the field work of gathering data on form or volume would be obviated by the printing and general distribution of the graphs giving the average form, from which tables could be prepared in the office for whatever use was desired.

169. Limitations of Taper Tables. The real weakness in this apparently sound method of preparing the basis for volume tables lies in the fact that the result obtained does not differentiate form classes of trees, but averages them on exactly the same basis as do the standard volume tables. Its only merit therefore is in the transferring of records

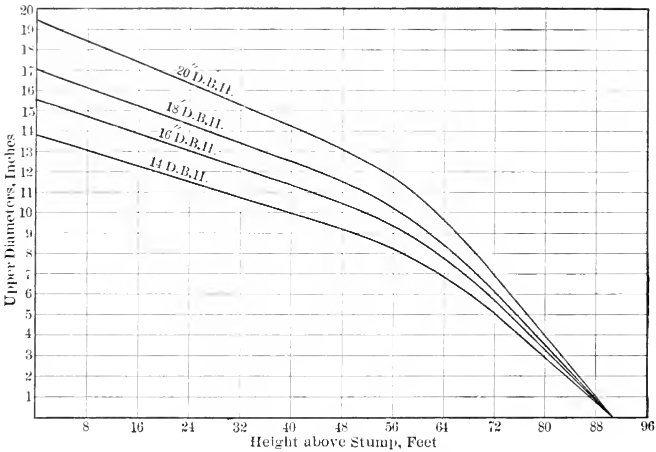

FIG. 35.—Tapers read from Fig. 33 for four diameter classes, showing effect of harmonized curves in smoothing out the irregularities of form shown in Fig. 32.
Similar curves are obtained from tapers replotted inform of Fig. 33 from curves shown in Fig. 34. Such tapers will be harmonized by diameter and height classes.

of average tree forms to the office as a basis for future volume tables. The form of the tables is bulky and does not lend itself to the further extension necessary to show the form of trees of several different form classes for each diameter and height class, though in the preparation of standard volume tables by the U. S. Forest Service, such taper tables have been extensively employed. The use of taper tables in connection with standard form classes as a basis for universal volume tables is discussed in Chapter XVI.

By preparing separate sets of taper tables for each form class based on absolute or normal form of trees (§ 174) a permanent basic standard of tree form is obtained which will fill all possible future requirements.

CHAPTER XVI

FORM CLASSES AND FORM FACTORS

170. The Need for Form Classes in Volume Tables. Trees which have the same D.B.H. and total height may vary in form, as shown, according as the tree is full boled, with "good" form, or concave boled, with "bad" form. These gradations of form correspond with differences in cubic volume. In order to further classify the volumes of trees of the same D.B.H. and height, this range of volume due solely to form must be separated into arbitrary classes or divisions. Such a series is based on measurable differences in form, and the classes thus established are termed *form classes*. The adoption of form classes as a third variable in constructing volume tables has been retarded in this country by the necessity for expressing volumes in terms of board feet, by the labor of constructing even the simpler tables based on diameter and height, and by the belief that the variations due to form could be more simply overcome by averaging them.

A second difficulty lay in the application of such form-class tables in timber estimating, since cruisers were unaccustomed to judging upper diameters by eye with the accuracy needed to distinguish between the form classes. Differences in taper were readily recognized, but differences in form were further obscured by the method of using merchantable top diameter limits instead of total height. Practical cruising did not seem to require such tables. But with the increasing use of the cubic foot and the cord for pulpwood and in second-growth timber, and the need for closer estimating, the desirability of distinguishing form classes in volume tables is increasing. Such efforts as have been made so far in this country follow standards prevailing in Europe, where the universal use of the cubic unit, close utilization and high values have made it necessary and possible to obtain more accurate measurements of the standing timber.

One great possibility in this field is the demonstration that when form classes are distinguished and the true form of the tree inside the bark is made the basis, all species of trees will be shown to have practically the same forms and total volumes for the same form classes; hence a single general table so classified would suffice for all field work. Were this fact established, a basic table might then be constructed for each of various units of measure in addition to cubic feet. Once the average form class of the trees or stand were determined, then volumes could be obtained from these basic tables. Recent research in Sweden tends to show that this generalization holds true for certain species already investigated, namely spruce, fir, larch and Scotch pine.

171. Form Quotient as the Basis of Form Classes. The first real step towards a solution of this problem was made by Schiffel in 1899, who developed a method of expressing differences in form, previously used (Schuberg, 1891) and known as the *form quotient*, which is the percentage relation that the diameter at one-half the height bears to the D.B.H.

The differences in form of the entire boles of trees (Chapter III) are expressed by their divergence from a cylindrical form through a series marked at definite stages by the complete paraboloid, cone, and neiloid. Each of these solids can be measured by Newton's formula:

$$V=(B+4b_{\frac{1}{2}}+b)\frac{h}{6}.$$

The middle point on the stem of a tree, regarding the entire bole as a single complete solid, is evidently the point of greatest weight in determining its form and volume with respect to the cylinder whose base is B and height h.

By a complicated calculation,[1] Schiffel derives the formula for obtaining at one operation the true cubic contents of an entire stem as,

$$V=(.16B+.66b_{\frac{1}{2}})h.$$

This is known as Schiffel's formula.

Newton's formula, regarding the tree as a perfect, i.e., complete conoid, and the diameter at top as zero would be,

$$V=(.16\tfrac{2}{3}B+.66\tfrac{2}{3}b_{\frac{1}{2}})h.$$

The "universal" character of Schiffel's formula failed to make the headway expected when it was first introduced in the United States for the reasons that, to apply it, one must measure the diameters of trees at one-half the stem height, and that the cubic unit of volume was little in demand.

The really valuable part of Schiffel's work was not the formula, which was nothing new, but the form quotient. This was his demonstration that the true form, and consequently the variation in form of

[1] "New Method of Measuring Conifers," Review by B. E. Fernow of Article by Schiffel, "Über die Kubirung und Sortierung Stehender Nadelholz Schafter," Centralblatt für das gesammte Forstwesen, Dec., 1906, pp. 493–505, Forestry Quarterly, Vol. V, 1907, p. 29.

different trees, could be indicated by the relation between diameter at one-half height and D.B.H. (not diameter at stump).

In its standard form of expression:

$$\text{Form quotient} = \frac{d}{D}.$$

In 1908 Tor Jonson corrected a slight inconsistency in Schiffel's method by insisting that the middle diameter be taken not at the middle point of the stem but at the middle point measuring from B.H. This he termed the *absolute form quotient.* This improvement finally secured a consistent basis for expressing tree forms, eliminated height as a variable, and got rid of the great drawback of butt swelling. The absolute form quotients of trees were now found to vary between .575 and .825, i.e., the diameter at the middle point above B.H. bore this relation to the D.B.H., whether both measurements were taken outside or inside the bark.

It was also discovered that in most cases the form quotient if reduced by a constant would give the form factor for cubic contents of the tree. For instance, J. F. Clark found that the reduction factor for the form quotients for balsam in the Adirondacks was 0.21. This fact is of minor importance since it aids only in obtaining the cubic contents of trees.

This standard of measuring form permitted the classification or differentiation of the third variable of volume, namely, form independent of diameter or of height. Trees could be grouped into form classes expressed by form quotients. Seven main form classes were formed, namely, .50, .55, .60, .65, .70, .75, .80. Five sub-classes were also interpolated as .575, 625, .675, .725, .775. The extreme lower and upper classes shown will be found only in individual trees. The average form class for a given stand will fall usually between .575 and .75 and may be correlated with the density of the stand as shown below.

Character of stand	Form class, based on form quotient *
Poor density	0.575–0.625
Fairly good density	.65
Good density	.675– .70
Overcrowded	.725– .75

* Tor Jonson, 1918.

But most important of all, the question as to whether the form of trees was independent of species, site and region and dependent on general laws, could now be determined.

172. Resistance to Wind Pressure as the Determining Factor of Tree Form. The theory explaining the form of the boles of trees, which is now generally accepted, was first advanced by Prof. C. Metzger, a German. This was, that the stem or bole is constructed as a girder to withstand the pressure of wind. Based on this theory, A. G. Hoejer, a civil engineer of Stockholm, devised the general formula for tree form discussed in § 173. Prof. Tor Jonson applied this formula first to spruce and then to Scotch pine, and demonstrated its correctness; as a consequence, developing the basis for tables of absolute form and volume for trees, and a new method of estimating timber (§ 203).

Jonson's conclusions, based on these investigations, are that tree form depends entirely on the mechanical stresses to which the tree is exposed, and is therefore independent of diameter, and height, and also of species, age, site or any other factor, except as these factors influence the form of the crown. The force of the wind operates on the crown of the tree and is focused or centered on a point representing the geometric center of the crown. The pressure of the wind on the tree crown constitutes a force which compels the tree to construct its stem in such a manner that the same relative resistance to strain is found at all points, the smallest possible amount of material being used. As the concentrated force of the wind strikes a point situated lower or higher on the tree, dependent on the crown area presented, we get larger or smaller taper respectively, which means bad or good form class. As the location of the point of attack of the bending force is determinative of form, this point is called the form point, and can be expressed as a per cent of total height.

Here is a natural law, to which growth of trees, as mechanical structures designed to stand up against wind, corresponds. The full bole of the forest-grown tree in a crowded stand, coinciding with a small crown and high form point, meant that this location of the strain required nearly equal strength along the total length of bole, which could be attained by rapid growth of the upper bole. If the tree were open-grown with a consequent long crown and a low form point, this would permit of smaller upper diameters and require greater strength lower down on the bole.

Since the form of the crown, especially its length, with relation to the length of bole, determines this form point, this relation of crown to bole, expressed by form point serves as an index to classify trees as to their relative form classes or form quotients.

Any variation in average form, such as the admitted fact that the average form quotient increases with age, is explained by a coincident change in this crown and form point relationship. Open-grown trees possess a low form quotient, not because they are open-grown but because the crowns of such trees are long and the form point low. Trees with long clear length and high crowns possess a high form quotient, whether they stand alone or in a crowded stand. Short trees may be full-boled or the reverse—the rapidity of taper as a whole has no effect, but the distribution of the taper, which alone affects the form quotient, will vary with short trees as much as with tall, and on poor soils equally with good.

173. A General Formula for Tree Form. On this basis, if the actual form of trees with the same form quotient is similar, it would be possible to construct taper tables based on each of the three variables, diameter, height and form class, which would apply to all species of trees. To apply this principle there was required a general formula which would give the diameter of a tree of given form quotient, at any point on the stem, and second, a demonstration that the actual measurements taken on trees of this form quotient coincided with the results of the formula.

Once this was shown, the formula would permit of the construction of a set of taper tables of universal application from which in turn any manner of volume table could be derived. This is a more ambitious program than the mere determination of form factors for cubic contents, and promises permanent results.

The formula devised by A. G. Hoejer is based on the portion of the tree above B.H.:

D = D.B.H. inside bark;
l = distance from top of tree to section;
d = diameter of section.

Then

$$\frac{d}{D} = C \log \frac{c+l}{c}.$$

C and c are constants whose value depends upon the form quotient of the tree; i.e., upon $\frac{d}{D}$ when d is measured at one-half height above D. Their value must be found separately for each form class, and will then hold good for diameters at any point on the bole of trees within this class, independent of total height of tree.

Absolute heights are not used in the formula, but percentage or relative heights, regarding the height of any tree above B.H. as 100, and the distance below the tip, of any other section as its per cent of this length, including sections below B.H., whose per cent of height would exceed 100.

In the same way, absolute diameters are not used, but the D.B.H. is taken as 100, and the relative diameter $\frac{d}{D}$ expressed as its proportion of 100.

These upper diameters are then measured at distances equaling tenths of this total height above D.B.H.—thus falling at the same proportional height on each tree; e.g., for the form class 0.70 with diameter at 0.5 of height above B.H., as 0.7 of D.B.H., the values in the formula are:

For upper section,

$$\frac{70}{100} = C \log \frac{c+50}{c} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

For D.B.H. section,

$$\frac{100}{100} = C \log \frac{c+100}{c} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

If equation (2) is divided into equation (1), then

$$0.70 \log (c+100) = \log (c+50) + (0.70-1) \log C.$$

The value of this constant c is then found by trial. Inserting this value in equation (2) the value for constant C is found for the form class. Values for the remaining form classes are found in a similar manner.

With the numerical value of the constants C and c determined, the normal diameter of a perfectly formed tree can be found by this formula at any point on the stem above B.H., and this normal diameter can also be calculated for stump height, thus disregarding the stump taper.

By determining these normal diameters for trees of each D.B.H. and height class, at intervals of one-tenth of the total height, and plotting these diameters graphically, a set of taper curves is constructed (§ 167), for normal tree forms, from which volume tables or form factors can be constructed which will have universal application.

174. Applicability of Hoejer's Formula in Determining Tree Forms. There remained to test accuracy of these results by comparing them with measurements on felled trees. The tests showed that for the conifers measured, spruce, fir, larch and pine, the formula expressed the form of the living tree, when applied inside the bark at all points including D.B.H., and that for species with thin bark such as spruce, the same relations applied when measured outside bark. For Norway Spruce the volumes of individual trees fall within ± 3 per cent of those derived by the formula. But for thick-barked species such as Scotch pine, a poorer form, less cylindrical, was obtained outside bark, which changed the form class, but did not seriously interfere with the application of the method. Claughton-Wallin has since shown that this formula holds good for Norway or red pine (*Pinus resinosa*) and white pine (*Pinus strobus*).

As with all attempts to study the laws of tree form, this formula depends on measuring a diameter which is not affected by the abnormal flare at the butt; hence any tree or species whose butt swelling extends above B.H. will not correspond in form to the diameters in the formula based on this abnormal D.B.H. It was found impossible to use the formula for western conifers since the form quotient $\frac{d}{D}$ was too low for this reason.

For general application, the second difficulty is the factor of bark thickness, whose effect upon the form quotient and form class must be worked out for different species with variable thicknesses of bark, so as to correlate the method with D.B.H. measurements outside the bark, which must continue to be used in practical estimating.

Can these two variables be eliminated for American trees, and taper and volume tables constructed for trees of each form class, thus attaining the goal of universal volume tables?

For second-growth, or young timber, in which the factor of butt swelling will not affect D.B.H., this can be done. Taper tables should be constructed from this normal formula based on diameter inside bark at B.H. The average thickness of bark at B.H. must be determined for the species, and by graphic interpolation these D.I.B. taper tables can be drawn for trees of each D.B.H. outside bark, from which volume tables can be constructed in any desired unit.

For the larger trees or species with butt swelling extending above B.H., as for instance, virgin stands of timber on the Pacific Coast, or Southern cypress, the present practice of adhering to D.B.H. will probably be continued, and trees with variable amounts of stump taper averaged together in volume tables regardless of true form. The only alternative is to attempt a standard measurement of diameter at a higher point on the bole, which will be difficult to adhere to in practice. Approximate rather than absolute accuracy will continue in the preparation and use of these tables for such timber.

When the variable influence of butt swelling is further aggravated by the obsolete practice of basing volume tables on diameter at the stump, no consistent volumes can be obtained to serve as standards for estimating.

175. Form Factors. The form of a tree is a variable independent of diameter or height, while the form of a cylinder does not vary at all. That of a cone is a constant, equal to one-third of the volume of a cylinder of similar height. Taking the volume of a cylinder as the unit of comparison, and dividing the volume of a cone by that of the cylinder of equal diameter and height, the quotient is always .333 or one-third. This can be termed the form factor of this cone, i.e., the factor by which the volume of the cone is derived from that of the cylinder. It expresses the volume of the cone, but not its form. In the same way the form factor of the paraboloid is .5.

Form factors of trees can thus be found by dividing their cubic volume by that of a cylinder of equal diameter and height.

B = Basal area of cylinder equivalent to that of tree;
h = height of cylinder and of tree;
Bh = volume of cylinder;
f = form factor or multiple expressing the relative volume of the tree;
V = volume of tree.

Then

$$f=\frac{Bh}{V},$$

and

$$V=Bhf.$$

Volumes of trees can thus be obtained from the volumes of cylinders, when once the average form factor is known.

The form factor is therefore, in theory, a direct expression of the relative volume of a tree compared with a standard or constant volume, and tables of such factors were expected to give the key to universal volume tables showing form classes. But the diameter of the cylinder which is to serve as the unit or basic volume must first be obtained and must equal that of the tree. If this diameter is taken at the stump or at ground, the butt swelling gives an abnormally large irregular variation in the cylindrical volume. This method is known as the *Absolute Form Factor.*

But the diameter can be shifted to B. H. with the cylinder *equaling the total height of tree as before.* Form factors so calculated give uniform or consistent results from which cubic volumes can be calculated, and are termed *Breast-high Form Factors.* These form factors in turn vary not only with the form of the tree, but with the total height as well, hence could not be used to indicate absolute form. The reason is that the diameter of the basic cylinder is taken, not at a height proportional to the total height of the tree, but at the fixed height of $4\frac{1}{2}$ feet. For short trees this point falls proportionally nearer the tip, with relatively smaller cylinder, than for tall trees of identical form. The breast-high form factor therefore decreases as height of tree increases.

In an effort to overcome this drawback and express form directly by means of form factors, the so-called *Normal Form Factor* was devised, in which the basal area is measured at a point on each tree representing a fixed ratio to the height of the tree. This plan has not proved practical, owing to the difficulty of determining this point rapidly and accurately.

By comparing only the portion of the tree above B.H. with the volume of a cylinder of equal height, the form factor for this portion alone corresponds directly with variations in form for the tree. This is known as *Riniker's Absolute Form Factor.*

The Riniker form factor of trees of each form class was calculated by Jonson from the normal form or tapers of trees of each D.B.H. and height class, taking the diameters at points representing one-tenth of the stem above B.H. Then

$$f=\frac{V}{Bh} \text{ for the bole above B.H. only.}$$

Since form quotients indicate correctly the relative forms of trees, absolute form factors of trees whose form quotients are equal should also be equal. That this is true is indicated by the following test, e.g., from investigations of Claughton-Wallin and F. McVicker:

Species	Form quotient	Cubic form factor	Basis trees
Red pine, Ontario, Can.	65	0.439	11
Scotch pine, Sweden	65	.441	
Red pine, Ontario, Can.	70.3	.480	30
Scotch pine, Sweden	70.3	.484	
Red pine, Ontario, Can.	74.4	.515	40
Scotch pine, Sweden	74.4	.524	
White pine, Ontario, Can.	70.8	.482	9
Scotch pine, Sweden	70.8	.489	
White spruce, Ontario, Can.	65.2	.441	6
Scotch pine, Sweden	65.2	.444	

176. The Derivation of Standard Breast-high Form Factors. The two possible uses for form factors are seen to be, first, an expression of relative forms of trees, second, a means of computing their total volumes from that of cylinders.

It is not possible to combine these two functions in the same table of form factors. The absolute form factors for *total* tree volume cannot be correlated with D.B.H. nor with any other point on the bole, while the form factors which are based upon D.B.H. and total volume are not absolute but vary with height. But these Riniker's absolute form factors can be used to obtain a set of breast-high form factors which represent the relative volumes of normally formed trees of all diameters and heights when compared with the corresponding cylinders.

The steps in this calculation are:

1. Compute the Riniker form factor for trees of each form class.

2. Obtain the normal stump diameter from Hoejer's formula. Stumps were taken as 1 per cent of the height of the tree. The actual stump diameter is always too large, due to butt swelling. The conception of a normal stump diameter is the diameter which the stump would have if the normal curve of the stem from top to D.B.H. were prolonged downward to stump height.

3. Find the diameter at one-half the distance from stump to top, by Hoejer's formula.

4. Express both the stump diameter and the diameter at one-half height in per cent of D.B.H. and compute the new form quotient, this time based on height above stump.

If diameter at $\frac{1}{2}h = 67.7$ per cent of D.B.H.

Stump diameter $= 103.0$ per cent of D.B.H.

$$\text{Form quotient} = \frac{67.7}{103.0} = 0.657.$$

5. From the table of absolute form factors interpolate for the form factor required to coincide with this form quotient.[1]

6. The basal area corresponding to the normal diameter at the stump is found as follows:

$$D_0 = \text{normal stump diameter};$$

$$D = \text{D.B.H.};$$

$$B_0 = \text{normal basal area at stump};$$

$$B = \text{basal area at D.B.H.}$$

If

$$D_0 = 1.0pD,$$

$$D_0^2 = 1.0p^2D^2,$$

$$B_0 = \frac{\pi D_0^2}{4}$$

$$= 1.0p^2 \frac{\pi D^2}{4}$$

$$= 1.0p^2B.$$

7. Total volume of the stem is then

$$V = B_0hf_0$$

$$= B\,1.0p^2hf_0.$$

8. Breast-high form factor is

$$f = \frac{V}{Bh}$$

$$= 1.0p^2f_0.$$

This series of breast-high form factors shows the diminution with increased height, the cause of which is set forth in § 175. These form factors are given in Table LXXXII, Appendix C, p. 497.

Since form is best shown by taper tables, and volume is best obtained directly from volume tables, the use of form factors in America has but little practical application and has been adopted to a very limited extent. Were the breast-high form factors more regular they would serve as a means of constructing volume tables by graphic methods (§ 138) in which the curves being comparatively straight could be extended and interpolated with less chance for error than by the ordinary methods.

177. Merchantable Form Factors. Form factors based on the merchantable contents of the tree in cubic feet, or upon the net cubic

[1] These absolute form factors are for the entire tree, but are based on the theoretical stump diameter, hence are inapplicable for practical use.

volume utilized as board feet or in any other unit, can be computed by first ascertaining this net volume. The form factor is

$$f=\frac{Bh}{V}.$$

These form factors serve no useful purpose.

178. Form Height. Form height is the product of form times height.

Since $V=Bhf$, tables of form height simply eliminate one of the two multiplications necessary in deriving cubic volumes.

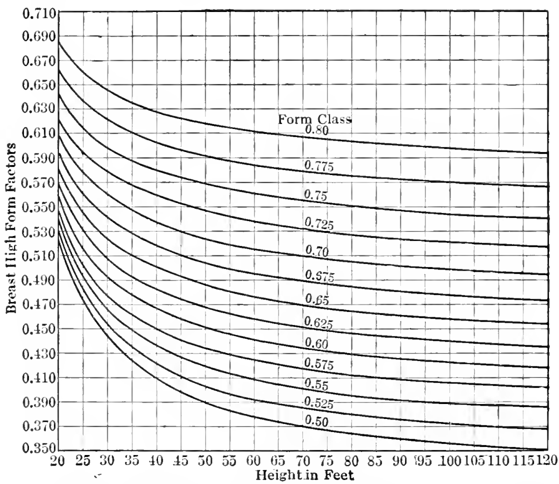

FIG. 36.—Curves of breast-high form factors for form classes from .50 to .80 inclusive, showing effect of height upon the form factor. From Tor Jonson.

179. Form Classes and Universal Volume Tables as Applied to Conditions in America. The standard form classes, when applied to trees of different diameter and height, thus distinguish three variables just as did the universal volume tables based on diameter, merchantable length and rate of taper. Universal volume tables if based on total heights would show volumes for the given unit in three instead of two dimensions; D.B.H., Height, Form Class.

But to derive universal volume tables by form classes to be based on merchantable length instead of total height would not be so simple, for the following reasons:

If taken to a uniform or fixed top diameter, trees with a high form quotient would be cut higher in the top and fall into a different merchantable height class than trees with a low form quotient. Therefore, for trees of different form quotients, to attain the same merchantable top diameter, trees with the lower quotients must be taller than those whose form quotient is high. Hence total and merchantable heights are not interchangeable for trees whose form quotients differ.

If taken to variable top diameters, this second variable will make it practically impossible to distinguish form classes based on total height in the volumes given, for these tops would not vary in any definite relation to total height or form.

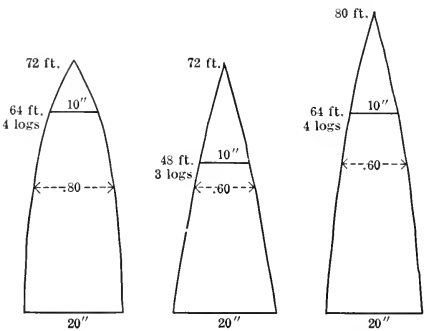

Fig. 37.—Effect of cutting to a fixed top diameter, upon merchantable height of trees having different form quotients. A form quotient of .60 requires either a shorter merchantable length or a taller tree than one of .80.

As long as merchantable rather than total heights are used in volume tables and timber estimating, form classes based on actual form of the tree cannot be used to construct volume tables in which trees of different form are separated, and the principle of averaging the differences in volume due to form must continue to be used for such tables.

But for cubic feet, basic volume tables may be made up giving the volume of each diameter, height and form class. Similar tables can be constructed in any unit of volume, or for any log rule, from tables of normal taper. In applying these tables, the method would be not to attempt to tally each tree in its proper form class, but to determine average form classes (§ 171) for stands or other subdivisions of the forest, the volumes for which can be taken from this basic table to form a standard volume table for the trees to which it applies. Not over three such tables would be apt to be needed for any tract, however large and varied.

Methods of rapidly determining the form class of sample trees, in order to apply such a system, are given in § 201, § 202 and § 203.

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CHAPTER XVII

FRUSTUM FORM FACTORS FOR MERCHANTABLE CONTENTS IN BOARD FEET

180. The Principle of the Frustum Form Factor. In an effort to simplify the construction and improve the accuracy of volume tables for board feet based upon merchantable heights and top diameters, a merchantable form factor has been devised by Donald Bruce.

Timber cruisers in the Pacific Northwest had already made use of the similarity in form of the merchantable portion of the tree to that of the frustum of a cone, but had neglected the possible differences in form and volume between the cone and the merchantable bole. The new method adopts the frustum of the cone as the basic volume, instead of the cylinder as for the form factors discussed in Chapter XVI, and then compares this volume with that of the tree, to determine their true relation. This relation is expressed as a form factor in the usual manner.

V = volume in tree;

V' = volume in frustum of cone;

f = form factor.

Then

$$f=\frac{V}{V'}$$

and

$$V=V'f.$$

The contents of this frustum were measured as the scaled board-foot contents of cylinders representing the logs into which the bole would be cut. The length of these sections was fixed at 16 feet, and their upper diameters were determined by the diameter of the frustum at the required point. The form factor obtained by comparing the total scaled volume of the merchantable bole with that of the frustum so measured is termed the *Frustum Form Factor* and is a merchantable form factor having values close to 1, since the deductions from full cubic contents of bole have been made both in the frustum and in the tree.

The merits of the frustum form factor method for constructing volume tables are that it applies directly to the merchantable portion of the tree, on the same basis as used in timber estimating to top diameters, and that the values of the form factors tend to vary but little from a straight line, thus permitting the construction of curves of board-foot volume with greater accuracy than when volumes are plotted directly (§ 138). This advantage permits of constructing such tables on the basis of fewer measurements of felled trees.

181. Basis of Determining Dimensions of the Frustum. The top diameter of the frustum is supposed to coincide with the top diameter inside bark of the merchantable length of each tree class. The diameter at its base, which is at stump height is arbitrarily fixed as equal to D.B.H. outside bark. No pretense is made that this form factor is a scientific basis for studying tree form. Actual D.I.B. at stump may or may not coincide with D.B.H. outside bark. The base of the cone must be correlated with D.B.H. rather than with stump diameters (§ 175) and this assumption is satisfactory.

Since the sides of a cone are straight, the upper diameters of each "log," or standard length into which this frustum is divided, are determined by proportion, to the nearest $\frac{1}{10}$ inch.

In calculating the volumes of the frustums of cones the determination of the diameter at the top of each successive 16-foot log for cones of different top and base dimensions is best performed by plotting the form of the cone on cross-section paper, on which the vertical scale shows diameters and the horizontal scale shows heights in feet. Plot, first, D.I.B. equals D.B.H. at zero or stump height; next, top diameter inside bark at the merchantable height. Connect these two points by a straight line representing the side of the frustum. The diameters inside bark at top of each log are then read at 16 feet, 32 feet, etc., to the nearest $\frac{1}{10}$ inch. The log rule should be tabulated to show the values for each $\frac{1}{10}$ inch.

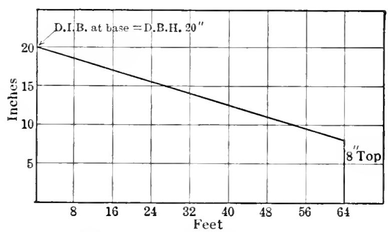

FIG. 38.—Method of plotting a frustum from which to determine the top diameters of the logs which it contains.

182. Character and Utility of Frustum Form Factors. That the frustum form factor is a practical rather than a scientific basis of measurement is shown by the following facts: The absolute form factor of the total contents of the bole (§ 175) would be 0.5 when the tree has the form of a paraboloid. A truncated portion of the bole, with the rapidly tapering top eliminated, when compared with a truncated cone having the same top diameter, represents the lower portion of a cone of considerably greater height than that of the tree or paraboloid.

For cone and paraboloid (or tree) of equal total height, the form factor of the tree, compared with the cone is $\frac{0.5}{0.33}$ or 1.50, since 0.5 and 0.33 are the respective volume form factors of the paraboloid and cone when compared with a cylinder of equal dimensions.

The nearer the top of the tree this upper diameter falls, or the closer the degree of utilization, the shorter will the completed cone become, until it coincides with the paraboloid in height. In the same manner the frustum form factor will increase, until it reaches a maximum of 1.50 for the completed cone.

Chandler,[1] in an extensive investigation of the frustum form factor of northern hardwoods, birch, beech and maple, determined that this factor was independent of species, site or other influences, and independent of diameter and height, but was dependent on the two factors, form quotient, and taper ratio. The form quotient agrees in principle with that of Tor Jonson. Based on D.B.H., instead of stump, it was computed for merchantable rather than total height, by first subtracting diameter at top or d from both diameter at B.H. and at middle of merchantable length. Then

$$q_2 = \frac{d_2 - d}{D - d}.$$

The taper ratio is the ratio between top diameter of merchantable bole, and D.B.H.

Merchantable cubic frustum form factors were found to diminish as form quotient diminished and as taper ratio increased. The first result is obvious. The second confirms the conclusions set forth above as to the effect of close utilization in increasing the frustum form factor.

These researches have definitely proved, on an empirical basis, the fact that, other things being equal, frustum form factors based on a fixed top diameter do not express a scientific relation between the form and volume, but will vary with the relation between cone and paraboloid. In its final analysis, the frustum form factor is an endeavor to express the paraboloidal forms of trees by the use of frustums of cones and the application of a correction or form factor. Although a great improvement over older methods if intelligently applied, it is not a universal method, since its results vary with taper ratio, butt swelling, bark thickness, and the top diameter utilized.

On the other hand, the natural divergence in the total form and cubic volume of trees which gives rise to the variation in form quotients of from 0.575 to 0.8 is overcome in a marked degree by the substitution of the merchantable frustum form factor since, first, trees with a high-form quotient and of the same total height will be cut higher in the tops than those with a low-form quotient (§ 179). The merchantable form factor in itself coincides with this greater utilization and therefore approaches closer to unity, for both forms. If all trees are utilized to a fixed top diameter, a cylindrical tree, being cut nearer to its tip than a conical tree, would have fallen into a larger total height class than the conical tree, hence its per cent of cylindrical contents would have been much greater for merchantable form factor than that of the conical tree—a difference not appearing in the frustum form factor. Second, where the actual top diameter is made to coincide with the point at which the tree is commonly utilized instead of with a fixed top, there is apt to be still closer approach to unity in the form factors. The length and character of the crown usually determines the amount of taper from the base of the crown to the tip of the tree and consequently its distribution on the stem (§ 172). In rough utilization, the last saw cut tends to bear a direct relation to the length of crown and to fall nearer to the base of the crown than to its tip. This is especially

[1] Bul. 210, Vermont Agr. Exp. Sta. 1918.

true of hardwoods with branching crowns. Measured from this point, the frustum of the tree will not differ greatly from that of either a cone or a paraboloid.

A great source of irregularity in frustum form factors, as in absolute form factors for cubic contents, is found to be the influence of butt swelling extending above B.H. and second, the influence of thickness of bark. Both of these factors reduce the proportion of woody contents to the dimensions and consequently reduce the form factor.

183. Calculation of the True Frustum Form Factor. A far more serious difficulty in the use of the frustum form factor lies in securing the exact coincidence of the top diameters of the frustums, used as the unit or standard for volume, and the average top diameters of the trees whose volumes are to be compared for the determination of the form factors. There is but one exact method, namely to compute the form factors of a given height separately for each tree whose D.B.H. and top diameter differ even by $\frac{1}{10}$-inch, by using a frustum whose three dimensions exactly coincide with those of the tree frustum. This method gives the most consistent form factors. The results for long-leaf pine given in the table on p. 222 were obtained by this method.

This method can be simplified by first averaging together for all the trees in a diameter and height class the four factors, volume, D.B.H., height, and top diameter. The frustum of a cone having these average dimensions is then used to determine the frustum form factor of the class, by comparing its volume with that of the average tree of the class. While less accurate, this method reduces the computations considerably and is within the required limits of accuracy of the method.

By this method, the computation of the frustum form factors is the first step in the construction of the volume table for which they are intended.

184. Calculation of the Volumes of Frustums. Influence of Fixed versus Variable Top Diameters. The purpose of the frustum form factors thus obtained is to make possible the construction of a volume table in board feet, by applying these factors to the volumes of frustums of cones. This may be done in the office, once the factors are known and the dimensions of the frustums determined.

The second step is therefore to determine these dimensions of frustums of cones. The base is fixed, being equal to D.B.H., in 1- or 2-inch classes. But the top diameter of these cones is a source of trouble. As seen in the construction of volume tables (§§ 157–158) the top diameters to which trees are actually utilized tends to decrease as height increases, and to increase with D.B.H. The table will be based on one of two plans, a fixed top diameter, or variable top diameters coinciding with actual utilization.

Whichever basis is adopted, the top diameters of the frustums must coincide with the average top diameter of the merchantable boles, whose volume is sought. If frustums having a fixed top diameter limit are used, the form factors should have been computed from trees measured to this same top diameter. If on the other hand, an attempt is made to base the table on variable or actual used top diameters, then the average actual top diameter for each diameter and height class should first be found and the frustum having the requisite top dimension for each class computed.

TABLE XXXV

True Frustum Form Factors for Longleaf Pine, from Frustums Whose Top Diameters Coincide Exactly with the Average Top Diameter of Trees of Each D.B.H. and Height Class

Merchantable Length in 16-foot Logs

D.B.H.	2	2½	3	3½	4	4½	Averaged by diameter, Weighted
Inches	Frustum Form Factors						
12	0.98	0.98	....	....	....	....	0.980
13	.97	1.21	0.99	....	....	....	.992
14	.96	.87	.97	1.03	....	....	.952
15	.90	1.01	1.03	1.05	....	....	.958
16	.92	....	.94	1.04	0.94	1.10	.953
17	.89	.95	.91	.99	.99	....	.932
18	.89	.98	.90	.96	1.13	1.00	.934
19	.96	.90	.94	.98	.99	....	.954
20	1.05	.95	.88	.97	.94	.99	.937
21	.90	....	.88	....	.94	.92	.902
22	....	.92	.89	.94	.96	.99	.938
23	.93	.97	.94	.88	1.00	.91	.926
24	.93	.94	.87	.95	....	....	.921
25	....	.96	.94	.98	1.04	....	1.000
26	.94	....	....	.90	1.07	.90	.934
27	.93	....	.96	.95	.93	.95	.941
28	....	....	....	.93	.80	.101	.913
29	....	....	1.01	.93	....	....	.970
30	....	....	.98	.85	.96	....	.948
31	.94	.80	.84	....	1.13	....	.927
32	....	....	.94	....	.89	....	.915
33							
34	....	.92	....	.85	.80	....	.817
Av'g'd by height, weighted......	0.939	0.961	0.932	0.958	0.966	0.962	Weighted average 0.9468

It is possible, of course, to prepare a table of frustum volumes using fixed top diameters, and compute the form factors of trees for those classes whose top diameters are larger or smaller, but in this case the form factors vary not with form alone but also with difference in volume due to difference in top diameter independent of form. The results are shown in Table XXXVI where an average top of 13.2 inches was used on all frustums.

TABLE XXXVI

FRUSTUM FORM FACTORS FOR 555 LONGLEAF PINES, COOSA COUNTY, ALABAMA, BASED ON AVERAGE TOP DIAMETER OF 13.2 INCHES FOR FRUSTUMS

D.B.H. Inches	Merchantable Length in 16-foot Logs: 2	2½	3	3½	4	4½
	Frustum Form Factors					
14	0.53	0.53	0.54			
15	.57	.59	.50	.55		
16	.71	....	.51	.56	0.53	0.57
17	.67	.76	.65	.69	.60	
18	.88	.55	.72	.74	.77	.69
19	1.03	.81	.84	.81	.78	
20	1.13	1.00	.87	.96	.87	.86
21	1.31	....	.98	....	.85	.79
22	....	1.39	1.00	.99	1.01	.88
23	1.54	1.39	1.19	.98	1.09	
24	1.40	1.40	1.13	1.26		
25	....	1.37	1.34	1.33	1.06	
26	2.60	.95	1.85	1.21	1.47	.97
27	1.97	....	1.52	1.22	1.23	1.14
28	....	....	....	1.26	.97	1.27
29	....	....	1.67	1.35		
30	....	....	1.98	1.37	1.17	
31	2.36	1.04	1.18	1.68	1.51	
32	....	....	1.76	....	1.43	

Such a table serves no useful purpose.

The variation of top diameters actually utilized is shown in Table XXXVII.

The values in this table, evened off by curves, would give proper dimensions for frustums for the volume table desired.

The two steps described mean a double calculation of frustum volumes, first, as a basis of regular form factors, second as a basis of regular volumes. The second set of frustums also serves the purpose of obtaining the volumes for exact diameter and height classes, instead of for the actual average diameters and heights of the trees measured (§ 137).

TABLE XXXVII

ACTUAL AVERAGE TOP DIAMETERS OF MERCHANTABLE LENGTHS, LONGLEAF PINE, COOSA CO., ALA. BASIS 555 TREES; AVERAGE OF ALL TOP DIAMETERS 13.2 INCHES

D.B.H.	Merchantable Length in 16-foot Logs						
	2	2½	3	3½	4	4½	5
Inches	Top Diameters, Inside Bark—Inches						
10							
11							
12	9.5	8.5					
13	9.7	7.5	8.8				
14	9.9	9.2	9.3	8.7			
15	10.4	10.3	8.9	9.1			
16	11.5	....	10.4	9.3	8.6	7.8	
17	11.3	11.5	10.4	10.2	9.1		
18	13.1	12.7	11.5	10.7	9.7	9.6	
19	13.8	12.3	12.1	11.3	10.9	9.2	
20	13.7	13.5	13.1	13.1	12.3	11.6	
21	16.7	....	14.1	13.2	12.1	11.4	
22	....	17.4	14.2	13.7	13.5	11.7	11.0
23	18.0	17.0	15.8	14.2	14.1	13.8	
24	17.4	17.7	16.2	15.9	14.1		
25	....	17.2	17.5	16.7	13.3		
26	21.3	15.4	19.7	16.9	17.7	14.1	
27	21.6	....	19.4	16.3	17.1	16.0	
28	....	....	....	17.4	16.2	16.6	
29	....	....	20.5	18.8			
30	....	....	24.0	20.8	16.2		17.3
31	25.3	16.4	18.3	14.6	17.8		
32	....	....	23.2	....	21.2		
33							
34	....	26.8	....	21.0	22.4		

Of the two methods, the use of a fixed top diameter is preferable wherever utilization does not depart too far from this standard. If necessary, such a table of volumes could be corrected for actual utilization, by subtracting the per cent of volume lost by cutting to a lower point and larger diameter. In this case the same method must be used in estimating the standing timber, namely, to tally the heights of the trees to the fixed top diameter used, and then discount for waste.

185. Construction of the Volume Table from Frustum Form Factors. A Short Method. The third and final step is to construct the volume table by multiplying the volumes of the frustums by the form factors for each class.

Frustum form factors can be computed if desired, in cubic feet. For board feet, any log rule may be used as desired.

A shorter but less satisfactory method is to first determine the top diameters of the frustums to be used in the base table and prepare the table of frustum volumes; second, to compute the arbitrary form factors which are obtained by dividing the average volumes of the trees in each class by the volume of the proper frustum, disregarding the possible difference in top diameter and average height for the class; and from these factors, to construct the volume table. This method works best when fixed top diameters are used in logging and the differences in top diameters between frustums and trees is small.

The method of frustum form factors has resulted in such a marked increase in accuracy and economy in preparation of standard volume tables based on merchantable board-foot contents that it has practically superseded the standard methods of preparing these volume tables, and until total height and tables based on form classes supersede the use of merchantable heights in timber estimating, this method will continue to be used extensively.

186. Other Merchantable Form Factors for Board Feet. Merchantable form factors based on the volume of a cylinder whose height equals the merchantable length in the tree have been proposed by E. I. Terry.

Merchantable volume tables based on the contents of frustums of paraboloids whose top diameters equal one-half D.B.H., scaled in 16-foot logs, have been computed by the Forest Service. These correspond in principle to the basic volumes of frustums of cones, and can be used for calculating form factors in the same manner, but offer no special advantage over the frustums of cones for the purpose required.

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CHAPTER XVIII

THE MEASUREMENT OF STANDING TREES

187. The Problem of Measuring Standing Timber for Volume. Standing trees are measured to determine their contents in cubic feet or in terms of manufactured products such as board feet or cross-ties. Trees are measured as a means of determining the contents of entire stands. These may be either average or sample trees, of which only a few are measured, or all of the trees in a stand or part of a stand may be tallied.

The volumes contained in standing trees cannot be measured directly. Even the volume of the logs in the felled tree is *computed from* the measurement of their diameters and lengths. These computations, tabulated as log rules and as volume tables reduce the problem of estimating the volume of standing trees to that of measuring their merchantable lengths and diameters.

The cruiser must determine the height of trees either by instruments based on geometric principles of similar triangles, at considerable expenditure of time or by the eye, which is the only practical method where all or a large portion of the stand is to be so measured.

Still more difficult is the actual measurement of diameters at the top of each log in the standing tree, which must be known when log rules are substituted for volume tables in timber estimating. Instead, the cruiser measures the diameter within reach, that at B.H. or stump, and judges the rate of taper as well as height, by eye, thus arriving at these upper diameters by calculation from a known measurement.

Diameter breast high (D.B.H) is the only actual and accurate measurement which it is practicable to take upon all or a large per cent of the timber. All upper points are either measured on a few trees only, to obtain averages, or else are judged solely by eye; and since such ocular measurements are confined to dimensions, heights or log lengths, and diameters at upper points on the bole, the cruiser is dependent entirely on the computed volumes for these dimensions shown in log rules or volume tables. He may by experience correlate these volumes with their respective dimensions, just as stock buyers learn to guess the weights of animals, and may arrive directly at the volume of the tree or stand, but the method is far more uncertain than if dependence is placed on the computed volumes of the logs or trees as shown in tables.

In the use of volume tables, then, the accepted standards of volumes set by these tables are substituted for guessing as to the contents. The measurements required may be :

1. Diameter at base.
   a. Standardized at D.B.H., outside bark.
   b. Stump diameter inside bark, still in use by old time cruisers.
2. Height of tree.
   a. Total height to tip.
   b. Merchantable height.
      1′. To a fixed top diameter.
      2′. To a variable top diameter.
3. Actual measurement of an upper diameter to determine form (when form classes are distinguished).
   a. At middle of stem above D.B.H. (Jonson).
   b. At middle of stem above stump (Schiffel).
   c. At top of last log.

188. The Measurement of Tree Diameters—Diameter Classes. Stand Tables. Diameters will be averaged in either 1-inch or 2-inch classes. In the East and with species of a small total range of diameters, 1-inch classes are preferable. Especially with such species as spruce and white pine, 1-inch diameter classes are necessary to give a proper basis for determination of the rate of growth, and the number of such classes is not great enough to act as a drawback in estimating.

A stand table is a tabular statement of the number of trees, in each diameter class standing on a given area. By dividing the total stand table by the area in acres, the stand per acre is shown, in which case the trees in each diameter class are usually expressed in decimals to two places, e.g., 12-inch class, 4.63 trees, etc.

On the Pacific Coast, with a wide range of diameters running up to 60 inches or over, it is unnecessary and inadvisable to make smaller than 2-inch diameter classes.[1]

189. Instruments for Measuring Diameter. *Calipers, Description and Method of Use.* Calipers have been the standard instrument

[1] In French forest practice, 5 centimeters is the division used. This corresponds to 1.97 inches.

The centimeter divisions were evidently too small and the next convenient division point was 5 centimeters. This is not an argument against the use of 1-inch diameter classes for Eastern species.

for measuring the diameter of standing trees and their use is necessary in taking taper measurements on down timber which cannot be measured with diameter tape. The standard type of calipers for eastern

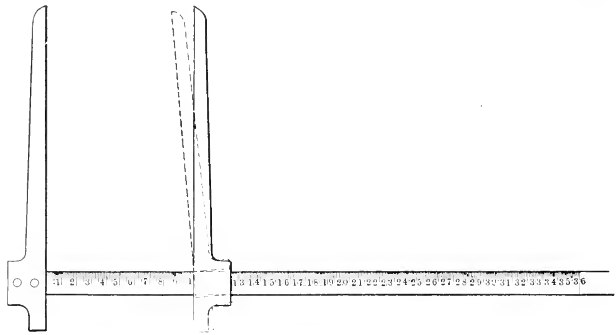

FIG. 39.—Calipers used in measuring the diameters of standing trees.

hardwoods has a beam 36 inches long with arms one-half that length. A smaller type may be used for trees whose diameter does not exceed 2 feet as in spruce or second-growth timber. The standard calipers have a beam graduated on both sides to inches and tenths, and two arms, one of which is bolted to the end of the beam, the other a sliding arm, the beam passing through a slot.

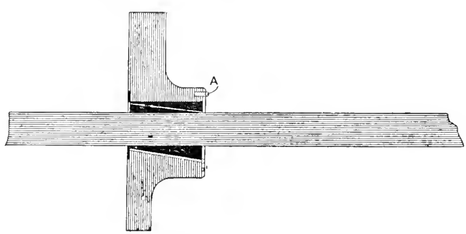

FIG. 40.—Construction of calipers, to secure adjustment of movable arm at right angles to bar.

Fig. 40 indicates the construction of this arm. The essential feature is that when not pressed against the tree, the arm is easily moved along the beam—but when in use it takes a position at right angles with the beam and parallel to the other arm. The position of this arm is adjustable by the movement of the screw (*a*) which sets a movable plate.

In use the arms must be at right angles to the beam. If warped or out of adjustment, corresponding errors in measuring diameters will occur. The correct diameter can be obtained only by holding the calipers horizontally, with the beam in contact with the tree at the point desired, usually at B.H. If measured with the tips of the calipers, the errors resulting from false adjustment or warping are exaggerated. If measured with the calipers held at an angle, the point measured is probably above D.B.H. and correspondingly too small. If measured below D.B.H., a large error results from the rapidly increasing diameter of the tree due to stump taper. An average measurement 6 inches below the desired point or at 4 feet will incur from 5 to 8 per cent excess volume, depending upon the rapidity of the taper.

Where the exact average diameter of a tree is desired, two measurements must be taken at right angles and the mean recorded to $\frac{1}{10}$ inch. In timber estimating, where large numbers of trees are measured, but one diameter is taken, with no efforts made to determine the average even on trees of eccentric cross sections since it is assumed that errors incurred in this way are compensating. A precaution sometimes used is to measure half of the trees in one cardinal direction, and the remainder in the other (French).

190. The Diameter Tape. The irregularity in the form of trees, both as to cross section and bark, makes it practically impossible to obtain consistent results in two successive measurements of diameter of the same tree with calipers even when the mean diameter is taken as above indicated. For permanent records on plots to be subsequently measured for determination of growth, consistency in diameter measurement is absolutely required.

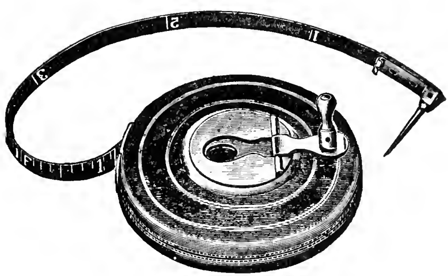

FIG. 41.—Tape for measuring girths and diameters.

For this purpose it has been found that the diameter tape must be substituted for calipers. The graduations on the diameter tape are in inches of diameter, each inch equal to 3.1416 inches in girth. In theory, the measurement of the circumference of a tree gives a plus error when compared with the actual mean diameter. Actual tests at the Fort Valley Experiment Station by Scherer on one hundred trees showed that the excess in diameter from tape over caliper measurement was 2 per cent, but the consistency of two successive tape measurements as compared with successive caliper measurements showed that the total error of calipers over tape was in the proportion of 21 to 1. The diameter tape should therefore be adopted for all measurements of permanent sample plots.

191. The Biltmore Stick. Although calipers can be taken apart for travel and packing, they are cumbersome to carry in timber estimating especially through brush and over rough ground. When in addition a beam of 60 inches in length is required, their use becomes extremely burdensome.

The Biltmore Stick, devised by Dr. C. A. Schenck, substitutes a straight stick for calipers and has been widely adopted by foresters for practical timber cruising.

The principle of the Biltmore Stick is as follows: A straight stick, if held horizontally, tangent to or in contact with the bole of the tree, and at arm's length from the eye, forms the far side of a triangle whose other two sides are lines of sight from eye to each side of the tree, and which intersect the stick at definite points. When the stick is held so that one of these lines of sight intersects one end, a scale can be placed upon the stick starting at zero at this end, and the point of intersection of the other line of sight, if the eye is held in its original position without turning the head, will indicate on the scale the diameter of the tree at this point.

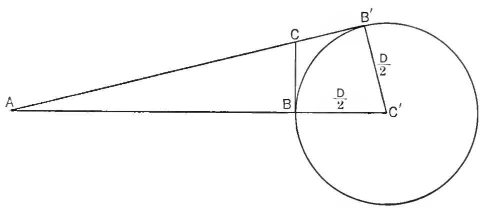

Fig. 42.—Principle upon which the Biltmore stick is constructed.

Since this intercepted distance on the stick is evidently less than the diameter of the tree, which is at a greater distance and cannot even be seen correctly, the distances corresponding to the diameters wanted will be less than these diameters and this difference increases with diameter of tree, so that the graduations on the stick for successive diameters fall closer together for the larger diameters. The values of the graduations on the stick are directly dependent on the dimensions of the triangle which is determined by the length of the arm or reach. This ranges from 23 to 27 inches with an average of 25 inches.

The formula for computing the values of this scale is

a = length of reach in inches;

D = D.B.H.

$$\text{Scale} = \frac{aD}{\sqrt{a(a+D)}}$$

$$= \sqrt{\frac{aD^2}{a+D}}.$$

The derivation of this formula is as follows:

$$\frac{AB}{BC} = \frac{AB'}{B'C'}.$$

$$AB = a \text{ inches, and } B'C' = \frac{D}{2}.$$

Substituting these values,

$$\frac{a}{BC} = \frac{AB'}{\frac{D}{2}},$$

$$\frac{aD}{2} = AB' \times BC.$$

$$\text{(I)} \qquad BC = \frac{\frac{aD}{2}}{AB'},$$

$$(AB')^2 = (AC')^2 - (B'C')^2.$$

By substitution,

$$(AB')^2 = \left(a + \frac{D}{2}\right)^2 - \left(\frac{D}{2}\right)^2 = (a)^2 + aD = a(a+D).$$

$$\text{(II)} \qquad AB' = \sqrt{a(a+D)}.$$

Substituting this value for AB' in equation (1),

$$BC = \frac{\frac{aD}{2}}{\sqrt{a(a+D)}}.$$

Since BC is the scale for $\frac{1}{2}$ of the diameter of the circle, the formula for the scale for the whole circle is [1]

$$\text{Scale} = \frac{aD}{\sqrt{a(a+D)}} = \sqrt{\frac{aD^2}{a+D}}.$$

The Biltmore stick is less accurate than the calipers or diameter tape and should therefore never be used for scientific measurements or permanent records. To insure complete accuracy in the use of a properly graduated stick, the following conditions are necessary:

The tree must be circular in cross-section.

The stick must be held against the tree at a point $4\frac{1}{2}$ feet from the ground.

[1] $$\frac{aD}{\sqrt{a(a+D)}} = \frac{\sqrt{a}\sqrt{aD}}{\sqrt{a}\sqrt{a+D}} = \frac{\sqrt{aD}}{\sqrt{a+D}} = \sqrt{\frac{aD^2}{a+D}}.$$

The eye must be on a level with the stick (assuming that the tree is erect).

The eye must be at the proper distance from the tree.

The stick must be held horizontal (assuming again that the tree is erect).

The stick must be held perpendicular to the line of sight from the eye to the center of the tree at the point of measurement.

Errors of 1 per cent in the measurement of diameter are incurred under the following conditions:

The figures given represent the distances by which the position of stick or eye departs from the above conditions.

TABLE XXXVIII

ERRORS IN USING BILTMORE STICK *

Sign	Cause	Resulting in Error of 1 Per Cent in Diameter — D.B.H. of trees: 10 Inches	30 Inches	60 Inches
−	Eye above or below stick by	9.2	7.3	7.1
+	Stick not horizontal—one end higher than other by	4.6	4.2	4.1
+	Stick not perpendicular to line of sight—one end nearer the eye than the other by	4.9	4.9	5.1
±	Eye too near to or too far from tree by	1.4	0.65	0.45
Usually −	Measurement at wrong height	(Variable)		
±	Tree irregular in shape	(Very variable—considerably greater than with calipers)		

* Donald Bruce, Proc. Soc. Am. Foresters, Vol. IX, 1914, p. 46.

A still more serious error is incurred through the inevitable tendency of the cruiser to raise the stick to the level of the eye, rather than lower the eye to the level of the stick. If the stick is held at 4½ feet and the eye remains at 5 feet 3 inches, with a difference of 7 inches in height, the error is but 1 per cent of the diameter, but if the stick is raised to the level of the eye, the diameter at the point measured is appreciably less than D.B.H. The resultant average error varies from 3 to 6 per cent, dependent upon the rapidity of taper, and increases consequently with the diameter of the tree.

The following table gives the graduations which should be placed upon Biltmore sticks for a reach of from 23 to 27 inches respectively:

TABLE XXXIX

FIGURES TO BE USED IN GRADUATING A BILTMORE STICK *

Diameter of tree. Inches	Distance from Eye to Tree—Inches: 23	24	25	26	27
	Distance to be marked on stick—Inches				
3	2.82	2.83	2.83	2.84	2.85
5	4.53	4.55	4.56	4.58	4.59
7	6.13	6.16	6.19	6.21	6.24
9	7.63	7.68	7.72	7.76	7.79
11	9.05	9.11	9.17	9.22	9.27
13	10.39	10.47	10.54	10.61	10.68
15	11.67	11.77	11.86	11.94	12.03
17	12.89	13.01	13.12	13.22	13.32
19	14.06	14.19	14.32	14.44	14.56
21	15.18	15.34	15.48	15.62	15.75
23	16.26	16.44	16.60	16.75	16.90
25	17.31	17.50	17.68	17.85	18.01
27	18.31	18.52	18.72	18.91	19.09
29	19.29	19.51	19.73	19.94	20.14
31	20.23	20.48	20.71	20.94	21.15
33	21.15	21.41	21.67	21.91	22.14
35	22.04	22.32	22.59	22.85	23.10
37	22.91	23.21	23.50	23.77	24.03
39	23.75	24.07	24.37	24.67	24.94
41	24.58	24.91	25.23	25.54	25.84
43	25.38	25.74	26.07	26.40	26.71
45	26.17	26.54	26.89	27.23	27.56
47	26.94	27.33	27.70	28.05	28.39
49	27.69	28.10	28.48	28.85	29.21
51	28.43	28.85	29.25	29.64	30.01
53	29.16	29.59	30.01	30.41	30.79
55	29.87	30.31	30.75	31.16	31.56
57	30.56	31.03	31.47	31.90	32.32
59	31.25	31.73	32.19	32.63	33.06
61	31.92	32.41	32.89	33.35	33.79
63	32.58	33.09	33.58	34.05	34.51
65	33.23	33.75	34.26	34.74	35.21

*W. B. Barrows, Journal of Forestry, Vol. XVI, 1918, p. 747

In this table, the graduations are given for odd diameters instead of even ones. For instance, when diameters are tallied in 2-inch classes, every tree larger than 13 inches and smaller than 15 inches in diameter is tallied as a 14-inch tree. These graduations thus mark the upper and lower limits of size of each 2-inch

D.B.H. class, instead of the average size, as 14 inches, enabling the cruiser to classify accurately all trees on the border line between two diameter classes.

In measuring trees of eccentric or irregular cross section, the errors incident to caliper measurement are exaggerated by the use of the Biltmore stick, but as before, these errors tend to compensate and can be neglected.

Bruce has suggested that the volume tables standardized at D.B.H. should be converted to values for diameter at the height of the eye, or D.E.H., standardized at 5 feet 3 inches. To do this, taper measurements are taken to establish the D.E.H. of trees of given D.B.H. By interpolation, the volumes corresponding to given even D.E.H. inches can easily be obtained.

In the ordinary use of the Biltmore stick, it is necessary to bevel the edge opposite the figures so that the measurement may be taken in contact with the bole. Otherwise the thickness of the stick reduces the distance from the eye and incurs an error whose magnitude is determined by this thickness. By deducting this thickness (t) from the distance (a) in the formula, so that this formula reads,

$$\text{Scale} = \frac{(a-t)D}{\sqrt{a(a+D)}},$$

the resulting values are correct for the face of the stick.

192. Ocular Estimation of Tree Dimensions. Where the diameter of every tree on a given area must be recorded, the time consumed in actually measuring the diameters is a considerable item of expense. Except when scientific measurements or permanent plot records are required, estimators plan to educate the eye to read as large a percentage as possible of the diameters directly without measurement, using the calipers, diameter tape or Biltmore stick merely as a check. This is especially desirable when the cruiser is doing his own tallying.

While the eye can be trained with considerable rapidity to a sufficient degree of accuracy for estimating, it is constantly liable to error and must never be relied upon for even a single day without instrumental checks. These should be made on starting work and at intervals during the day. The eye may be trained to judge diameters at different distances equally well. Some men develop this faculty more rapidly and to greater degree than others. It is the general tendency in ocular estimation to favor a tree of a given size, diameters of trees of lesser size being over-estimated while larger diameters are under-estimated. The use of 2-inch diameter classes greatly facilitates ocular estimating.

In training the eye to estimate diameters, the greatest progress is made by repeated guesses followed immediately by the measurement of the tree which is then closely observed to fix the known diameter and correct the faulty observation. Since ocular estimating is not a matter of reasoning but of impression, the decision as to the dimensions of the tree should be made instantly. Otherwise fatigue and consequent inaccuracy ensue.

193. The Measurement of Heights. While in measuring diameters it is possible to use the instrument upon every tree as a practical measure when necessary, the greater difficulty and time required in measuring heights makes the general use of an instrument for even a large per cent of the trees impossible. Only on small, permanent sample plots will the height of each tree be actually measured. Height measures, or so-called *hypsometers*, are commonly used to obtain the height of average trees from which the average height of the remaining trees is determined, or to check the eye when the merchantable heights of all trees are recorded.

In the latter case, ocular estimation of the number of merchantable logs in each tree, or total merchantable height, is the only practical means possible. It takes no longer to estimate the height of a tree by eye than its diameter, but the measurement of height by hypsometer takes about ten times as long as to caliper the tree.

The eye is slightly more unreliable in measuring heights than diameters. The height scale is more difficult to fix in the mind. Consequently the tendency is to arrive at the height of trees by comparison with other trees. The result is that the standard of height for all trees tends to shift from day to day unless heights are carefully checked at the beginning of each day's work in order to maintain this mental basis or standard. In no other feature of ocular timber estimating are such serious errors made even by experienced cruisers as in estimating heights, and the novice should never trust his judgment overnight.

194. Methods Based on the Similarity of Isoceles Triangles. Measurement of heights is based on the principles of similar triangles. From the observer's eye, the tree forms one side of a large triangle, the other two sides of which are the lines of sight to the top and base of the tree. The base of this triangle can be measured. The length of the vertical side which is the height of the tree is the dimension sought. To determine this inaccessible dimension, a smaller, measureable, similar triangle is used.

Similar triangles must have their three sides proportional and the three angles equal. This is secured when either two sides are proportional and one angle equal, or one side is proportional and two angles equal.

The isosceles triangle with two sides of equal length forms the simplest method of measuring the height of a standing tree. In this triangle the base from the eye to the foot of the tree is equal to the height of the tree and may be directly measured. The small triangle in this case is used to find the point on the ground at which this base will be equal to tree height. A triangle which has its own base and height equal and whose line of sight from eye to top coincides with that from eye to tip of tree gives this result.

A straight stick or short pole may be grasped by the thumb and first finger at a distance from its top exactly equal to the distance from the eye to the point thus marked. Holding this stick vertically, which is best accomplished by having the greatest weight below the hand to act as a pendulum, the observer moves backward or forward until the line of sight *Ab* in Fig. 43 cuts the desired upper point on the tree, and at the same time the line of sight *Ac* cuts the tree at its base. At this point the triangle *Abc* has become similar to the triangle *ABC*, and *AC* is equal to *BC*. The measured distance from eye to base of tree is then equal to the height of the tree. This distance can be measured along the ground to the point below the eye with sufficient accuracy, provided the slope is even. This measurement of height can be taken from any point of elevation, either on a level with, above, or below the base of the tree without affecting its accuracy.

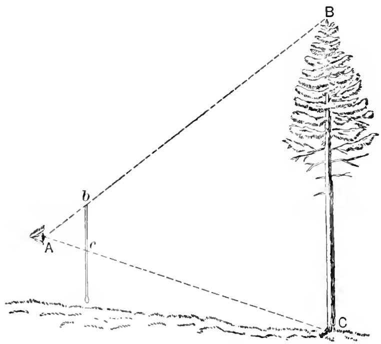

Fig. 43.—Similar isosceles triangles formed by use of pole, for measuring height of trees.

195. The Principle of the Klaussner Hypsometer. For height measurements which require greater accuracy than is obtainable by such ocular methods as the one just described, the small triangle is constructed in the form of an instrument called a hypsometer, on which two of the sides corresponding respectively to the lines *AC* and *BC*, or distance to tree and height of tree, are graduated to units of distance. This enables the observer to first adjust the scale *AC* for distance, to equal in feet the known distance from the tree, hence to determine what this distance shall be. The line of sight from the eye, beginning at the zero point of this scale or apex of the small triangle is now brought into line with the point on the tree whose height is to be measured, which makes the small and large triangles similar. The point at which this line of sight cuts the scale *BC*, whose graduations are equal to those on the scale *AC* indicates the height of the tree. These graduations may be of any size so long as both scales are graduated equally. They will serve to read height in feet, or in any other unit of distance, as meters, since whatever unit is used to measure the distance from the tree applies as well to its height.

The Klaussner Hypsometer. In hypsometers based upon similar triangles as shown in Fig. 43 the vertical scale represents tree height, the scale at base, distance to the tree. If the scale bc is on a movable arm, it may be set on the scale Ac at any required distance. By sighting along Ac towards C and by raising the sight or bar Ab to intersect the line of sight AB, the total height of tree is read directly from the scale bc. The standard hypsometer of this make is known as the Klaussner, Fig. 44. The vertical scale is weighted to insure its vertical position.

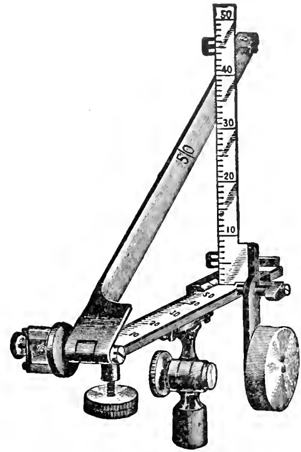

Fig. 44.—The Klaussner hypsometer.

As is seen, two lines of sight must be adjusted for this reading. The instrument is therefore used with a tripod and is rather slow in execution.[1]

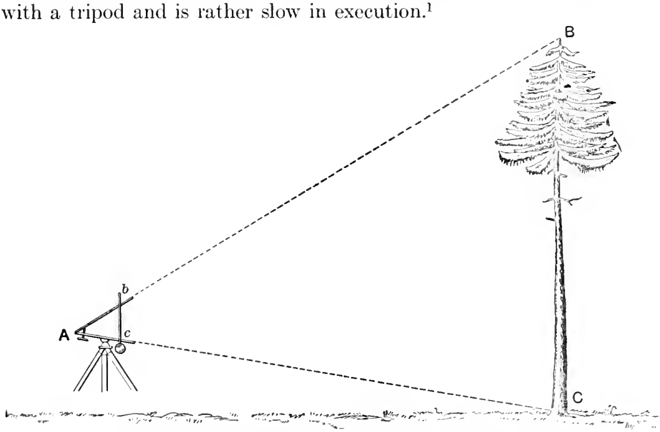

Fig. 44a.—Method of application of the Klaussner hypsometer.

[1] In Forestry Quarterly, Vol. XIII, 1915, p. 442, S. B. Detwiler has suggested a simple hypsometer based upon this principle, which for practical work does away with the tripod apparently without sacrificing accuracy.

The Klaussner principle differs from that shown in Fig. 43 only in that the height is measured on the vertical scale *bc*, the measurement may be taken at any point from the tree by adjusting the scale *Ac* to correspond with this distance, and the triangles may be of any form, provided one side is vertical.

Merritt Hypsometer. The Merritt hypsometer is a scale placed on the reverse side of the Biltmore stick (§ 191) and is read by holding the stick in a vertical position at arm's length, when standing at a given distance from the tree.

Six inches on the stick will give the height of a 16.3-foot log under the following conditions:

Arm length, inches	23	24	25	26	27
Distance from eye to tree, feet	62.5	65.2	67.9	70.6	73.3

The similar triangles used here correspond in principle with those of the Klaussner hypsometer.

For accurate results the stick must be held vertically and not raised or lowered during the reading. Only approximate accuracy can be secured, but the method serves as a ready check on ocular measurements of log lengths.

196. Methods Based on the Similarity of Right Triangles. The second general method for measuring heights is the use of the right triangle. This method is based on securing a horizontal line of sight from the eye to a point on the bole of the tree, and requires two readings, one above, the other below this point of intersection, the sum of which gives the height of the tree. This disadvantage is offset by the fact that these instruments may be held in the hand, thus eliminating the tripod, and making them compact and portable.

The horizontal line of sight may be secured by using either a bubble or a plumb-bob. The simplest application of this method is that of a right isosceles triangle, for which purpose a clinometer is used. This is an instrument with bubble mounted on a graduated arc reading in per cents, or in degrees. In the latter case the graduations must be reduced to per cents.

When the arc on this clinometer is set at an angle of 45°, the line of sight *Ab* coincides with the line *AB* at a definite distance from the tree, from which a horizontal line of sight, which can then be taken by setting the arc at zero, gives a distance to the tree equal to the height of the tree above the intersection of this line with the bole. If used on fairly level ground, the distance below this point is within reach and can be measured on the tree and added to the distance to the tree to get its total height.

This instrument can also be used to measure heights from any distance from the bole, by taking two readings or angles, one to the upper point, and one to the base. In this case the actual angle from station to point on tree is read, and indicates the height in per cent of the horizontal distance. At 100 feet distance, an 80 per cent angle to tip equals a height of 80 feet above the eye. If the lower angle to base is

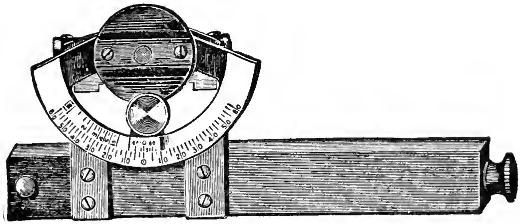

Fig. 45.—The Abney hand level and clinometer.

now 5 per cent, the additional height is 5 feet, total height 85 feet. At 50-foot distance these per cents applied to 50 feet give a total height of $42\frac{1}{2}$ feet. It is convenient therefore to read heights by this method from distances easily converted into equivalent heights.

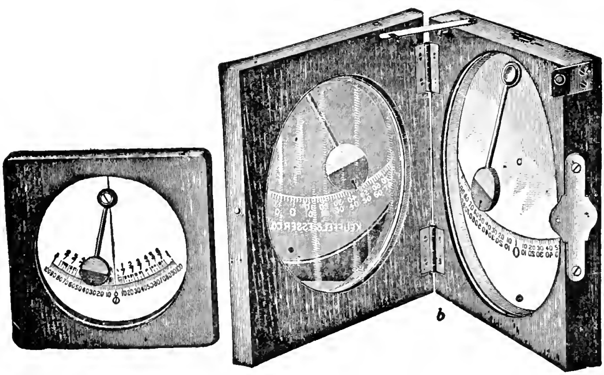

Fig. 46.—Goulier's Clinometer.

197. Hypsometers Based on the Pendulum or Plumb-bob. These angles can be read as easily from a pendulum, with graduated arc placed below. A clinometer constructed on this principle, and used as a hypsometer, is illustrated in Fig. 46.

The Faustmann Hypsometer. Instead of graduating a circular arc in per cents, which requires a decreasing scale with increasing per cent (since the tangents of the angles increase faster than the angle), the height scale corresponding with this arc may be placed on a straight arm as in other hypsometers (§ 195) and graduated evenly.

The Faustmann hypsometer employs this principle of the pendulum, using a plumb-bob to determine the angles *BAD* and *CAD*, and indicating the height of the tree above and below the point *D* by the intersection of this plumb-bob string with the " height "scale on the base of the hypsometer. This instrument is illustrated in Fig. 47. Its method of use is shown in Fig. 48.

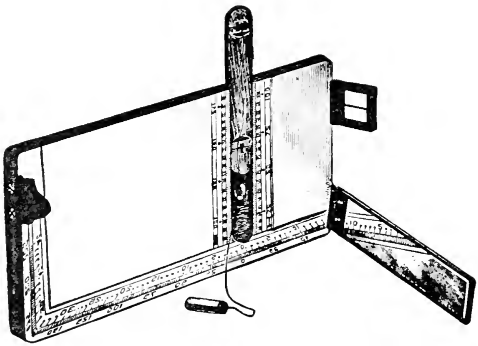

FIG. 47.—The Faustmann hypsometer.

The slide is first moved upwards until the number of units on the vertical scale, from zero, thus set off, equals the distance to the tree in feet (or in yards). When sighted at the upper point on the tree, the plumb-bob falls to the near side towards the eye, and the number of units or height is read in the mirror. The second reading is shown in Fig. 48, the plumb-bob falling to the far side. The horizontal scale thus extends in both directions from zero. On fairly level ground, this second reading is sometimes omitted, providing the height of the eye above the base of tree is regarded as a constant and added for total height. For accurate measurements both readings must be taken.

Practice has demonstrated that the use of a plumb-bob and weight reduces the serviceable character of the instrument, since the seweights are easily lost and the strings broken. The mirrors also are easily damaged.

Weise Hypsometer. The Weise hypsometer (Fig. 49) is the same in principle as the Faustmann but substitutes a metal pendulum for the string and plumb-bob. The two arms when not in use can be placed within the cylinder. The instrument is more durable than the Faustmann but slightly less accurate.

Forest Service Hypsometer. A more durable type of hypsometer based upon this principle is known as the Forest Service hypsometer. The distance at which this instrument reads the heights *BD* and *DC* is fixed at 100 feet. The scale showing these heights is computed from the tangents of the angles read at this distance and expressed in terms of feet in height. This scale is placed on a circular pendulum which

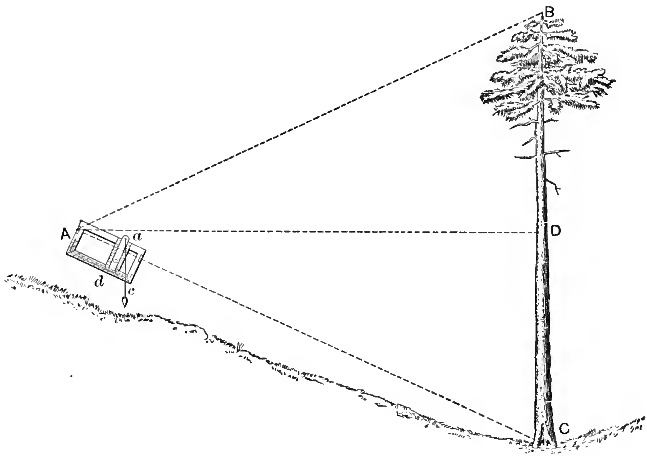

FIG. 48.—Method of application of the Faustmann hypsometer.

is released by pressing a small knob with the thumb while sighting through a peep-hole along the line of sight *AB* or *AC*. This scale is enclosed in a metal frame in the form of a disk, and the instrument is practically indestructible and can be operated with one hand. If read at 50 feet, the readings shown must be divided by two. If at 200 feet, they must be multiplied by two, and proportionately for other distances. As in the case of other clinometers this hypsometer may be used to read per cents of grade.

The Winkler Hypsometer. The same principle may be used in constructing a hypsometer in the form of a square or rectangular board or cardboard. In this instrument the line of sight, *AB*, coincides with the top edge of the board.

A board whose top and bottom edges are parallel is laid off with a horizontal scale at base and a vertical scale *ad* intersecting the scale at base at right angles, at a point to permit this horizontal scale to extend in both directions as in the Faustmann Hypsometer. Both scales are marked off in the number of equal units or graduations desired, to correspond with the distance from the tree at which the hypsometer is to be used. A plumb-bob is suspended from point *a*, and the heights above and below the eye read as usual. If but one fixed distance is desired this is represented by a scale reproduced on the line at base of card.

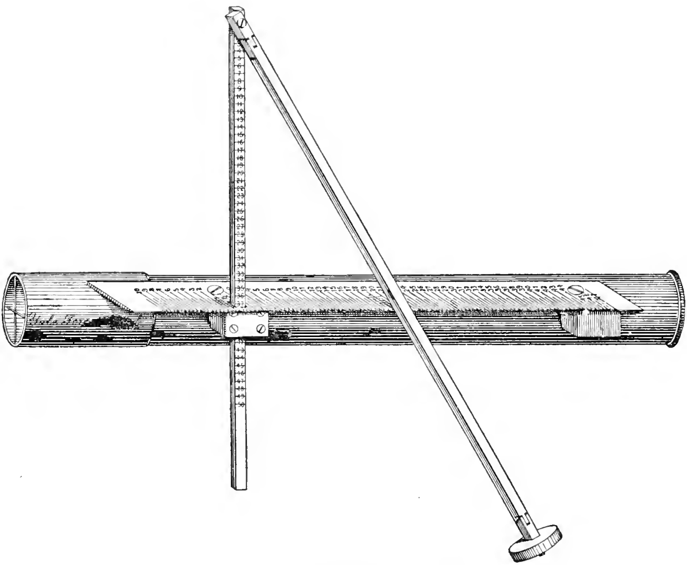

FIG. 49.—The Weise hypsometer.

This board may be graduated to read at lesser distances from the tree, by placing other horizontal scales upon the board intersecting the vertical or "distance" scale *ad* at the point below the apex *a*, representing the distances desired, and graduating these horizontal lines to the same scale as the base. This home-made hypsometer is described in Farmers' Bulletin 715, U. S. Dept. of Agriculture, 1916, p. 18.

The original instrument from which this type of hypsometer was derived is known as the Winkler hypsometer, shown in Fig. 50. This instrument is also used as a dendrometer (§ 200).

198. The Principle of the Christen Hypsometer. Many hypsometers have been invented, principally by Continental foresters, using one or the other of these general principles. The Christen hypsometer introduces a different principle but has no special merit except the simplicity of its operation. Description of this instrument, taken from Graves' Mensuration is as follows:

This instrument consists of a metal strip 16 inches long, of the shape shown in Fig. 51. The instrument is made of two pieces hinged together, which are folded

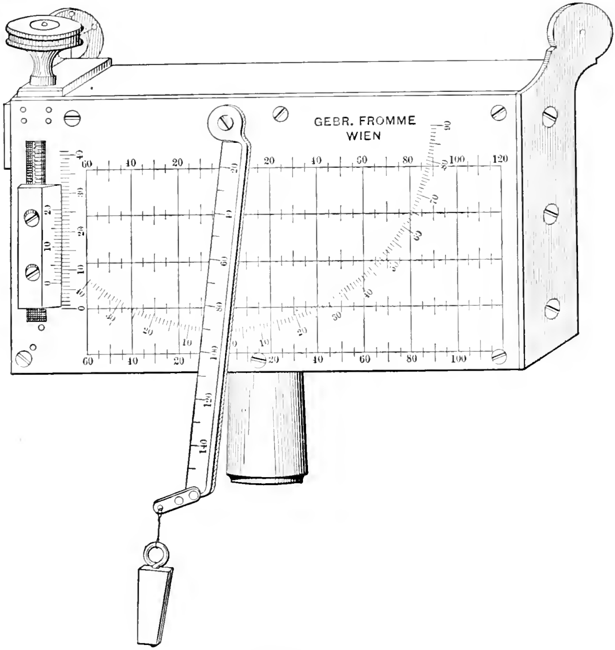

Fig. 50.—Winkler Hypsometer.

when it is not in use. A hole is pierced in the upper end, from which it is suspended between the fingers. Along the inner edge is a notched scale which gives directly the readings for heights. The instrument is used as follows: A 10-foot pole is set against the tree. The observer stands at a convenient station whence he can see the tip and base of the tree and also the top of the 10-foot pole. The instrument is suspended before the eye and moved back and forth until the edge b is in line of vision to the top of the tree and the edge c in line of vision with the base. The point where the line of vision from the eye to the top of the 10-foot pole intersects the inner edge of the instrument indicates on the scale the height of the tree.

Each instrument is constructed for use with a specified length of pole. The instrument described above is one designed by the author for convenience with the use of English units. It was constructed in the following way: The distance *bc* on the instrument was chosen arbitrarily as 15 inches and the length of the pole as 10 feet. It would, of course, be possible to construct an instrument for a pole 12 feet or any other length and on a basis of any desired length of instrument. The theory of the construction of Christen's instrument may be shown by Fig. 52. When used as above described, two pairs of similar triangles are formed: *ABC*, and *Abc*; *ADC*, and *Adc*, in which $BC = \frac{bc \times DC}{dc}$ and $dc = \frac{bc \times DC}{BC}$. With a known value of *DC* and *bc*, *dc* may be determined for all different heights which are likely to be required. Thus it may be assumed that it would not be necessary to measure trees less than 20 feet high, so that the lowest graduation on the instrument is made for that height. To find the proper point for the 20-foot graduation on the scale, the following formula was used:

$$\frac{BC}{DC} = \frac{bc}{dc} \quad \text{or} \quad \frac{20}{10} = \frac{15}{dc} \quad \text{or} \quad dc = \frac{150}{20} = 5.7 \text{ inches.}$$

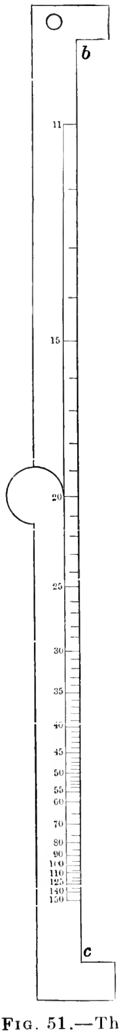

Fig. 51.—The Christen hypsometer.

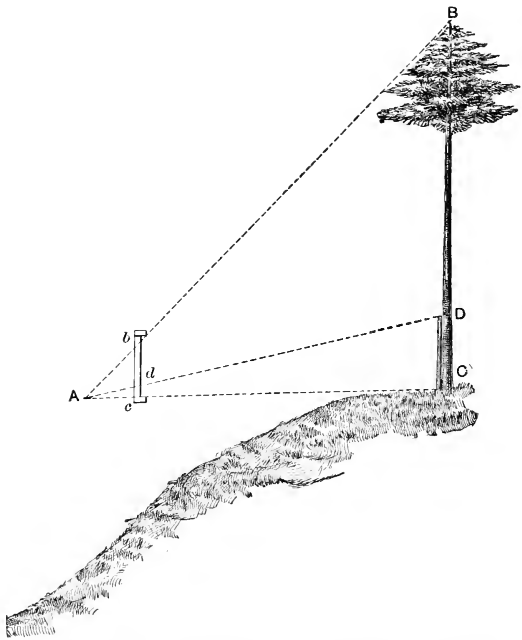

Fig. 52.—Method of application of the Christen hypsometer.

This same method was used to determine the value of *dc* for a 25-, 30-, 35-, 40-foot tree, etc., up to 150 feet, and the proper graduations made on the scale. The scale is somewhat more easily read when a notch is made at each graduation.

The instrument is light and compact, and with practice can be used very rapidly, provided one has an assistant to manage the 10-foot pole. It requires no measurement of distance from the tree, and the height is obtained by one observation. It is more rapid than either the Faustmann or Weise instrument.

Its disadvantages are that it requires a very steady and practiced hand to secure accuracy, that it cannot be used accurately for tall trees, and that it is not adapted for steady work because it is extremely tiresome to hold the arm in the position required. This last objection may be overcome by using a staff to support the hand.

199. The Technique of Measuring Heights. In rough checks for timber cruising, the distances used in obtaining heights are usually paced. Care must of course be taken to carefully check the paced distance desired to avoid incurring a cumulative error. For the measurement of average trees, depended upon to secure the heights of stands, the distance should, if possible, be measured with the tape. This latter method is the only one permissible in measuring the heights of trees on permanent sample plots.

By the method illustrated by the Klaussner hypsometer, this distance is measured along the ground whether the slope be level, gradual or steep. By the method of right triangles the distance must be measured horizontally to the bole of the tree, and a considerable error would be incurred in measuring it along the surface on very sloping ground.

Since the entire basis of the similar triangles used assumes that the tree which forms one side of the larger triangle stands in a vertical position, the consequences of measuring a tree which leans either towards or away from the observer are very serious (Fig. 53).

From the position A, the distance to the base of the tree is AC. But if the observer sights at the tip of the tree B_1 which leans towards him, its height, when compared to the distance AC will be read as B'_1C, an error of $+16$ per cent. If the distance is measured instead to the point directly below the tip B_1 the height is read as B_1C_1, with an error of -2 per cent. Again, if the tree B_2 leans away from the observer, and its distance is measured as AC, its height will be read as B'_2C with an error of -16 per cent, but if this distance is measured to the point C_2, the height will be read as B_2C_2 with an error of -2 per cent as before.[1]

If it is necessary to measure leaning trees, this can be done by taking a position at right angles with the line AC in Fig. 53, or at right angles with the vertical plane in which the tree lies. The ocular measure-

[1] Some New Aspects Regarding the Use of the Forest Service Standard Hypsometer, Hermann Krauch, Journal of Forestry, Vol. XVI, 1918, p. 772.

ment of heights largely avoids this specific error since the eye allows for the leaning position of the tree while the instrument does not.

Where total heights are measured to the tip of the crown, the greatest accuracy is obtained in the measurement of conical-crowned conifers. Broad- or deliquescent-crowned trees are difficult to measure accurately. The source of error is the same as that which applies to leaning trees. A line of sight AB, in order to be directed at the tip B, must penetrate the foliage of the crown while if directed tangentially to the edge of this crown, it will take the position of AB_1. The error from the measurement of broad-crowned trees, unless this precaution is observed, is cumulative and tends to over-estimate their heights.

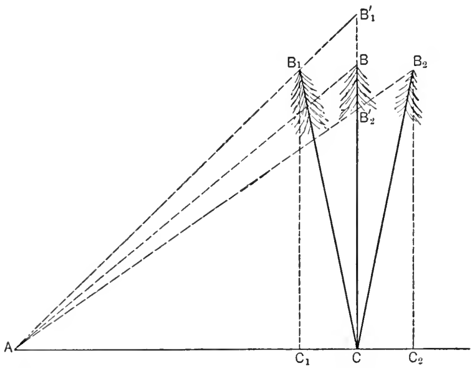

Fig. 53.—Errors which may be incurred in measuring the height of a leaning tree. To avoid error the measurement should be taken at right angles to the plane in which the tree falls.

Merchantable heights are measured by exactly the same principles as are applied to total heights, and upon broad-crowned trees may be obtained more exactly. The element of uncertainty in the measurement of merchantable bole is not height, but the determination of the point on the bole at which the used length will terminate, that is, the merchantable top diameter of the bole. Merchantable heights may be measured in 16-foot log lengths by the use of the principle in Fig. 43. (Merritt hypsometer, § 195.) This same principle may be more accurately applied by leaning a pole of known length against the tree and then noting the length of a pencil required to take up this given length at the distance of the observer. This pencil length may then be measured off by eye on the remainder of the tree to divide it up into logs.

It is common practice amongst timber cruisers to measure the total or merchantable height of windfalls as a check on ocular timber estimating.

200. The Measurement of Upper Diameters. Dendrometers. Upper diameters of standing trees must be measured, first, in estimating timber to a merchantable top diameter; second, to determine the form quotient of the tree, where form classes are to be distinguished.

In timber estimating, ocular methods are used entirely, and the probable upper diameters approximated by knowledge of rates of taper checked by the measurement of diameters on the boles of down trees. But for the measurements required to determine form quotients, it is not safe to depend altogether on chance windfalls, nor can cutting sample trees be resorted to on account of the time and expense involved. The eye is not sufficiently accurate to gage diameters at upper points, hence these measurements for form quotient must be taken on standing trees by instrumental means.

An instrument intended to measure the upper diameters of standing trees is termed a *dendrometer*.

The principle of the dendrometer is that of similar triangles; but in this case two sets of triangles are used, first, those required in determining the height to the point to be measured, and second, those used to measure the diameter at this point by comparison with the side of a smaller triangle on the dendrometer. These principles are illustrated in Fig. 54.

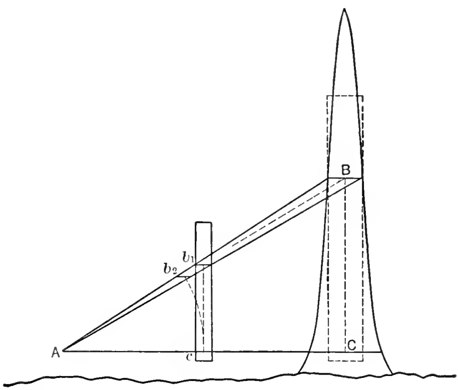

Fig. 54.—Principles underlying construction of dendrometers, as illustrated by the Biltmore pachymeter.

In determining the form quotient for standing timber, either according to Jonson's or Schiffel's methods, the diameter at the middle point, either above D.B.H. or above the stump respectively, is sought. As pointed out, the absolute form quotient cannot be determined with scientific accuracy from measurements taken outside the bark or on standing timber, but approximate results can be obtained.

The triangles whose bases are respectively B, b_1 and b_2 are similar, and the relation between B and either b_1 or b_2 determines the diameter at B. But the points b_1 and b_2 are not the same, and this difference distinguishes two different principles used in constructing dendrometers.

When the distance Ac to the horizontal scale on which will be read the upper diameter B, is fixed, so that on sighting at point B this distance coincides with b_2, as it does on most dendrometers, the proportion between the upper diameter B and its equivalent C, corresponding to c on the instrument, is altered since the side Ab remains of the same length and coincides with Ab_2 in the figure. This discrepancy increases in proportion to the cotangent of the angle A and the distance read on the dendrometer scale at b_2, which is graduated for inches, will be less than the true diameter B by just the amount of this error. The use of all dendrometers built on these principles requires correction by a table, to obtain true upper diameter.

This difficulty is illustrated by a dendrometer attached to the Barbow cruising compass, used to some extent on the Pacific Coast. The dendrometer on this compass was a brass scale 1 inch long, finely graduated to read the apparent diameter in inches at the upper end of the desired log, when held exactly 1 foot from the eye by means of a string. But the true diameter had then to be looked up in a table furnished with the compass. The correction varied with the angle of sight; that is, with the number of log lengths in the tree. All readings were made at 100 feet from base of tree.

On the Pacific Coast a second plan has been adopted, that of making the length of the scale b_1 equal to the diameter B, thus substituting two parallel lines of sight for the horizontal triangles shown, and reading the diameter of the lower side of a parallelogram directly in terms of inches of diameter at B. In an instrument invented by Judson F. Clark and C. A. Lyford, a telescopic sight moves on a bar. In one invented by Donald Bruce, both lines of sight are brought into the same plane by means of two reflecting mirrors, set at exact angles of 45 degrees.

201. The Biltmore Pachymeter.[1] By employing the second principle, in which the side of the small triangle b_1C remains vertical, the diameter indicated at b_1 on the hypsometer remains in the same proportion to that desired at B, as when the reading is taken at position C. Since the point opposite c may be taken at the base of the tree, regardless of whether this point is horizontally opposite the eye or above or below it, a projection of the diameter B upon the base of the tree enables it to be directly measured on the tree, or on a scale c upon the instrument, graduated for the distance Ac. This principle is employed by an instrument termed the "Biltmore Pachymeter." (Ref. Forestry Quarterly, Vol. IV, 1906, p. 8.) A slot, the two edges of which are absolutely parallel, or a stick or cane of which the same is true is suspended in a vertical position in front of the eye. A scale marked in inches is held by an assistant tangentially to the tree trunk at D.B.H. The diameter at any desired point on the stem is obtained by finding the distance from the tree at which the diameter of the slot or stick exactly obscures that of the tree at the desired point, when the width corresponding to this diameter will be indicated by the intersections of these edges on the scale below. The instrument and its projection upon the tree trunk are shown in Fig. 54.

202. The d'Aboville Method for Determining Form Quotients. This method depends on the measurement at b_2, but is simplified by using a horizontal line of sight from eye to tree, and an angle of 45 degrees at point A, in which case the proportion between the lines AC and AB in Fig. 54 becomes 1.4, and the diameter at B becomes $1.4b_2$. To make this measurement, a distance is found which is just equal to the length of the bole between the point horizontally opposite the eye, as in Fig. 54, and the upper point to be measured.

Substituting d and D for diameter at $\frac{1}{2}$ height and D.B.H. respectively, the form quotient of a tree, as read on the dendrometer, is

$$f=\frac{d}{D}\times 1.4.$$

[1] Pachymeter—an instrument for measuring small thicknesses.—Century Dictionary.

The instrument consists of a graduated scale or straight-edge. For determining merely the form quotient the actual diameters need not be ascertained but only their proportion or relation. The two measurements are taken by eye, holding the horizontal scale at arm's length (Ac and Ab_2) for each reading. The principal error to be guarded against is failure to secure the horizontal line of sight and the corresponding distance, which will result in correspondingly large errors in reading the proportional diameters. Failure to select the right point on the tree, provided a definite point *is* selected and the method otherwise properly applied, incurs only the error due to difference in taper between the point measured and the point desired, which depends on rapidity of taper.

This simple method should be of great assistance both to practical woodsmen in determining upper diameters, and to foresters desirous of testing the form quotient of trees in order to ascertain the applicability of volume tables based upon principle of form factors.

203. The Jonson Form Point Method of Determining Form Classes. In connection with his studies of the form of trees and form quotients, Tor Jonson has evolved a method for determining the form class of standing trees without the necessity of measuring the upper diameter or the form quotient.

This method consists in locating a point on the stem of the tree, which he terms the form point. The percentage relation which the height of this point from the stump bears to the total height of the tree, he claims, bears a consistent relation to the form quotient, and by means of a table showing these relations the form quotient and form class of the tree may be determined.

Mr. Jonson describes the method as follows:

The shape and position of the crown has been found to be the most dependable and useful indication of different tapers and form classes. This is connected with the bole's function to carry and steady the crown, especially against the breaking forces of the wind, and it has been found that in the building of the bole only enough material is used to make it equal in strength to the force of the winds. It may therefore be said that it is the strength of the winds that determines the necessary dimensions of the trunk, and as the force of the wind is generally applied to the crown of the tree, it will be found that its weight, shape and position indirectly influence the size and taper of the trunk.

While estimating, the D.B.H. is measured with caliper and the taper is then determined through finding by ocular means the form point, i.e., the point where the pressure of the wind is apparently concentrated which is usually the geometrical center of the crown. By sighting at this point and at the same time at the base and tip of the tree over a stick, approximately 30 cm. long, divided into 10 equal parts (Christen's hypsometer), the height of the form point can be easily found expressed in per cent of the total height. This form point can then be looked up in the table giving the form point heights which are characteristic for each form class. The higher the crown is placed, the less the taper and the more cylindrical the form, and conversely, the lower the crown extends, the more rapid will be the taper and the poorer the form.

When, as is often the case, the estimating is based on diameter outside bark, the difference which is caused by variable thickness of the bark must be taken into consideration. The spruce, fir and other species with thin even bark show no difference in form when measured inside or outside bark, for which reason the given normal form point heights give the form with, as well as without, the bark for these trees.

White birch, larch and others, but especially the pine, show great reduction in form when measured with bark, for which reason the form quotient outside bark is different from what the crown normally signifies. On this account special tables have been made up for use with outside bark measurements, but, as the Scotch pine shows many different types of bark, four tables have been compiled for trees whose bark is thin, medium, thick and very thick.

When judging the location of the form point, it should be remembered that it is at the base of the branches where the acting forces of the wind are transferred to the bole, for which reason deciduous trees with branches pointing up will have the form point not in the center of the crown contour but as much lower as the bases of the branches lie lower than the foliage on which the wind is acting. In estimating trees which have quickly cleared themselves of branches, a better result will be obtained, if the newly shed crown be imagined reconstructed before the position of the form point is determined.

Finally, should the butt swelling extend so high as to influence the D.B.H., and consequently make the final result inaccurate, it will be satisfactory for practical work either to round the diameter off downward or measure the diameter above the swelling; for scientific work, however, the form class should be lowered as much as is made necessary by the butt swelling, which can be easily found through a number of measurements taken above and below B.H.

In extensive timber estimating the density is a good indication of the general form which the trees ought to possess, as the tree grown up in dense stands will have a clean bole and high crown, while on the contrary the tree grown in the open will have a heavy, low crown and consequently a poor bole form.

TABLE XL

TABLE FOR DETERMINATION OF FORM CLASS OF TREES BY MEANS OF POSITION OF FORM POINT[1]

Height of tree in feet	Form Class												
	0.50	0.525	0.55	0.575	0.60	0.625	0.65	0.675	0.70	0.725	0.75	0.775	0.80
	Form point height in per cent of height of tree												
10	37.5	43.5	47	52	57	62	69	73	79	85	92	98	....
20	35.5	40	44	49	54	59	65	70.5	76.5	82.5	89	95.5	....
30	34.5	38	43.5	47.5	52.5	58	63.5	69	75	81	87	94	....
40	34	38	43	47	52	57	62	68	74.5	80	86	93	....
50	34	38	42.5	47	52	57	62	68	74	80	86	93	....
60	34	38	42	47	52	57	62	68	73.5	80	86	92.5	....
70	34	38	42	47	52	57	62	68	73.5	79.5	86	92	....
80	34	38	42	47	52	57	62	68	73	79	86	92	....

[1] For spruce and fir in Norway, either inside or outside bark. Adapted from Massatabeller för Träduppskatnung. Tor Jonson, Stockholm, 1918.

The prevailing density of a stand causes the greater number of the trees to acquire a certain similarity as to form, and only a very small number, usually the smallest and largest trees, differ from this average form class. Accordingly it is often

204. Rules of Thumb for Estimating the Contents of Standing Trees. A rule of thumb represents an attempt to formulate a simple rule which can be memorized and by the use of which the contents of trees of any diameter and height may be found. Such a rule would enable the cruiser mentally to compute the volume of average trees without looking them up in a table. It is also desired as a substitute for a universal volume table because of the difficulty of finding volume tables for the different species.

The factors of variation in tree form are exaggerated by application of units of product and the variation in board-foot log rules, and the further differences in the per cent of total contents utilized in trees of different sizes make it impossible to devise rules of thumb which are as accurate as good volume tables; but since their use in ocular timber estimating frequently accompanies methods of cruising by which a close degree of accuracy is not attained, a slight possibility of error in application is not considered a sufficient drawback to offset the advantage of simplicity. They are especially desired in judging by eye the contents of single trees.

Rules of thumb must be based upon either the cubic or board-foot unit. The simplest forms ignore the influence of height and are therefore inaccurate except when applied to trees within a given range of heights.

The effort is always made to devise rules which may be applied to the dimensions measured by the eye; that is, to diameter and height. Rules which require the use of basal area call for tables.

For cubic contents, the following rules of thumb will serve as illustrations:

1. To obtain cubic feet multiply the basal area in square feet by the height and divide by 2. This is based on the theory that the cubic form factor of trees will average 0.5 which is the form factor for a paraboloid.

2. For trees averaging 80 to 100 feet in height, with a form factor of 0.49, the contents in cubic feet equals the radius in inches squared (B. E. Fernow). For "average" trees, volume in cubic feet equals one-fifth of the diameter squared (C. A. Schenck).

Both of these rules of thumb are good only for trees of a given height and form factor. They are similar to the European rule of thumb—volume in cubic meters equals the diameter squared divided by 1000. In this rule, D is measured breast-high in centimeters. This rule applies to pine 30 meters high, beech, oak and spruce, 26 meters high, and correction factors are indicated as follows: for each additional meter of length above or below these heights, for pine, a 3 per cent correction; for beech, 5 per cent; for spruce and fir, $3\frac{1}{2}$ per cent. Hersche's rule of thumb reads, cubic meters $= D^2\left(\frac{h}{3}+1\right)$, using meters. This applies to trees 50 to 115 feet in height.

possible to estimate the whole stand in the same form class, the smaller dimensions a little higher and the larger dimensions somewhat lower than the average, e.g., 0.70 for over topped trees, 0.675 for intermediate and co-dominant trees, and 0.65 for dominant trees (§ 171). The highest and lowest form classes will never occur as an average, but only for single trees.

Graves gives the following cubic rule of thumb for white pine:

Square the breast-high diameter in feet and multiply by 30. The rule gives approximately correct results for trees 10 to 14 inches in diameter and 80 feet high, 16 to 20 inches by 85 feet, 22 to 28 inches by 90 feet, and 30 to 36 inches by 95 feet. Other heights require a correction varying between 5 and 6 per cent, for each 5 feet of length. It can thus be seen that both simplicity and accuracy in these rules of thumb are seldom obtained in the same formula without considerable cumbersome modification and it would seem that a volume table could be referred to almost as easily and give as accurate results.

The use of rules of thumb based on board feet is primarily caused by lack of suitable volume tables. This is illustrated by the development of rules of thumb based upon the Doyle log rule. These board-foot rules are efforts to obtain the total board-foot contents of the trees from the sum of the contents of the logs which they contain and were usually formulated before volume tables had come into use.

The simplicity of the formula for obtaining the contents of a given log in the Doyle rule, namely, "subtract 4 inches from the upper diameter inside bark, square the remainder, and the result is the scaled contents of a log 16 feet long" (the length used in estimating), was an inducement to supplement this rule so as to obtain the contents of the average log in a given tree. There are two rules for this.

1. Take the average diameter of the top and stump inside the bark for the diameter of the average log. Scale this and multiply by the number of 16-foot logs in the tree.

2. Multiply the diameter at breast-height inside the bark by the same diameter minus 12. Multiply by the number of logs in the tree. This gives the scale of the tree (C. A. Schenck).

Schenck also gives a rule which ignores height, as follows: For "tall" trees, volume $=\frac{3}{2}$ diameter squared, measured at breast-height.

Efforts to formulate general rules of thumb, not based on the Doyle rule are illustrated by the following examples:

1. Subtract 60 from the square of the estimated diameter at the middle of the merchantable length of the tree. Multiply by 0.8 and the result is the contents in board feet of the average log in the tree. Multiply by the number of 16-foot logs for the total scale. (Graves' Mensuration, p. 153.)

2. Average the base diameter of the tree and the top diameter of its merchantable timber. Get the scale of a log of that diameter, 32 feet long. Multiply by the number of 32-foot logs less $\frac{1}{2}$ log. (Cary's Manual of Northern Woodsmen.)

3. Board feet $=\dfrac{D^2\times L}{60}$,

when $D=$ inches and $L=$ feet.

(A formula method of estimating timber, E. I. Terry, Journal of Forestry, Vol. XVII, No. 4, p. 413.) This formula, according to author, requires modification by substitution of a divisor of

70 for trees from 12 to 19 inches D.B.H.
60 for trees from 20 to 29 inches D.B.H.
55 for trees from 30 to 35 inches D.B.H.
50 for all trees above 35 inches.

4. To base diameter, add one-half of base diameter and divide by 2; multiply by 0.8, square and divide by 12. The result is the number of feet in the stick per foot of its length. Three to 5 per cent may sometimes be added for contents above the point stated.

There are two steps involved in these rules of thumb for board feet:

First, a rule or formula is required, which gives an approximation of actual board-foot contents of logs of different sizes. This can only be obtained by rules based on cubic instead of board-foot contents (§ 39). Taking a fixed per cent of the contents of all logs, the last rule above quoted reduces to $\left(\frac{0.6D}{12}\right)^2$.

The second step is to get the dimensions of an average log in a tree, thus averaging large and small, or top, butt and middle logs together. Empirical results rather than mathematical soundness has usually been the basis of all such rules of thumb.

Practically all these rules of thumb for board feet are based upon the log unit, as might be expected. A more scientific application of a universal rule of thumb is that devised by F. R. Mason (Ref. Rules of Thumb for Volume Determination, Forestry Quarterly, Vol. XIII, 1915, p. 333). This rule is as follows:

5. The volume of a tree of each diameter and height class will correspond closely with the volume as obtained by averaging the scale of the butt and top logs and multiplying by the number of logs, using 16 feet as the standard log length.

Mason states that this rule has been in use by Minnesota cruisers. Its superior accuracy is based upon the fact that it conforms to the form quotient of the tree as well as to its diameter and height, by introducing upper diameters at two points. For Douglas fir this rule was 3 per cent below actual scale; for cedar, above 24 inches, 10 to 15 per cent high. For white pine, spruce, yellow pine, larch, lodgepole pine and fir, average results were within 5 or 6 per cent of actual volume for individual trees of all sizes, a result which is closer than may be expected in the use of average volume tables for single trees. The only difference between this rule and the tally and computation of each log in the tree is elimination of the need for tallying logs lying between butt and top. The size of the top log is constant where a fixed top diameter is used. Mason states that $3R^2$ is the approximate board-foot contents for 16-foot logs over 24 inches in diameter.

6. A rule given by J. W. Girard is, "add 6 inches to the D.B.H., divided by 2 and use this result as the diameter for the average log in the tree. Multiply the scaled volume of this log by number of logs for the tree volume." This rule holds good for white pine and spruce cut to 6-inch top and for larch cut to 8-inch top. For Douglas fir cut to 8-inch top, add 4 instead of 6 inches. For lodgepole cut to 6-inch top, add 5 inches. For yellow pine under 20 inches, add 6 inches; 20 to 25 inches, add 8 inches; 26 inches and over, add 10 inches.

Any rule of thumb should be based upon the log rule and standard of utilization in use. Such rules are largely worked out as a matter of personal efficiency by individuals and should be tested carefully before placing too much reliance upon them.

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CHAPTER XIX

PRINCIPLES UNDERLYING THE ESTIMATION OF STANDING TIMBER

205. Factors Determining the Methods Used in Timber Estimating. There are five basic considerations which determine the conditions and methods to be used in estimating timber. These are:

1. The form of product in which the volume of the timber is to be estimated. This determines the unit of volume to be used, as the piece (poles, railroad ties), the board foot for saw timber, and the cord for bulk products (§§ 9–12).

2. The economic conditions, customs and usages governing the business of logging and lumbering. These determine the basis on which standing timber is to be sold and the place and form in which it is to be measured. The three considerations which affect the work are, whether the basis of volume measurements is to be the contents of logs or the sawed output in the form of lumber, what log rule is to be used in scaling the logs, and the practice of scaling as to log lengths, diameters and cull as affecting the scaled contents of the timber (§§ 81–83).

3. The character of the demand for timber products and the resultant closeness of utilization of the trees in the stand. This will determine the top diameters and stump heights to which the timber must be estimated, and the minimum D.B.H. (diameter limit) of trees to be estimated as part of the merchantable stand, and consequently the per cent of the total cubic volume of the stand which is estimated as merchantable (§ 23).

4. The available volume tables, their reliability and basis of numbers, their method of construction, their basis of diameter, height and merchantable top diameters (§ 124). This will determine,

(*a*) Whether to dispense with a volume table and substitute a log rule, tallying the contents of the trees in the form of separate logs or to depend upon a volume table for entire trees.

(*b*) The point at which diameter must be measured in timber estimated, as stump, D.B.H., or top of first log inside bark.

(*c*) The point at which heights are taken—total height or merchantable log length.

(*d*) The top diameters to which tree must be estimated. Divergence in these conditions from those used in the volume table will make it impossible to apply the same.

5. The local characteristics of the timber to be estimated as to fullness of form or "form quotient," quality and defects. This determines,

(*a*) For sound trees, the applicability of existing volume tables without modification or their need of local percentage corrections.

(*b*) For the defective trees, the amount of deduction for defects and losses in scale to be made from the standard volume table.

The object of any estimate of standing timber is to obtain the total volume as indicated by the above five conditions upon the entire area of a specific tract of land. This may be done in one of three ways:

By direct ocular guess or appraisal.

By actual estimate or measurement of the volume of every tree of merchantable size.

By measuring or estimating a part of the timber as an average of the whole.

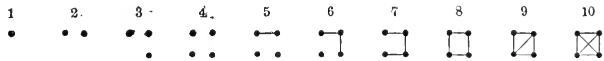
206. Direct Ocular Estimate of Total Volume in Stand. The direct estimation or guess of the total volume of a tract of timber can have but one basis, that of experience in cutting tracts of similar character. This eliminates all doubtful factors, and the experience thus gained is invaluable as a standard of estimating.

Skill and accuracy in this method depend upon the uniformity of the stand, and the ability of the estimator to compare this uniform stand with those of similar character whose yield he has ascertained.

As the area of timber so estimated increases, its variability of stand becomes greater; yet the necessity for obtaining a true average of these variable conditions persists. Even in stands as large as 40 acres it becomes very difficult even with the closest inspection to arrive at the average stand on the tract, no matter how skillful the cruiser is for smaller and more uniform areas. With increasing size of area, accuracy soon becomes utterly impossible. For this reason, in spite of the simplicity of the plan in theory, in practice cruisers who depend solely upon this principle are apt to be unreliable and inaccurate. Under no circumstances can this method be applied to timber with which the cruiser is unfamiliar. It therefore limits his field of activity to a narrow basis.

207. Actual Estimate or Measurement of the Dimensions of Every Tree of Merchantable Size. This is known as a 100 per cent estimate and differs radically from the total ocular estimate of stand just described. It consists of recording the dimensions of each log on the tract in case no volume table is used, or with a volume table, the dimensions of every tree of merchantable size. The total volume is then simply a matter of computation.

The trees are tallied by dots and lines, in blocks of ten, as indicated in the following table, which shows the marks corresponding to different numbers:



When diameter alone is being tallied, a single column giving diameter classes suffices for each species. Where the height, either total or merchantable is also recorded for each tree tallied, each species will require a tally similar to that shown below.

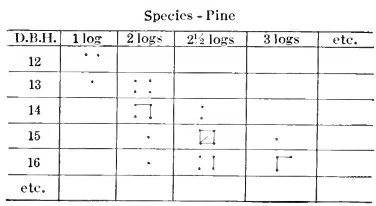


Fig. 55.—Method of tallying trees by diameters and log lengths.

Where several species are tallied by both diameter and height, it is not customary to make half-log divisions, since too many columns would be involved. Where the top diameter of logs, instead of D.B.H., is the point tallied, the same system of diameter classes or tallies is used. It is possible to combine this tally of D.B.H. for one species with top diameter of logs inside the bark for others, using the same horizontal columns for diameter in each case.

208. Estimating a Part of the Timber as an Average of the Whole. Where the greatest possible accuracy is demanded, it is obvious that 100 per cent of the trees should be measured. Only in extreme cases can this be done, owing to the excessive cost. The process of measurement accomplishes no constructive change in the form of the forest (§ 6) as does logging or silviculture, but is of use merely in the orderly management of the business of regulating these operations as to location, quantity and time. Efficiency then demands the reduction of the cost of obtaining these statistics to the lowest figure which will suffice for the proper conduct of the business and avoid loss through errors in appraisals of quantities and values.

With timber whose average value per tree is small, the cost of measuring each tree is far too great to be undertaken. It is often physically impossible to obtain the necessary force and personnel to perform the work on this scale. Finally, the time required is too long since the results of estimates, especially for the purpose of sale are usually required within a limited period. For these reasons, the third of the above methods, by which the principle of averages is utilized as a means of reducing expense, diminishing the number of persons required and shortening the time demanded for completing the work, is almost universally used in estimating timber.

The use of this principle in timber estimating does not differ from that applied in the commercial process of sampling employed in mines or in grad'ng wheat. If the product is uniform, a single sample suffices, as in wheat, but if variable, as in ore, far greater care is required in order that the samples may represent the average value for the entire body to be tested. The advantage in timber estimating is that all of the timber is actually visible and only the handicap of costs and time prevent it from being seen and measured.

209. The Six Classes of Averages Employed in Timber Estimating. There are six classes of averages employed in estimating timber. The first three differ in regard to the methods of recording the dimensions of trees. These methods are as follows:

1. The average height of the trees of each separate diameter class is obtained. For this purpose, only a few sample heights for each separate diameter are measured. The heights so measured are plotted on cross-section paper on which diameter is the determinate variable plotted on the horizontal scale, while height is the indeterminate variable plotted on the vertical scale.

An illustration of a curve to obtain average heights based on diameter is shown in Fig. 56. The trees to be measured for height must be selected in such a manner that the resultant curve will give the true average heights for each diameter class for the entire area to which it is to be applied. When a very few trees are taken, these must be carefully chosen from those whose crowns are of average height compared with the remaining stand. This is best accomplished in even-aged stands. On large areas and in many-aged stands, a mechanical distribution of trees measured for height is best, in order to secure a weighted average of differences caused by variation of site and of growth.

In plotting the data, two methods are shown. By the first, all heights are plotted above their respective diameters. A height curve may thus be sketched by eye through the band of points shown. This eliminates mechanical averaging. By the second method, the average height is calculated for the trees in each diameter class, and this point is plotted ⊗. The points are then connected by straight lines, their weight in numbers shown, and the curve drawn, as before, guided by the original data.[1]

[1] In the first system, when two heights fall on the same point, the number is indicated as ^{2}.

A combination of these two systems may be used as follows: First plot the points, then compute the mechanical averages from the plotted data by using the scale as follows: For the 9-inch trees, assume the 40-foot point as 0. The trees are then entered as having the weights 0, 3, 8, 8; total 19; average 4.8 plotted as 5 above the 40-foot point, or an average height of 45 feet. This method combines the advantage of visualizing the data to indicate abnormally high or low trees, with a slight reduction in the work of mechanical averages.

2. Instead of tallying the diameters of all the trees, they are merely counted, but a certain fixed percentage of the total number is tallied for diameter (the heights are either tallied individually or the method

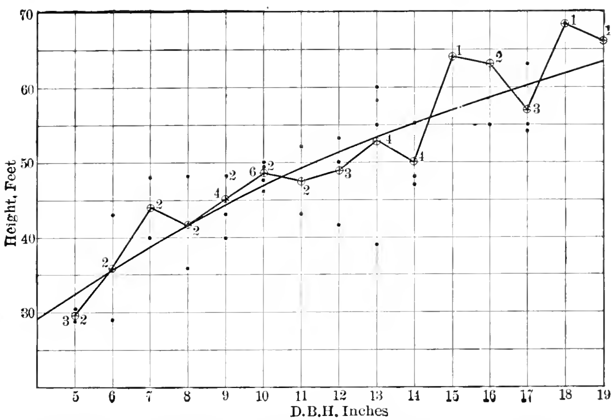


FIG. 56.—Method of constructing a curve of height based on diameter at B.H. White Pine, Milford, Pike Co., Pa.

of averages described above is applied). The volume of the average tree of the per cent tallied is used to find the average volume of the numbers counted but not measured.

In Southern longleaf pine, it is possible to count all of the trees on a tract, and to tally the diameter and merchantable height of one tree in every three in such a way that the trees tallied represent the mechanical average of those counted. When the volume of the tallied trees is computed, it represents one-third of the volume of the stand. The work of tallying has been reduced one-third and the accuracy greatly increased, when considered with reference to the time required to complete the work.

3. None of the trees in the stand is tallied for either diameter or height. The trees are merely counted and the cruiser then decides upon the volume which will be contained in the average tree of the stand. He may obtain this either through a direct guess as to volume or through

the selection of what he believes to be a tree of average diameter and height whose volume he then ascertains. There are two modifications of this system, dependent upon whether the unit used is the log or the tree. When the log unit is used, the cruiser estimates the number of logs in the average tree and the contents of the average log or log run (§ 120).

In the above three methods of averaging, nothing has been said about the question of area covered. The averages apply to that portion of the area on which the timber is either counted or in addition is tallied for dimensions. This may be 100 per cent or the total area. Although it may not be possible to measure, by diameter and total height, each tree on the entire area, yet by the employment of one of these three methods of averaging the contents, all of the trees may actually be accounted for.

The remaining three of the six methods of employing averages apply to tracts whose area is too large to permit of 100 per cent estimates, even by the simplest plan of counting and obtaining the average tree. The principle here is to estimate the stand on a portion of the area in an effort to derive the volume of the stand upon the remainder. The systems used are as follows:

4. The stand per acre is guessed at or estimated by eye. This stand multiplied by the area in acres presumably gives the total stand on the tract. This is merely a modification of the method of total ocular estimate, in which the problem of arriving at the average is approached in a different manner. It is possible for a skilled estimator to guess closely the stand on a given acre, but the difficulty lies in either finding a specific stand whose volume per acre happens to agree with the average on the entire tract or else to decide from the inspection of given stands how much the actual stand per acre observed on specific plots must be modified in order to obtain the true average for the entire tract estimated. The probabilities of error in estimates made on this basis increase with the size and diversity of the stand to be estimated.

5. The dimensions and volume of the trees on a given per cent of the total area are obtained by one of the first three methods and the stand thus found is assumed to represent the average stand per acre for the entire tract. This requires, first, the accurate determination of the area of the tract and of the area covered by the estimate, and second, the location of this latter area in such a way that the assumption that it represents the average of the remainder can be accepted as approximately correct.

6. The same principle is employed as described under 5, but the assumption that the per cent of area so measured will give an accurate mechanical average applicable to the remaining tract is not accepted. Instead, the remainder of the area is inspected by the method of ocular

comparison. None of the trees is actually measured except on the per cent estimated. Using this estimated strip as a standard, the estimate upon the remainder is taken as equaling, exceeding or falling short of the stand per acre upon the estimated strip, and its volume is obtained by applying a correction to this estimated stand per acre.

210. The Choice of a System for Timber Estimating, with Relation to Accuracy of Results. All systems of timber estimating involve the choice, first, of one of the three methods for determining the contents of the trees and second, of one of the three methods of covering the area. There are many different systems of timber cruising, involving the possibility of an endless combination of these six elements Each of these systems represents a decision as to the per cent of area required to get the average stand per acre for the total area, the method of covering the area to obtain this per cent, and the question as to acceptance or modification of the stand per acre as applicable to the whole tract; it also involves the further reduction in the work of measuring dimensions to get the volume of trees by substituting averages for height, a per cent of total tallies for total tallies and average volumes for individual volumes. These two groups of factors are closely interrelated. For instance, where the per cent of area covered is reduced to a low figure, the area which is actually estimated must be covered thoroughly by careful measurement of distances and widths of strips, the diameter of every tree should be measured or tallied, and each tree may be tallied for height, especially if merchantable heights are used. Where, on the other hand, all of the area is covered, it may be sufficient merely to count the trees, substituting the method of an average tree or log for the more detailed and time-consuming method of measuring each diameter. The gain in accuracy in one of these factors may be offset against possible inaccuracy in another, the sum of the factors being determined by the total cost of the method. These points may be briefly summed up as follows:

Area—
- Full estimate, 100 per cent.
- As modified by averages.
  - Sample plots taken as the average.
  - A given per cent accepted as the average.
  - A given per cent estimated as a basis for obtaining the remainder by comparison and correction.

Trees—
- Full estimate, 100 per cent tallied for both diameters and height.
- As modified by averages.
  - Average height obtained from sample measurements.
  - Volume of average tree obtained from tally of dimensions of a fixed per cent of the total stand.
  - Volume of average tree obtained by inspection, from sample tree, or average tree on sample plots.

Both the degree of accuracy obtained and the expense of estimating the timber are reduced:

By the reduction of the per cent of area covered.
By substituting tree counts for measurements of dimensions and averages for totals.
By substituting ocular measurements of dimensions for instrumental measurements.
By substituting pacing for chained or measured distances.

As an offset to the loss of absolute accuracy by the substitution of these laws of averages and reduction of detail, the relative accuracy or efficiency of the application of the cheaper methods can be enormously increased by the development of technical skill, experience and judgment, so much so that the old-time timber cruiser depended upon these factors both for his reputation and the reliability of his estimates. This relative accuracy is increased:

By the choice of methods and care in location by which partial areas are secured in such a manner as to insure the highest probability of average volumes. This is similar to the methods used in sampling ore.

By the development of skill and accuracy in the use of pacing and in the use of the eye for measuring diameters, heights and width of strips or plots.

By the ability to apply the methods of tallying a fixed per cent of the stands or selecting average trees in such a manner that the true average volume of the total number or count is obtained.

By painstaking observance of obtainable standards of accuracy in the use of instruments for measuring distances, diameters and heights, and in proper record or tally.

By individual training and ability to make the proper discounts for defects.

By the careful checking of the reliability of volume tables used, and the correlation of field methods with the conditions for which they were constructed.

Finally, by correlating all of the above factors with the actual conditions of the tract or stand to be estimated, which in themselves will determined the degree of accuracy required in each step as above outlined.

211. Relation between Size of Area Units and Per Cent of Area to be Estimated. There are two elements to be considered in arriving at accurate averages in estimating a given tract. First, the problem of distributing the samples throughout the area in order to obtain the greatest probability of true average; second, the uniformity of the stand itself as increasing or decreasing the probability of accuracy for a given method of sampling.

The first of these problems is influenced by the size of the tract. In any method of estimating based upon measuring a part of the area, the system employed must be that of strips or plots spaced at regular intervals. Otherwise the element of judgment in selection introduces a difficult factor which will improve the average obtained only when accompanied by considerable individual skill. With plots or strips at fixed intervals, the number of such strips depends upon the dimensions of the tract.

The choice between plots and strips does not affect this principle. Plots, when substituted for strips and taken along compass courses at regular mechanical intervals, serve to reduce the per cent of total area covered. Since the distribution of the sample areas is more evenly diffused on the basis of the per cent covered, by plots, than it is by strips, the loss in accuracy by substituting plots for strips is not in proportion to the reduction in per cent of area covered, but is considerably less, thus resulting in a material saving where the use of plots permits of the reduction in size of crew (§ 224).

The size of the separate units of area on which accurate estimates are desired—as for instance, when owners require the estimates separately by " forties " (§ 8), is the basis for determining the effect of the spacing of these strips. If the estimate must be accurate only for the entire tract, a quite different problem is presented from that when the same degree of accuracy is required for smaller subdivisions. Assuming that the tract is in the form of a square, the coefficient of accuracy bears a close relation to the number of strips run across this area, rather than to the distance between these strips. This may be expressed as follows:

The per cent covered by strips will be the product of the number of strips and width of each strip, divided by width of the area. With strips of a uniform width, e.g., 8 rods or 132 feet, run at intervals of $\frac{1}{8}$ mile, the per cent of area covered is $\frac{8}{80}$ or 10 per cent, whether the tract be 40 acres, 1 square mile or 25 square miles. But the probability of accuracy in securing an average stand is not in the same proportion for each tract, but increases with the size of the tract. The reason is that, regarded as a unit, the larger tract is more uniformly sampled, and with reference to its total area, the strips or plots are more thoroughly distributed than on the smaller areas. The relative accuracy is in proportion to the distribution of the sampled or estimated strips with respect to this total unit, which for large tracts tends to reduce the per cent of area required to obtain a given standard of accuracy.

Standard distances between strips or plots are 80 rods, or once across a forty for very extensive work of low accuracy; 40 rods, or twice across a forty for work of average accuracy; 20 rods, or four times across a forty for work approaching a 50 per cent estimate; 10 rods, or eight times across a forty, which with a 10-rod strip permits 100 per cent of the timber is to be measured.

The first problem then, in estimating a tract, is to decide upon the proper per cent of the area which must be covered to secure the desired standard of accuracy, and this per cent will be a direct function of the size of the smallest unit of area upon which a separate estimate is required (Fig. 57).

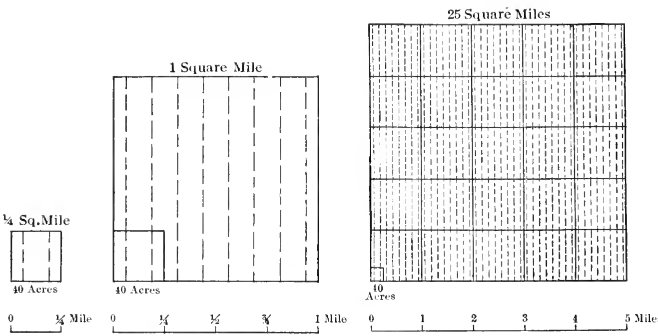


Fig. 57.—Influence of size of tract upon probable error in obtaining average volume per acre, by running strips 40 rods apart in each instance. Dotted lines indicate location of strips.

Narrow strips spaced at one of these standard intervals are commonly used for large tracts. Upon small tracts, the necessity for increasing the per cent of area covered, as a substitute for increasing the number of strips run, takes the form of widening the strip. This is usually accompanied by a modification of the method of tallying the trees and the substitution of a count for the measurement of every diameter. For small areas as low as 40 acres, this frequently takes the form of a 100 per cent estimate, the strips being so arranged that they cover the entire area, and where the value of the timber and its size is such that accuracy is desired for each forty, 100 per cent of the entire tract is covered, no matter what its total size.

The relations between the distance apart of strips or plots, width or size of these strips or plots, and resultant per cent of area covered, to the size of the unit of area to be estimated, is the most practical problem of timber cruising upon whose solution depends the attainment of the desired standard of efficiency secured by properly relating costs to accuracy of results.

212. Degree of Uniformity of Stand as Affecting Methods Employed. The second factor affecting the probability of accuracy in obtaining the average stand per acre is the character of the stand as affecting its uniformity. Uniformity depends, first, upon the range of sizes both as to diameter and height of the trees which compose the stand; second, on the regularity or evenness of their distribution or the variation in the density of the stand over the area. The greater the extremes, both in sizes and density, the more difficult the attainment of a correct average stand by a measurement of a part of the area, and the greater the necessity of increasing either the number of strips or the per cent of area covered in each strip to get a larger total per cent of area in obtaining the average.

Age of timber increases both the range of sizes and the variation in density. Old timber is never as evenly distributed as a young stand, owing to the progressive losses from natural causes. Mixed forests, composed of several species, are more difficult to average than pure forests of a single or of two or three similar species. There is greater irregularity both in size and distribution in the mixed forest. The greatest irregularities for a given tract are caused by differences in topography and soil, or site conditions, which are reflected in the character of the stand. In mountainous topography, the entire forest changes from bottom to lower slope and from lower slope to upper slope. In more level topography, the type changes as abruptly and completely on the basis of the moisture content of the soil from swamp to drained bottom, from drained bottom to dry upland. Any system of timber estimating must be planned to secure:

1. The separation of areas which differ radically from each other, but which within themselves are fairly uniform. These areas conform with the types of forest cover.

2. An arrangement of the strips such as to secure the greatest possible accuracy in sampling, which is done by crossing these variations of density, type and form, at right angles with their longest dimensions of area, as far as possible (§§ 219 and 228)

The degree of detail and cost of the work as reflected either in an increased per cent of area or number of strips or an increased per cent of trees tallied for dimensions, either diameter or height, will thus be increased in proportion as

The size of the unit diminishes.
The size of the timber increases.

The variety of the timber increases.
The topography is more mountainous or varied, resulting in a greater diversity of types.
The number of products required increases.

Finally the degree of accuracy required, other things being equal, will depend upon the stumpage value of the products to be estimated, as influenced, first, by the character of the timber itself, and second, by the unit price of the product. In the earlier days crude and inaccurate methods of timber estimating were justified by the low price per acre and per thousand feet at which stumpage changed hands. With record stumpage prices running up to $27 per thousand feet for white pine in state auctions in Minnesota, in 1920, a degree of accuracy is justified which would not be thought of by old-time timber cruisers.

CHAPTER XX

METHODS OF TIMBER ESTIMATING

213. The Importance of Area Determination in Timber Estimating. Except in a few instances where every tree on a tract is separately measured, all methods of timber estimating depend upon the principle of applying the results obtained on part of an area to the entire area, or on small portions of an area to larger subdivisions. Any error in determining the total area included within the boundaries of a tract, or the correct area of any subdivision made within it, will incur a corresponding error in applying the results of the estimated portion to the whole. The separation of timbered from non-timbered areas is an example. If the average stand of the timbered portion is correctly found, but its area is estimated to be 10 per cent greater than it actually is, an error of plus 10 per cent is incurred in the estimate. Correct determination of areas of the tract and its timbered subdivisions is the first consideration in the field work of timber estimating and counts for fully half in the total scale of accuracy.

The first essential is to locate and determine definitely the boundaries of the area to be estimated. Where the tract lies in regions subdivided by a rectangular system of government surveys this is not ordinarily difficult. The area may be approximately located with sufficient exactness for the work. Even here it is necessary to identify the section corners and sometimes to re-run the lines if time permits. In other regions where the land surveys follow an irregular pattern, the identification of the corners and lines is best accomplished by the aid of some local resident who is familiar with these bounds. The retracing and mapping of the boundaries of a property is an essential step in management, but its cost is not properly chargeable against the item of timber estimating alone.

If methods are used by which 100 per cent of the timber is estimated, the total stand can be obtained independent of the actual area or shape of the tract provided only that all of the trees upon it are counted and their contents determined. When for a 100 per cent estimate is substituted an estimate covering only a part of the tract, the cruiser requires a knowledge of its shape and size. In the rectangular system of surveys most of the subdivisions are square and the smallest unit commonly used contains 40 acres. Even here fractional lots lying along the north and west boundaries of a township or adjoining meandered streams and lakes call for a plot which shows their dimensions. With these rectangular areas it is a simple matter to obtain a definite per cent of the total by running strips of a given width.

On irregular tracts, a map showing the boundaries and area is required to enable the cruiser to determine, first, in what direction and relation to lay out his lines or strips, and second, to compute the exact per cent of the total. This desired per cent is approximated and the exact relation secured is determined after the lines are run.

214. The Forest Survey as Distinguished from Timber Estimating. Timber estimating may be undertaken for the sole purpose of determining the volume of timber on a tract, but as commonly carried out, this requires the running of numerous definitely located compass courses, gridironing the area, which gives an opportunity for the collection of a large amount of additional data required in its permanent management and in the logging of the area. The collection of this additional data, together with the timber estimate, constitute what is termed a *forest survey*. Even the crudest work of timber cruisers embraces some elements of a forest survey. The features of such a survey are:

1. A map showing the topography of the area either by hachures or contours, giving streams and ridges and other important features which influence logging and management.

2. A map showing the character of the forest cover, classified as to

   (*a*) Timber types, corresponding with divisions made in the stand in timber estimating and showing blank areas, such as water, barren, cultivated or grass-land.

   (*b*) Divisions due to age of the timber such as burns, re-stocked or barren, reproduction or immature timber, older age classes.

3. Soil maps, locating land of agricultural value and land fit only for forest purposes.

Under timber estimating proper, the forest survey makes an inventory showing both the quantity and quality of timber by different products, grades and sizes as required for the purpose of valuing the tract as follows:

1. Quantity or volume.

   (*a*) Separately by species.

   (*b*) Separately by units of merchantable volume, as board feet, poles, cords.

   (*c*) Separately by character, as live or dead timber, sound or cull, and giving the net volume after deductions for cull.

2. A statement of amount and character of damage present due to rot and other defects such as shake, fire damage to standing timber, the presence of insect damage, windfall.

3. The quality and sizes of the timber under the items; average diameters, average merchantable length in logs, form of bole as to straightness, taper and clearness and finally the grades present, classified either as log grades or as grades of lumber.

The third class of data is that needed for permanent forest management for the production of timber by growth. These data are frequently omitted or overlooked in a timber survey, first, by old cruisers who have not been trained to collect them; second, by foresters who have failed to formulate a definite plan for their proper collection in anticipation of the need for its use. These data fall under:

1. Age classes in the merchantable timber, either by area (maps), or by size or diameter (stand tables of diameter classes), or both.

2. Age classes in immature timber either by areas as mapped, by per cent of area occupied or by tree counts; the ages and sizes of these age classes, their condition, thrift and the chances of survival.

In addition, a forest survey may include data on all other resources of the forest such as forage for grazing, while under timber it should determine the areas included within different site classes (§ 227). Forest surveys include all data of every kind necessary for the making of a working plan for the management of the area for permanent forest production.

215. Timber Appraisal as Distinguished from Forest Survey. The forest survey as described above is the preliminary step in the appraisal of the value of timber stumpage. This appraisal constitutes a separate operation, although the survey and the appraisal are so closely bound together that they are frequently performed by the same man. They must not be confused, however, for a timber appraisal is not a part of Forest Mensuration, but belongs under the separate subject, Forest Valuation (§ 5). It may begin where the timber survey leaves off, using the data acquired by this survey. Separate parties may conduct the timber survey and the timber appraisal with satisfactory results.

A timber appraisal covers the following points:

1. Logging conditions summarized for each logging unit, under topography, slopes, surface, rock, brush and character of bottom as affecting logging. Transportation possibilities, availability of streams for log driving, routes for roads, flume or railroads, methods best adapted for skidding and hauling the timber and the costs of these processes.

2. Costs of forestry such as the per cent of the stand to leave for seed or second cut, the cost of brush disposal and other protective measures.

3. Economic conditions, markets and prices for lumber.

4. General appraisal, cost of milling, cost of logging, cost of transportation, profits required.

5. Specific appraisal, the direct cost of logging the specific body of timber and the resultant stumpage value of this unit.

A clear-cut distinction between the work of timber estimating and of timber appraisal will prevent the mistake so often made of burdening the timber estimating crew with the work of recording in great detail items of cover, surface, brush, etc., *which instead should be summarized for an entire unit by the person who appraises the value of the timber and sizes up logging conditions.* It is seldom that the two jobs can be effectively combined in the same party or individual. The work of timber estimating requires routine and concentration on the details of the job. The actual appraisal, even if the same party makes it, should follow rather than accompany the estimate and should be based first, upon the data on topography as shown by the map and second, upon the data on volumes as shown in the estimate.

216. Forest Surveying as a Part of the Forest Survey. A forest survey as above outlined includes the work of forest surveying or the determination of the boundaries and area and the mapping of the topography of a forest tract. This subject is not a part of Forest Mensuration, but must be treated separately. Since the gridironing of the tract requires the measurement of distance and direction and the plotting of these lines will give the framework of a map, it follows that the work of making a topographic map which may employ the same general methods of examination for the area, *can be advantageously combined* with the work of timber estimating. Timber cruisers usually prepare a crude map showing the intersection of streams and the position of ridges and other topographic features of importance. The preparation of a map based upon basal elevations and giving contours is a development of the timber survey introduced by foresters and adds greatly to the efficiency of the survey. By combining this map-making with the entirely separate operation of estimating, a crew of two men can complete both operations with a very slight increase in expense, not comparable with the cost of doing each piece of work separately.

At the same time the preparation of the type or timber-cover map can proceed, and upon this in many instances depends the accuracy of the timber estimate itself (§ 225).[1]

[1] The detailed methods of Forest Surveying employed in a forest survey cannot be discussed in a text on Forest Mensuration without exceeding the limits of the volume. Any summary of a system of forest survey must include a description of the methods of surveying and topographic mapping which are to be used. The various methods of survey must be co-ordinated with the methods of cruising and with the cost and relative accuracy of the work desired, both for the survey and the estimate.

217. The Cull Factor, or Deductions for Defects. Most timber estimating for board-foot contents of stands is based on the amount which the logs will scale (§ 116). Since a sound scale of logs requires deductions for defects which will not make sound boards, the timber estimator must make the same deductions in the standing trees. This deduction from total sound scale is independent of any separation of the timber into grades or quality, which calls for additional special attention. Deductions from full sound scale of standing timber are made either by the log unit or by the tree unit on the basis of the judgment and experience of the cruiser. Where the estimate is made by logs, only sound logs are tallied. Culled logs are dropped from the tally altogether and trees which contain defective portions are scaled by shortening the length or decreasing the size of the logs tallied so as to represent only their net sound volume. Where it is impossible or inaccurate to use this method of omission, a straight percentage deduction for cull is either substituted for the method of dropping or reducing logs or is subtracted after all of the clearly visible defect has been deducted.

Tree units are handled in the same manner. Trees so defective that they are practically cull are not tallied at all, but in species where few, if any, trees are cull and the defect constitutes a portion of a large per cent of the logs and is not easily deducted, cruisers deduct a straight per cent from the total sound scale of the trees tallied. Usually a combination of these methods is necessary since the per cent deducted represents more accurately the loss in the sound scale of logs actually sawed and taken to the mill, while a considerable additional cull is found in logs and trees not utilized at all.

Foresters, in making a tally of diameters and heights, customarily tally all trees, regardless of their condition, omitting only dead timber which is unmerchantable, and then apply to the total volume a percentage deduction for total cull, which will cover both that portion left in the woods and that lost in sawing.

218. Total, or 100 Per Cent Estimates. To completely cover a small area, it is only necessary to avoid duplicating the count or measurement of the individual trees. This may be done by the use of a bark blazer or scratcher, or by tagging the trees, a method employed in India where labor is cheap.

Trees may be given a light bark blaze. In working over a tract in this manner, the blaze is placed upon the same side of all trees, facing the direction towards which the measurement is proceeding. Where topographic features are present on small areas, duplication may be avoided by covering sections bounded by these natural features without the necessity of spotting the trees.

On larger areas, where it would be impossible to keep track of the individual trees, parallel strips may be run. The trees on the outer edge of a strip can be blazed facing the strip which has not yet been measured, and in this way the entire tract covered with a minimum of effort. In dense swamps men may be employed to hew parallel lanes through the underbrush; the cruiser then estimates all trees between these lanes.

It is possible to dispense with all methods of marking the trees provided sufficient care is taken, first, in running the strips accurately as to direction so that they lie parallel and at fixed distances apart, and second, by estimating or measuring the trees on strips so placed that they cover the entire area; i.e., strips whose borders are contiguous. There is danger of overlapping or duplication by this method, and if it is the intention to run a 100 per cent estimate, a slightly greater accuracy can be insured by blazing. This ocular method, however, is commonly employed as a substitute for blazing.

A modification of this method of completely covering the area by strips, is the laying out of rectangular plots whose dimensions are such as to cover the area without overlapping. These plots are estimated consecutively and may be of any convenient width and length. As an example, a method given in Graves' Mensuration, page 196, consists in laying out two tiers of plots, each 40 rods wide and 16 rods across. Ten of these plots give the area of 40 acres. The cruiser proceeds 20 rods from the corner of the forty, and then crosses the center of the first tier of five plots, returning through the center of the second tier.

To get the contents of the trees on areas 100 per cent of which is estimated, the following systems may be used:

1. Tally the merchantable contents of each tree directly. This is estimated by eye, or from a universal volume table which may be printed on a Biltmore stick, or any other convenient form.

2. Tally the upper diameter, inside bark, of each log in the tree, or tally the upper diameter of the butt log and top log (see Rule of Thumb by F. R. Mason, § 204). The contents are then computed from a log rule.

3. Tally the diameter and merchantable height in 16- or 32-foot logs or half-logs of every tree. The contents are then computed from a volume table based on similar dimensions.

4. Tally the diameter only, of every tree, either by eye or by the use of calipers. Measure, by a hypsometer, several sample trees of each diameter to give a curve of average height on diameter. The contents of the trees are then computed from a volume table based on diameter and height. The heights measured may be either merchantable or total, but are usually the latter. In this method, types or areas

which differ in average height and diameter must be estimated separately.

5. Count all the trees on the area and tally a fixed percentage such as 1 in either 3, 4 or 5, whose volumes are found as by method 4 above.

6. Count all the trees on the area and determine their volume by arriving at the contents of an average tree. This may be done:

By guessing at the average contents.

By selecting a tree of average diameter and height and determining its contents by the use of volume table.

By determining the number of logs per tree or average merchantable height expressed in logs, thus getting the total number of logs on the area and then guessing at the contents of the average log or number of logs per thousand.

Method 6 may be applied to all of the timber considered as one class, or the timber may be separated into two or possibly three different classes, corresponding with marked differences in size and character.

219. Estimates Covering a Part of the Total Area. The Strip Method. There are two methods generally employed to estimate a portion of the area, the strip method and the plot method. The strip method adopts the principle of endeavoring to obtain the average stand per acre for the whole area, from the portion estimated by the running of strips parallel or in a given direction and spaced at mechanically regular intervals. By this means it is sought to eliminate judgment or choice in the obtaining of the required average.

This average is still further improved by the choice of direction of running these strips. The effect of differences in elevation and in drainage or soil moisture is to produce differences in the density and character of the forest corresponding with these changes. The belts of forest which have comparatively uniform stands usually run parallel with contour lines and at right angles to the direction of slope. A basic principle of strip estimating is therefore to cross these belts at right angles or proceed directly up and down slopes or directly across the larger stream or drainage bottoms as far as possible, and to avoid traveling along contour lines or bottoms and in general along the long axis of belts of timber. If this fundamental principle is neglected, very large errors may be incurred in applying the average estimate so obtained to the larger area.

In rectangular surveys, it is customary to run the strips in one of two cardinal directions, and the choice is therefore narrowed down to either north and south, or east and west. In irregular surveys, or where the topography is so mountainous that the estimate will be made by topographic blocks and units, rather than by forties or legal subdivisions, the system of strips will be planned with reference to base lines run along the main bottoms and streams, from which, at regular intervals, the strips will be run directly up the slopes and as nearly parallel to each other as possible. The strips in each separate unit may, therefore, have a different direction.

220. Factors Determining the Width of Strips. The standard widths of strips used in timber estimating are six in number and their dimensions are given in the following table:

TABLE XLI

RELATION OF WIDTH AND NUMBER OF STRIPS TO AREA COVERED

WIDTH OF STRIPS			Area covered by one strip per forty acres or four per mile.	Strips per $\frac{1}{4}$ mile to cover entire area.
Feet	Rods	Chains	Per cent	Number
33	2	$\frac{1}{2}$	$2\frac{1}{2}$	40
66	4	1	5	20
110	$6\frac{2}{3}$	$1\frac{2}{3}$	$8\frac{1}{3}$	12
132	8	2	10	10
165	10	$2\frac{1}{2}$	$12\frac{1}{2}$	8
330	20	5	25	4

On rectangular surveys, to compute this per cent of total area covered by the strips, multiply the number of strips run per forty or one-fourth mile square, by the width of the strip in rods, and divide by 80 rods. These two factors, number and width of strips, are not reciprocals since each has a distinct function to perform. The number of strips per forty increases directly the probability of accuracy in securing an average stand or proper sampling of the timber on the area (§ 211). The width of the strip affects this average to a lesser degree. Its principal function is to enable the cruiser to determine accurately the dimensions and volume of the trees which stand upon the strip estimated, and the factors which affect his ability to obtain this accuracy will determine the width of strip without respect to its effect upon the total area covered. If narrow strips must be run in order to get accurate estimates of timber on the strip, and it is necessary to increase the per cent of area, the number of strips will have to be increased rather than the width of the strip.

An example of the relations between these two factors is cited by Austin Cary, Manual for Northern Woodsmen, where a system on the Pacific Coast of using two strips per forty, each 10 rods wide, covering 25 per cent of the area was abandoned in favor of the use of a narrower strip $6\frac{2}{3}$ rods wide to increase the accuracy of the estimate on the strip. The number of strips was then doubled, or four strips run per forty, and the total per cent of the area estimated was thus increased from 25 per cent to $33\frac{1}{3}$ per cent. If, instead, the number of strips had been kept the same, but the width of each strip increased to 20 rods, a lesser degree of accuracy would have been attained in spite of an increase to 50 per cent of the area covered.

In determining the number of strips required for a forest survey, the character of the topographic map desired must be considered with reference to the topography. Lines run $\frac{1}{2}$-mile apart will give only a rough scale map in bold mountainous topography. Lines placed at $\frac{1}{4}$-mile intervals in mountainous slopes with large features, are sufficient for an accurate topographic map with a large contour interval of from 50 to 100 feet. On all flat or gently rolling forested slopes with no outlook, cut up by drainage or interspersed with swamps, it is impossible to make an accurate topographic map with proper contour interval of from 10 to 20 feet and show all details of drainage and slope, unless lines are run at $\frac{1}{8}$-mile intervals, but this interval is sufficient for all maps on the ordinary scale of from 2 to 4 inches per mile. Only for a much greater detail will lines be required at less than this interval.

The influence of the forest cover upon the number of strips required for accuracy increases with the two factors, density of the forest cover and variation of the timber, whether caused either by age, size or diversity of species. Finally, the increasing value of the timber from any cause, whether through quality or unit price, will require an increase in the per cent of area covered, which means a greater number and more closely spaced strips.

These conditions frequently require a full or 100 per cent estimate by forties, the best examples of which are the heavy stands of rapidly increasing value in the Pacific Coast States, or stands of large mature hardwoods with great variety in size and value.

The width of strips is determined by the accuracy with which this width can be measured by the eye and the dimensions of all the trees standing thereon ascertained, or the timber upon it measured and counted. This width is diminished directly by the amount of brush and undergrowth which obstructs the vision. In brushy country, strips seldom exceed from 4 to $6\frac{2}{3}$ rods. The width of a strip is also diminished by decreasing size and increasing number of trees on the strip. In young timber, with many stems per acre, a greater degree of accuracy is obtained on a 4-rod strip accurately measured and counted than upon a strip of twice the width. Conversely, open and large timber with fewer and more scattered trees and an unobstructed view not only permits a wider strip to be measured accurately, but requires an increase in the per cent of area, which is easily obtained by increasing the width of the strip without an appreciable increase in the cost. This is independent of the need for running more strips per acre, by which the per cent is still further increased. With unobstructed vision, a wide strip may be estimated with almost as great accuracy as a narrow strip, since the error may be in proportion to the total width without affecting the percentage of error in the estimate.

With increasing openness and irregularity of timber, strips may give way altogether to a total count of timber on an entire forty, since no system of partial or sample estimates can be depended upon to secure an average or a correct total.

The method of determining the volume of the trees on the strip affects the width of strip which can be used accurately. Where trees are counted, without measuring the diameter of each tree, nearly double the width of strip can be used because trees can be seen for this additional distance while it is less possible to judge their diameters accurately. Upon a calipered strip, the additional width sometimes slows up the work and introduces a greater per cent of error.

The counting of trees in open country is so simple a matter that cruisers accustomed to estimating such species as longleaf pine in the South have usually abandoned the strip method altogether. Guided by the compassman, they cross a forty about twice, pursuing a snake's course back and forth, and attempting to see and roughly to count all of the trees on the forty.

221. Method of Running Strip Surveys. Record of Timber. Strips are universally run with the compass. A hand compass is commonly used by cruisers working in dense, swampy or brushy country, as it is more quickly read and increases the number of sights possible without delaying the work. For ordinary accurate surveying, in which a topographic map is made, the use of a staff compass adds to the accuracy of the direction of the strips, and is commonly employed (Fig. 58). In the use of either hand or staff compasses, it is a great advantage to be able to turn off the declination of the needle on a movable arc with a vernier so that a cardinal direction is indicated by the sights. This is especially true in the Pacific Northwest, where variations up to 25 degrees are encountered.

The size of the field party for strip estimating depends upon the methods used in measuring and recording the timber. Where the diameters of each tree are measured either with the calipers or Biltmore stick, the party will consist of three or four men to best advantage. One man runs the compass and makes the topographic and type maps. A second man tallies the diameters; the third and fourth work, one on each side, calipering trees. Heights are usually taken at regular intervals so as to be distributed uniformly over the area. Considerable errors may be incurred in bunching sample heights in timber which may be too tall or too short for the average of the stand.

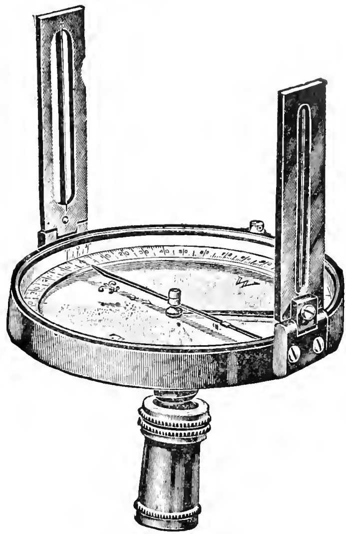


Fig. 58.—Staff compass.

Where diameters and merchantable heights are measured by the eye, the party is usually reduced to two men, one for the compass and map, the other to record the dimensions of the trees which he estimates. It was a common practice in the Lake States in earlier days, for timber cruisers to work alone without the assistance of a compassman. The system of counting timber and recording merely the average dimensions and volume enabled a man to run his own compass, keep track of his paces, and at the same time count the trees.

The record kept by cruisers on strip estimating consists primarily of a tally of the trees by diameter, height, or volumes direct; second, of the cull, per cent; third, notes on damage to the stand; fourth, quality of timber and grades; fifth, young timber and reproduction; sixth, soil and ground cover. A report or summary sheet for each separate unit, usually by forties, is worked out. The following headings are submitted as samples (p. 278):

In the Appalachian region upwards of twenty species and a variety of products may be estimated. For the hardwoods, volume tables based upon diameter and merchantable log lengths are used. It has been found necessary to have available a table for one- and two-log trees to avoid errors in inaccurately applying small top diameters for these trees rather than the actual merchantable top. Cull is deducted from each tree by reducing the D.B.H. or number of logs. An additional per cent is deducted for unseen defects. The tally is coordinated with existing volume tables to secure a record of lumber, cordwood (principally acid wood), poles, ties, posts, or other products. An example of the tally form used is shown on p. 279.

On All Sheets
Block..... Township, 20N Range, 12E Section, 33 Meridian, N. La. County.......... State, La.

SHEET No. 1

ESTIMATE OF MERCHANTABLE TIMBER

Lot (Forty)	Area, Acres		Conifers				Hardwoods, by Species, Net Estimate				Remarks
	Blanks	Timbered	Species, Per cent	Gross estimate	% Cull	Net estimate	White oak	Black oaks	Hickory	Red gum	
N.E.–N.E.	0	40	Short-leaf 100	200M	5	190M	2M	....	1M	1M	

SHEET No. 2

DESCRIPTION—MERCHANTABLE TIMBER

Lot (Forty)	Species	Age class	Dimensions				Character			Defects and Losses				Grades		
			D.B.H.	Height logs	Vol. average tree	Logs per M	Clear Length	Crook	Taper	Fire	Wind	Insects	Rot	Uppers	No. 1	No. 2
N.E.–N.E.	Short-leaf	Mature	18	$2\frac{1}{2}$	280	10	2 log	....	....	....	2%	....	4%	10%	60%	30%

SHEET No. 3

DESCRIPTION—IMMATURE TIMBER

Lot (Forty)	Conifers species, Per cent	Area reproduced Acres	Age Classes			Size		Damage		Hardwoods species, Per cent	Area reproduced Acres	Effect on conifers
			Character	Origin	Distribution	Height	Diam.	Cause	Extent			
N.E.–N.E.	Short-leaf 100	10	Groups	In forest	Uneven	1 to 50 feet	5 to 9 inches	Hogs Fire	20%	Oaks Gum	16	Serious suppression

Form 1001
(Revised Sept., 1916)

U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

Acres estimated, forest 4.4
Location Bannister Branch
Course S

Chains { *Forest* 0–26 0–18; *Open* 19–26 }

Per cent estimate 10 *Width strip* 1 ch.
Type Lower slope
Tract Arcadia
Tallied by D. K. Hendee, *Esta* E. B. Stone
Date 10/11/20 *Sheet No.* 1

Chain tally, forest 0 //// //// //// //// //// 26 0 /—//// //// //// /// 18

	Chestnut						Chestnut Oak						Poplar					White oak				Mixed oak				Red oak			Scrub pine			Yellow pine			White pine			Cedar and locust			Hemlock			Hickory			Others		
D.B.H.	0	1	2	3	Ties	Poles	0	1	2	3	4	Ties	0	1	2	3	4	1	2	3	Ties	1	2	3	Ties	1	2	3	0	1	2	1	2	3	1	2	3	1	2	Posts	0	1	2	1	2	3	1	2	3
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36																																																	
38–44																																																	

Chain tally, open, 19 //// /// 26 *Method of measuring diameters* Cruiser's stick *per cent ocular* 10 *Offsets* 0 //// //// 10

REVERSE SIDE OF BLANK

Forest types, Lower slope

Age classes, 1–60

Condition of timber, Immature

Thrifty	95	per cent			
Mature	2	per cent			
Decadent	3	per cent			
Fire killed	..	per cent;	*damaged,*	5	per cent
Insect killed	..	per cent;	*damaged,*	–	per cent
Other killed	..	per cent;	*damaged,*	2	per cent

Name of disease, Bark disease

Species affected, Chestnut

Quality of timber (give by log grade; percentage of tall, medium or short clear boles; or number of clear logs of stated minimum length and diameter):

80% tall; 15% medium; 5% short

. . . .

Logging factors:

Undergrowth; light-medium-dense, Light

Windfall; light-medium-dense, None

Bowlders and broken rock; numerous; occasional; absent, Absent

Other factors, Easy gradient. Logging conditions ideal as skid and wagon roads can be constructed anywhere

Replacement:	*Species*	*Per cent*
No replacement,	. . . .	. . . . . .
Ground one-third stocked,	. . . .	. . . . . .
Ground two-thirds stocked,	. . . .	. . . . . .
Ground fully stocked,	Chestnut, 50%; white, 5%, red, 5%, black, 20%, and chestnut oaks, 10%; white, 1%, pitch, 2%, and scrub pines, 2%; gum, 2%; sourwood, 1%, and maple, 2%	100%

The stand shows an absence of poplar due to grazing

Additional Notes: This is a stand which was cut over for charcoal during the war and since then was culled for chestnut ties and poles. Bark infested chestnuts should be cut as well as suppressed chestnut for extractwood. The few mature "wolf" trees left from former cuttings should be removed as well as some of the scarlet and black oaks where the stand is too dense. Removal of the latter can be made for ties. The dead and down timber from the laps in the tie and pole cuttings should be removed for extractwood

Explanation of Blank, by Supervisor J. H.Fahrenbach.

All saw timber is tallied by the number of 16-foot logs in each tree. If a tree happens to have odd lengths " we give and take."

Under chestnut all trees to be removed for extract wood are tallied in the " 0 " column. All trees to be left are tallied in the one-log column, even though they are not large enough to make one 16-foot log as is the case in trees under 10 inches D.B.H. Street railway ties (6 by 6 inches by 8 feet) are tallied in trees which have reached their maximum value for hewn ties. Standard gage ties are usually sawed in saw timber operations, and are tallied as saw timber. Poles are tallied by diameter class. In this way we are able to approximate the number of 25-foot, 30-foot, 35-foot, etc., poles.

Chestnut oak and hemlock trees, suitable for bark alone, are tallied in the " 0 " column. In figuring the estimate for bark the number of trees tallied as saw timber must also be included. It sometimes happens that we also have a market for black oak bark, and in this event a " 0 " column must be entered under mixed oak.

Poplar and scrub pine pulp wood are entered in the "0 " column.

We class black, scarlet, pin and Spanish oak under mixed oak. If a " 0 " column is added, it is understood that black-oak bark is to be entered. Under mixed-oak ties red-oak ties are included.

Pitch, short-leaf and table-mountain pine are tallied under yellow pine.

If there is a market for locust-tree nails they are tallied in the one- and two-log columns for the larger locust trees and the smaller trees are tallied as posts, using as a basis a post 4 inches in diameter and $7\frac{1}{2}$ feet long.

Under others are tallied beech, birch, gum, maple, sourwood and sycamore.

If there should be other valuable species for which provision has not been made in the headings the diameter and number of logs in each tree are given at the bottom of the Form. This includes walnut, ash and wild cherry.

If there is a market for fuel wood, provision must be made for a " 0 " column for all those species which cannot be utilized for either bark, pulp or extract wood. All the oaks can be thrown together in one heading, the pine in one heading and the remainder of the species, except hickory, in another heading.

222. Tying in the Strips. The Base Line. In laying out and recording the strips run in estimating, independent of the question of topographic mapping, it is necessary to tie in each strip to a known point at each end, so that its position and the error incurred in running it in both distance and direction may be determined. For this purpose, and also to form the basis of a map when one is constructed, a base line is first surveyed along the route from which the strip will be later laid out. The strip, whether rectangular or irregular areas are being estimated, will start as nearly at right angles as possible from points on this base line, and will either be tied in to a second base line approximately parallel to the first, or by offsets will be run back at the proper interval and tied in to the original base line.

In laying out this base line, therefore, stations or measurements are established at the exact points and intervals from which these strips must later be initiated and tied in. Methods of survey and establishment of base lines fall under the subject of Forest Surveying. The base line is a primary feature of the forest survey. Where a land survey exists which is accurate and easily traced, or where such a survey is retraced, it may serve as a base line.

Where the area is small, and a survey and map exists, the corners and known or located points on the boundaries of the tract are substituted for a base line as points from which to initiate strip surveys. The same rules apply as to the necessity of tying in each strip on its completion to some known point on the map, in order to check errors in the survey which would affect the areas determined.

In running the strip, the estimator is dependent upon the compassman for the distances from which the areas are determined and the estimate separated by 40-acre tracts. Errors in measuring this distance will cause the cruiser to misplace timber, thus altering the accuracy of the individual estimates per forty. Where types or differences in stand are separated in estimating, the distance across each separate type, as kept by the compassman, will determine the area and consequently the accuracy of the estimate within the type. If errors are incurred, their character and extent is revealed by tying in to known points, which enables the construction of a correct map and the correction of the estimates.

In running estimates over separate forties, it is customary to run strips 1 mile in length, cruising a tier of 4 forties before returning. Where one strip per forty is run, the estimate for the forty is completed at the end of 80 rods. Where two or more strips are run per forty, the tally of the timber on each forty is separated for each strip as indicated to the cruiser by the compassman, and is not completed until the last strip on each forty is run. The results for each strip on the same forty are usually tallied together on the same sheet, and care must be exercised not to misplace or mix up these tallies.

223. Systems of Strip Estimating in Use. Examples of systems of estimating in which the various factors itemized above are harmonized to meet a given set of conditions, are given below:

Forest Service Standard Valuation Survey. This system was used almost universally by the Forest Service and with minor modifications is still a standard method used on national forests. Its characteristics are:

Width of strip	4 rods or 1 chain
Number of strips per forty	1 to 2
Per cent of area estimated	5 to 10
Measurement of distances	By chain or tape
Measurement of trees, diameters	By calipers or Biltmore stick or ocular
Heights	Sample heights by hypsometer
Forest types	Separated and coordinated with average heights
Cull factor	Estimated by a total per cent
Corrections from strip estimate for average stand	None

In this system, as indicated in the last item, no effort was made to modify the average stand per acre obtained from the strip in order to get a more correct total for the area. The employment of inexperienced men made necessary the use of instruments for diameter and height measurement, and the rigid elimination of the element of judgment on every point possible. Where the unit of area was large, from 1 square mile up, this method gave excellent results, since the mechanical average for areas of this size is quite dependable on the basis of a 5 to 10 per cent estimate. The errors possible could be easily avoided by conscientious effort. These errors consisted of too wide or narrow a strip, diameters measured too low, average heights measured too high, dead trees calipered for live ones. When applied to large timber in units of 40 acres or less, these mechanical results cannot be depended upon.

Lake States Cruisers' Method

Width of strip	8 to 10 rods—2 to $2\frac{1}{2}$ chains
Number of strips per forty	1 to 2
Per cent of area estimated	10 to 25
Measurement of distances	By pacing
Measurement of trees	Counted
Heights	Average number of 16-foot logs per tree
Volume	From number of logs on tract and log run, or contents of average log
Forest types	Timber of different age classes and quality separated
Cull factor	Usually by per cent deduction from total estimate
Corrections from strip estimate for average stand	Close inspection of remaining area and modification of average whenever necessary to obtain correct total

Of late, timber cruisers in these states have been adopting the use of volume tables, but in many instances these tables are based upon stump diameter inside the bark which makes them less consistent and accurate than if based on D.B.H. The more modern cruisers are adopting the use of standard volume tables constructed by regular methods and differentiated by D.B.H. and height.

Southern Timber Cruisers' Methods

Width of strip	A strong tendency to substitute ocular estimate, based on the stand per acre, for the running of strips. Great carelessness in methods until recently
Measurement of distances	Paced by a compassman, the cruiser usually riding a horse. Consequently estimates frequently stopped at the edges of swamps
Measurement of trees	Cruiser gets located by compassman, but does not follow the strip. Trees are counted on acre plots
Volume of average tree	Guessed at, using rule of thumb based on Doyle rule. Trees on entire forty may be counted to check results of plots and get reduction factor

Forest types........................Accuracy of the better class of cruisers greatly increased by careful elimination of blank areas and containing net area of timber to which reduction factor from stand per acre is applied for total
Cull factor........................Usually neglected on account of deficiencies in Doyle scale
Corrections from strip estimate for average stand....................This is based on general inspection and counting since no systematic strips are run

Many Southern cruisers have adopted more systematic methods of late.

Yale Forest School Method in Southern Pine.
Width of strip.....................10 rods—$2\frac{1}{2}$ chains
Number of strips per forty...........2
Per cent of area estimated...........25
Measurement of distances...........By pacing
Measurement of trees...............Count of the trees on the strip, tally of one-third to one-fifth of the timber by mechanical selection to avoid choice.
Diameters ....Tallied by eye
Merchantable height................Tallied by eye in 16-foot logs and half-logs of all trees whose diameters are tallied
Volume on strip....................From volume table for trees tallied multiplied by 3, 4 or 5, according to per cent tallied
Forest types.......................Areas not stocked with merchantable timber eliminated by mapping. Net area of timber obtained. Types not usually separate within a forty except on the map
Cull factor........................By per cent of total estimate
Correction from strip estimate for average stand........................Careful inspection at stated intervals of stand on remainder of forty. Comparison by weighted volumes with stand estimated. Weighted correction factor applied to area estimated to obtain proper stand per forty

Horseshoe Method. This is a modification of the strip method, by which two strips are practically combined in one by running a horseshoe or angular course through the forty as shown in Fig. 59. This results, first, in a saving of time, cutting down a certain amount of travel from one strip to another; second, in a better inspection of the timber and, it is thought, in a better average, since the strips run in both cardinal directions. This method was employed extensively by a firm of Southern timber cruisers, who used a 10-rod strip, thus running 25 per cent of the area.

Pacific Coast Method.
Width of strip......................10 rods, or $2\frac{1}{2}$ chains
Number of strips per forty...........4
Per cent of area estimated...........50
Measurement of distances...........By pacing

Measurement of trees	The volume of each tree recorded directly, based upon the universal volume tabies
Forest types	Not necessary to regard them
Cull factor	Deductions made for each tree when its volume is ascertained
Correction from strip estimate for average stand	By running 50 per cent, corrections are usually avoided. Where inspection reveals the necessity, modifications are made in the total estimate

Separate record under this system may be made of the board-foot contents and of other products, such as poles. The estimate is frequently increased to 100 per cent.

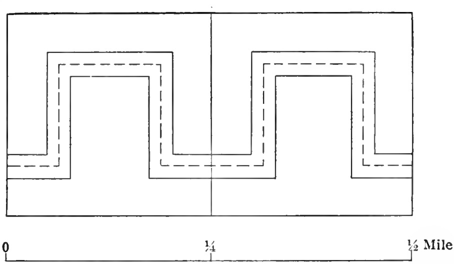

Fig. 59.—Horseshoe method of strip estimating. Route of compassman shown by dotted line.

These examples are cited merely to show the various combinations of elements which go to make up a system of timber estimating. The securing of accuracy consists in adapting the number and width of strips to the local conditions described as, first, character of timber to be estimated and, second, size of the smallest unit of area to be estimated. The details of measurement, whether by eye or instrument, for distance or for tree dimensions, must be coordinated with the volume table and with the skill and personal ability of the individuals employed in the work. The saving in time by the substitution of the eye and of ocular judgment requires dependence upon personal skill. Where cruisers with sufficient experience are unobtainable, accurate results may still be obtained by mechanical measurements, carefully supervised and conscientiously applied.

224. Methods Dependent on the Use of Plots Systematically Spaced. In the use of plots in timber estimating, the method employed depends upon whether the principle of mechanical arrangement or spacing is to be observed, in order to obtain an average stand, free from the element of personal judgment, or whether instead, plots are to be selected by the use of judgment in an effort to obtain thereby an average stand which will apply to the area as a whole. By the first principle, the plot method, so-called, is merely a modification of the strip method. Compass strips are run at the usual intervals, but instead of a continuous belt or ribbon of area being covered, this is broken or separated into plots at fixed or stated intervals along the line.

These plots may be rectangular, but the use of such plots is not common. In the measurement of rectangular plots, a crew is usually employed, and this same crew can probably run out the entire strip with better results. Rectangular plots for the measurement of young growth and reproduction, which is desired only on a small per cent of the area, are frequently used in conjunction with a strip for the merchantable timber.

The common form of plots is circular to enable one man to work to advantage without the assistance of a compassman. By dividing the functions of pacing and compass work from those of estimating and recording the diameters and heights of timber, the mind is kept free for concentration on each task in turn. A crew of two men is sometimes used for circular plot estimating with the same advantage to the timber cruiser, who can inspect the stand for defect and quality between the estimation of the volumes of his plots. The common size of plots is as follows:

TABLE XLII

Sizes of Circular Plots

Size of plot.	Radius.	Diameter	
Acres	Feet	Feet	Rods
$\frac{1}{4}$	59	118	7.15
$\frac{1}{2}$	83	166	10.0
1	118	236	14.3

The relation of these plots to the per cent of area covered is given below.

TABLE XLIII

Relation between Plots and Area Covered

Size of plot.	Shortest distance between centers.	Plots for $\frac{1}{4}$ mile of strip	Total area included in plots.	Per Cent of 40 Acres Included in Running	
Acres	Rods		Acres	1 strip	2 strips
$\frac{1}{4}$	8	10	$2\frac{1}{2}$	$6\frac{1}{4}$	$12\frac{1}{2}$
$\frac{1}{2}$	10	8	4	10	20
1	16	5	5	$12\frac{1}{2}$	25

Great care must be taken in the use of circular plots to obtain the width of the plot correctly. An error in this factor is more serious than that on a strip, since it affects the entire boundary. The same principle as to size and number of plots and per cent of area covered applies to these methods as to strip estimating. In dense brush and with small timber, the common size is one-fourth acre, while plots 1 acre in size are required for old and large trees. The amount of timber on each plot is obtained by the use of the same variety of methods as for strips.

Examples. Spruce in the Northeast on large tracts.

Size of plot	$\frac{1}{4}$ acre
Number of strips per forty	1
Distance between plots on strip	20 rods—5 chains
Per cent of area covered	$2\frac{1}{2}$
Measurement of distances	By pacing
Measurement of trees	D.B.H., calipered or tallied by eye
Heights	A few sample heights taken on each plot for curve of height on diameter
Types	Separated in mapping
Cull	By per cent applied to total estimate
Correction of estimates to get average	None

Large Timber on the Pacific Coast.

Number of strips per forty	1 to 2
Size of plots	1 acre
Number of plots per strip	5
Per cent of area	$12\frac{1}{2}$ to 25
Measurement of distance	By pacing
Measurement of trees on plot	Average tree selected for each species. Diameter at stump inside bark and at top measured. Average of these diameters taken as diameter of the average log
Volume	Obtained by rule of thumb (§ 214). (Any of the three standard methods for obtaining the contents of trees on a plot or area apply to this method.)
Types	Blank areas eliminated and stand obtained for average acre
Cull	By a per cent of the total estimate
Correction factor to the estimate	Obtained by general observation and comparison with stands on the plots

CHAPTER XXI

METHODS OF IMPROVING THE ACCURACY OF TIMBER ESTIMATES

225. The Use of Forest Types in Estimating. When only a part of the area of a tract is covered in estimating, the accuracy of the resultant estimate depends upon the success with which the actual average stand per acre has been obtained. Although the per cent of area taken has been properly chosen to fit the topographic conditions and character of the timber and although the measurement of the timber upon this area and the width of the strips has been accurately carried out, so that no avoidable error remains in the work done, yet the estimate may still be in error by the failure to secure the same proportion of the different types and variations of stand on the strips as exist on the area as a whole. On account of the prohibitive expense of running a sufficient per cent of the area to get this average mechanically, a margin of error in timber estimating is permitted, and is gaged by the value of the timber and the purpose of the estimate. Any modification which will secure the required degree of accuracy and at the same time avoid incurring an unreasonable expense will necessarily become a part of the system employed.

The more uniform the stand as to sizes and density of stocking, the better the averages. This applies to the use of all six of the classes of averages cited in § 209.

For the purpose of securing a greater degree of uniformity in the stand on those subdivisions of total area to which the estimates obtained on strips or plots are applied, the distinction of forest cover types is indispensable. A forest type includes all stands of similar character as regards composition and development due to given physical and biological factors, by which they may be differentiated from other groups of stands. A cover type is the forest type now occupying the ground, whether this be temporary or permanent. Timber estimating concerns itself only with the existing forest cover.

The factors which are reduced to greater uniformity by the separation of forest types in estimating are composition of stand as to species, and consequent relative per cent of total volume of stand represented by the different species, a vital consideration in timber estimating. This factor has an influence upon the total volume of the stand, as well as its average height, though both of these are influenced even more profoundly by differences in quality of site within the same cover type.

These differences in type may be caused by altitude, slope, moisture and depth of soil. By separating the total into sub-areas, a far greater uniformity of size and density of the timber in these subdivisions may be obtained, first by securing a more uniform mixture of species in the per cents of the different species represented in the stand; second, by reducing differences in the density of stocking per acre; third, by securing more uniform sizes both in height and diameter, and a smaller range. The subdivision of an area into a number of smaller units is a means of avoiding the necessity for securing a weighted average of these factors in order to get the average acre. Doubling the number of strips would probably secure the same result, but the expense of separation of the estimate into two or more types is much less than this increase in field work.

The only increased expense of separating types consists of the increase in computations required by separating the areas and the precaution required in changing the tally sheet on entering the type. Proper coordination between the compassman who maps the area and the estimator who records the timber is necessary.

Where areas as small as 40 acres are mapped and a large per cent taken, distinctions between the two types of timber are not often made by old woodsmen. The total volume of each species is obtained without separate computations of area.

But the principle of type separations is universally applied in separating areas which do not contain merchantable timber from those which do. Blank areas caused by cultivation, burns, swamps, or unmerchantable reproduction must be subtracted from the total timbered area under any system which permits the completion of a cover map. The arbitrary inclusion of these unstocked areas makes it practically impossible to obtain an average stand on the remainder. In theory the same law of averages applies even in this case and with a sufficient number of strips which cross blank areas in such a way that a per cent of the blanks is taken as the merchantable stand, no error would be incurred in the average. But the extreme danger of obtaining a different per cent from that on the whole tract, and the comparative simplicity of mapping out these blanks to obtain net timbered area, makes this method universal wherever the number of strips per forty or $\frac{1}{4}$-mile amounts to at least two, and possible even when but one strip is run. This correction requires, first, the area of the type whether timbered or blank, from a map; second, the area covered by the strip in estimating. The latter expressed in acres is computed by multiplying length of strip by its width. The most convenient units are rods, since 160 square rods equals 1 acre, or chains, 10 square chains to 1 acre. Distance in chains on strip required for 1 acre may be computed for each width of strip and the area of the strip obtained by dividing its length by this factor.

226. Method of Separating Areas of Different Types. To determine the total area of the type accurately from a map, *a planimeter* may be used. By the use of this instrument a direct reading on the map is obtained in square inches of the area whose boundary is traced by the needle, moving clockwise. The stationary pin is placed outside of the area to be traced. When placed within the area so that the movable pin finally encircles the pivot before returning to its point of origin, a deduction or correction must be made in the indicated area, the size of which depends upon the make of instrument used.

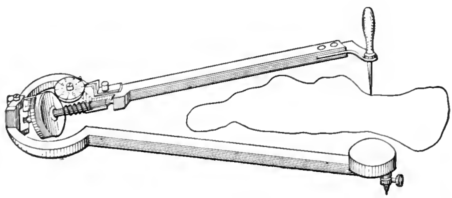

Fig. 60.—Polar planimeter.

The equivalent in acres for square inches, as determined by scale of the map, gives the acreage. Lacking a planimeter, the area of types can be computed by the method of approximation through triangles or the sum of small squares. For the latter purpose a map should be plotted on fine cross-section paper. The area of these types is required only to a reasonable degree of accuracy since the determination of their field boundaries is a matter of inspection and sketching and the total area of the tract is not involved.

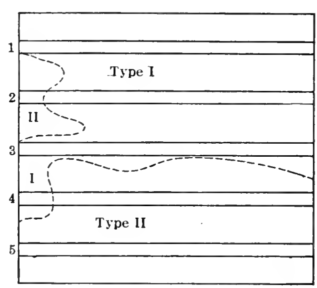

Fig. 61.—Relation of areas of types to strips in timber estimating.

As an illustration of the effect of using type areas in estimating, the following example may be cited: Area of tract, 200 acres, divided into two types containing 100 acres each. The stand on the first type is 30,000 board feet per acre, and on the second 10,000 board feet. The total stand is therefore 4 million board feet. Twenty-five per cent of this area or 50 acres is to be covered by strips. The result of the cruise is shown in Fig. 61.

The result of running the five strips at regular intervals is to include within type I, 30 acres, which at 30,000 board feet per acre would give 900,000 board feet. In type II, 20 acres was included which at 10,000 board feet gives 200,000 board feet, a total for the 50 acres run, of 1,100,000 board feet. As this is 25 per cent of the area, the required factor for the tract without subdivision into types would be a multiple of 4, giving an estimate of 4,400,000 board feet, an error of +10 per cent caused not by errors in the strip but by failure to get the weighted average stand from the strips run.

But if while running these same strips the tally sheet had been changed wherever the strip passed from one of these types to the other, and both the map of the area and the corresponding estimate of the timber, or tally, had thus been separated into two areas, corresponding with each of the two types, the computed estimate would show that while on 30 acres 900,000 board feet was tallied the average acre for type I is 30,000 board feet, but instead of this applying to three-fifths of the total area, it applies only to the actual area shown to be in the type, or one-half of the total, which is 100 acres, totaling 3,000,000 board feet. The less fully-stocked type in the same way is shown to contain 1,000,000 board feet or a correct total for the tract of 4,000,000 board feet. The 10 per cent error incurred in the first method is eliminated. The accuracy of this area correction obviously depends first upon ability to obtain by sketch a correct map of the actual areas of the different types, and second, to convert this area from the map into acres by use of the proper methods of map reading as explained in this paragraph.

This system of type divisions is of especial value in mountainous regions where sharp distinctions can be drawn between types coinciding with great differences in the average density, volume, size and value of the timber. Under such circumstances the more valuable types would require a greater per cent of the total area to be estimated, to obtain the same basis of accuracy as could be secured for the less densely stocked and less valuable tracts with a smaller per cent. The type divisions also are more conveniently made in large or irregular areas than where estimates are separated by rectangular tracts of 40 acres.

227. Site Classes and Average Heights of Timber. Differences in the quality of the site on which timber is growing cause very great differences in total volume per acre, and in the total heights of the trees and stands. To quite an extent these differences are closely correlated with changes in cover types, different types being found on wet soils, fresh well-drained soils, and dry, shallow soils. But it often happens that the same type of forest cover will extend without appreciable changes in composition over a range of site quality so great that it becomes necessary to subdivide the area within the type into from two to three site classes, ranging from good to poor. This is made necessary by the effect of site upon the height of the trees in the stand, on account of the methods usually required, of selecting sample trees to measure for height.

Heights constitute an extremely variable factor in timber estimating. Not only do total heights range through limits of at least 100 per cent for the same diameter, but merchantable heights, especially in old hardwoods, vary still more widely. Just as, in a 100 per cent estimate, the necessity for averages is eliminated, so when the height of every tree in a stand is tallied there is no necessity for average heights. Only when merchantable log lengths are used as the basis for height will the height of every tree measured for diameter be tallied. Where total height is used, far greater accuracy can be obtained by the measurement of a few trees with a hypsometer than by attempting to guess by eye the height of each tree.

In a large tract with varying site qualities, the securing of the average height for each diameter class from a range of heights of 100 per cent would require the selection of heights on the basis of the principle of a weighted average. If exactly the same proportion, as for instance, 1 per cent, of the heights for each diameter were obtained from large, medium and short trees as existed in the original stand on the entire tract, the height curve could then be applied to the tract as a whole. Any failure to secure this weighted average would result in a curve giving too high or too low an average for the timber as a whole.

The difficulty of securing a weighted average is eliminated if the tract can be divided into two or three site qualities, separated as distinct units in the field in estimating. On each of these separate sites the heights conform to a much closer range for the same diameter than for the entire area, and a few selected trees for each class will give a dependable height curve (§ 209) from which the volumes in each diameter class may be accurately computed.

228. Methods of Estimating which Utilize Types and Site Classes; Corrections for Area. An example of the application of these principles is found in the standard methods of timber cruising adopted by the Forest Service in the Appalachian region. Four types are used, termed cove, lower slope, upper slope and ridge. The variations in the per cent of estimate required are shown in the following table:

TABLE XLIV

PER CENT OF TOTAL AREA REQUIRED IN ESTIMATING

Area of estimate unit.	Total Area Estimated		
	Average of all types.	Heavily timbered types.	Lightly timbered types.
Acres.	Per cent	Per cent	Per cent
0– 100	50–100	50–100	50 – 100
100– 500	25– 50	25–100	10 – 25
500–1000	10– 15	20– 50	5 – 10
1000–5000	5– 10	15– 25	2½– 5
5000+	3– 5	10– 25	1½– 2½

The problem of combining a large per cent of area on a heavily timbered type, as the cove type, with a small per cent elsewhere, has been solved here by running strips across the entire area, embracing the minimum per cent. Where these strips cross the cove types, points are marked on the ground which serve to tie in the strips run through the coves. Where 100 per cent is not estimated, a plan of running strips in a zigzag course from one boundary to the others of the type through these coves has been adopted. The more acute the angle between two courses and the more nearly parallel the resultant strips, the greater the per cent of the type included.

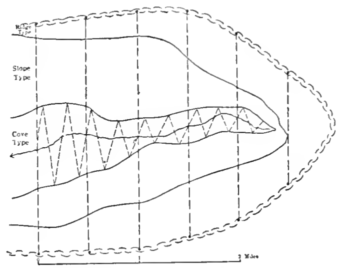

Fig. 62.—Method of running strips to cover an additional 20 per cent of area in heavily timbered type, on basis of original 5 per cent estimate for entire area. Strips 8 rods wide.

229. The Use of Correction Factors for Volume. The purpose of all estimates is to secure the actual volume of timber on the entire tract as accurately and inexpensively as possible. In systems of covering partial areas, even after the probable error has been reduced by adopting subdivisions based on type or forest cover and site, there remains a final possibility that the average stand per acre within the type differs from that secured by the methods employed.[1] The older and more diversified a stand, the greater will be its irregularity of stocking, and the greater the necessity for accuracy. Can this accuracy be still further improved? A correction of an average, mechanically obtained, rests upon the assumption of definite knowledge that this average is wrong, and the ability to determine approximately how much it is in error. Since the timber on the area lying outside the measured and estimated strips is neither counted nor measured, the impression that the average is wrong depends upon the ability of the cruiser to estimate or size up timber by the eye and to compare it ocularly as a whole with the stand upon the strip which he has measured. This comparison is useless unless enough of the remaining timber can be seen so that it is practically certain that the average stand on the whole remaining area is greater or less than that measured on the strips. Where strips are narrow and run at wide intervals, it is impossible to arrive at this judgment and no reliable correction can be made by eye.

[1] Errors in Estimating Timber, Louis Margolin, Forestry Quarterly, Vol. XII, 1914, p. 167.

But where strips are run at intervals of $\frac{1}{8}$ mile and the timber is open and large, and especially in coniferous stands which have a fair degree of uniformity of sizes, although varying materially in density, it is possible to view the remaining timber without counting it or calipering. If there were time for additional measurements, these would be made. The application of a correction factor is based on the assumption that the per cent actually measured is the maximum possible under the limiting conditions. Where an error would evidently be incurred unless the mechanical average is corrected, this correction should always be made.

The method of applying this sort of a correction in the past has been as unsystematic as the ocular estimation of timber itself. The estimate from sample plots or strips was arbitrarily raised or lowered according to impressions obtained by the cruiser. This system may be greatly improved and a much higher per cent of accuracy obtained by observing the following principles:

1. The comparison sought is not an absolute estimate of the volume per acre on the remaining area, but a percentage relation between this stand and the strip which is measured, by which the estimate on this remaining area may be obtained by increasing or diminishing that on the strip.

2. The correction is an average for the whole area to be corrected, in the form of a per cent of total volume. Single observations must therefore be carefully weighted to obtain average results.

3. The correction actually applies only to the area lying outside the strip and not measured. If applied to the entire area of the unit, the estimate on the strip itself is arbitarily raised by the same percentage as applied to the residual area and this factor cannot be neglected in arriving at the proper per cent.

To illustrate the last point, assume that 50 per cent of a tract has been estimated. By observation, the correction factor on the remainder is assumed as +10 per cent. The estimate is 100,000 board feet on the strip. The correct estimate on the remaining area is therefore 110,000 board feet and the total, 210,000 board feet. If 10 per cent is applied to the results obtained for the forty, the process would be, 100,000 times 2 gives the uncorrected estimate for the area, or 200,000 board feet. A correction of 10 per cent gives 220,000 board feet, which is an error of 4.8 per cent in the estimate.[1]

[1] This multiple, which in this illustration is 2, is sometimes termed the correction factor, but assumes no correction. It is merely the extension of the mechanical average over the entire area. For a 25 per cent estimate, the multiple is 4; for 20 per cent, it is 5, etc. A method of applying the correction factor is in use, by which this multiple is raised or lowered. Where the multiple is 4, a +25 per cent correction calls for 5; $+12\frac{1}{2}$ per cent requires $4\frac{1}{2}$, etc.

Since this error consists in applying the per cent erroneously to the area estimated within the strip, it diminishes with the per cent covered by the strip; e.g., should 25 per cent of the above tract be estimated and found to contain 50,000 board feet, and the correction factor be actually 10 per cent, the remaining area, which if uncorrected would have a stand of 150,000 board feet, has actually 10 per cent more than this or 165,000 board feet or a total for the tract, of 215,000 board feet. But applying 10 per cent to the entire tract indicates a total stand of 220,000 board feet or an error of +2.4 per cent. But with the decrease in the per cent tallied, the probability of obtaining a close observation of the remainder and applying a correct per cent also diminishes so that if a correction factor is used at all, there is less need for modifying the per cent. The conclusion is that when, on account of measuring a large per cent of the area, it is possible successfully to use a correction factor as applied to the remainder, there is all the greater necessity for making a correct application of this factor.

To determine the actual correction from a per cent obtained by weighted observations, two methods may be used. The first of these methods applies to irregular areas where the per cent estimated is not uniform, that is, in areas estimated by the separation of types. The steps are as follows:

1. Reduce the stand on strip to stand per acre.
2. Apply the per cent correction to this stand per acre.
3. Calculate the stand separately for the area not estimated, using the corrected average stand.
4. Add together the estimates on and off the strip for the total; e.g., on 100 acres, 17 per cent is estimated and the remaining 83 acres is judged to run 10 per cent heavier than the strip. The tally on the strip is 170,000 board feet, averaging 10,000 board feet per acre. The 10 per cent correction gives 11,000 board feet per acre off the strip, or a total estimate off strip of 913,000 board feet. The total, both on and off strip is 1,083,000 board feet.

The second procedure may be applied when the per cent estimated is uniform and type or area correction seldom applied. The rule is, *reduce the correction per cent by the proportion which the area estimated in the strip bears to the total area.* E.g., where the strips cover one-half the area or 50 per cent, a correction factor of 10 per cent applies to the other 50 per cent or one-half. Then, $.50 \times .10 = .05$. A 5 per cent correction can be applied to the total normal estimate. Where 25 per cent is estimated and a 10 per cent correction is found, this applies only to three-quarters of the area; $.75 \times .10$ is $.075$. The correction factor of $7\frac{1}{2}$ per cent may then be applied to the total area. It makes no difference whether a correction of 10 per cent is applied to 75 per cent of the area or 75 per cent of a correction of 10 per cent is applied to the whole area.

Since the greatest danger in applying corrections to mechanical averages lies in failure to obtain a proper weighted average, and since it is better to let these mechanical averages stand rather than to introduce an unknown factor, dependent merely upon a guess, observations intended to demonstrate the need for a correction factor must be made as systematically as the strips themselves are run. Fixed points should be chosen at definite intervals along the strips at which to take these observations. These may be taken for instance at points 20 rods apart on the strip. At these points, the areas on either side of the strip should be compared with the stand upon the strip.

The final result is expressed in terms of a per cent, but if each separate observation of a series is so expressed, the resultant per cent will not be weighted by the volumes to which its components apply; e.g., two successive observations may give the following result:

Stand on strip	Correction per cent	Weighted volume correction
10,000	+10	+1000
5,000	−10	− 500
Average of 2 plots	0	+ 250

The actual correction factor is $+2\frac{1}{2}$ per cent instead of zero.

This principle of weighting the observations by volume is very simply applied. It consists of entering for each observation, not the per cent of comparison, but a comparison based on an ocular estimate of the stand per acre. The estimator puts down in two parallel columns, first the stand per acre estimated to be on the strip at that point, second, the stand per acre estimated to be on the remaining area. In arriving at this he includes as large an area as comes under his observation both on and off the strip. For double observations, i.e., taken on both sides of the strip, it is necessary to record the stand on the strip twice, once for each observation off strip.

On the completion of the unit, these stands on and off strip are totaled. By dividing the total off strip by the total on strip, the true weighted volume correction factor is obtained.

This factor is a percentage relation and therefore does not require that the ocular estimates per acre on which it is based be correct, provided they are in the proper proportion. Each ocular guess may be 25 per cent too low, yet the resultant correction factor will be identical with that obtained if the ocular guess in each case were correct. This increases the probability of accuracy in applying the method. Actual tests of this principle have shown that where the average stand per acre off the strip differs as much as from 10 to 15 per cent from that on the the strip, under conditions permitting the inspection or actual seeing of the greater part of the timber, it is possible to reduce the error incurred by the mechanical average by at least one-half, provided the cruisers have some training and skill in application of the principle of ocular estimating.

230. Methods Dependent on the Use of Plots Arbitrarily Located. In discussing the methods of estimating by means of sample plots, only the systematic or strip method of arrangement has been described. A second plan is to locate these plots arbitrarily by selection based upon individual judgment, the purpose being to get the total estimate by means of a few typical plots and greatly cut down the work required in systematic measurements. As in the strip systems, one of two things is done; either the plots which are measured are taken to represent the average stand per acre for the larger area of which they are a sample, or these plots are merely the basis of arriving at the stand by subsequent application of a correction factor.

The first plan can be used only in conjunction with the area or type method in order to eliminate, as far as possible, variations in the stand by separating uniform and comparatively small areas. In this case, sample plots selected with care after a thorough inspection may be relied upon within reasonable limits of accuracy. By the second method, the plots chosen are seldom relied upon without further close inspection of the stand. Cruisers using this method employ these plot measurements in order to establish in their minds the volume of typical stands having a definite density and appearance. Once fixed, this standard is used as a basis with which to compare the average stand on the area by exactly the same methods as were described under the correction factor in the strip method. The plots are merely much smaller and have more definite standards than the strips, and their application to the larger area is more difficult. The use of these plots is still further restricted, with improved accuracy, when they are intended merely to determine the volume of the average tree of certain classes of timber, and the estimate on the remaining area is determined by a tree count covering practically 100 per cent.

Various combinations of the above plans are used, especially in the South, by cruisers working in pine in an effort to cover the ground accurately with a minimum of time and expense.

231. Estimating the Quality of Standing Timber. An estimate of standing timber is in effect an inventory of raw materials intended to establish the total value of the stock on hand. It is not sufficient to know the quantity of wood in the forest in terms of board feet or cubic feet. The estimation of poles, ties and other piece products by sizes and grades illustrates this need. An inventory requires a statement of the total quantity of each class of product, and of each grade or quality within that class, which has a different unit price or value.

Lumber grades differ enormously in value (§ 352), and the quantity of separate grades of lumber which may be sawed from trees of different ages and sizes differs as widely as their values. The estimation of the amount of the different standard grades of lumber in standing timber is as essential in determining its value as the measurement of the total quantity in board feet. The neglect or inability of many foresters, whose training was along lines of mechanical estimating (§ 223) to determine the amount of the product by grades has done much to withhold a recognition among practical cruisers of the great services rendered the profession of cruising by foresters in contributing volume tables and in systematizing the making of topographic maps.

What is wanted is the estimation of the total quantity of timber on a tract, separated into the amount of each of several standard grades, covering the range of the products and sufficient to include practically the entire cut and to determine its average value on the stump. This problem is closely related to that of discounting for defects in that both require a close observation of the character of the standing timber rather than its mere dimensions.

All defects which reduce the value of sawed lumber reduce its grade. When these defects are of a character to reduce the grade below a certain standard (§ 358, Appendix A), the material is no longer scaled under the rule of sound scale. It may still be sawed and sold as lumber. But when it ceases to hold together as boards it is cull.

The deduction of a per cent of the total estimate for defects brings the estimate into conformity with the quantitative "sound" scale. The further separation into grades of the sound portion of the timber which will be scaled and estimated, recognizes the influence of defects, chiefly knots, but including other classes, such as wormholes, sound stain, and twisted grain, which lower the grades and nature of the log contents (§ 352, Appendix A).

To determine grades, a knowledge of the results of sawing and the study of logs as they are opened up and graded into products on the sorting table is far more valuable than the experience gained in studying the apparent defects of standing timber. This knowledge must then be supplemented by a knowledge of the growth of trees in stands. Open-grown trees, although large, are of low quality due to the presence of knots, while trees grown in dense stands have a higher per cent of upper grades due to the history of their development. The skill required in judging the per cent of grades in standing timber is based directly on these two sources of information and is not a matter of guess work.

232. Method of Mill Run Applied to the Stand. Data on grades produced in sawing takes two forms; the total output by grades for mills sawing in a given region and character of timber, and the specific contents of logs of different sizes and quality, as determined by mill-scale studies (§ 361, Appendix A). This corresponds with two different methods of applying the information on grades to the standing timber, namely, application to the stand as a unit, and application to the tree or log units.

In applying mill-run grade per cents to the stand, the total estimate in board feet is arbitrarily divided into the different grades which it will probably yield, by per cents of this total. This method corresponds with that of ocular estimate of a stand (§ 206) and its results are about equally unreliable. The basis is the sawed output by grades from mills in the vicinity. These per cents so obtained will apply to the timber in question, only if it happens to average the same in quality as that sawed, which assumption, considering the great variation in standing timber, is wholly untrustworthy. This means that the per cents of grade must be modified as the timber is better or poorer than that sawed, which requires a knowledge of the standing timber previous to sawing.

233. Method of Graded Volume Tables Applied to the Tree. Evidently, a better basis is required and, just as in timber estimating for volume, this must be found in the use of the tree unit or the log unit, by which the varying quality of the timber can be standardized.

The tree unit has not proved a satisfactory basis for grading, though it is possible to use it. The basis is graded volume tables (§ 165) which show the per cent of standard grades in trees of different diameters, preferably in the form of per cents of contents.

These per cents could be applied to the trees in each diameter class and the total estimate divided in this way into the component grades.

The objection to this method is that it is not sufficiently elastic to take care of the great range of quality in trees of the same diameters. A given graded table will hold good only for timber of a certain character; if more open-grown, shorter bolled or limbier, or otherwise different, the volume table is not applicable. The method is probably better than the ocular guess, but is equally subject to large corrections in the field.

234. Method of Graded Log Rules Applied to the Log. The third method employs the log as the basis of grades, and applies this basis to the standing timber. The graded log table (§ 74) appears to satisfy the requirements of the problem. Log grades are such as can be recognized in standing trees, on the basis of diameter, surface appearance, presence of knots or limbs, and character of the tree and the stand in which it is growing. In turn, these log grades can be analyzed by mill-scale studies, so that the average per cent of grades of timber in each log grade is known. Since three grades are usually made in valuable species, and at least two for the less valuable, trees of the same D.B.H. can easily be thrown into the lumber grades corresponding with differences in their character, by recording the logs which they contain as grades No. 1, 2 or 3. By contrast, if graded volume tables are used, ordinarily only one classification is available for the tree—that corresponding with the table.

The final problem is the application of these graded log tables to the standing timber, in a manner to conform to the methods used in timber estimating. Cruisers who use the method of selecting an average tree (§ 209) usually analyze this tree by the use of the log grades, or directly by per cents, into the grades of lumber which they believe it will cut, and apply these per cents to the remainder of the stand. This is a crude method.

Where the method of tallying the diameter of every log (§ 119) is used, each log can be tallied under its proper log grade. The total volume in each log grade is thus obtained directly. Where timber is sold as logs, it is unnecessary to go beyond this point.

But where the sawed product determines stumpage value, these log grades are merely the basis of application to the standing trees of the grades of lumber which they probably contain, and the contents of the log grades, in lumber of each grade, will be computed for the estimate.

235. Combination Method Based on Sample Plots and Log Tally. Where the tree tally and volume tables are used in estimating (§ 121), the application of the log-grade unit to each tree is not possible, since it would mean a shift to the tally of logs and not trees. Here a combination method is necessitated, based on the principle that grades or quality of timber can be determined by the measurement of a much smaller per cent of the total volume than is required for volume estimate.

The method is to lay out sample or representative areas in the form of strips crossing the types as for timber estimating (§ 209) and comprising a per cent of the area estimated, sufficient in the judgment of the cruiser to obtain the average quality sought. On these areas, every log in each tree is totaled by upper diameter, in the log grade in which it belongs. Instead of guessing at these upper diameters, taper tables based on D.B.H. (§ 167) and total, or merchantable, heights, possible if the latter are cut to a fixed diameter, or if made to conform to average utilization, are used to get these diameters; e.g., for a tree 38 inches D.B.H. containing eight logs, the upper diameters are respectively, from the table, 32, 30, 28, 25, 22, 18, 14, and 10 inches, and are so recorded, each log under its proper log grade. (See § 207 for form of tally.)

The determination of the number of board feet of each standard grade in logs of each diameter and grade, and the total scale for each lumber grade, is based on the contents given for these log grades from mill-scale studies of log contents. The purpose is to obtain the per cent of each grade, regarding the total contents of the logs tallied as 100 per cent, and then to apply these per cents to the volume estimated for the tract. These per cents can be obtained more accurately if over-run is included in logs of each separate size (§ 46). The mill-scale study will show the amount of over-run in logs of different diameters and standard lengths. The scaled volume of these logs should then be increased by this per cent of over-run, before the division into lumber grades is made. On the total sawed contents thus obtained, the per cent of each grade is based.[1]

Even if considerably in error, the value of an estimate expressed by grades of lumber is much greater than one which entirely ignores the quality and consequently the relative stumpage value of the tract.

In the absence of specific information on grades, a record of the sizes of the trees, their clearness of bole, and the density of the stand may furnish a basis for approximating the probable grades.

236. Limits of Accuracy in Timber Estimating. Purely ocular estimates vary in accuracy up to errors of 100 per cent, dependent upon how far the method is stretched from its original limitations. This does not include errors due to inexperience, inefficiency or carelessness.

In mechanical methods of measurements, serious errors may occur in computations. Such errors, of course, are inexcusable, but their avoidance requires careful checking. The mechanical errors due to the operation of the law of averages have been pointed out as a function of the factors influencing these averages, the chief of which is the size of the area unit.

The degree of accuracy must be based upon the standard of utilization. It is entirely unfair to judge the accuracy of estimates based upon one standard against the results of sawing attained by the application of an entirely different standard. Where the standard is the same in both cases, the present demands of timber estimating require

[1] The details of this method are taken from the article by Swift Berry, Journal of Forestry, Vol. XV, 1917, p. 438.

an accuracy of within 10 per cent. The error should be conservative rather than an over-estimate if possible. Greater errors than 10 per cent may be caused by differences in scaling practice alone, or in the length of logs cut, or the thickness of lumber sawed.

237. The Cost of Estimating Timber. No figures will be given for the costs of various methods of timber estimating. These must be determined locally. The elements of cost are:

1. The size of the crew and the wages paid each member; the character of supervision, such as the combining of several crews under one supervisor; and the employment of a cook.

2. Accessibility of the tract as affecting transportation of men and of supplies, especially of food. The means of transportation, such as pack versus wagon haul.

3. Cost of location of boundaries and surveys and cost of establishment of base lines from which strip surveys are to be run. This is a function of the size of the tract and the character of the boundary survey and monuments already established.

4. The number of strips or miles of line to be run per unit of area. The cost is not exactly proportional to the miles run since certain items such as travel to and from work and from one strip to another, cost of computing the estimate, and cost of mapping in the office, increase in a lesser ratio. Doubling the number of strips increases the cost from 50 to 80 per cent, dependent upon the saving in these items.

5. The rapidity of traverse or number of miles of line which may be run per day. A standard day's work varies directly with topography and brush, and with the amount of detailed work required in the actual estimate along the strip, as determined by the number of products, the number of species, the number of trees and the details of record required. In very brushy and mountainous or precipitous country with a variety of species, 1 mile per day may be all that is possible, varying up to 2 miles. An average day's work in fairly open country varies from 2 to 4 miles; on level open land with sparse timber and no brush, 4 to 8 miles may be made.

6. The character of the topographic map required. To a certain extent, a detailed topographic map appreciably slows up the work. It is the object of a forest survey to require only that degree of accuracy and detail which will not add appreciably to the cost by delaying the party.

7. Computation or office work required. By practical cruisers, this is almost eliminated through the methods employed. Methods of tallying dimensions and the use of volume tables increase this additional expense.

8. Holidays, sickness and lost time. Only the number of hours

on the actual work of running lines and estimating can be considered as the basis of costs. All lost time for any other cause adds to the costs per hour of work.

9. Personal efficiency. The training and personal efficiency of the men employed may make from 25 to 50 per cent difference in the actual cost of the work, but its principal effect is in greatly increasing the relative accuracy of the estimate.

Cost of estimating should be computed as follows:

Total cost itemized under salaries, and cost of supplies, transportation and subsistence.

Cost reduced to the cost per hour of actual work by dividing this total by the number of hours employed in estimating. These costs can be separated into field work and office work, including mapping. The costs can then be expressed as cost per unit of area or per acre and finally as cost per unit of product, as per thousand feet or per cord. This is the final test of cost. The cost should then be compared with the stumpage value per unit. If possible it should not exceed 1 per cent of this value.

238. Methods of Training Required to Produce Efficient Timber Cruisers. Mechanical methods of timber estimating, dependent upon the measurement of diameters and heights with instruments, and securing the mechanical average stand per acre by strips, do not require anything more than conscientious work and care in details. Skill and training enter with the application of the laws of averages, even for the construction of height curves. The demand for training is increased by the use of ocular methods of measurement and reaches its maximum in the application of cull for defects and in judging the quality of timber. Aside from familiarity with cull and grades, there are no principles of timber estimating that cannot be learned in a month's intensive training. The common impression that it takes several years to develop ability as a timber cruiser is based upon the unscientific methods employed in training these men. They usually acquire their skill by a maximum of hard work in the woods, with a minimum of accurate comparisons of the estimated volumes with an actual cut. Even in the matter of judging defect, the basic training should not be in the woods, but in the mill and in scaling. It is comparatively easy to recognize the signs of defect in standing timber, but much more difficult to judge of the amount of cull which it causes. In actual training of timber cruisers it has been found that ability to secure accurate estimates is greatest in men who have best developed their mental faculties by education, close observation, memory and systematic coordination. This same combination of qualities is desirable for success in any line. Many cruisers lack this ability and remain permanently inefficient to a marked degree. The only reason that such individuals have in the past continued to practice timber cruising as a profession is the almost complete absence of a reliable check on their results for years at a stretch, and the comparative indifference of purchasers to the accuracy of estimates due to a rising market and a plentiful lumber supply.

Standing timber cannot be "measured." There is always a residual error in the closest work. Hence the use of the term "estimates." Although the only basic check on estimates is the measurement of the timber after it is cut, yet it is possible, by the use of intensive methods, to measure plots of standing timber so closely that they will serve as checks on individual estimators.

[1] An example of this check is cited below in the case of a Minnesota lumber company, which in 1907 required each of its timber cruisers to estimate an area which had previously been carefully calipered and measured with a volume table and was afterwards cut and checked out with these measurements. The results speak for themselves. These men were given all the time they desired to make this estimate.

TABLE XLV

Comparative Estimates on a Tract of 40 Acres

Board Feet

	Calipered, and measured by volume table. Defects deducted	Estimators, by Individual Methods			
		No. 1*	No. 2	No. 3	No. 4
White pine	250,800	220,000	300,000	400,000	130,000
Norway pine	4,120				
Spruce	9,870	......	......	......	10,000
Tamarack	35,480	23,000	45,000	35,000	10,000
Jack pine	730	......	......	3,000	15,000
Balsam	2,220				
Hardwoods	9,910				
Total	313,130	243.000	345,000	438,000	165,000
White pine.†		No. 5	No. 6	No. 7	No. 8
		199,000	175,000	125,000	115,000

* Number of cruiser. † No other species estimated by these four cruisers.

The tract, when cut, scaled by Scribner Decimal C log rule 314,350 board feet, an error of $\frac{4}{10}$ of 1 per cent.

The best system of training men for timber estimating is by the use of sample plots on which the diameter and merchantable heights in log lengths of each tree are estimated by the eye and checked against the records. On these same plots, each of the six classes of averages (§ 209) can then be tested and their application mastered. Each day's training can be checked against the measured volume of the plot that night and not only the total error in per cent but the exact cause of this error ascertained. On this basis, the progress of training is rapid and the cruiser is advanced in a short time more than would be possible in several years of estimating without these checks. The following outline will illustrate the possibilities:

1. Plots of 20 acres, 40 by 80 rods, are laid out with compass. The boundaries are marked by blazing the trees facing each of the four sides on the face towards the plot. Stakes are set on all four sides at distances of 20 rods apart. Two plots are laid out adjoining each other, together comprising 40 acres.

2. Every tree on the plot is calipered at B.H. in two directions, the average being taken to the nearest even inch and the bark blazed to prevent duplication. The blazes are made facing the portion or strip not yet measured. A crew of one tally man and two caliper men are used and all trees above a fixed diameter are taken, corresponding with the minimum exploitable diameter class.

3. The merchantable heights to the nearest 8-foot length or half-log are measured by two or three additional men with Faustmann hypsometers. From 30 to 40 per cent of all heights can be measured during calipering in this way. Height men work with the diameter crew taking the diameter as measured, pacing for distance from the tree and recording heights based on diameter. Forty to sixty heights per hour can be recorded by each man. Upper diameters or merchantable lengths are based upon the practice of sawing as applied to the species measured, provided this is the basis on which the volume table was constructed.

4. The determination of the merchantable height of every tree from that of 30 to 40 per cent of the trees is made separately for each diameter class. The heights tallied within the diameter class are taken to indicate the percentage or proportion of the different height classes existing in this diameter class and the total number of trees are then distributed according to the same proportion. As the result required is a proper distribution for the plot as a whole, and not for each diameter separately, this method gives a sufficient degree of accuracy.

5. The record for the plot will show the following data: total estimate in board feet, total number of trees, average stand per acre, volume of average tree, volume of average log or log run per thousand board feet, exact number of trees in each diameter class, exact number of trees in each log and half-log height class independent of diameter.

The exact number of trees in each separate diameter and height class is the basis for the last two summaries; but the summaries rather than the detailed classification are made the basis of the estimating, i.e., the tally is totaled for each diameter class, and in turn, is totaled for each height class irrespective of diameter.

For each day's work the cruiser hands in a report on the first five of the above seven items and brings in his notebook in which he has totaled the number of trees for each diameter class and each height class separately. His accuracy is computed as a per cent of the total stand on the plot. The error in per cent is recorded. The sources of error are then examined. These are four in number.

1. The width of the strip may be too great or too small. This is shown by an error in the number of trees tallied.

2. The trees may not be counted accurately. This error is identical with the first, but usually shows up as a deficiency of small timber near the minimum diameter tallied.

3. The diameter of the trees may be over- or under-estimated either as a whole, or in certain classes. There is a strong tendency to bunch diameters towards a tree whose size seems to be the standard in the cruiser's mind. This results in over-estimate of small trees and under-estimate of trees of larger diameters.

4. The heights may be over- or under-estimated. When this happens it shows up consistently for the whole tract, the standard of height apparently being temporarily distorted in the mind of the cruiser.

A fifth source of error, the volume table and the failure to coordinate upper diameters and merchantable lengths with the standard used in this table, serves to exaggerate the per cent of error in the judgment of heights, but is always indicated when the average heights are too high or too low to agree with the measurements. When the volume of the average tree is high or low, it usually means an over- or under-estimate of diameters or heights. The exact character of the error in diameter and height is ascertained by a simple check as follows: the cruiser compares the number of trees in each diameter class with that of the standard record and sets down his difference plus or minus. If he is over-estimating, but has the right number of trees, the minus sign will appear opposite the smaller diameters and the larger diameters will show excess numbers. If under-estimating, the plus signs will appear opposite the small diameters. The same rule applies to heights. An over-estimate causes minus signs to appear opposite the lower height classes and corresponding plus numbers in those of greater log lengths. The size of these discrepancies shows the degree to which the error has been carried.

It is the tendency in cruising as in scaling logs, in an effort to correct a known error, to incur immediately a still greater error in the opposite direction; but when it is possible to check against a measurement which the cruiser admits is infallible and in which he has confidence, this tendency to fluctuation is soon overcome and rapid improvement is noted, not only in the total per cent of accuracy which is sometimes merely the result of large compensating plus or minus errors, but in each of the four elements of accuracy, thus insuring a consistent degree of accuracy from day to day.

The cruiser is expected to master but one detail at a time, and the schedule is as follows:

1. During the calipering of the standard plots, the eye is trained in estimating diameters which are then promptly checked by the measurements. The same is true of heights.

2. The second period is devoted to a total or 100 per cent tree by tree estimate with a tally of each diameter and merchantable length. The total area of the plot is covered by eight strips, 5 rods wide, the cruiser working not in the center, but on one side of this strip with compassman marking the opposite border. Width of strip and success in getting 100 per cent of the area is dependent absolutely upon use of eye, checked by pacing and judging distance, and the men are not permitted to mark the boundaries of these strips to prevent overlapping. Twenty acres per day are covered by this method.

3. The third step is to increase the area covered per day to 30 acres by doubling the width of the strip to 10 rods, the cruiser taking the middle of the strip and judging 5-rod distance on each side. In all of this work, the cruiser tallies his own dimensions of the trees. In these preliminary 100 per cent estimates, constant repeated checks are made of the diameters and heights to continue the improvement of the eye.

4. The 100 per cent estimate is continued, but the tally of every diameter is

discontinued and a total count substituted with a tally of one tree in three. The area is increased to 60 acres per day. It is the universal testimony of cruisers that this simplification of the tally relieves the mind of a strain and improves the accuracy of the dimensions tallied and consequently of the total estimate. It has been found that an average volume is obtained through a tally of one-third of the stand under the following conditions:

When there are at least 500 trees per 40 acres of the species tallied and preferably 1000.

When the judgment or process of selection is entirely eliminated in favor of mechanical selection of the trees to be tallied. This may be done by taking every third tree in succession or by taking the nearest tree in each case. Where there are insufficient trees to insure the mechanical average, or where the range of size is large, the count may be separated into two groups, segregating the large from the small trees, one tree in three tallied separately in each group. This adds very little to the detail required when working with a single species.

5. Only 50 per cent of the area is estimated by the above method. The area per day is nominally 120 acres. The remaining area is inspected by eye at distance of 20, 40 and 60 rods in order to apply a weighted volume correction factor as described in § 229. In this method, four strips are run, each 10 rods wide, as before, starting from points, 5, 25, 45, and 65 rods from the corner and alternating with strips not estimated as per Fig. 63.

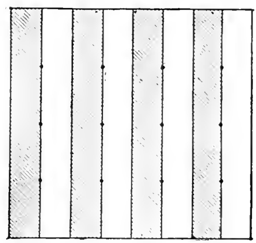

Fig. 63.—Method of estimating a forty by use of the correction factor. Points at which observations are taken shown by dots.

In order to check the correction factor, the alternate strips not previously estimated are now in turn estimated, keeping the record separate from the original four strips. The correction factor derived from observation is first computed and the corrected estimate is then compared with the tally of the strips estimated.

6. Up to this time no effort has been made to deduct for cull which would introduce an arbitrary factor interfering with the comparison of the work of the cruiser with the measurement of the plot, both of which have been on basis of sound contents, disregarding possible cull. The cull factor is now tested by close examination of 10 acres in which every tree is individually estimated and the per cent of probable cull recorded and subtracted from the estimate. Per cent figures also are obtained from the scale of logs of similar timber in the vicinity and these per cents are used as a basis of cruising.

7. In actual cruising, the per cent of area covered is reduced to 25. The area is increased to 320 acres per day, and 4 miles of line run. A cull factor is used and hardwoods are added to the estimate by tallying the top diameter of each merchantable log, inside the bark.

8. The cruiser is then brought back to the sample plots to receive training in individual estimating. This consists of:

The use of circular plots covering different per cents of the area by a systematic plot method and finally by the selection of a sample plot by eye. On these plots, he first arrives at the volume of the average tree either by direct approximation or by selection of a typical tree whose volume is ascertained from a volume table;

A tally of the diameter and height of each tree on the plot and the immediate computation of the volume to ascertain the true average tree for comparison with the ocular guess. Two days of this work will greatly improve the ability of the cruiser to substitute ocular methods for measurements.

An opportunity to run out strip estimates in which he does his own compass work, counting the trees ahead of him in rectangular blocks. The volume of these trees is obtained:

By the log-run method of estimating the number of logs in the average tree and the average contents of the log or log run per thousand;

By selecting an average tree in volume for each of eight separate strips, the total tally of which is kept separate. This principle could, after practice, be applied to the entire forty, or to separate groups.

The exact details of this system as to size of sample plots, widths of strip and methods of tallying heights were worked out for Southern yellow pine, and several of these points would need modification if applied to timber of radically different type and conditions. But the general method of careful, original measurement of the control plots and of proceeding from a 100 per cent intensive estimate through various stages of less intensive work in which the six classes of averages are employed as substitutes for the full tally, can be worked out for any forest type and form the basis of rapid and practical training in the art of timber cruising.

239. Check Estimating. Just as in the training of a cruiser his greatest drawback is lack of any check on his estimates, so check estimating does not benefit the cruiser unless he can be told, not only what the extent of his error is, but just how he made it. Check estimating must depend either upon the infallibility of the check estimator, which may be questioned in the mind of the person checked, or by the substitution of actual measurements on a basis which removes all source of doubt, leaving only cull and quality to be judged. Check estimates should therefore be made on definite areas or strips, prevously or subsequently estimated by the cruiser and on which a record has been kept similar to that indicated in the description of the methods of training timber cruisers. The tree count, the total volume, the average volume per tree, but most important, the tendency to over-estimate heights and diameters should all be checked separately. When this is done, one of two things will happen. Either the cruiser will rapidly acquire a much greater accuracy or he will demonstrate his complete unfitness for the job of timber cruising and can be put on other work.

240. Superficial or Extensive Estimates. The preliminary examination of a tract of land for the purpose of determining roughly whether it has timber of value and approximately how much, calls for the exercise of the maximum of skill and experience in order to attain a reasonable degree of accuracy in the minimum of time allowed.

A description of the estimation of a tract of 2300 acres for the Blooming Grove Hunting and Fishing Club, located in Pike County, Pennsylvania, will serve as an illustration of methods possible in such an examination. The field work on Taylor's Creek logging unit occupied two days including travel to and from the unit. Not much over one day was put on the estimate itself. The fundamental basis of the methods employed was the location of corners with the aid of a guide, the use of a map and the sketching of the boundaries of areas of different types by intersection, aided by rough triangulation from known points. Cardinal directions for strips were not attempted in any instance. This tract was afterwards estimated by the strip method, running 5 per cent of the area. The comparison of the two methods and

TABLE XLVI

Estimate of Taylor's Creek Logging Unit, Blooming Grove Tract, Pike County, Pa., 1911

A. By extensive methods, in two days' time, one man with guide.

B. By 4-rod strip, 5 per cent of area, diameters calipered, average heights.

Type	Area. Acres	Species	Method of cruising employed under A	Estimate. M feet B.M.	Error by First Method: Amount. M feet B.M.	Error by First Method: Per cent
Pitch pine, pure stands	375	Pitch pine	¼-acre circular plots for sizes 8-rod rectangular plots counted, when convenient	A 2178 B 2214	− 36	− 1.7
scattered on burns	1275	Pitch pine	16-rod strip counted, when convenient			
White oak and hardwoods	200	White oak	Total count of large trees Average trees guessed at	A 248 B 445	−197	− 47
Swamps with hardwood and conifers	450	Spruce	¼-acre circular plots, selected by guess for average stand per acre	A 750 B 397	+353	+ 88
		Hemlock	....	A 750 B 527	+223	+ 42
		Yellow poplar	Some poplar counted	A 250 B 89	+161	+181
		Ash	....	A 100 B 125	− 25	− 20
		White pine	Treetops counted from hill. Average tree guessed at Uniform old growth	A 250 B 282	− 32	− 11.3
Total.....	2300	.....	....	A 4526 B 4079	+526	+ 10.9

their results is made on the basis of the assumption that accurate results on this area were obtained by the strip method. The cost of the original estimate was $60.00 or 2.6¢ per acre, 1.3¢ per thousand. The cost of the subsequent strip estimate was 8¢ per acre or 4¢ per thousand. The results clearly show that the average stand per acre was successfully obtained for the pitch pine types in which the timber could be seen, and where the area was carefully mapped in two degrees of density of stocking and checked by strips and plots carefully selected there was no need of a subsequent estimate.

The method of counting every tree was successful for white pine since all of the tree tops were seen and the average tree was correctly guessed at, but for white oak, the total count apparently failed. This was due not to a defect in the method or its application, but to the fact that 123,000 feet of white oak was found later concealed in the swamps. This reduced the error to 23 per cent for the portion seen and counted.

The estimate of spruce, hemlock and poplar broke down because of the fundamental difficulty of applying the sample plot method when based upon selection and not on systematic arrangement. The swamp should have been crossed and all parts examined. As it was, the sample plots were selected near the boundary where the timber was one-half to two-thirds again as heavy a stand per acre as in the wetter portions. This resulted in over-estimating spruce, hemlock and poplar. An area or density correction here, or another day spent on that portion of the tract would have greatly reduced this error.

In extensive mapping and estimating of large areas for purposes of classification as in the preliminary examinations for the establishment of national forests, rough sketch maps of the areas of timber types are made on the above principles by location of the cruiser on a map and by triangulation. The estimate must depend upon the location of occasional sample plots chosen with the best skill possible to get average stands.

In State work the construction of maps showing the timber resources of the State or of various counties is usually carried on by similar methods of mapping, using roads and the principle of the wheel or odometer for distances and sample plots for average stands. In Massachusetts a different principle is employed. Strips 4 rods wide are run at ½-mile intervals on which detailed measurements are taken of the stand. No attempt is made to complete the map of timber in the intervening areas, but the data are assumed to show the average for an entire town, an assumption which is probably correct owing to the large area involved.

241. Estimating by Means of Felled Sample Trees. In the absence of volume tables in earlier European practice, it was found that volume of stands could be determined by calculating the diameter of the average tree, felling it and determining the cubic volume. This volume multiplied by the number of trees in the stand was supposed to give the number of cubic feet in the entire stand. Since height and form factor of individual trees both varied over a wide range, it was quite difficult to get a tree which was actually an average for the stand, but when the stand was divided into *diameter groups*, any required degree of accuracy could be obtained, according to the number of groups made.

In determining the diameter of the average tree, the arithmetical mean of diameters gave too small a result since the volumes of trees of uniform height are in proportion to D^2. With a table of the areas of circles, the total basal area or sum of the areas of the cross sections at D.B.H. for all the trees on the plot was obtained and divided by the number to obtain the average basal area. The diameter corresponding to this basal area was that of the tree sought. Where a tree of this exact diameter to $\frac{1}{10}$-inch could not be found, a larger or smaller tree was selected and the difference found by the proportion existing between the basal areas of the tree measured and the tree desired. This method is termed the Mean Sample Tree Method.

In this country the application of these methods has been confined to a few early investigations into the cubic volume of cordwood in second-growth hardwoods. The difficulty of selecting a tree of average height and form as well as basal area and the expense of felling and measuring a tree makes the use of volume tables far preferable whenever these are dependable, and their substitution is practically universal.[1]

242. Method of Determining the Dimensions of a Tree Containing the Average Board-foot Volume. Another use of sample trees is in connection with the determination of the age and growth of stands rather than to determine their volume. For this purpose, the volume of the stand is first found from volume tables and the average tree then determined. The volume sought is that of a tree which when multiplied by the number of trees on the plot, will give the total volume of the plot in the unit of volume which was used in estimating.

[1] A recent test, 1920, by J. Nelson Spaeth, Harvard Forest School, in second-growth hardwoods, in which mean sample trees for each 3-inch diameter group were measured, gave the following comparison of accuracy with the use of a standard volume table, although the latter was for but one species, red maple, comprising but 15 per cent of the stand:

Method	Yields per $\frac{1}{2}$ acre. Cords	Error. Per cent
Actual volume cut	5.725	
Standard volume table	5.772	+1.70
Mean sample tree method	5.935	+3.84

The refinements of these methods, known as Draught's, Urich's and Hartig's Methods, are set forth in Graves' Mensuration, pp. 224–242. For application to American problems that of the Mean Sample Tree is probably sufficient.

When cubic volume is used the average tree will not be the same in diameter as when the board-foot unit is employed. The explanation for this difference is that the volume sought is a weighted average of the merchantable contents of all of the trees on the plot. Trees of different diameters do not have the same weight in this average when measured for board feet as when measured for cubic contents. The tree containing the average board-foot volume will be larger than the other. The smaller trees in the stand when measured in board feet are more immature than they are for cubic feet and the merchantable portion of the stand actually includes a lesser proportion of the whole. In stands which are not of even age, this merchantable portion would exclude many of the younger trees as being unmerchantable although they would be included in the cubic volume, and the average age as well as size of the portion merchantable for board feet is greater than that included in the cubic volume. (The increase in average age of stands due solely to the exclusion of a portion of the stand is a recognized fact in European practice.)

To determine the size as well as volume of the average tree of a stand, we have two variables, height and diameter, one of which must be fixed or eliminated before the other can be determined. The first step is, therefore, to determine the average height of trees of each diameter by a height curve (§ 209). The average tree can then have but a single height and diameter and these dimensions may be found from a curve of volume based on diameter for the plot.

This curve may be taken from a standard volume based on diameter and height (§ 143) by selecting the volumes corresponding to the average heights for each diameter interpolated if necessary to the nearest foot. At only one point on this curve will the average volume coincide with the diameter.

243. The Measurement of Permanent Sample Plots. The purpose of locating and measuring permanent sample plots is to determine the growth of stands. Their original measurement therefore must be made by methods which will permit of an exact scientific comparison of these with subsequent measurements. In this way, not only can the growth of individual trees be determined, but all changes which take place in the forest by decadence and by the operation of natural forces, insects, fungi and cutting and thinning, or other silvicultural measures may be noted.

Permanent sample plots should be located on land under permanent and stable ownership and should be accessible and easily found for subsequent inspection and for a maximum of protection. The plot should be square or rectangular and marked by permanent corners, plainly labeled. Sample plots should be located in stands having uniform conditions and their size should be governed, first, by the possibility of securing this uniformity and second, by the expense of measurement which limits the size of the plot. Third, wherever possible, there should be a control strip of exactly similar timber surrounding the plot on all four sides in order to eliminate the influence of different conditions of density or site around the borders of the plot.

The merchantable timber on these plots is measured as follows:

Tree Number. Each tree should be permanently numbered either by white paint or by attaching a metal tag to the tree with a copper nail.

D.B.H. The point at D.B.H. is measured and spotted with white paint or by the position of the tag. The D.B.H. is measured with a diameter tape.

Crown Class. The crown class is one of the following:

x = trees standing alone;
d = dominant;
c = co-dominant;
i = intermediate;
s = over-topped, suppressed.

Height. The height is measured to the nearest even foot with a standard hypsometer. The Klaussner principle, which gives one measurement, is preferred.[1]

Forms are used which provide, for each tree, five vertical columns in which to record the original and four subsequent measurements which are taken at either 5- or 10-year intervals.

The trees on such plots are usually numbered and measured individually down to 4 inches, although in some instances 2 inches is adopted as the basis for individual tree records.

Immature timber below these sizes usually calls for smaller plots which are sometimes laid out as subdivisions of a larger permanent plot. The sizes of these plots are in proportion to the intensiveness of the problem and the age of the timber. For determining the conditions which affect germination, plots from 10 to 20 feet square are large enough. On these plots every seedling is counted and sometimes each is marked by inserting a pin on which a tag can be attached. In this way the mortality and survival of the seedlings can be later ascertained. For the study of the development of reproduction, larger plots, up to 1 acre in size, are required. On such plots there is no effort to keep

[1] Some New Aspects Respecting the Use of the Forest Service Hypsometer, Herman Krauch. Journal of Forestry, Vol. XVI, No. 7, p. 772.

Comparative Tests of the Klaussner and Forest Service Hypsometer, D. K. Noyes, Proc. Soc. Am. Foresters, Vol. XI, 1916, p. 417.

a history of each individual tree, but the total number of trees in each class is recorded in height classes as follows:

Overtopped $0 = \frac{1}{2}'$ in height;
$\frac{1}{2}' = 2'$ in height;
$2' = 4'$ in height;
$4' = 1''$ in diameter.

Free, same classes.

By inch classes, 1, 2 and 3 inches. In these inch classes the trees are recorded in five crown classes: *x*, *d*, *c*, *i*, and *s* previously indicated.

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PART III

THE GROWTH OF TIMBER

CHAPTER XXII

PRINCIPLES UNDERLYING THE STUDY OF GROWTH

244. Purpose and Character of Growth Studies. The growth of timber is studied in order to determine the rate of annual production of wood as a crop on forest land. The yield of farm products is annual and is measured at harvest. The essential difference between farm and wood crops is that the period required to produce the latter is many years in extent, and due to this fact forest land is not the only capital involved in crop production. The growth which the trees lay on annually becomes in turn part of the capital to which future growth is added in the same manner as interest which is added to a savings account.

This increase in total volume of a stand of timber does not continue indefinitely, but only up to a certain age, which marks the culmination of growth of the stand, from which time the losses occurring in the stand more than counterbalance growth, and its volume and value diminish. Forest crops therefore mature as do annual crops and one of the purposes of growth study is to determine the period required for maturity.

The basic facts to be determined in the study of growth are, first, *the total yield* of stands in terms of quantity of products, quality, and money value, for the period required to grow a crop of timber from origin to maturity; second, the average annual rate of growth to which this final yield is equivalent, which is termed the *mean annual growth* and is comparable to simple interest on land as capital or to annual crops; third, the actual growth or increase in volume, quality, or value, laid on during definite periods in the growth of the stand. The growth for these short periods is expressed either as *current annual growth* which is the growth for a single year, *periodic annual growth* which is the average annual growth for a short period, or *periodic growth* which is the total growth for the short period. The length of these periods is commonly a decade, but may be from 5 to 40 years. The term *current annual growth* is commonly used in place of the term *periodic annual growth*, as indicating the average annual growth for a short period instead of the separate growth for a single year, though this use of the term is technically incorrect.

Finally, the relation which the increase in volume or growth bears to the volume of the tree or stand on which it is produced may be expressed as *growth per cent*, and indicates the rate of increase with relation to the wood capital required for its production. This growth per cent may be computed for volume alone, for growth in quality of wood, or for growth in the unit price of the product (§ 334). A growth per cent figure is not an index of absolute increase in either volume, quality or price, since it is merely the expression of a relation between capital and increment existing at a given time. Growth per cent is usually based upon a single year's growth, either current or average for a period. One year's growth is seldom measured, since a decade, or at a minimum, a five-year period is required to eliminate variable factors affecting a single season's growth caused by climatic conditions. Hence periodic annual growth is commonly substituted for current annual growth as a basis for computing growth per cent.

245. Relation between Current and Mean Annual Growth. Growth may be studied either for an individual tree or for a stand, expressed in terms of growth per acre. In either case, the current annual growth in volume increases at first slowly and then more rapidly to a maximum, after which it begins to decline and finally ceases with the death of the tree or the beginning of actual decadence of the stand. The sum of the current annual growths laid on for the entire period gives the total growth. The total growth or volume divided by the age in years gives the mean annual growth (Fig. 64).

The mean annual growth is an *average rate* of growth representing the total growth or yield at a given age, distributed or spread over this period. The actual productiveness of the forest is in this way compared with annual crops, which basis is otherwise obscured by the varying rate or curve of growth in volume of the trees from decade to decade.

The mean annual growth at any given year is this average of past production. Current growth for the year or decade tends to increase constantly up to a given maximum. During this period the volume added each year to the total volume of the stand is greater than the average or mean annual growth up to that year. Hence this average is raised and the curve of mean annual growth increases. But it cannot increase at as rapid a rate as the current growth curve, since the effect of this increase for the year upon the *average* increase is spread over all previous years.

When the current annual growth curve reaches its culmination and begins to decline, the successive average or mean annual growth figures for each year still continue to increase in spite of this fact, since the amount of growth added to the stand during the year although less than formerly is still greater than the average or mean.

When the current growth for the year finally falls to an amount equal to the average or mean for the entire crop period, the curve of mean annual growth has reached its highest point. During the following and subsequent years the current growth laid on is less than this mean, hence this average or mean begins to drop, but only to the extent that it is pulled down by the effect of this lesser current annual growth for single years upon the fraction, $\frac{\text{total volume}}{\text{age in years}}$. Hence as before, this mean growth curve falls more slowly than the current growth curve. Unless these stands are cut, losses in the stand will finally exceed the growth, and the current growth curve would then become negative. But until the entire stand is destroyed, the curve of mean annual growth will still be positive. When properly computed on the basis not merely of volume, but of quality and price increment as well, the year of culmination of mean annual growth, rather than the current growth data, indicates the maturity of a stand and the age at which, if cut, it will produce the greatest average yields, when the period of production is taken into account.

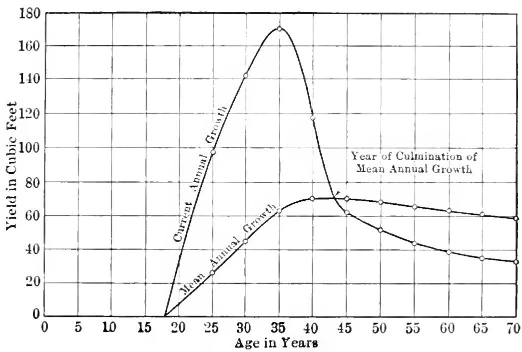

FIG. 64.—Current and mean annual growth of a normal stand. Jack Pine Minnesota.

246. The Character of Growth Per Cent. The growth per cent of a tree or stand cannot be compared with the per cent of interest earned annually on a fixed capital, since this growth is not separable from the wood capital on which it is laid, and thus causes this capital or base volume to increase annually. To maintain the same rate of growth per cent on this increasing volume, the *amount* of the annual growth must continue to increase at a geometric rate. Although the increase in volume of a stand during the period of most rapid current growth for a time does approach a geometric rate when compared to a given or fixed initial volume, yet even here the *effect of the constantly and rapidly increasing volume of accumulated wood capital upon the current annual rate of increase* will cause this rate of growth per cent to drop consistently throughout the entire life of a tree or stand. The actual behavior of the growth per cent of a stand is shown by the following table:

TABLE XLVII

GROWTH OF JACK PINE, MINNESOTA *

Age. Years	Yield per acre. Cubic feet	Periodic annual growth. Cubic feet	Mean annual growth. Cubic feet	Periodic annual growth. Per cent
20	160	....	8	
25	650	98	26	24.20
30	1360	142	45	14.12
35	2210	170	63	9.52
40	2800	118	70	4.68
45	3160	72	70	2.40
50	3420	52	68	1.56
55	3640	44	66	1.24
60	3840	40	64	1.08
65	4010	34	62	0.88
70	4180	34	60	0.80

* From Bul. 820, U. S. Dep. Agr., 1920, Table 10, p. 14.

247. The Law of Diminishing Numbers as Affecting the Growth of Trees and Stands. The growth in volume of individual trees tends at first to follow a rate of geometric increase. Were the diameter growth of trees to remain uniform for a long period, a condition characteristic of many species, notably white and sugar pine, the resultant area and volume growth would increase at a ratio similar to that of D^2, rather than D (§ 270). This rate of volume growth is strengthened by height growth. With maturity, the height growth of trees falls to insignificant proportions and the diameter growth of many species falls off to a marked extent. The result is a flattening out of the curve of volume growth, which would otherwise continue to ascend sharply. This influence of age and maturity upon individual trees which survive is due to loss of vitality, but the same effect is observed in all the remaining trees which are suppressed during the growth of the stand and ultimately die because the space needed for their normal expansion is appropriated by more vigorous trees.

A forest or stand represents an area of land stocked with trees. The number of trees which can grow and thrive upon the acre is in inverse ratio to the size of crown spread and space required by the individual tree. As trees increase in size their numbers will be reduced. The enormous number of seedlings which may spring up on an acre is merely a guarantee that a few will survive to maturity. The curve of diminishing numbers which is characteristic of all species and classes of timber, drops very rapidly in the first few years, and more gradually later on. Numbers diminish most rapidly during the period of rapid height growth and crown expansion. When trees have reached their mature heights, their numbers have been reduced to a point where the further diminution is a much slower process.

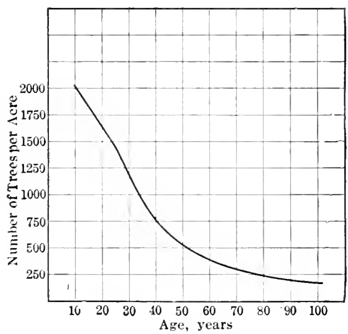

Fig. 65.—Number of trees per acre at different ages in fully stocked stands of white pine. From Table XLVIII.

The cause of reduction is at first failure to survive the juvenile period because of unfavorable climatic or soil factors and competition with other vegetation, followed by suppression due to the competition of older trees or of trees of the same age which have attained dominance by some advantage at the start. The crown is restricted in size and spread, is finally overtopped, and the tree dies.

This process is accompanied by a change in the rate of diameter growth for the trees whose crowns and growing space are restricted in the struggle. Consequently the dominant trees maintain at all times the most rapid rate of diameter and volume growth, while others which at a given period have not yet lost their dominance and still show a rapid rate of growth, will later on, with the closing of the crowns and crowding of the tree, show a falling off in growth, sometimes quite sudden in character. The prediction of the future growth of any single tree is therefore impossible without knowing whether the tree will maintain its position in the stand and subdue its competitors. The net growth on an acre is the sum of the growth of the surviving trees.

At any given period or year in the life of a stand, the number of trees is considerably less than were present and living at any previous period or decade, and is considerably greater than the number which will be alive at any given period or decade in the future. This loss in numbers, accompanied by rapidly lessening rates of growth of a portion of the surviving trees, plus the normal growth of the remainder, produces the net result or increase in the stand for the period, and any method of study of growth which does not take this natural loss and change into account will be ineffectual in predicting or measuring the growth of forests or stands.

248. Yields, Definition and Purpose of Study. The past growth of the surviving portion of stands is represented by their present volume, the measurement of which is dealt with in Part II. This present volume represents the yield of the area, provided nothing has previously been removed as thinnings or otherwise. But without a knowledge of the period required to produce this volume, the word yield is meaningless as it cannot be expressed in terms of the rate of production per year or mean annual growth. An estimate of standing timber is merely a statement of the volume at present found on the area. A yield, on the other hand, is a statement of the volumes produced on the area *within a definite period of time.* If the total volume is to be expressed as a yield, then the total age of the stand must also be known. If the yield for a shorter period, such as a decade, is to be stated, then only that portion of the volume of the standing timber must be shown as was laid on during this period. Otherwise, the rate of growth per year is not indicated.

The growth of forests is studied primarily for the purpose of *predicting future growth* on forest land. On the basis of past records of growth of trees and stands as shown by measurements of present attained volumes and of age, predictions can be made as to the future growth of these and of similar stands.

This application or prediction may be made in one of two ways:

1. By *projecting* the rate of growth of an existing stand into the future. This is done either by assuming that the rate shown in the immediate past will *continue unchanged* in the immediate future, or else that this rate *will change* and that this tendency of future growth may be predicted by the shape of the past growth curve. Of these two assumptions the second is apparently the more accurate, but in neither case is it possible to predict the growth for more than a short period.

2. Some better method of prediction is required to cover longer

periods and to determine the probable yield of crops of timber, the production of which is the purpose of forestry. This is accomplished by the second general method of prediction which rests on the principle of *comparison.* The past growth of existing stands is taken as an indication of the expected future growth of other younger stands whose prediction is desired for a similar period. It is assumed that similar stands will grow in a similar manner. The task consists of demonstrating *the relation* between the stands whose past growth is measured and those whose future growth is sought.

249. Yield Tables. The most practical and useful expression of growth is a yield table which shows the yields per acre for even-aged stands at different ages by five- or ten-year periods separated into different qualities of site. An example of such a yield table is shown below:

TABLE XLVIII

YIELD TABLE FOR WHITE PINE *

Quality II †

Age. Years	Average height of dominant trees. Feet	Diameter breast-high of average tree. Inches	Number of trees per acre	Basal area per acre Square feet	Total Yield	
					Cubic feet	Board feet
10	6.0	1.4	2015	20	650	
15	12.0	2.2	1834	50	1,150	
20	19.5	3.2	1626	90	1,750	
25	28.0	4.1	1420	131	2,420	5,400
30	36.5	5.1	1192	169	3,250	9,600
35	44.5	6.1	950	193	4,180	15,900
40	51.5	7.1	760	209	5,130	23,500
45	58.0	8.0	633	221	6,100	30,600
50	64.0	8.9	537	232	7,000	36,600
55	69.5	9.8	460	241	7,800	42,000
60	74.5	10.7	397	248	8,500	46,900
65	79.0	11.6	348	255	9,200	51,600
70	83.0	12.4	311	261	9,840	56,100
75	86.5	13.3	277	267	10,400	60,200
80	90.0	14.1	251	272	10,930	64,000
85	93.0	14.9	229	277	11,400	67,500
90	95.5	15.7	210	282	11,850	70,900
95	98.0	16.4	195	286	12,250	74,000
100	100.0	17.1	182	290	12,630	77,000

* Taken from Tables 4 and 6 in "White Pine under Forest Management," U. S. Dept. Agr., Bul. 13, Washington, 1914, pp. 22 and 23.

† Similar tables are prepared for Qualities I and III.

From the above table, the periodic growth for separate five-year periods may easily be obtained by subtracting the volume at one age from that of the succeeding period.

250. The Application of Yield Tables in Predicting Yields. An example of the prediction of volume growth in existing stands of timber, on the basis of periodic growth by decades is given in the following table which shows the present yield of timber over 10 inches and the future yield which may be realized upon the timber left standing below this diameter limit, and not shown in the table.

TABLE XLIX

YIELD PER ACRE OF SPRUCE CUTTING TO VARIOUS DIAMETER LIMITS *

Based on stands containing approximately 5000 feet B.M. of timber 10 inches and over in D.B.H. per acre

	Am't of first cut.	Second Cut after Ten Years		Second Cut after Twenty Years		Second Cut after Thirty Years		Interval required between equal cuts in years
	Board feet	Number of merchantable trees	Board feet	Number of merchantable trees	Board feet	Number of merchantable trees	Board feet	
Cutting to a 10-inch limit	5213	7.3	365	16.2	1087	26.8	2483	43
Cutting to a 12-inch limit	4341	14.3	1208	21.6	2325	30.5	4109	32
Cutting to a 14-inch limit	3382	10.3	1470	16.8	3044	40.8	6351	21

* Compiled from Yield Tables in "Practical Forestry in the Adirondacks," Bul. 26, Division of Forestry, U. S. Dept. Agr., 1899, pp. 83 and 84.

To understand the use or application of a yield table in predicting growth, it must be realized that the stand or rate of growth upon a given acre or tract will seldom if ever exactly agree with that shown in a yield table even when these yields are separated by qualities into 3, 4 or 5 classes of site. In the case of bare land or very young timber, this probable difference may be ignored, the site regarded as equivalent to one of the site classes given and the yield predicted as if it would coincide with that of the table. But for most stands which have already reached a considerable age and the prediction of whose further growth is desired, a comparison with the yield table should give a more exact prediction of the growth of the stand in question. The yield table in this case, instead of predicting *exact* future growth, is used as a standard to express the *relative* increase or decrease in the yield or stand per acre. The yields may be plotted and will form curves of growth in volume per acre. The yield of any stand whose present volume and age are known represents a definite per cent of some existing yield from this table. The growth of this stand may be predicted by using the same per cent of the values in the table for the future.

In Fig. 66 the present yield of a plot of white pine of fifty years is indicated and the basis of prediction for its future yield is shown. This percentage relation based upon standard yield tables is extensively applied in forestry to obtain the actual yields of large forest

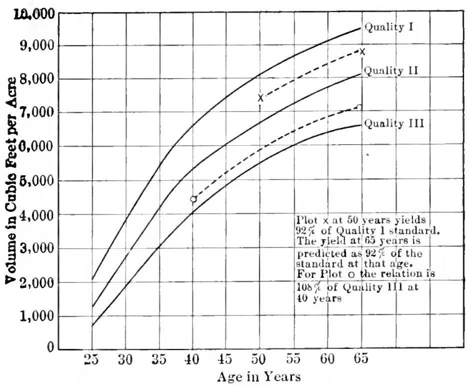

FIG. 66.—Method of predicting yields of specific stands by comparison with standard curves of yield for different qualities of site. White Pine, Mass.

areas. It is the basic idea underlying the prediction of growth by the method of comparison.

251. Prediction of Growth by Projecting the Past Growth of Trees into the Future. By either of these methods, comparison or projection, it is assumed that no records exist of the past condition of the stands whose growth is to be found. Their present volume, and the age and past growth in diameter, height and volume *of the trees now standing* can be studied, but there is no reliable indication of the number of trees lost during the past period, though evidences remain for a time in the form of dead and down trees.[1]

[1] The writer once noticed in a densely stocked stand, the stems of hundreds of small lodgepole pine which had fallen across a tamarack log and been preserved from decay, when all trace of similar dead trees on the forest floor had disappeared.

In using the past growth of a stand on which to base the prediction of its future growth, these records of past growth of the living trees in diameter, height and volume are the only data available. This prediction is based on one of two assumptions, either that the growth for a future period will continue *at the same rate* as shown for a past period, or that this future growth will be *at a different rate, either increasing or decreasing,* and that the amount of this change may be determined by a study of past growth.

In the use of either of these methods to predict the growth of trees, the method may be applied either to the volume of the tree or to its diameter and height instead. If a volume analysis is made for two or more past decades, it may be assumed either that this rate of volume growth will continue unchanged, an assumption which is practically never correct, or that the curve of volume growth which may be plotted from past volumes can be prolonged to indicate the growth of the next decade.

But the method more commonly employed is to substitute a study of diameter and height growth for volume analysis. If future diameter growth is assumed to be at the rate shown in the past decade, future volume growth will increase (§ 270). If the past growth in diameter is plotted, and a curve projected, the future diameter so obtained is the basis of the predicted growth in volume.

252. The Effect of Losses versus Thinnings upon Yields. The first conception in the study of growth is apt to be that it consists chiefly of measuring the growth in diameter, height and volume of individual trees. Although it is true that growth per acre is based primarily upon the rate of growth of the individual trees which make up the stand and that according as this rate of tree growth is rapid or slow, the yield per acre will be large or small, yet the total growth per acre, which is the result desired in all growth studies, is the product of the growth of individual trees and the number of trees surviving to the end of a future period plus such growth as may take place on trees which die and are removed during the period. The death of a certain number of trees in the stand during the period will have this effect, that if these trees can be removed as thinnings, their volume at the beginning of the period, augmented slightly by growth which takes place in them before they die, is part of the yield for the period, but does not appear in the volume of the standing timber alive at its end. If these trees cannot be harvested, their total volume as originally measured will disappear from the live stand, and constitute a negative growth or loss which must be deducted from the *growth on the surviving trees* before the actual volume of the stand at the end of the period can be correctly ascertained from its volume at the beginning.

This problem may be illustrated as follows:

A stand of pine has now 10,000 board feet per acre. The growth for ten years upon the trees which will survive will be 4000 board feet. The trees which will die in ten years have now a volume of 1500 board feet. This means, first, that the growth of 4000 board feet is actually put upon a present volume of 8500 board feet; second, that the remaining 1500 board feet must either be included in or deducted from the final yield, on the basis of whether it is actually salvaged or not. There may have been some growth on these trees, but this can be neglected. On the assumption that no cutting of thinnings is possible, the net yield on this acre at the end of the decade is 12,500 board feet. If thinnings are harvested, the yield is 14,000 board feet. Had the growth prediction been attempted by measuring the growth of individual trees, those representing the 1500 board feet would have to be excluded from the calculation of total growth in either case. Unless salvaged, they represent an actual negative growth reducing the net gain by 1500 board feet.

Unless it is possible to guess just how many and which trees are going to die, not only the volume, but the growth for ten years on some of these trees will probably be erroneously included, instead of being subtracted from the predicted total yield in ten years. The possible error in subtracting either too few or too many trees is very large since the size of the error is doubled for stands when thinnings are impractical. It is obvious that a method depending instead on direct measurement of the result at the end of the period on older stands and the comparison of such measurements with similar younger stands furnishes a safer basis of growth predictions on these younger stands for any considerable period than efforts to project into the next period the rate of growth of the trees now standing.

Where stands are under intensive management, the trees which will die are thinned out, probably at the beginning of the period, and utilized. The loss for the succeeding ten-year period is then exceedingly small unless accidental inroads occur from wind, insects or other destructive agencies not anticipated. It is therefore safer to predict growth for short periods on stands which have been under management and have been thinned than it is on stands where thinnings and utilization of the dying material is impossible.

253. The Factor of Age in Even-aged versus Many-aged Stands. Where stands are measured as a unit to determine the production per acre, three factors are needed: first, the present volume of the stand; second, its average age or the time which it took to produce this volume; third, the area which it occupies. The age of the stand as a whole is desired. If the stand is even-aged it is sufficient to determine merely the age of one of the trees adequately to measure the period of production and the rate per year. This can be done by counting the annual rings of growth without any measurement whatever, on the assumption that the species has formed but one annual ring per year. This premise does not always hold good, since with certain species in certain localities, false rings may be formed, giving two rings per season (§ 256). Provided age can be determined, the study of diameter, height and volume growth of individual trees is entirely unnecessary for even-aged stands, as a means of determining the yields per acre.

But where stands are composed of trees of different ages on the same area, it becomes practically impossible to determine the average age of the stand by any such direct method. Within certain limits, that is, if the ages of the trees composing the stand do not vary too greatly, it is possible to determine an age which may be accepted as the average period required to produce the present volume. Where the diversity of age is so great that this is impossible, it is necessary to shift the basis of age determination from the mere counting of the rings to a determination of the age of trees of a given size or diameter. To determine ages, trees must be cut down or the center reached by borings or choppings. While possible on one or two trees, it becomes out of the question to test every tree in this manner without cutting down the stand. Diameter, on the other hand, can be readily measured. For stands of mixed ages, therefore, two methods are possible. By the first, the average diameter of the trees in the stand is found, and the age of a tree of this size is determined and is assumed to indicate the average age of the stand. By the second, no attempt is made to determine the age of the stand, but instead the growth may be studied for trees of given diameters, and for a short current period, past and future. Either method requires the measurement of the diameter growth of trees to determine the number of years or period which is required to produce trees of given sizes or to grow 1 inch in diameter.

254. The Tree or Stem Analysis and the Limitations of its Use. The volume growth of an individual tree may be analyzed with almost absolute accuracy by cross-sectioning the bole and measuring the width of the annual rings at different sections by decades. This is termed *stem analysis*, or *tree analysis*. The accuracy of these results for a single tree is apt to create a false impression in the minds of investigators as to the value of the figures thus obtained. To what use will volume or total tree analyses of growth of trees be put? What question will they answer? Will they predict the growth per acre of stands or the rate of growth per year on an acre of land? The cost of a tree analysis is excessive compared with the direct measurements of yields and total age or even the measurement of diameter growth on the stump. The number of trees which may be analyzed is therefore limited. How shall these trees be selected? It has been seen in the study of volume tables that trees vary quite extensively in form. To get average growth we must be sure of obtaining average form. Average form is best obtained by averaging hundreds of trees as is done in the preparation of volume tables, but the few trees analyzed for growth may be either cylindrical or neiloidal in form. We therefore may have a perfect record of the past growth of certain selected trees which vary in form and volume at least 10 per cent from the average desired.

Even if this difficulty can be overcome by careful selection of trees of average form quotient, and a few of these average trees analyzed for past growth, how are these past results to be applied in predicting future growth? It is evident that the growth of individual trees is only a part of the problem, for the average tree in a well-stocked stand at a given age does not remain the average tree for future periods and was not the average tree at any period in the past. The trees which die in a stand are naturally the smaller, more suppressed specimens with the smallest diameters. In the lapse of a ten-year period, the loss of a number of trees from the lower diameter classes will raise the average diameter and volume of the remaining trees so that the tree which is now the average is in ten years dropped into a class below the average.

There is but one way of even approximating the growth of a stand in the future by means of the analysis of volume growth of individual trees. If the number of trees which will probably survive to a given age can be predicted (which can best be ascertained by the method of comparison and yield tables), the selection of this number from a younger stand, taking trees wholly in the dominant class, will indicate the character of tree which must be cut and measured to determine the growth for the future. Yet even here it is better to take a tree which is fully mature and shows the growth for the entire period, in which case the stand, rather than the tree, is the better unit.

255. Relative Utility of Different Classes of Growth Data, and Chart of Growth Studies. To sum up these principles: past growth is measured in order to predict future growth. Growth on an area and not the growth of single trees is wanted. The three essentials of growth are volume, time and area. For even-aged stands the time element is the total age and may be determined by counting rings on one or two sample trees. This requires a minimum of investigation in addition to volume measurements.

Diameter growth of trees comes next in importance and is used when size must be depended upon to determine age either for the total period or for shorter current periods of growth when diameter is substituted for age.

Height growth of trees comes third in importance since it is used to indicate site quality (§ 296). It may also be used together with diameter growth, to predict the volume growth of trees by a method much shorter than volume analysis (§ 288).

Volume-growth analysis of individual trees, although apparently the most accurate and scientific basis of growth, is in reality the least important and most inefficient when expense is compared with results. It is invaluable to determine the laws of tree growth and the changes which may take place in the form of individual trees as the result of changed conditions, as for instance, on cutover lands, and as a precaution against accepting general figures based on volume tables and other short methods of growth study. But ordinarily, even where volume of trees is desired, it will be obtained from diameter and height growth supplemented by use of the form quotient rather than from the stem analyses of trees. Many thousands of stem analyses have been made in the past whose results were either not worked up at all or since compilation have reposed in the archives of Government and States while investigators vainly sought an answer to the pressing problems as to what was the actual rate of growth per year on national, state and private forests.

The best possible basis for growth predictions is the actual records of the growth in successive periods of specific forest stands whose history is known and whose conditions of management are fixed. The establishment of sample areas which are measured successively by ten-year periods will give a firm basis for growth predictions superior either to the method of comparison, based on past growth of older

CHART OF

Purpose of growth study § 244			Basis	Field measurements
I Productive capacity of different qualities of forest land—§ 303			Normal or index yields per acre for even-aged stands 1. Pure stands—§ 304 2. Mixed stands—§ 314	1. Diameters B.H.—§ 309 2. Heights, total 3. Count of annual rings on average trees—§ 262
Prediction of future growth and yields on natural forest areas—§§ 247–248	For total age or long periods—§§ 249–250	II For even-aged stands—§§ 256–262	Comparison of stands with normal yields at same age—§ 301	1. Timber estimate separated by age classes—§ 344 2. Counts of annual rings on average trees—§ 262

stands, or to the effort to predict the growth of stands from that of the trees which they contain. As a result of similar actual records of production the working plans for some European forests dispose of the subject of growth quickly, stating substantially that the growth in this class of forest is known, from past records covering (perhaps) 200 years, to be about so much.

In the chart, on pages 328–333, eleven main lines of investigation of growth are listed, as a guide to the discussions in the following chapters. The object of a study should first be understood, and the condition of the stands to which it is to be applied, as indicated in the three columns under "Purpose of Growth Study." In the column under "Basis" the principles on which the solution of the problem depends are outlined.

The remaining columns are self-explanatory. Column 6 shows the steps by which the study can be applied to large areas of forest land, thus securing the data for which the preceding steps are merely preliminary.

By using this chart as a guide, and consulting the references to discussions of principles and methods, under each step, one may hold the purpose of growth studies clearly in mind and choose the best method of accomplishing the desired object.

The relative importance and reliability of the methods given are indicated by the quality of type used in the table.

Growth Studies

Office records	Final data obtained	Application to forest areas	Data derived from the investigation
		Classification of site qualities—§ 294, § 345	
1. Area of sample plots—§ 308 2. Volumes of trees (volume tables)—§ 131 3. Age of sample trees—§ 256, § 257 4. Height of dominant trees—§ 310, § 311, § 312	1. Volume per acre—§ 306 2. Age of stands—§ 256 3. Height of stands	1. On basis of height growth—§§ 296–310 2. On basis of volume growth—§ 295, § 312	1. Mean annual growth—§ 245 2. Number of trees per acre 3. Basal area per acre 4. Maturity of stands—§ 244 (rotation) 5. Maximum yields
1. Area of stand or age class 2. Volumes of trees (volume tables) § 131 3. Age of sample trees—§ 256, § 257 4. Average volume per acre for age class	1. Reduction per cent or relative volume derived from this comparison—§ 317 2. Empirical yield table based on this reduction—§§ 304–316	1. Empirical yield table to predict future growth on each age class 2. Correction for influence of number of trees per acre at different ages—§§ 301–317	1. Future yields based on actual stocking—§ 301, § 343 2. Losses due to natural agencies—§ 293 3. Gains possible from protection and silviculture

CHART OF GROWTH

Purpose of growth study			Basis	Field measurements
Prediction of future growth and yields on natural forest areas—§§ 247–248	For total age or long periods—§§ 249–250	III For large age groups—§ 318, § 321	1. Segregation of large age groups—§ 320 2. Comparison of group with normal yields at average age—§ 301	1. Diameters B.H. 2. Heights, average based on diameter 3. Growth in diameter at stump, based on age of trees—§§ 265–269, § 320
		IV For many-aged stands—§ 298, by diameter groups—§ 323	1. Diameter groups substituted for age classes—§ 276 2. Comparison of diameter group with normal yields at indicated age—§ 301	1. Diameters B.H. 2. Heights 3 Counts of annual rings on trees of each diameter class—§ 276
		V*a* For many-aged stands based on crown space—§ 298	1. Space required for development of individual trees—§ 300 2. Normal number of trees per acre at different ages—§ 247	1. Diameters of crowns based on D.B.H.—§ 324 2. Growth in diameter at stump based on age of trees—§§ 275–279 3. Growth in height based on age—§ 284
		V*b* On thinned areas—§ 326	Same as V*a*	Same as V*a* Measure only dominant trees—§ 263
Prediction of future growth and yields on natural forest areas—§§ 247–248	For short periods or current growth—§§ 251–252	VI For even-aged stands—§ 335	Same as II	Same as II
		VII For many-aged stands § 253, § 299	Past growth of existing trees—§ 336	1. Diameters B.H. by crown classes 2. Heights, average based on diameter 3. Growth in diameter at B.H. or stump —for given period of years—§ 278 —separated into 2 or 3 periods of five to ten years—§ 279

STUDIES—*Continued*

Office records	Final data obtained	Application to forest areas	Data derived from the investigation
1. Total number of merchantable trees 2. Volumes of trees (volume tables) (average, on diameter) 3. Age as basis of each group, from normal yield table 4. Diameter of tree of indicated age—§ 275 5. Volume of tree of indicated diameter—§ 278 6. Number of trees in each age group—§ 321	1. Areas occupied by each of two age groups—§ 319 2. Volumes in each age group—§ 321 3. Reduction per cent—§ 317 4. Empirical yield table—§ 316	1. Empirical yield table applied to area and age of each group—§ 322 and § 346 2. Correction by segregation of areas occupied by immature age classes—§§ 341–348, § 349	Same as for II—§ 301
1. Stand table by diameter classes—§ 188 2. Volumes of trees 3. Average age of trees of given diameters—§ 276, § 323	1. Areas occupied by each diameter group—§ 319 2. Volumes in each group 3. Reduction per cent—§ 317 4. Empirical yield table—§ 316	1. Empirical yield table applied to area of each diameter group 2. Correction by segregation of areas occupied by immature age classes—§ 341, § 348, § 350	Results only approximate due to substitution of diameter for age
1. Space occupied by circular crowns and resulting number per acre—§ 324 2. Relation between crown spread and diameter—§ 324 3. Height and volume of trees of each diameter—§ 288 4. Average diameter of trees at each age—§ 275	Artificial normal yield table based on number and size of trees at each age—§ 324	Reduction per cent for application of yield table determined by comparison of numbers of trees of each diameter on area with number per acre in table—§ 325	Substitute for yields based on even-aged stands when latter cannot be obtained
Same as V*a*	Same as V*a*	Same as V*a*	Means of predicting yields of thinned stands
Same as II	**Same as II**	**Same as II**	**Most accurate basis for current growth for short periods, on even-aged stands—§ 327** **Growth per cent**
1. Stand table by diameter classes—§ 188 2. Growth in diameter and height of trees by diameter classes for past period—§ 277 3. Volumes of trees now and at end of period. From volume tables—§ 288. (Stem analyses only as a check on accuracy of 2 and 3)—§ 254	1. Growth in volume of trees for future period 2. Number and character of trees which will die during period—§ 257 3. *Net* volume growth for stand—§ 252	As applied to trees and stands 1. Future growth of trees by comparison with growth attained by other larger trees formerly of same diameter—§ 278 2. By extending into future the past growth in diameter on trees whose future growth is sought —by assuming it to equal past growth —by prolonging curve based on past periodic diameter growth—§ 279	General method for current growth of stands of any character of stocking, form or ages, and mixture of species—§§ 245–342 Growth per cent (§ 246) for trees or stands—This cannot in turn be substituted for growth measurements except on similar stands—§§ 331–333 For stands whose age classes cannot be determined

CHART OF GROWTH

Purpose of growth study			Basis	Field measurements
Prediction of future growth and yields on natural forest areas—§§ 247–248	For short periods or current growth—§§ 251–252	For many-aged stands § 253, § 299	Past growth of existing trees—§ 336	—for last inch or half-inch of radius—§ 278 4. Growth in height —by cutting back tip for required period—§ 294 —by substitution of relation of height to diameter—§ 285
Prediction of future growth and yields on cutover areas on residual stands—§ 280	For short periods—§ 336	VIII For many-aged stands—§ 254	Past growth of trees for period since cutting, on formerly cut-over areas—§ 286, § 336	1, 2 and 4 same as VII 3. Growth in diameter preferably at B.H.; for period since previous cutting. May be separated into five- or ten-year periods—§§ 278–280
	For long periods—§ 338	IX For even-aged, or large age groups or diameter groups—§ 339	1. Proportion of total area remaining stocked after cutting, based on density equal to empirical yield tables for forest previous to cutting 2. Residual area assumed to be clear cut 3. Growth predicted for stocked area by empirical yield table—see II—§ 316	Same as III or IV—§ 320
X **Historical record of growth per acre—§ 326**			**Permanent sample plots remeasured at stated intervals—§ 243**	**1. Diameters B.H. with diameter tape—§ 190** **2. Total heights, from fixed stations—§ 199** **3. Crown classes and condition** **4. Plot description** **5. Tree tags and permanent boundary monuments**
XI Effect of numerical density of stocking, and of thinnings on growth of individual trees and on stand—§ 270, § 273, § 274			Relation between diameter growth, crown classes and number of trees per acre, from sample plots—§ 300	1. Diameters B.H. 2. Heights 3. Growth in diameter based on age, but rings counted inward, permitting study of current growth on same trees—§§ 265–269

STUDIES—*Continued*

Office records	Final data obtained	Application to forest areas	Data derived from the investigation
4. Tally of trees with suppressed crowns or those apt to die		As applied to forest areas 1. Stand table by diameter classes 2. Growth from diameter and height growth and volume tables 3. Correction for loss in numbers of trees	Source of inaccuracy is in determining mortality per cent, hence cannot be applied to long periods
1, 2, 3 and 4 same as VII 5. Partial stem analyses for current growth in volume on sample trees as check on effect of increased growth at stump—§ 290	1. Probable growth in volume of trees left on cut-over areas 2. Proportion of stand showing increased growth—§ 337 3. Loss in numbers and net growth in volume	Future growth of trees by comparison with growth attained by trees on areas after cutting Growth on forest areas 1, 2 and 3 same as VII 4. Per cent of stand showing increased growth—§ 337	Effects of —expansion of areas of crowns and increased growing space —competition of species left after cutting —degree of severity of cutting on remaining stand
Same as III or IV—§ 321	1. Areas in each age class for timber left on cut-over area 2. Volumes in each age class—§ 339	Same as III or IV—§ 322	Minimum or conservative yields on cut-over areas No increased growth assumed Conditions would coincide with cutting of even-aged stands Results contrasted with VIII as check on that method of prediction Safe for application to long periods
1. Individual record of each tree on plot by number, compared for successive measurements at five- or ten-year intervals **2. Record of conditions and of external influences**	**1. Permanent record of changes in volume, number of trees, and dimensions for plot** **2. Causes and extent of damage**	**1. Location of plots within control strips on areas showing typical conditions to be studied**	**Current growth, measurement of all factors of change in stands under conditions selected—§ 340** **Yield tables for stands grown under management. Ultimate solution of all growth problems—§ 313**
Diameter growth for trees of separate classes, by diameters, and crowns—§ 275, § 276, § 277	Effect of spacing or thinning upon volume growth and upon average sizes and quality of individual trees—§ 301	1. Stand tables by diameter classes 2. Ages of stands. The data are applied intensively to individual stands in silviculture	Proper spacing for plantations Character, and frequency of thinnings Class of material to grow Character of initial natural stocking desired Growth per cent on standing trees—§ 330

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CHAPTER XXIII

DETERMINING THE AGE OF STANDS

256. Determining the Age of Trees from Annual Rings on the Stump. The age of standing timber can only be determined from the ages of the trees which compose the stands. The age of a tree is the period elapsing from the germination of the seed or origin of the sprout to the present year. A record of the number of years of growth in a tree is made by the formation of the annual rings in which the light spring wood is sharply differentiated in color and texture from the heavier and darker band of summer wood of the year preceding. The counting of these annual rings determines the age of the tree.

It is not always possible or easy to make this determination. Unless the growth of a tree is marked by annual seasonal changes, there are no annual rings to distinguish. This is true of most species of tropical woods, except those growing in regions marked by an annual cessation of growth due to annual recurrence of dry seasons. In some species of hardwoods there is such a slight difference between the texture of the spring and summer wood that the annual rings can be detected only with difficulty and by the aid of coloring matter and magnifying glass. This is true of such trees as basswood, hard maple and sweet gum. Many trees on dry sites grow so slowly that the annual rings are almost impossible to distinguish except by a glass. In counting rings it is usually necessary to smooth off the surface with a sharp knife or chisel in order to bring out the contrast.

Where growth is affected by severe droughts, and sometimes where the trees are defoliated by insect attacks and later acquire new foliage, a false ring may be formed, giving two rings in a single year which would lead to an exaggeration in the age of the tree. This was found to be the case with Rocky Mountain juniper on dry sites. False rings may be detected if sufficient care is used, since they seldom form a complete circle, but are present on only a portion of the circumference and are therefore imperfect.

The last annual ring of wood is not completed until after the growth for the year is finished. It must be distinguished from the ring of new bark laid down in the same season. The first two or three rings on some seedlings are difficult to distinguish.

The increment borer (§ 277) may be used to determine the age of standing trees at breast height or at any section accessible, provided the diameter is not too great and the position of the core of the tree can be found by the instrument. This method is used with such species as spruce.

257. Correction for Age of Seedling below Stump Height. The number of rings in any cross section of a tree will indicate only the age of the tree at that cross section and not the total age. No rings can be formed at a given height above the ground until the tree reaches that height. The age of each cross section made in sectioning a tree will be less than that of the section below by just the number of years occupied in height growth between the two points. Although the total age of a tree can be determined theoretically by taking a section even with the surface of the ground, this is seldom if ever done. The rings are counted at the stump, which gives the age of the tree minus the time which it took the seedling to reach this height. To get the true age of any tree, seedling ages based on height must be added to ring counts taken at stump heights. By cutting at the ground and counting the rings on a sufficient number of dominant seedlings which are sure to survive and therefore represent the average height growth of mature timber when at this age, a table is constructed showing the relation between the age of seedlings and different stump heights. In rapidly growing trees this makes from one to five years' difference in the total age, but with some species which have a long juvenile period, as much as twenty years may be required for a seedling to grow 2 feet in height. This is true of certain Western conifers. Hardwood sprouts on the other hand attain stump height in the first year.

TABLE L

HEIGHT OF SEEDLINGS AT DIFFERENT AGES, WESTERN YELLOW PINE, COLFAX CO., NEW MEXICO

Age. Years	Height. Feet	Age. Years	Height. Feet
1	...	7	1.7
2	0.5	8	1.9
3	0.7	9	2.2
4	0.9	10	2.4
5	1.1	11	2.7
6	1.4	12	3.0

* Forest Tables—Western Yellow Pine. Circular 127, U. S. Forest Service, 1908.

The juvenile period for conifer seedlings is, as a rule, longer than that for hardwoods, though there are exceptions. Stump height may be separated into 6-inch height classes for determining the number of years to add for seedling heights to get total age of tree.

258. Annual Whorls of Branches as an Indication of Age. There is another method, of very limited application, for determining the age of standing trees. This is applied to conifers and is confined to those species which form but one whorl of branches per year. Species like jack pine or loblolly pine, which form two or more whorls per year, cannot be judged in this manner. The approximate age of the tree and stand is obtained by counting the number of whorls. This record holds good only when the branches or dead stubs remain visible and when the height growth continues normal. The record is lost if all traces of the lower whorls are obliterated. If this is only for a height of from 5 to 10 feet, the average age of trees of this height may be obtained from a study of seedling heights and used to supplement the remaining count. When the height growth of the tree has reached its maximum, a new whorl of branches is no longer formed annually, but the leader, as well as the branches, extends its growth by prolonging a single shoot.

The ages of seedlings of many species may be determined by counting whorls of branches, or terminal bud scars if the whorls are not all there. In such cases it is not necessary to cut the seedlings and count rings. The bud scars are distinct for many years on species such as Douglas fir, Alpine fir, and others.

259. Definition of Even-aged versus Many-aged Stands. The age of trees determines the age of stands. But unless it is known that the entire stand originated in a single year, as is the case with sprouts or with some species of conifers, such as jack pine or loblolly pine on burns, there will be a variation in age due to natural seeding for a period of reproduction which may extend to fifteen or twenty years. Stands are termed even-aged if their crowns form practically a single canopy or one-storied forest, which is true when the period of reproduction does not exceed approximately one-fifth of the rotation or period required to reach full maturity. Where the crown cover of stands of mixed ages varies so greatly that it is composed of different stories, and must be separated into component age classes whose average age is separately distinguished, the stand is termed many-aged or in some cases all-aged. The separation of such stand may be either directly into age groups, or into groups based on size or diameter with a limited range of age, whose average age is sought.

260. Average Age. Definition and Determination. The average age of a group of trees showing a range of ages must be that age which indicates or determines the rate of volume production per year at which the stand has grown; therefore, the average age must be a weighted age based on volume. The determination of average age applies only to those stands which fall under the definition of even-aged stands, yet have within the limits of the group a sufficient range of ages so as to require a further investigation in order to fix the weighted or average age of the group. For many-aged stands, the average age of each age class must be determined separately.

For a given age class or even-aged stand as thus defined, the average age is the age which would be required to produce an even-aged stand containing the same volume as that of the uneven-aged stand in question.

The methods possible for determining the weighted average age of the trees comprising the age class usually involve the choice of

1. Treating the entire age class as a single group, or subdividing it into from two to three, usually not over two, sub-groups.
2. Determining the average tree, for the entire class, or separately for each sub-group.
3. Ascertaining the age of these average trees.
4. Weighting the resultant ages of average trees of sub-groups, to determine the weighted average age of the age class.

261. Determining the Volume and Diameter of Average Trees. Subdivision of a group into two or more sub-groups will be made, if at all, on the basis of diameters, by the diameter group method (§ 251).

In determining the average tree for the age class, or for a sub-group, there are two reasons for basing this selection on average volume. In the first place, if these selected trees are to be felled, and their ages taken as indicating that of the stand, the larger trees must be avoided, for in all probability they are advance growth, several years older than the rest or possibly belonging to an entirely different age class. The smaller trees would also be rejected since they may be late seedlings some years younger than the average, or in extreme cases, so badly suppressed that a certain number of rings may be lacking and the growth difficult to determine. Trees of about average size for the group or stand must then be chosen. Where two or more groups are made, an average tree for each group is separately selected.

Volume is the determining factor upon which the weighted average age is to be based, hence the tree whose age is taken to indicate that of the stand must be a tree whose volume is an average of the stand. This principle applies not merely to cubic volume, but to the merchantable volumes expressed in units of product, such as board feet. Since the purpose of the investigation is to determine the period which will produce *an equal volume of material in an even-aged stand,* the product in terms of which this volume is measured actually affects the average age (§ 260). For board-foot contents which increases more slowly at first and more rapidly later in the life of an individual tree, the average tree will be larger and older than for cubic contents, since a portion of the stand will be rejected altogether and fall in a younger age group or else will logically receive a smaller weight in the average for determining the equivalent age of an even-aged stand.

The first step is therefore to determine the volume of the average tree of the stand or sub-group. It is evident that the inclusion of a large number of trees of the smaller diameters in a large group will pull down the volume of the average tree and tend to unduly lower its age. The plan of subdividing age classes into smaller diameter groups is chiefly useful in avoiding this tendency to error, and is accomplished by throwing together trees varying but little in size, to obtain the average. It is of advantage therefore to make two or more of these sub-groups where possible.

When volume is measured in cubic feet, basal area may be substituted for volume and the diameter of a tree of average basal area determined. To obtain this, the sum of the basal areas of the trees in the group is divided by the number of trees to obtain average basal area. The diameter of a tree of this area is found in Table LXXVIII, Appendix C, p. 490.

When measured in board feet, the volume of the average tree is found directly by dividing the total volume of the stand or of the sub-group in board feet by the number of trees. As in case of basal area, the diameter of a tree of this volume is now required if sample trees are to be felled to determine age. For this purpose a local volume table based on diameter is used (§ 142) from which the D.B.H. of a tree of the given volume can be determined to within $\frac{1}{10}$-inch.

262. Determining the Age of Average Trees and of the Stand. The age of these selected trees can then be obtained by felling trees of this diameter. In stands of variable age from two to three trees are preferable to one. As a substitute for this method, where it is extremely uncertain that the tree selected will have the average age, a table of diameter growth showing the ages of trees of different diameters may be prepared from similar stands in the vicinity. If the average rate ot growth thus obtained applies to the stand in question, the age of a tree of the given diameter may be taken from this curve instead of from felled timber. On account of the uncertainty of the correlation between the growth figures obtained in this way and of the age of the stand in question, the method has not been widely used and the felling of the test trees or their age determination by borings or choppings is the standard practice in determining the age of stands. When the stand is treated as a single group, the average of the ages of the test trees, all of which will be of the same average diameter, is taken as the age of the stand. When two or more sub-groups have been separated, the age of the entire stand must be calculated by weighting the predetermined ages of the sub-groups, in the proper proportions.

The following illustration will bring out the different methods possible in doing this. An "even-aged" stand composed of 30 trees is divided into two groups as follows:

Trees	Average volume. Board feet	Total volume of group. Board feet	Average age of trees in group. Years
10	500	5000	100
20	125	2500	70

1. If each of these groups occupies an equal area and is given equal weight, the average age may be found by adding the ages of the sample trees and dividing by 2. This gives eighty-five years, and is known as the arithmetical mean sample tree method. This method does not conform to the basic principle of weighted ages sought.

2. When the trees are weighted by number the result is :

$$10 \times 100 = 1000$$

$$20 \times 70 = 1400$$

$$\text{Total, } 2400 \div 30 = 80 \text{ years}$$

This overemphasizes the number of trees rather than their volume, hence is unsatisfactory.

3. Trees are weighted by volume on the principle by which weighted volume averages are always obtained:

$$100 \text{ years} \times 5000 = 500{,}000$$

$$70 \text{ years} \times 2500 = 175{,}000$$

$$\text{Total, } 675{,}000 \div 7500 = 90 \text{ years.}$$ This method is acceptable.

4. The sum of the mean annual growth for the groups is obtained. The total volume divided by this sum gives the average age. This method is considered by European investigators to be more accurate than the others. As applied:

$$5000 \div 100 = 50$$

$$2500 \div 70 = 35.7$$

Total mean annual growth for stand, 85.7

$$7500 \div 85.7 = 87 \text{ years.}$$

By either method 3 or 4, it is seen that the average age is influenced by volume rather than by area or number of trees.

263. Age as Affected by Suppression. Economic Age. When stands are comparatively even-aged and the trees composing them have grown up as dominant individuals, free from suppression, the actual age of such trees is a fair indication of the age which an even-aged stand would require to produce an equal volume. But under this same definition, the age of a tree which has been suppressed in the early period of its life does not indicate the required age but one considerably greater. The correction of the actual ages of suppressed trees to determine the age desired is known as the determination of *economic age*. What is wanted is the rate of growth of an average dominant tree on the same site as that occupied by the suppressed trees. Where reproduction takes place under a stand either of the same or of a different species, the problem of growth is one of having two crops of timber on the same land at the same time, and the rate of production per acre is the sum of these two successive crops divided by the total period required to produce them both. To isolate the period required for a single crop, we must determine the rate of growth of the crop as if it were in sole possession of the area.

A composite growth curve may be built up for average trees by measuring the growth on these trees only down to the point at which they were evidently freed from suppression and substituting from this point on the average growth of seedlings and saplings measured on dominant specimens. For instance, if the first 2 inches of an average tree shows suppression, the average rate up to 2 inches must be taken from other dominant, younger trees, and added to the remaining years to get the total economic age of the tree in question. This factor has been neglected in American growth studies, for the reason that with such species but few attempts have been made to determine total age, investigators being content with ascertaining growth for short period based upon the diameter of the trees.

CHAPTER XXIV

GROWTH OF TREES IN DIAMETER

264. Purposes of Studying Diameter Growth. One purpose of studying the growth of trees in diameter is to determine the total volume of trees of given ages, or the growth in volume of trees for a short period. The volume of trees is based on D.B.H. and height. The diameter growth must always be correlated with D.B.H. for the trees measured, and height growth is usually required. A second purpose is to determine the dimensions or sizes reached by trees in a given period.

265. The Basis for Determining Diameter Growth for Trees. It is impractical to cut sections at B.H. for growth measurements. Not only is there a needless waste of timber, but the labor of felling and sectioning the tree may also be avoided if the measurements are taken at the stump following logging operations. Where current growth for short periods is tested with an increment borer (§ 277) the measurement is taken at D.B.H. The growth measurements on stumps require three steps to determine the ages of trees of given D.B.H. outside the bark; namely,

1. Diameter growth on the stump.
2. Correction for age of the seedling.
3. Correlation between stump diameter inside bark and D.B.H. outside bark.

As diameter increases rapidly at the stump, the lower a stump is cut the greater will be the apparent rate of growth for the tree. Stump height classes differing by 6 inches may be made in growth studies, but this is not often done. Stump heights usually vary with stump diameters in a ratio of from one-third to two-thirds of the diameter, depending on the closeness of utilization. For a given region and standard, the stump heights for given diameters are fairly constant and the average rate of growth is found for stumps of each diameter with all stump heights averaged together.

266. The Measurement of Diameter Growth on Sections. The section measured must be at right angles with the axis of the bole. In stumps this means a horizontal cross cut. Slanting cross cuts exaggerate the length of the radius and result in a slight plus error in growth measurements. The procedure is as follows:

An average radius is located. Its length must equal just one-half of the average diameter inside bark (§ 25). To determine the average diameter, calipers graduated to $\frac{1}{10}$-inch may be used (§ 189). In all cross sections which are not perfect circles, the lengths of the radii from the pith or center of growth vary more widely than the diameters owing to the fact that the pith is always located at one side of the geometric center of the cross section. Leaning trees grow largely on the under side and this general law accounts for the position of the pith. On an eccentric cross section there are but two radii which are average in length and can be measured for growth. It often happens that one or both of these radii (Fig. 67) are interfered with either by the undercut or by the presence of rot or defects which prevent growth measurement. If either one is clear, the section may be measured. Otherwise, if measurement is absolutely necessary, a longer or shorter radius can be taken and the measurements reduced by proportion to the required length.[1]

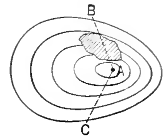

Fig. 67.—Stump section fifty years old showing eccentric growth, position of the two average radii *AB* and *AC* and rot on radius *AB*. Decades of growth are shown. The growth must be measured on radius *AC*.

Method of Counting Decades. The next step is to count the number of annual rings and indicate with a pencil the points at which the decades fall. Except in scientific investigations where each year's growth may be separately measured to determine the influence of climate on annual growth, the decade is ordinarily the smallest interval used in measurement of diameter growth. For current periodic growth a five-year period is sometimes used in order to get points for a curve in predicting the growth (§ 279).

Unless the total age of the stump falls on a decade, as thirty, or forty years, there will be one fractional decade laid off, representing from one to nine years, depending on this total age. The *diameter growth is always measured outward* beginning with the pith or center of growth. But in counting the annual rings to lay off these decades of growth, two distinct methods of procedure are followed. In one, the count begins at the center, laying off ten years from the pith, and throwing the fractional decade to the outside as on the right side of Fig. 68. By the other, the count begins at the cambium layer or outer ring, and this throws the fractional decade to the center as on the left side of the figure.

Purpose of Counting Inward from Outer Ring to Center. The choice

[1] E.g., if the average radius is 9 inches, and a radius of 10 inches is measured, each measurement must be reduced by the factor $\frac{9}{10}$ or .9

of these methods is based on the purpose of the study. In all measurements of diameter growth, an average rate is to be found by combining the growth of a large number of trees. This means averaging together the growth by decades. The trees so averaged usually differ in age, sometimes over a wide range. The growth of the last decade, or current periodic growth on all trees, regardless of their total age, is represented by the outside or last ten rings. Any influence, such as cutting, fire or climate, which affects diameter growth, must be studied on the basis of current growth. In making a tree analysis, which requires the growth

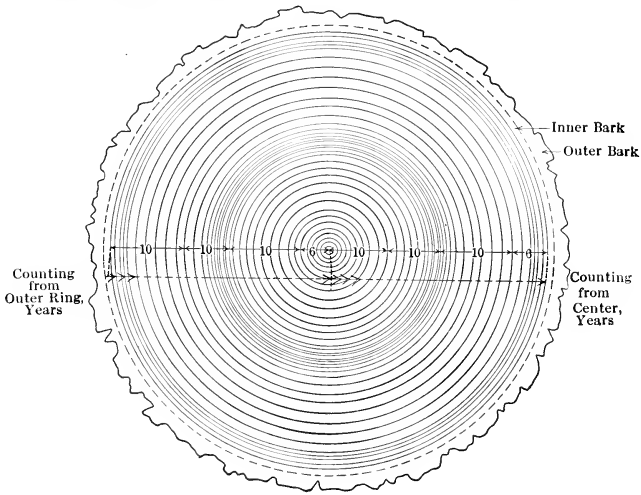

Fig. 68.—Alternate methods of counting and measuring annual rings on a cross section 36 years old. On left, rings are counted in decades beginning with outer ring. On right, count begins with center and odd rings fall on outside.

in diameter of upper sections (§ 289) the separation of the growth in volume for each past decade requires the measurement of the same ten rings on each of the sections analyzed. This is secured by counting back from the outer ring. When growth is studied for these purposes, rings must always be counted from the outside inward. In this case the first measurement from the pith outward will be the fractional decade. The average growth for this period represents the average number of years less than 10 which were measured. This may vary from 1 to 9 years but tends to average 5 years. The second decade will include, on different trees, the years 2 to 19, the third, 12 to 29;

TABLE LI

Diameter Growth on Five Spruce Stumps

Decades Counted from Outside Inward

Tree No.	Height of stump.	Diameter, outside bark.	Width of bark, single.	Diameter, inside bark.	Age of stump.	Fractional decade (1)	Distance on Average Radius from Center to Ring — Decades													
							1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Feet	Inches	Inches	Inches	Years	Years	Inches													
1	1.5	11.5	0.35	10.8	106	6	0.20	0.35	0.55	0.70	1.10	1.70	2.20	2.80	3.55	4.60	5.40			
2	1.5	10.2	.3	9.6	101	1	.05	.30	.55	.70	.95	1.30	1.50	1.80	2.55	3.60	4.80			
3	1.0	10.7	.15	10.4	129	9	.20	.70	1.20	1.70	2.05	2.10	2.45	3.00	3.45	4.00	4.45	4.95	5.20	
4	0.8	11.2	.4	10.4	120	10	.30	.45	.60	.85	1.30	1.70	1.95	2.30	2.85	3.55	4.40	5.20		
5	1.0	10.2	.25	9.7	137	7	.30	.70	1.05	1.35	1.75	2.05	2.45	2.75	2.90	3.10	3.45	3.80	4.40	4.85
Total......		....	....	....	....	33	1.05	2.50	3.95	5.30	7.15	8.85	10.55	12.65	15.30	18.65	22.50	13.95	9.60	4.85
Average....		....	....	....	....	6.6	*0.21	.50	.79	1.06	1.43	1.77	2.11	2.53	3.06	3.73	4.50	4.65	4.80	4.85

* If this average is weighted on the basis of mean annual growth per tree, the result for this decade is a growth of 0.235 inch instead of 0.21 inch.

e.g., on a tree 21 years old, the decades are 1, 2–11, 12–21 years. On a tree 29 years old the decades are 9, 10–19, 20–29 years.

Purpose of Counting Outward from Center to Outer Ring. In tracing the growth of trees in diameter, based on their age, to determine the average sizes reached at each decade, the above averages might tend to conceal or flatten out any changes characteristic of the juvenile period. In this case a more clear-cut definition of growth may be obtained if age is actually made the basis, and the same decades averaged for each stump, e.g., 1–10, 11–20 years.

For this purpose the count would be made outward from the pith, coinciding in direction with the measurement of growth, throwing the fraction to the outside. But this causes the fractional decades to fall in as many different columns as there are trees of different ages by decades. In tree analyses it would result in measuring different fractions at each upper section instead of the same rings. It does not give current diameter growth for a stand. The age of the seedling, which is usually a fractional decade, must still be added. For these reasons the first method is considered standard. But for the purpose indicated, diameter growth based on age, the last fractional decade on the outside although recorded could be dropped in obtaining average growth of several trees; e.g., a 43-year stump can be computed for its first four decades only. By this plan, the averaging is simplified.

Method of Measurement. The measurement of diameter growth is usually made with a steel rule graduated to inches and twentieths, or .05 inch, which is the smallest graduation commonly employed. When the radius has been laid off and each decade marked, the zero of the rule is placed at the center and the distance read to each decade point. The measurements are cumulative, that is, the rule remains in the same position until the complete radius is read. This avoids errors which are sure to occur in moving the zero from one decade to another to separate the decade measurements. The form of record is shown on p. 345. The accuracy of the reading should be checked by noting that twice the total radius should equal the average diameter.

267. The Determination of Average Diameter Growth from the Original Data. The average diameter growth for the trees measured may be obtained by arithmetical means, and by the aid of graphic methods.

Table LI shows the method of computing the average growth. When the decades have been counted from the pith with the final fraction rejected, each decade is full and the averages fall at 10, 20, 30 years, etc. This completes the table in the form desired. But when the rings are counted from the outside, the first decade being fractional, the growth is not shown for full decades, but for odd years as 7, 17, 27 years, etc.

To obtain the growth at the required decades, a curve of radius growth based on age is plotted as shown in Fig. 69, each point being plotted above its proper age. The radius scale is then doubled to read directly in diameter growth. From this curve, the growth at 10, 20, 30 years, etc., is then read for the table.

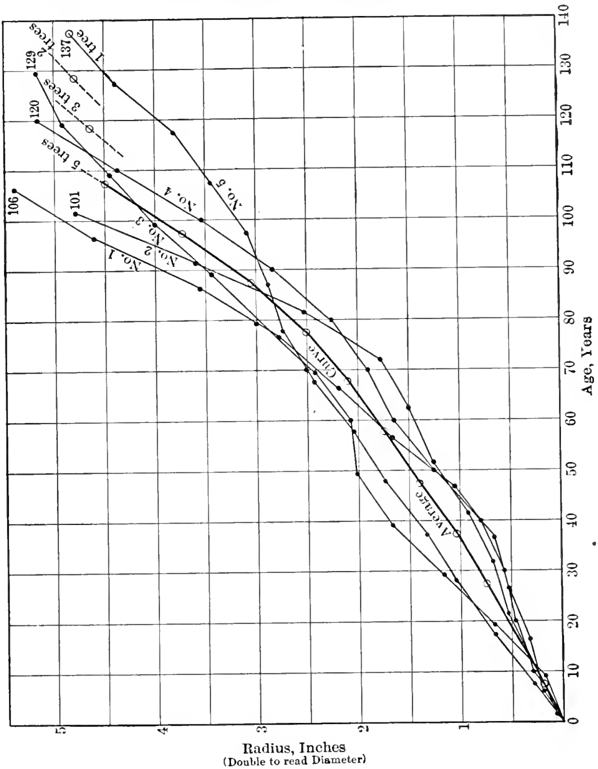

FIG. 69.—Growth in radius of 5 spruce trees plotted separately, and curve of average growth. The average number of years in first fractional decade is 7. The successive decade averages are plotted on 17, 27, etc. The last three points represent averages based on less than five trees and should not be plotted on the same curve.

The growth of each tree is shown by curves. In plotting data for a growth curve the points plotted for single trees would not ordinarily be connected. The average would either be sketched by eye, or plotted from the position of the average points as indicated.

Substitution of Graphic for Arithmetical Method. For this computation graphic plotting of the original data is sometimes substituted. This method is also illustrated in Fig. 69, in which the growth of five spruce trees is plotted, their rings being counted from the outside inward. Each tree is plotted on the exact years on which its measurements fall as determined by its total age. Where a large number of trees are plotted, the points are not connected but form a band, on which the curve of average growth is sketched by eye. This method is intended to save the labor of calculating the averages arithmetically.

Where trees of different ages are included in the average, the upper extremity of the growth curve will represent a smaller number of trees, whose growth, if dominant, will exceed the average rate, but if suppressed, will fall below it, causing the curve to depart from a true growth curve, as illustrated in this Figure.

268. Correction of Basis of Diameter Growth on Stump to Conform to Total Age of Tree. The next step is to correlate this curve of growth with the total age of the tree. The average age of seedlings must be determined for the given average stump height (§257). The number of years thus indicated is added to the scale by moving the zero the required number of points to the left. This new zero causes a shift in the age of each section to correspond. The curve now shows, not the diameter of *stump sections* of various ages, but the diameter of *trees* of various ages when measured at the height of the stump.

269. Correlation of Stump Growth with D.B.H. of Tree. The third step is to determine the D.B.H. for these same trees in order to correlate this with age. What is desired is not the age of the section at B.H. but *the D.B.H. of the tree, whose total age* and growth at stump are now known.

A tree of a given stump diameter, whose total age has been found, has a set of upper diameters or tapers representing its form, as expressed in a taper table (§ 167). Of these the most important is D.B.H. This third step then consists simply of determining the average taper of the butt, from stump height to B.H. so as to find the D.B.H. corresponding to each inch stump-diameter class.

Standard stump tapers show the D.I.B. (§135) of stumps at heights of 1, 2, 3, 4, and $4\frac{1}{2}$ feet, corresponding to each D.B.H. class. But to determine *growth* of trees at B.H. corresponding to growth on the stump inside the bark, heights of stumps are usually averaged, and a direct comparison is made of average D.B.H. outside bark with average D.I.B. on the stump for all trees falling in the given stump-diameter class.

Stump tapers may be taken on the butt logs of felled trees in the measurement of volumes (§ 168). The number of measurements so obtained is often insufficient and may be supplemented by measuring the diameter at stump height and width of bark to get D.I.B., on standing trees, together with D.B.H. Owing to the great variation in diameters at the stump compared with D.B.H., a large number of stump tapers are required to produce a curve free from irregularities, as illustrated in Fig. 70 for loblolly pine. These data can be obtained very rapidly and without much extra cost.

These stump tapers are then classified on the basis of stump diameter inside bark and not on D.B.H. since they are to be plotted on the curve of stump diameter. An arithmetical average of these relations is obtained, and expressed in the form of Table LII (p. 350).

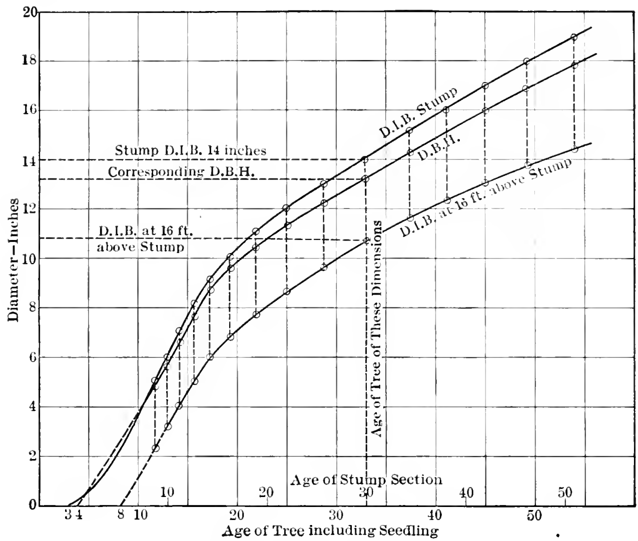

FIG. 70.—Diameters, inside bark at stump, outside bark at B.H., and inside bark at 16 feet above stump, for trees at different ages. Loblolly pine, old fields, Urania, La.

The D.B.H. outside bark for each stump-diameter class is now plotted on the curve of D.I.B. on the stump as shown in Fig. 70. Since this curve is based on age of tree, the diameter at any point on the bole of a tree of a given age will fall on the indicated vertical line corresponding to this age. Thus, a tree measuring 14 inches on the stump in Table LII is 30 years old at the stump, and 33 years old when corrected for age of seedling which is 8 years. The D.B.H. for a 14-inch stump is 13.2 inches, which is plotted above 33 years. In the same way, D.I.B. at the top of the first 16-foot log, which is 10.8 inches, would fall above the same 33-year point on the scale. In this manner the stump tapers are each plotted by first finding the corresponding

D.I.B. at stump, on the curve of growth, which indicates the required age of the tree above which the remaining dimensions are to be plotted.

TABLE LII

Stump Tapers—Based on Stump D.I.B. for Stumps 1 Foot High

Loblolly Pine, Urania, La.

Stump diameter class. Inches	Average D.I.B. stump. Inches	Average D.B.H. Inches
5	5.1	4.5
6	6.0	6.1
7	6.8	6.8
8	8.2	7.0
9	9.1	8.3
10	10.0	9.6
11	11.1	10.4
12	11.9	11.0
13	13.2	12.3
14	14.1	12.7
15	15.1	12.9
16	16.0	15.6
17	17.2	15.8
18	17.8	16.7
19	18.7	18.2

The D.B.H.'s for different stump diameters are now connected by a curve, which shows D.B.H. for trees of intervening ages, and for all stump diameters. From this curve the D.B.H. corresponding to each decade in the li e of the tree can be read, in the form of Table LIII.

TABLE LIII

Growth of Loblolly Pine, Old Field, in D.B.H., Based on Age of Tree, Urania, La.

Age. Years	D.B.H. Inches	Diameter at top of first 16-foot log inside bark. Inches
10	3.6	1.0
20	9.8	7.0
30	12.5	9.9
40	14.7	12.0
50	17.0	13.8

Since there can be no D.I.B. at 16 feet until the tree has reached this point in height, the curve of these points would terminate at zero diameter at an age equal to that required for the tree to grow 16 feet in height, above the stump, which is 8 years in Fig. 70. In the same manner the D.B.H. curve would terminate at a point representing the year in which the tree reached $4\frac{1}{2}$ feet in height, which is 4 years. The stump curve has already been shown to terminate at an age representing the growth of the seedling to stump height at 3 years. This principle is later explained more fully in connection with a method of plotting the volume growth of different trees (§ 291).

270. Factors Influencing the Diameter Growth of Trees Growing in Stands. Diameter is the most variable factor of tree growth, differing with a wider range of conditions and showing greater diversity between trees in the same stand than height growth. Growth in diameter influences growth in volume of the tree to a much greater extent than does height growth, the relation being that of d^2 or area. Since the growth in area bears this fixed relation $\frac{\pi d^2}{4}$, the area growth of individual trees is never studied, as all problems for which it is desired are solved by the study of diameter growth. The rate of diameter growth is determined by four factors: species, quality of site, density of stand, and crown class.

Secondary factors modifying diameter growth are the amount of shade endured by the specific trees studied, and the treatment of the stand.

271. Effect of Species on Diameter Growth. Different species have developed specific differences in average rate of diameter growth. Those accustomed to growing on soil of good quality as dominant species have acquired the fastest growth rate. Intolerant trees usually grow faster than tolerant since they must maintain their dominance. Of this, the cottonwood is an example. Trees which have the power of enduring shade usually grow, even in the open, at a somewhat slower rate than intolerant trees.

Trees do not indefinitely maintain a given rate of diameter growth. Until a tree actually dies, it continues to increase in diameter, but there comes a period when, in spite of the dominant position of the tree, its rate of diameter growth diminishes. The period at which this diminution sets in marks the maturity and the beginning of decadence of the tree. The life cycle of different species of trees is as distinct as that of different animals. Short-lived trees, like jack pine and tamarack, show this falling off at 70 or 80 years or sooner, and disappear within 30 or 40 years thereafter. The same is true of aspen. The life cycle of conifers is apparently affected by general climatic conditions.

That of western conifers is double the cycle characteristic of those in the East, while that for redwoods and Sequoia is fully five times as great as for most of the remaining western conifers.

The life cycle of any individual tree is governed by the average for the species but appears to depend on size and not age. A tree is mature when it has reached the maximum size permitted by its site and vigor of crown, whether this is secured by continuous rapid growth as a dominant tree or is delayed by a period of suppression. Trees characteristically intolerant and dominant, and accidentally suppressed in youth, if they recover from this suppression, will add the period of suppression to the average age which they attain and continue to grow until they reach the usual size. Trees naturally undergoing and recovering from a period of suppression, such as spruce and balsam, may attain maturity under these conditions 100 years later than trees of the same species growing in the open, and their life cycle will be that much longer. This law was also found to hold true for the Sequoia gigantea.[1]

272. Effect of Quality of Site. The greater productive capacity of better sites is reflected in the increased rate of growth in diameter of the species on these sites. Either deficiency or continuous excess of moisture greatly reduces the site quality and slows down diameter growth. The final expression of site quality is found in terms of total volume or rate of growth per year, of which this average diameter growth is one of the best indications.

273. Effect of Density of Stand. The rate of growth of the individual or average tree is profoundly influenced by the number of trees in the stand. The original number of trees germinating and becoming established on a site bears no relation to the number which may grow to maturity. The reduction of numbers with increased size and crown spread is accomplished by competition between individuals, resulting in the death of the weaker trees. With species which become established in dense stands in a single year and maintain an even height growth, the inability of the stand to differentiate itself and destroy the necessary proportion of the weaker trees is reflected in a great reduction in diameter growth on all of the trees. Of this tendency, lodgepole pine gives the best examples. In almost all species of conifers and many hardwoods, dense, even stocking, unless artificially corrected by thinning, gives a much lower rate of diameter growth than the average which may and should be secured by the species. Diameter growth is therefore apt to be greatly reduced by increased number of trees per acre in the stand, or overstocking.

[1] Ellsworth Huntingdon, The Climatic Factor, as Illustrated in Arid America, Carnegie Institution of Wash., D. C., 1914, Chap. XII.

274. Effect of Crown Class. The individual rate of diameter growth varies over a wide range with the same species, site and stand. The rate of growth is coordinated directly with the crown spread of the tree. There exists a relation between width of crown and diameter which is found to hold good under almost every condition and for every species, although varying with the species and its habit of growth. This law, which might be of great use in determining the number of trees which should exist per acre for a given species in mixed stands, is somewhat interfered with by the fact that the volume of the crown, rather than its mere diameter, is the factor affecting diameter growth, and with western conifers, with very tall and slender crowns, width alone does not properly express this value. As crowns receive more growing space and expand, diameter growth correspondingly increases. This elasticity of diameter growth correlated with crown spread is the principal means of adjustment which a stand of trees possesses, by which it constantly tends to fill in blanks and form a complete crown canopy provided only that the distribution of the trees is such as to bring these blanks within the possible maximum spread of individual crowns.

Effect of Shade. Diameter growth during the life of a tree depends upon its history with respect to the remaining trees in the stand. A tree which has remained dominant since germination maintains a maximum rate of diameter growth. The crown spread at successive decades is a maximum. Trees which are at first dominant and later suppressed, cease to grow in diameter because their crowns cease to expand. The relation between diameter and crown is maintained, but neither continues to increase. Trees which were originally suppressed and later freed may show a marked increase in diameter growth coinciding with an increased spread of crown, thus maintaining the proportion under the changed conditions. But if their crowns have lost the power to recuperate, which depends upon both the specific character and the age of the tree, no increase is made in diameter growth by reason of this liberation.

Effect of Treatment. The growth in diameter of trees can be profoundly influenced by the artificial treatment of a stand. Since for the individual tree it is a function of crown spread and its rate is governed by the ability of the crown to expand, diameter growth is the most easily governed and most adaptable function of tree growth. The stand per acre or rate of growth for a period measured in cubic contents may not be subject to great modification, but the sizes of the stock produced and consequently the value per acre can be greatly influenced by management. The behavior of trees in thinned stands and on cutover lands must be studied separately from those subjected to the natural laws of survival in original unthinned forests.

275. Laws of Diameter Growth in Even-aged Stands, Based on Age. The struggle of the individual trees for space produces different results in even-aged and in many-aged stands, although the general effect is a final reduction in numbers in either case. In the even-aged stand the area occupied by an age class is definitely fixed. Expansion of the crowns of individual trees can occur only by the prevention of corresponding expansion of other crowns and by securing of additional space through the actual death of the weaker trees. This process results in a continuous differentiation of diameter classes in an even-aged stand with advancing age. As the trees become fewer in number, the difference in size of the survivors increases. These relations are shown in Fig. 71, in which the number of diameter classes existing at different ages in an even-aged stand is indicated.

The growth in diameter of the trees which compose this even-aged stand is shown in Fig. 72. The diminution in diameter growth due to suppression of crowns affects successive trees of larger and larger diameter. The average tree at a given decade is seen to fall into the lower half of the stand in the succeeding decade and at some future period will become suppressed and finally die.

In Fig. 71 is shown the difference in basis and composition of the curves based respectively on age and on diameter. The curve based on age in this figure is composed of averages of all the diameter classes in successive even-aged stands, as shown in the vertical columns. The curve based on diameter takes all trees of a given diameter for each successive average, thus including trees from a number of different age classes or stands as read horizontally in the diagram. This curve as plotted in Fig. 71 is reversed, with the basis, diameter, plotted on the vertical scale. The proper form of such a curve is shown in Fig. 73. The wide divergence possible in the two bases, for dominant larger trees, is indicated in Fig. 71.

It is evident that growth measurements of diameter based on age, which include trees whose total age varies from 20 to 50 years, corresponding with the diameter classes *A* to *L* in Fig. 72, will not be correct for any single tree in the stand *D*. The portion of this curve representing the earlier decades is depressed or lowered by the inclusion of the slower growing trees *F* to *L* which afterwards die. With the successive dropping out of these trees from the average, the latter portion of the curve shows a more rapid growth than that of the trees which compose it.

To get the actual past growth of an average tree for a stand of a given age, *C*, it is evident that only trees which have reached this age must be measured, *A* to *E*. To secure average diameter growth for mature timber which in the future will be grown to the given sizes and numbers per acre characteristic of this class of timber, it is incorrect to include measurements of average trees for stands which have not yet reached this age, *F* to *L*. By confining the selection of trees to timber of the desired age and by taking the growth of all of the trees found on an area of sufficient size, we obtain an average rate, showing the past growth of these trees, which is a true growth curve, *C*. If it is desired to predict the rate of growth for the average tree of a given age and character of mature stand, dominant trees must be selected from younger stands rather than the average tree. The fewer of these trees, and the greater their relative crown spread or dominance compared to the remaining stand, the greater the age with which the resulting growth curve will coincide as an expression of yield per acre and average tree; e.g., for predicting the growth to 35 years of stands now 20 years old, the group of trees, *A* to *H*, whose average tree is *D*, must be included, omitting classes *J* to *L* which would lower the average tree at 20 years to *F*.

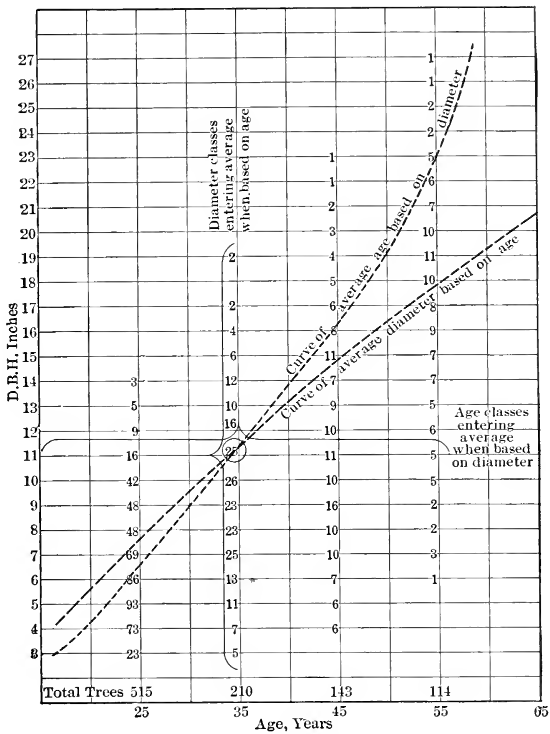

FIG. 71.—Number of trees in each diameter class in normal stands at four successive ages, and resulting curves, when averaged respectively on basis of age and of diameter.

The composite curve of average growth in which each successive decade is based on a lesser number of trees than the preceding period, is a useful tabulation to show the average diameter of surviving trees at given ages, but as shown does not correctly indicate the progress of growth for any of the trees on which it is based, unless it is confined to a given number of trees throughout.

Diameter growth based upon age is used, in practical studies, principally as an aid in indicating the difference in rate of growth of species, sites, and different methods of treatment and as an aid in determining the average age of stands in the forest under different conditions. This application is much more limited than is commonly supposed

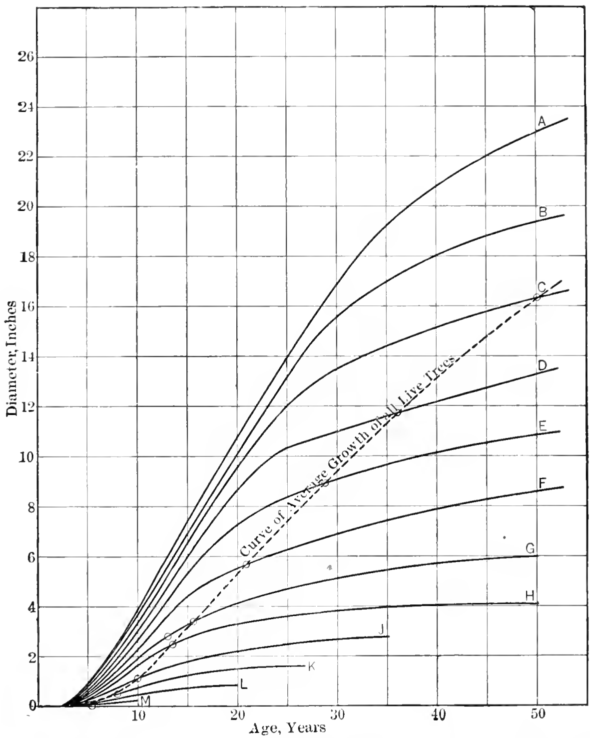

FIG. 72.—Differentiation of diameter growth as result of different rates of development of crowns, in normal stands, even-aged.

since for many problems the substitution of yields per acre based directly on total age answers the questions more directly and accurately, while for forests in which the average age for stands cannot be ascertained, diameter growth is not based on total age, but on diameter classes (§ 336).

276. Laws of Diameter Growth in Many-aged Stands, Based on Diameter. When diameter growth is studied in order to determine the age of trees of given diameters, the basis of the average is entirely different from that required when the diameter or size of trees of given ages is required. By the inspection of Fig. 71, it will be seen that when based on age for each decade, several different diameter classes are averaged together. The average diameter even for the oldest age class is several inches less than the maximum diameters reached by the dominant trees. To prolong a curve of growth based on age until the diameter of the maximum tree is reached, would add several decades to the apparent age of a tree of this diameter.

On the other hand, if diameter is actually the basis and the average age is sought, the classes included to obtain these averages are read horizontally in Fig. 71 and include under the same diameter several different age classes. The principal effect of this difference in the basis of averaging is found when the larger diameters are reached. In stands composed wholly of intolerant trees, where suppression and prolonging of the life cycle is not a factor, the difference between the age of the larger, dominant diameter classes which exceed the average and the average age of smaller diameter classes, which include many trees fully as old as the dominant classes, is much less than would be indicated by a curve based on age. A curve showing the average age of trees of given diameter is not expected to show the progress of trees in diameter from decade to decade, but expresses directly the result of the total growth or period for the specific class of trees concerned.

There is but one way to determine accurately the average age of trees of separate diameter classes and that is by a total count of rings for several trees in each diameter class to obtain the average age directly on this diameter basis. When these points or averages are plotted, they will show a relation about as indicated in Fig. 73.

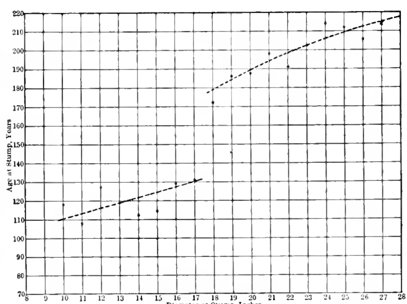

FIG. 73.—Ages of trees of different diameters, shown for two groups of longleaf pine, the first composed of second-growth stands, the second of veteran or old-growth timber.

The application of such a growth study is to determine correctly the average age of trees of given diameter classes and diameter groups in a forest or stand when the basis of age for the stand cannot be directly determined (§ 320). This presupposes that the stands are not even-aged, but many-aged in character. In mixed many-aged stands or groups, suppression usually plays a large rôle and again interferes with this determination by requiring the substitution of the economic age for the actual age (§ 263). But for the species such as the Southern pines, which are fireproof to a certain extent, and the Western yellow pine, for the same reason, the age groups may be intermingled and yet the dominant character of growth maintained. Under these circumstances, the direct determination of age based on diameter may be used for determining the average age of diameter groups, especially for the upper or dominant classes.

277. Current Periodic Growth Based on Diameter Classes. The Increment Borer. A more common application of growth based on diameter classes is for the prediction of current periodic growth in specific stands, for short periods, by predicting the growth of each tree in the stand in diameter and correlating this data with volume growth. The drawbacks to this method have been discussed in § 251. Dealing, as it does, with the specific stand and actual number of trees, it is directly applicable to stands of all degrees of density and to the actual stocking found on the ground, and to this extent is applicable directly to the existing forest without the necessity for a yield table. Tables showing the growth in diameter which may be expected of trees of given diameters may be applied directly to stand tables showing the number of trees of these diameters on the average acre.

The current growth of trees of given diameter is measured either on the stump or directly at B.H. Growth measurements taken on the stump must be laid out on an average radius (§ 25). As the growth in D.B.H. outside bark is frequently less than that on the stump inside bark (§ 269) correct results would require the reduction of the radial growth on the stump to its equivalent at D.B.H. This is not usually done, first because for trees of the smaller diameters D.O.B. at B.H. tends to coincide with D.I.B. on the stump; second, because the total error thus incurred in measuring the growth based on age is proportionately reduced in measuring current growth, although the percentage of error remains the same. This may be considered too small to require correction. When measured directly at B.H., it is important to secure an average radius if possible. The only method by which this can be done is to take two readings on opposite sides of the tree, and determine the mean.

The increment borer (Fig. 74) can be used for measuring radial growth at B.H. This instrument consists of three parts:

(*a*) A hollow auger, *A*, from 4 to 10 inches long, tapering and threaded at one end, and square in cross section at the other end.

(*b*) A hollow metal handle, *B*, with a square opening in the center into which the auger fits when in use. At the ends of this handle are detachable caps.

(*c*) A narrow wedge, *C*, furnished at one end with a flat head, and incised on one side at the other end.

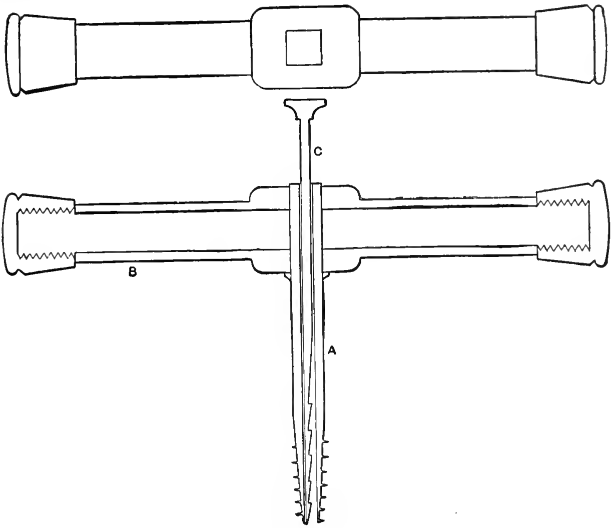

Fig. 74.—Increment borer, showing construction.

The wedge and the auger are carried inside the hollow handle when the instrument is not in use.

To use the instrument one bores into a tree to the desired depth, then inserts the wedge through the auger with the incised side turned inward. The wedge is jammed down, thus holding tightly in place the core of wood within the auger. The handle is then turned sharply to the left, severing the core from the wood. The cylinder of wood is then drawn out, and the rings counted or measured.

The best type of instrument is made in Sweden, and cores of from 6 to 8 inches may be secured by the larger sizes. The instrument is easily taken apart and is convenient to carry. When taken at B.H.

these measurements require no correction. Care must be taken if but a single measurement is made on standing trees, to select the point for testing on neither the lower nor the upper side of a leaning tree, the growth of which is very eccentric, coinciding with its position.

278. Method Based on Comparison of Growth for Diameter Classes. In Chapter XXII it was shown that growth is measured in order that future growth may be predicted. This may be done either by projecting the growth of a past period into the future on the specific trees or stands measured, or by the method of comparing the growth on trees or stands which have reached a certain size or age, with younger or smaller trees which are assumed to grow at a like rate. These principles must be applied in utilizing the growth of trees for determining that of stands.

Since diameter, not age, is now the basis of the growth study, trees are classified for growth on the basis of their present diameters at B.H. and an average rate is determined for each class. The result of such a study is applied to trees of given diameter classes in the stand or forest. By the method of comparison, a tree now 15 inches in diameter which has grown 1 inch in the last 8 years, was 14 inches D.B.H. 8 years ago, and trees now 14 inches D.B.H. if *compared* with this growth, will presumably grow at like rate for 8 years.

This requires current growth to be measured by inches of diameter, or half-inches of radius, and not by decades or periods, in order that the basis of comparison, D.B.H. classes in the past, may be obtained. The rings in successive half-inches of radius are counted and averaged, by diameter classes, in the following form:

TABLE LIV

CURRENT GROWTH OF SPRUCE, ADIRONDACKS REGION, NEW YORK

Present diameter. Inches	Number of rings in last inch of diameter	Diameter to which applied. Inches
5	6.5	4
6	5.0	5
7	5.3	6
8	6.6	7
9	5.4	8
10	5.1	9

By plotting the values in column 2 on the basis of diameter, a curve may be drawn to even out the irregularities shown. To apply such a table in predicting growth for a period of 20 years, for 4-inch trees, the growth of successive inch classes is used; e.g., the 4-inch tree takes 6.5 years to reach 5 inches, 5 years to reach 6 inches, and 5.3 years to reach 7 inches, or a total of 16.8 years. The next inch requires 6.6 years, 3.2 of which lie in the 20-year period, equivalent to about ½-inch. The tree will grow to be 7½ inches in diameter in 20 years. In this way the growth for each D.B.H. class can be predicted for any given period on the assumption that the basis of comparison is trustworthy. This is the simplest method of growth prediction for trees in many-aged forests. In obtaining the average number of years in the last inch, all trees included in the table must be measured for the same period, i.e., the *basis* must be ½-inch of radius. If instead the last 20 years is measured, divided into half-inches of radius, and a fast-growing tree used in the table as the equivalent of several smaller inch classes, its influence on the average will be increased in like proportion and too rapid an average rate obtained.

Where trees are measured for a past decade or fixed period of years, the results are expressed as growth in inches for the period. This rate of growth may then be reduced to mean periodic growth (average growth per year for the period). Dividing 1 inch by this annual growth gives the number of years required to grow an inch in diameter for each inch class. This method is equally reliable, and most tables of current diameter growth have been derived in this manner.

The assumption underlying the basis of comparison, namely, that the rate of diameter growth is a function of diameter, is most nearly approximated in many-aged forests of tolerant species such as spruce and for averages which include a wide range of ages and conditions.

279. Method Based on Projection of Growth by Diameter Classes. For single stands or specific conditions, growth for trees of the same diameter varies tremendously (§ 274 and § 275) and shows its greatest diversity, first in even-aged stands, second, between open-grown and shaded trees. For such problems, prediction based on past growth of the present trees, rather than comparison, is a more reliable method.

For this purpose, past current growth is measured for the last 5- or 10-year period, or for two to four such periods, as required. If it is assumed that future diameter growth will equal past growth, the growth is tabulated as follows:

TABLE LV

Short-leaf Pine, Louisiana

Growth by Diameter Classes

D.B.H. Inches	Growth in 10 Years. Inches	D.B.H. Inches	Growth in 10 Years. Inches
10	1.03	16	1.76
11	1.60	17	1.82
12	1.36	18	1.84
13	1.44	19	1.78
14	1.67	20	2.05
15	1.52		

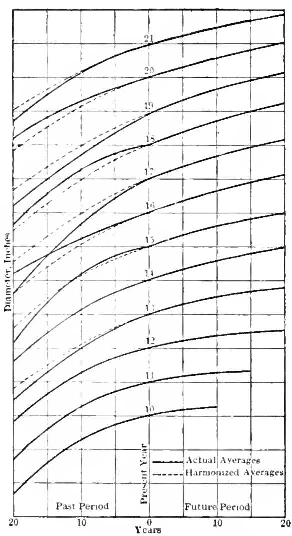

Fig. 75. — Method of predicting future growth of trees of different diameter classes based on past growth in diameter and harmonized curves. Loblolly pine, La.

These values can be evened off as described for Table LIV (p. 360).

This assumption of unchanging future diameter growth is a makeshift, inaccurate under most conditions and not as reliable as the method of comparison. But by measuring the growth for two or three periods, which for the purpose are preferably shortened to 5 years so as to bring out any recent tendencies of current growth, the past growth of trees of each diameter class may be used to predict future growth by means of a curve drawn through these past points (Fig. 75).

The original data, and the resultant prediction of growth are shown in Table LVI.

The advantages of this method show most distinctly with even-aged stands, in which case the flattening out or termination of the curve of the lowest diameter classes occurs successively, and indicates the death of these smaller trees by suppression.

TABLE LVI

CURRENT GROWTH, LOBLOLLY PINE, BY DIAMETERS

D.B.H.	Growth in Past		Growth in Future	
Inches	10 Years. Inches	20 Years. Inches	10 Years. Inches	20 Years. Inches
10	0.76	2.26	0.3	
11	.76	2.24	.3	
12	.77	2.19	.4	0.6
13	1.00	2.50	.5	.8
14	.82	2.40	.6	1.0
15	.80	2.90	.7	1.0
16	.76	1.77	.7	1.1
17	1.22	3.32	.7	1.2
18	.75	2.23	.7	1.2
19	1.33	2.77	.6	1.1
20	.77	1.83	.6	1.0

280. Increased Growth. Method of Determination. The effect on diameter growth of trees of releasing their crowns by removal of a portion of the stand in logging cannot be predicted accurately on stands previous to cutting. The release of additional supplies of soil moisture and fertility, increased light and other favorable influences, is not determinative. The ability of the tree to take advantage of these favorable circumstances varies with the age and vigor of the individual crown. When trees have passed a certain relative age and have become overmature, they no longer respond as vigorously, and some species make no response at all, while others, such as lodgepole pine, seem to retain the power of increasing their growth throughout their life. Some trees are not released in partial cuttings; hence increased growth cannot be expected except on those trees which are benefited and have the power of response.

The factor of increased growth after cutting must therefore be measured by studying trees growing on tracts which have been cut over at some previous period coinciding in length with the period for which the prediction of growth is desired. This may be 10, 20 or 30 years. Increase in growth due to cutting tends to disappear as the stand adjusts itself to the new conditions and closes its crown canopy. The competition of different species in a mixed stand and their ability to occupy space released by cutting, determines which of these species will benefit in form of increased growth.

In order to predict growth of trees for any given set of conditions from a study of diameter growth of existing trees, it is necessary to select trees whose conditions of growth, for the past period measured, coincide as closely as possible with the conditions of site, density of stand and crown spread of the trees whose growth is to be predicted. Only in this way can the excessive variability of diameter growth be averaged on a useful and accurate basis.

Probably the greatest utility of the study of diameter growth is as an indication of the possibilities of management. Its direct relation to the crown, and its dependence on growing space make it an index of the results of thinning, spacing in plantations, and selection of trees for removal in mature stands. Maintenance of diameter growth throughout the life of a stand is the proof of successful intensive management. Since the rotation, or period required to grow timber, is indicated in part by the sizes or diameters of the trees which permits of their use for given products, the rate of diameter growth in unthinned versus thinned stands gives a direct indication of this rotation period, and is so used.

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CHAPTER XXV

GROWTH OF TREES IN HEIGHT

281. Purposes of Study of Height Growth. The rate of height growth in trees is desired in order to determine the relative ability of different species in a mixed stand to survive and dominate their competitors. Height growth is the factor which largely determines the future composition of mixed even-aged stands. A condition of suppression is indicated by the diminution of height growth. Trees capable of living under suppression have the power of maintaining a much reduced height growth for a long period and of afterwards recovering and increasing this rate. In the second place, data on height growth are desired to determine the quality of site as a basis for classifying plots in the study of yields per acre for yield tables. The relative heights based on age which are attained by trees and stands are a close indication of the site quality, even superior to volume production as a reliable index of site. Finally, height growth is desired as a step in the determination of the growth of trees in volume whenever the latter data are required.

282. Influences Affecting Height Growth. *Species.* The juvenile period following germination (§ 257) is followed by a period of rapid height growth which is maintained until the tree has reached from two-thirds to three-fourths of its total maximum height. This period is coincident with the rapid reduction of numbers in an age class and with the expansion of the crowns and the elimination by suppression of those trees which are unable to maintain their position and crown spread in the stand through being overtopped.

The third period is marked by increasing slowness and finally by practical cessation of height growth and a marked change in form of crown. In some hardwoods this is the result of division of the main stem into several branches, and in conifers it is characterized by the loss of the habit of producing annual whorls of branches. This habit, however, is retained by many species such as spruce and fir. When the power to produce annual whorls is lost, the growth in height becomes similar to that of branches. The power of recovery of height growth, which has been retarded or suppressed, is lost at an early age in intolerant species, but with tolerant species may be retained for a long period.

Unless trees can maintain a satisfactory continuous rate of height growth individuals so stunted never attain the full height and form of an average mature tree.

The rapidity of height growth and the total heights ultimately attained are a specific characteristic which is retained whether the species is growing in mixture with other species having different rates of height growth, or in pure stands. Competition of faster growing species does not serve to stimulate the rate of height growth of a species to an appreciable extent. Height growth plays an important rôle in the survival, dominance and suppression of competing species.

Quality of Site. The height growth of trees and stands is directly affected by the quality of the site, to such an extent that the rate of growth of trees in height, and the total heights attained serve as the most reliable index for determining differences in site qualities and formulating a basis of classification for sites. This relation between height growth and site quality is largely independent of one of the factors which influence diameter growth of trees (§ 270) namely, density of stand. Although in some species, especially hardwoods with deliquescent stems, total height attained is less for open-grown trees than for crowded trees, this is not always the case and the rate of height growth is usually retained. On the other hand, stands, especially of conifers, which are so densely stocked as to lead to stunting and starvation, will show a decided loss of height growth. One instance is recorded in which a stand of lodgepole pine 70 years old containing 70,000 trees per acre, had attained a height of but 10 feet.

The law of height growth of trees in a stand is to maintain as far as possible an even rate of growth for all the trees in an age class or crown canopy. There is considerable differentiation between trees with dominant, intermediate and overtopped crowns, the individual rate of height growth decreasing progressively with the loss of vigor and dominance of the crown; but this differentiation is constantly diminished for the surviving trees in an age class by the death of the overtopped trees whose rate of height growth has slowed down.

When the growth in height for stands is measured, it is gaged by the growth of dominant or sub-dominant trees, which gives very consistent results. By thus eliminating the effect of crown class, height growth of stands becomes almost directly an expression of species and of site quality.

Crown Class ana Suppression. The influence of shading, which kills overtopped trees in an even-aged stand, also has a very marked influence on height growth of trees of an age class growing under suppression or in the shade of older trees. The normal rate of height growth is checked by shade, and if it does not result in death the tree survives with so greatly reduced a rate of growth in height that this rate is no indication of the capacity of the species nor of the quality of the site. Normal heights, both as to growth for a current period and total height attained at a given age, can be determined only for trees which have grown throughout their life cycle free from suppression or overtopping.

283. Relations of Height Growth and Diameter Growth. Although both growth in height, and growth in diameter, are responsive to site quality, they follow different laws in response to density of stand and crown class. As the result of the tendency for all trees in even-aged stands of intolerant species either to maintain the average height growth of the stand or to die, the relation between diameters and heights for individual trees is not consistent. The diameter growth of dominant trees is relatively faster than the height growth, while the height growth of the trees in danger of being overtopped, although a little slower than that of these dominant trees, is still relatively faster than their diameter growth which falls off in proportion not to height but to spread of crown. For this reason a dominant tree of a given height will be a stout tree with low form quotient (§ 171) while a suppressed tree in the same stand will be slender and cylindrical.

These relations are emphasized when trees of different stands are compared on the *basis of diameter.* Dominant trees of a given diameter will be comparatively short, while suppressed trees of this diameter will be tall and slender. When the ages of these trees are compared, the short dominant tree is found to be a young tree, compared with the suppressed tall tree, which is much older.

These relations between height and diameter of stands and trees are shown in Fig. 76. Within a given age class, the curves indicate the somewhat slower growth in height

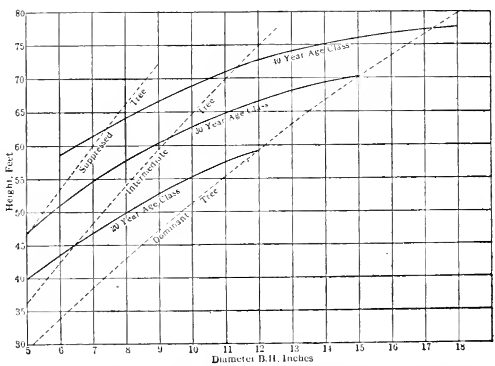

FIG. 76.—Heights of trees based on diameter in three even-aged stands compared with heights of dominant, intermediate and suppressed trees of different diameters.

of the suppressed trees, but the maintenance of nearly the average rate for all surviving trees. But the dotted lines indicate the greater height of suppressed trees having a given diameter, when compared with dominant trees.

284. Measurement of Height Growth. For the juvenile period of height growth of seedlings and saplings a practical method of measurement is to determine the total age and the total height of dominant trees (§ 256 and § 257). Trees which will not survive should not be measured for height. For young conifers showing annual whorls, the exact height growth for each year may be determined by measuring the length of the whorl. This method is used in measuring the annual height growth of coniferous plantations (§ 258).

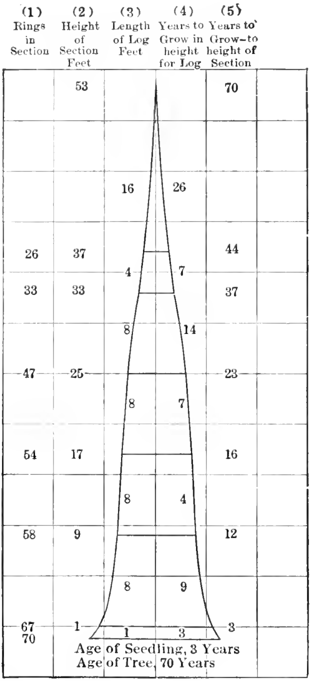

FIG. 77.—Method of determining the growth in height of a tree from the ages of upper sections, or ring counts. The difference in age between consecutive sections indicates the period required to grow in height from the lower to the upper section.

On older trees height growth should be measured by analyzing the growth of individual trees. Total height growth for a given tree is obtained when its height and total age are known, and a composite growth curve may be built up as suggested for seedlings, by obtaining these data for a number of trees of different ages on the same site quality, plotting the heights on the basis of age and drawing an average curve of height on age. But a more accurate method is possible when each tree has been cut into several sections, the age of which can be determined from ring counts. In this case as many points for a curve of height growth are found as there are sections cut, and these points form a true growth curve for the tree. Diameter growth begins, at a given section, in the year in which the tree reaches the height of this section. The number of rings shown by the section, when subtracted from the total age of the tree (age of stump plus seedling age) gives the years required to grow to this height. The process as shown in Fig. 77 consists of the following steps:

1. Determine age of tree from stump plus seedling age (§ 257).
2. Count the rings at each successive upper section, and measure length of section to get height from ground. Include height of stump.

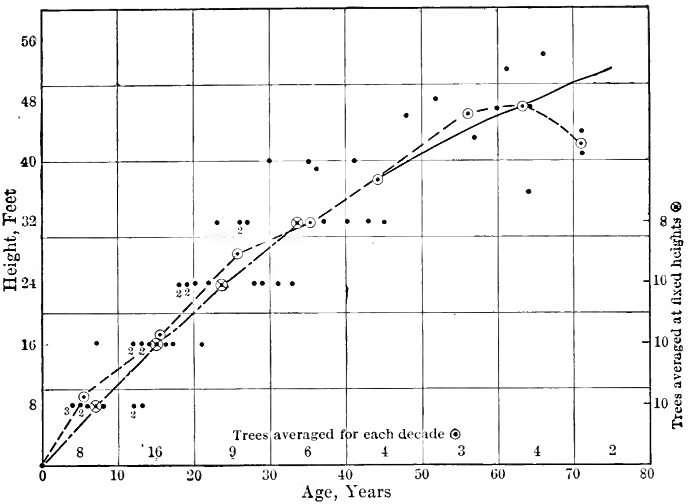

FIG. 78.—Alternate methods of averaging the heights of trees, for a curve of height based on age. Original data plotted. For curve - —— -⊗- —— - average age at fixed heights is found. For curve — —⊙— — average height for each decade. The prolonged curve —— is made necessary by dropping out of fast-growing trees from the average by decades.

3. Subtract these counts successively from total age of tree, to obtain *total* height growth at each section and age.
4. Subtract the age of any section from that of the one below, to find the period required for the *current* growth in height for the length of section.

This method may be simplified by first computing the height growth curve for the portion above the stump, on all trees, and afterwards making the average correction required for stump height and corresponding age of seedling, on the final curve or table.

Graphic Method. In averaging together the data for height growth on the basis of age, it is evident that few if any points will fall at the same age, even if taken at the same height above ground. For this reason, the most convenient method of determining an average rate of height growth based on age is to plot the original data for each tree, and draw a curve based on ocular inspection of the result assisted by weighting the points or calculating the position of the average point if the data are not sufficiently abundant to dispense with this step. In this graph, age is placed on the horizontal scale and height in feet on the vertical scale.

It is not practicable to determine the arithmetical average height at each separate age previous to plotting the data. This is best done from the graph. The height growth of ten trees, which were sectioned at 8-foot intervals above the stump is shown in Fig. 78. Stump height is omitted. The heights at each 8-foot section fall on the same horizontal line, i.e., have the same ordinate. The total or final heights represent the height of the tree.

Two methods of averaging the data are shown. By the first, all points falling in the same decade are averaged for the points marked ⊙. The number of points used is indicated at base of Fig. 78. This method is based on age, but in some decades the same tree enters twice while in others it does not appear. The depression of the curve at final decade is caused by the dropping out of eight of the ten trees from the average.

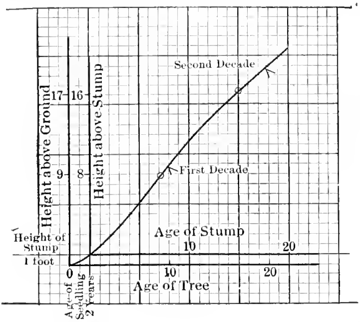

FIG. 79.—Method of correcting curve of height growth based on stump, by adding height and age of seedling, thus giving height growth of tree based on its total age.

The second method is to average the age at each 8-foot point. This average, marked ⊗, is then based not on age but on height, but is plotted on age. Since all ten trees enter this average at each of three points, the curve is more regular than the first. There is not the same objection to interchanging the basis of this curve between age and height as outlined above, as there is in studying diameter growth, since the rate of height growth has been shown to be more consistently a function of age and vice versa, for the same quality of site, while for diameter growth two or more additional variables influence the rate of growth (§ 296 and § 270).

The height growth, as read from the above curve, may be shown in a table based on total age and height of tree, by adding average stump height (of 1 foot), and seedling age (of 2 years) to the curve, and reading the corrected values from the prolonged curve, as shown in Fig. 79.

The values, read for even decades are given in Table LVII:[1]

[1] The averaging of the above data to obtain the weighted average points may be simplified, after the points are plotted, by the following method. For the first decade, average heights include 7 trees, each 8 feet or points above the base of the graph, or "up" and 1 tree 16 feet "up" or a total of 72 points "up"; average for 8 trees, 9 points "up." Average age includes 3 trees 4 years or points to right of the left margin of the graph, or "over," 2 trees 5 years "over," 1 tree 6 years, 1 tree 7 years and 1 tree 8 years, a total of 43 years, average 5.4 points "over." These

TABLE LVII

HEIGHT GROWTH OF CHESTNUT OAK, MILFORD, PIKE CO., PA.

Basis, Ten Trees

Age. Years	Height. Feet	s	Height. Feet
2	1	40	35
10	10	50	41
20	19	60	46
30	28	70	50

The total height, based on total age, of these ten trees is shown by the last ten points. It is evident that with a sufficient number of trees of all ages, a height curve based on age could be constructed without analyzing the trees above the stump section, but it is equally evident that such analyses, as shown in the figure, not only multiply the weight of each tree by the number of sections taken but substitute actual growth of given trees for composite growth by comparison of different trees. Such a history or record of growth, whether it is of diameter, height or yields per acre, (§ 256 and § 326), is the most reliable basis of growth data.

Current Height Growth. The current or periodic height growth for the last decade or two may be required to complete the data for determining the current volume growth of trees. This should be measured on felled trees by cutting back the tip until a section is found containing the required number of rings. For determining growth for short periods this is a simple process. Only on young trees should the last period of growth be determined by counting back the number of whorls from the tip In older timber and especially on standing trees, it is impossible to secure accuracy by this method.

285. The Substitution of Curves of Average Height Based on Diameter for Actual Measurement of Height Growth. In studies intended to determine the volume growth of trees, especially of seed trees and young timber left on cut-over lands, a method has been sought

data are identical with the original figures, the advantage lying in the graphic classification of the data for averaging. But for the next and subsequent decades the base, for age, can be shifted to the right by one decade, so that the points " over " include only the fractional decade, while for height the base can be raised to exclude that portion of the graph which includes no points. Thus, for the third decade there are 9 points, whose weights vary from 1 to 10 years or points. For age, the basis or zero is 20 years and the points " over " are 1, 2, 3, 6, 6, 7, 8, 9 and 10, or a total of 52, average 5.8 points " over " or 25.8 years. For height the base may be taken at 10 feet and the points " up " are then 6, 14, 14, 14, 22, 22, 22, 22, 30, a total of 166 points " up," average 18.4 points up, or 28.4 feet. In plotting, where two or more dots fall on the same point, a numeral must be written in, as indicated, to show the weight of the point.

by which this volume growth can be predicted by a study of diameter growth and by the determination of the resultant volume of the tree from its average height and volume as shown in a volume table. In order to save the expense of determining the actual growth in height of these trees, recourse is had to the relation between height and diameter as expressed by a curve of heights based on diameter such as is illustrated in Fig. 76. The process is as follows:

1. The increase in diameter for a given period for a tree of a certain diameter is predicted or determined; e.g., the tree may grow from a 10-inch to a 12-inch diameter.

2. The average curve of height on diameter shows the heights of a 10-inch and 12-inch tree respectively.

3. It is then erroneously assumed that the 10-inch tree will grow in height by the amount of this difference, that is, that it will have, when 12 inches in diameter, the height of a 12-inch tree. The fallacy of this reasoning is clearly evident when applied to any single tree or to any stand of a given age. If the tree or stand is young and the curve of height on diameter has been prepared for trees of this class or age in the vicinity, the tree will grow much faster than the difference in height indicated by this curve, and the same is true of the trees in an even-aged stand. But for old or mature even-aged stands, the reverse may be true and the trees may grow more slowly than the difference shown. Such a curve is not a growth curve at all, but a curve showing the average heights attained by trees which may be all of the same age. Only when the curve of height based on diameter includes trees of all ages as well as diameters, does it approach the form of a true growth curve, as shown by the dotted curves in Fig. 76. To do this it must harmonize two variables, namely, diameter and age. In general, small trees are young trees and large trees are old trees. If sufficient data have been included, covering wide enough ranges both of diameter and of age, and the measurements are taken on the same site quality, a rough average is obtained in which the height of a tree of given diameter is correlated with the age of tree of the same diameter. The more nearly this general result is obtained, the more reliable will be the average results of applying this curve in predicting the growth in height through the medium of the growth in diameter to trees or stands of all ages, and thus avoiding a direct study of height growth. It is obvious that for special problems on specific classes, ages and stands of trees, no such generalized curve should be depended upon, but a few measurements of height growth on the trees in question will give results whose accuracy justifies the expense.

The height curve of even-aged stands is determined either from the height growth of the maximum or dominant trees in the stand, or from that of trees containing the average volume of the stand. It has been found that the relation between dominant and average trees in height growth is very consistent, and either basis furnishes an index to the growth rate, which may be used later in classifying the plots on a basis of site for the construction of yield tables.

On account of its uniformity for a given site quality, average height growth may be determined from the analysis of from five to twenty-five average or dominant trees with very satisfactory results.

References

Relation between Spring Precipitation and Height Growth of Western Yellow Pine, G. A. Pearson, Journal of Forestry, Vol. XVI, 1918, p. 677.

Relation between Height Growth of Larch Seedlings and Weather Conditions, D. R. Brewster, Journal of Forestry, Vol. XVI, 1918, p. 861.

CHAPTER XXVI

GROWTH OF TREES IN VOLUME

286. Relation between Volume Growth, Form and Diameter Growth. The growth of trees in volume is the product of the growth in height and the growth in area at different portions of the stem, which is expressed in diameter growth. The exact form of the tree and the relation between diameter and resulting area and volume growth at different heights from the ground are the result of mechanical laws of resistance to stresses. The form of the tree is intended to resist wind pressure in order to maintain its upright position and not be snapped off or blown over. As was shown in Chapter XVI this pressure is directly caused by the force of the winds acting on the crown and focused in the center of area of the crown exposure (§172). Growth in diameter will be distributed in response to this strain to give the maximum resistance with the minimum of material.

As the form of crown and its position with respect to the bole changes, the point of average pressure shifts and the form of the tree will be modified by a more rapid diameter growth at the points requiring strengthening. An increase in the stress to which the tree is exposed will also cause changes in the distribution of growth. Trees which have grown in a protected stand and are exposed by cutting will either blow over or will rapidly strengthen their resistance by laying on increased growth at the base or stump where the effect of this change in exposure is most evident. The upper form of the tree, being influenced by crown, does not change appreciably. Trees in a leaning position continually add most of the diameter growth on the under side.

Where the growth in volume of a tree on cut-over areas is judged from the growth in diameter on the stump, without correction, a rate of from 50 to 100 per cent in excess of the true volume growth may be obtained. Such measurements should therefore be taken at B.H. where the effect of this increase is not felt, or else growth measurements taken on the stump must be carefully compared with measurements at upper points on the tree.

287. Tree Analysis, its Purpose and Application. The analysis of an individual tree by the measurement of diameter growth at upper sections, in order to determine its volume growth, is termed tree analysis, (synonym, stem analysis, § 254). This process enables one to determine the upper dimensions and volume of trees of a smaller size than those which exist in a given stand. This is an advantage in case such smaller sizes are lacking, but where present they may be directly measured. The volume which trees produce at given ages can thus be obtained in one of two ways, either by measuring trees of different ages directly for volume or by analyzing a single tree or a number of trees in order to determine the past growth in volume. The latter method alone will bring out the changes which take place in form, as described above, due to altered conditions. In applying such growth figures to answer the fundamental question of growth studies, namely, what is the rate of growth in volume per acre, annually or for a given period, not only must the growth of average rather than individual trees be determined, but the relations of these average trees to the number of trees which will survive on an acre at different ages must also be known (§ 275). Since the recording and working up of growth measurements to determine total volume growth is slow and expensive, only a few trees may be taken. It is necessary that these trees have the average form quotient for the stand to which their results will be applied. This means either a careful selection or a chance of incurring an error of from 10 to 15 per cent by the accidental selection of trees which depart from this average in form.

288. Substitution of Volume Tables for Tree Analysis. The growth of an average tree is determined by the average growth in D.B.H., the average height growth and the average growth in diameter at upper sections, of which the most important is the diameter growth at one-half of the height. The growth of upper diameters is usually accompanied by a change in form, caused by a change in the length and position of the crown. This is illustrated in Fig. 80 (§ 290) for which tree both butt swelling and upper diameters increased faster than growth at 8 feet.

Relying upon the maintenance of a consistent tree form for average trees, a method is in common use as a substitute for the analysis of trees to determine their volume growth. This method depends upon the use of volume tables to determine the volume of trees whose height and diameter are known. Since a standard volume table expresses the actual volume of average trees much more accurately than it can be obtained by the analysis of a few sample trees, the substitution of a volume for the average tree taken from this table enables the investigator to concentrate his effort on determining average growth in D.B.H. and in height. The actual measurement of height growth involves the counting of rings for determination of age of upper sections on at least a few trees (§ 284), but dispenses with the measurement of diameter growth on these upper sections, and requires from one-fifth to one-tenth as many trees as are required for the study of average diameter growth on account of the greater consistency of height growth based on age.

From a curve of growth in diameter, based on age (§ 267 and § 268), the diameters of the average trees at different ages are determined. From a second curve of height based on age (§284), the heights of the same average trees for different ages are found. Since diameter and height determine the volume as classified in these standard volume tables, the requisite volume is interpolated from the values in the table for the nearest $\frac{1}{10}$-inch in diameter and foot in height. The successive volumes found in this way indicate the growth laid on by the average tree. This may be expressed in whatever unit of volume is represented by the volume table employed. This method is almost universally substituted for volume growth analysis wherever figures on average volume growth of trees are desired. This method is illustrated by Table LVIII.[1]

[1] The method of interpolation is illustrated as follows. The 60-year-old tree is 6.6 inches in D.B.H. and 46 feet high. The values in the standard table from which to interpolate are, in cubic feet.

D.B.H.	Heights	
	40 Feet	50 Feet
Inches	Cubic Feet	
6	4.2	5.0
7	5.7	6.6

The difference for 1 inch is 1.5 cubic feet for 40-foot trees, and for .6 inch, is .9 cubic foot, giving for 6.6 inches, 5.1 cubic feet. The average difference between 40- and 50-foot trees is .85 cubic foot. For 46-foot trees it is .6 times .85 = .51 cubic foot. Then 5.1 + .51 = 5.61 rounded off to 5.6 cubic feet as the interpolated volume sought. These interpolations are more expeditiously made from graphic plotting of the values in the volume table.

One drawback to the use of volume tables as a substitute for actual growth analysis is illustrated in the attempt to measure growth at successive decades on sample plots for scientific purposes. Even here, if a single volume table is carefully prepared, combining all age classes, the transition in form from young to old trees is blended with the volumes shown in the table for small and large trees, but where, as for instance with Western yellow pine, separate volume tables were made for black jack or young trees and for yellow pine or old trees which differed by about 10 per cent in the average volume due to difference in form, the application of a different volume table to trees passing from one age class to the other caused a jump of 10 per cent in the volume due apparently to growth, but in reality due to the irregular distribution of this growth by separation of form classes in these tables.

TABLE LVIII

GROWTH OF CHESTNUT OAK

In Cubic Volume, from Diameter and Height Growth and Use of a Standard Volume Table

Age. Years	D.B.H. Inches	Height. Feet	Corresponding * volume from table by interpolation. Cubic feet	Periodic growth. Cubic feet
10	1.2	10		
20	2.5	19		
30	3.8	28	1.3	
				1.35
40	5.0	35	2.65	
				1.55
50	5.9	41	4.2	
				1.40
60	6.6	46	5.6	
				1.40
70	7.2	50	7.0	

* Cubic volumes taken from Frothingham's table for chestnut oak in Bul. 96 Forest Service, "Second Growth Hardwoods in Connecticut." Height from Table LVII, § 284. Diameter from growth of the same ten trees used in this table.

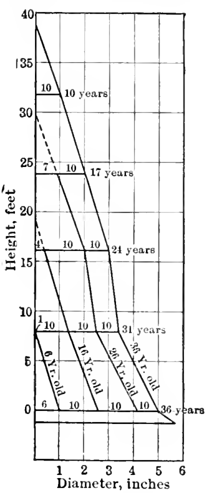

FIG. 80.—Stem analysis of a tree 36 years old, by decades, counting in from outer ring, based on stump. Stump is shown below point marked 0.

289. Measurements Required for Tree Analyses. The data required in a tree analysis, in addition to those taken for volume and itemized in § 134 and § 135, are,

1. Age of each section (height above stump and length given).

2. Growth on average radius from center to outer ring, by decades.

3. Where needed, width of sap and number of rings in sapwood.

290. Computation of Volume Growth for Single Trees. The method of computing the growth in volume for a given tree is best shown by graphic illustration. Fig. 80 shows the dimensions of a chestnut oak 36 years old at the stump, and the size which this tree had when 26, 16 and 6 years old.

To correlate the growth of upper section for the same decades, these decades are counted from the circumference inward, as shown, with the odd rings at the center. Diameter growth for each decade is then measured from center outward. The full data for this tree analysis are given in the following table:

TABLE LIX

STEM ANALYSIS OF A TREE

Species, Chestnut Oak. Locality, Milford, Pike Co., Pa.
Date, 1912. D.B.H., 4 inches. Height Stump, 1 foot.
Total Height, 40 feet. Merch. Length, 20 feet.
Width Crown, 14 feet. Length Crown, 17 feet.
Tree Class, Suppressed.

	Height above stump. Feet	Length of section. Feet	Diameter, outside bark. Inches	Width bark, single. Inches	Diameter, inside bark. Inches	Age. Years
Stump	0	1	6.05	0.5	5.05	36
1	8	8	3.95	.3	3.35	31
2	16	8	3.5	.2	3.1	24
3	24	8	2.3	.15	2.0	17
4	32	8	1.0	.05	.9	10
Tip	39	7				

Distance in inches on average radius from center to ring, by decades. The first column shows the number of years in the first fractional decade.

	(1)	(2)	(3)	(4)
(6)	0.5	1.3	2.1	2.5
(1)	0.05	0.65	1.25	1.7
(4)	0.25	1.05	1.55	
(7)	0.55	1.0		
(10)	0.45			

In addition, for a group of trees analyzed, the site, density of stand, character of trees shown, conditions of cutting or other factors whose influence on growth is to be determined, are recorded. With diameter at each decade for each section recorded, the total volume of the tree and its volume at each decade in the past, e.g., for 36, 26, 16 and 6 years, is obtained by methods indicated in Chapter III, using the Smalian or the Huber formula for cubic contents.

But one detail is lacking—the actual height which the tree had at the above decades, in case the former tip falls between two of the sections counted. This tip contains a very small per cent of total volume, and for merchantable contents would be ignored. But for accurate studies of total cubic contents the height is obtained by assuming that the height growth maintained the same rate per year as shown for the entire section concealing the tip; e.g., in Fig. 80 the third section took 24 − 17 = 7 years to grow 8 feet. The tip contains 4 rings, or 4 years' growth. Hence its height is $\frac{4}{7}$ of 8 feet = 4.5 feet. For the second section the period required was 31 − 24 = 7 years. The tip has 1 ring, hence its height is $\frac{1}{7}$ of 8 ft. or 1.1 ft. or

$$\text{Length of tip} = \left(\frac{\text{Age of tip}}{\text{Years to grow length of section}}\right)\text{Length of section.}$$

The age of any one tree will probably fall at an odd year instead of an even decade and the age of the average tree whose volume is calculated will fall on one of these odd years; e.g., for the chestnut oak above analyzed which took 2 years to grow to stump height, the table and figures above will show the age of a tree 8, 18, 28 and 38 years in age. To find the volume of the tree at even decades, as 10, 20, 30 years instead of odd years, the volumes as determined are now plotted on cross-section paper on which age is placed on the horizontal scale and volume on the vertical scale. From these curves the volumes for even decades can be read. By averaging these volumes on the basis of age the average growth in volume is obtained for all the trees analyzed.

291. Method of Substituting Average Growth in Form or Tapers, for Volume. The taper measurements or diameters determined from Fig. 80 thus enable one to ascertain the volume of the tree at different ages expressed in any unit. In this it does not differ from taper tables disoussed in § 167 except that age is now the basis of the dimensions shown.

The advantage of recording the tapers for the individual tree rather than its separate volumes at different ages applies equally to the average of a number of trees analyzed for volume growth. For this reason the method of computing volumes directly for each tree has given way entirely to the method described below by which the average tapers or dimensions of all of the trees studied are first determined. From the average tree thus plotted, the volumes can then be found for any of the desired units, such as cubic feet, board feet in any given log rule, standard ties or poles, for each age or decade. This method reduces the work of computing volumes to a single average tree for each tree class.

The first requirement of this method is a curve of average growth in height based on age (§ 284). This establishes the year or age in the life of the tree at which the diameter growth of each upper section at a given height originates and marks the zero or origin of the curve for this section when plotted on the age of the tree (§ 269). Second, a separate curve of diameter growth based on age is constructed for all sections which fall at the same height above the ground. The sum of the age or period required for the average tree to reach this height, plus the age or period represented by the growth of the section equals the age of the tree regardless of the height of section. It is evident then that the average curve of growth in diameter for any of these sections can be plotted on a single sheet of cross section paper whose horizontal scale represents the age of the tree and whose vertical scale represents the diameter of any cross section. A cross section which does not begin to grow in diameter for 17 years will diminish to zero and the curve representing its growth will intersect the base or zero diameter at 17 on the horizontal scale representing age of tree.

In Fig. 70 (§ 269) a curve of stump diameter based on the age of the tree was shown as intersecting this base at the age represented by the seedling. On this same sheet a curve representing the D.B.H. and one showing the diameter at the top of the first 16-foot log were indicated with their points of intersection. On a single vertical line the points shown were the diameters of a tree of a given age and indicated the D.B.H., D.I.B. at stump and D.I.B. at top diameter of first log for this age. But to get a curve showing these three dimensions for trees of different ages in the illustration given, the points were not taken from the growth of one tree, but by the measurement of several trees differing in age, stump diameter and corresponding D.B.H. and upper tapers. The connection of the points for these separate trees which differ on the basis of age, gives the curves showing the increase in the upper diameters or tapers for trees of different ages.

The method of plotting the upper diameters showing the growth of an average tree at the different ages of its life is identical with this previous method, with the exception that instead of these ages being represented by the final, present or outer dimensions of separate trees, they include the past, interior dimensions as well, by the measurement of past growth. Even though the growth is an average of many trees, the method still remains the same since each decade's growth is a composite of the actual growth or internal dimensions of a number of trees. The method of plotting the data is as follows:

1. Prepare and plot a curve of average height based on age on a separate sheet.

2. Prepare on separate sheets, curves of average diameter growth for all cross sections falling at each separate height, as for instance a curve for sections falling at 8 feet, 16 feet, etc., including one for the stump section. It is assumed that the height of seedlings based on age has been determined and that D.B.H. has been correlated with stump D.I.B.

3. After determining the initial or zero year for each of the curves

of diameter growth, including the stump section, transfer or assemble each of these curves on a single sheet whose zero represents the zero year of the tree's age.

In Fig. 81 the curve of stump growth from Table LIX is plotted with the zero at 2 years, age of seedling of stump height. This is usually assumed to be also the origin of the D.B.H. curve. For the curve of diameter growth at 8 feet, the period required to grow to this height by Fig. 81, or by interpolation in Table LIX is 7 years plus 2 years for seedling. The zero is placed at 9 years. Since the first fractional decade averaged 6 years on these sections, the first diameter is plotted above 9+6=15 years, and subsequent decades at 25, 35 years, etc., as indicated by the points.

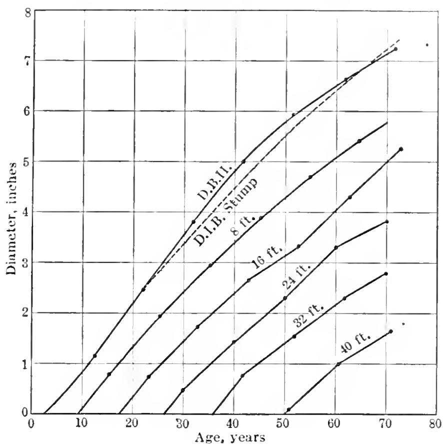

Fig. 81.—Diameters at 8-foot points, for an average tree at different ages, or growth analysis. Chestnut Oak, Milford, Pike Co., Pa.

The height growth for section 3 at 16 feet took 15+2=17 years. The first fractional decade was 6 years. The points are plotted above 23, 33, 43 years. In this way each upper section is plotted on the sheet representing the age of the average tree.[1]

To read this record for the purpose of determining the volume in any given unit for a tree of a given age, the dimensions of a tree of the required age fall in the vertical line intersecting this age. For instance, a tree 40 years old will have its diameter inside bark at the 16-foot cross section indicated in Fig. 81 as 2.4 inches. Reading upwards as the diameter increases, the next lower cross section has a diameter of 3.4 inches and D.B.H. is 4.8 inches. Since the height or distance between these cross sections cannot be shown on this diagram, but

[1] In the above figure, D. B. H. outside bark exceeds D. I. B. at stump up to about 7 inches. This frequently occurs on small thick-barked trees.

only diameter based on age, it is necessary to indicate upon the curves the height which each curve represents.

This series of curves can be used only to determine the diameters at the definite points, as 8, 16, 24 feet, etc., for which curves have been drawn. It corresponds with Fig. 32 (§ 168) for taper curves. To obtain the growth in form for the tree at intervening points, these curves should be replotted in the form shown for a single tree, in Fig. 80.

From the average tree thus shown, the growth by decades in any form or length of product can be directly computed, to any required diameter limit.[1]

292. Substitution of Taper Tables for Tree Analyses. Just as the above method substitutes the form of the average tree at different ages for the direct calculation of the volume at these ages, so it is possible to go one step further and to substitute the entire form or taper of trees of different diameters, heights and ages, just as was done in Fig. 70 on the curve of stump diameter growth, for D.B.H. and top of first log. To make this substitution, the diameter and height of average trees are first determined for each decade in age. Second, from a table of average tapers, the form or taper of trees of the corresponding diameters and heights are taken. This may be done by interpolation in case the required diameter or height falls between inch diameter classes or 5- to 10-foot height divisions expressed in taper table. The tapers thus borrowed are assumed to be those of the tree at the different ages.

This method has the same advantages and drawbacks as the substitution of the volumes from a volume table for the actual volume of sample trees as described in § 242. The average tapers are taken in most instances from a much larger number of trees than could be analyzed for form at the different decades of their growth. These tapers therefore probably represent quite closely the average form of the tree of these sizes and ages. On the other hand, this average, just as for volumes, may depart from the actual average of the trees to be measured in case the data do not coincide in origin and the trees differ in average form quotient.

The best check upon the accuracy of substitution of taper tables for tree analyses is to test the form quotient both of the taper tables and of the trees desired. A considerable departure in this form quotient indicates that the tapers do not represent the average sought.

[1] This method of graphic plotting of average growth in diameter at each upper section was devised by A. J. Mlodjiansky (Measuring the Forest Crop, Bul. No. 20, Division of Forestry, U. S. Dept. Agr., 1898). The method of assembling all the curves on the same sheet was devised by H. S. Graves (Forest Mensuration, 1906, p. 295).

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CHAPTER XXVII

FACTORS AFFECTING THE GROWTH OF STANDS

293. Enumeration of Factors Affecting Growth of Stands. The rate of growth per acre or total volume production of stands is the result of five classes of factors, namely, site, form, treatment, density, and composition.

Under site are included all factors of local environment such as soil, exposure and altitude, which influence growth (§ 294).

The term form alludes to age, and the forms of stands distinguished in yield studies are even-aged and many-aged (§ 259).

Treatment refers to the silvicultural management of the stand, in the form of thinnings, and protection; untreated stands are those grown under natural conditions (§ 300).

Density means primarily the completeness of crown cover, but this factor is also influenced by the number of trees per acre (§ 301).

Under composition, pure and mixed stands are distinguished. Pure stands are those in which a single species comprises 80 per cent or more of the volume. Mixed stands are those made up of two or more species, none of which amounts to 80 per cent of the volume. Stands may be alluded to as pure if 80 per cent or more is composed of trees of the same genus, such as pure pine or pure oak stands.

Natural enemies such as insects and fungi, and climatic factors such as tornadoes and ice storms reduce the density of stocking and lower the rate of growth, thereby widening the gap between average and fully stocked stands.

294. Site Factors, or Quality of Site. In estimating the volume of stands, the forest type is made a distinct unit of area for the purpose of increasing the probability of accuracy in obtaining an average stand per acre, or in securing a curve of average height on diameter (§ 225 and § 227). In the measurement of growth and yields, not only is the forest type also a fundamental factor, since it determines the species and composition of the stand, whose capacity for growth underlies the results obtained, but these types must be further subdivided into site classes.

The rate of growth per year or total yield for a given period for different species depends directly upon the combination of factors which influence this growth, chief among which are quality and depth of soil, average moisture contents, slope and exposure, altitude and climate. Site factors cause a variation in total possible yields of from 200 to 300 per cent. Hence for a given stand or area the yield cannot be predicted within a reasonable degree of accuracy unless the quality of site is taken intoaccount. This difference in yieldon good and on poor sites is caused by the more rapid growth in height, diameter, and volume, of the trees in the stand, when growing on more favorable sites. Fewer trees may mature on good sites than on poor, because of the larger sizes and crown spread attained, but the sum of their volumes will exceed those of the trees maturing on the poorer sites. When the period of years required to produce these yields is considered, and the mean annual growth is computed (§ 245) it will be seen that the more rapid growth on good sites produces even more striking differences in the annual rate of growth between poorer and better sites. These differences are further increased when the value of the yield is compared with the cost of production, so that it becomes of utmost importance in forestry to determine, for any large area of forest land, the acreage embraced in each of several grades or qualities of site.

295. Volume Growth a Basis for Site Qualities. Forest types sometimes show abrupt transition from one to another, corresponding to sharp differences in soil moisture; but more often the change is gradual and the separation of areas in each type, as made in the field, is arbitrary. The differences in site quality within a type form an unbroken series of gradations, which must be separated, on a purely arbitrary basis, into a convenient number of site classes, whose average yields may be expressed in tables. In European practice five qualities are recognized when a few species occupy a wide range of conditions. In America three qualities have so far sufficed to cover the range of a single species.

The problem of classifying site qualities is two-fold. First, the plots whose yields are measured to determine the average rates of growth for different sites must be separated into the predetermined site classes. Second, some convenient means must be found to apply this site classification to forest lands during a forest survey in order that the total area may be subdivided on this basis for the prediction of growth on the forest.

The most direct method of classifying plots measured for yield is by the rate of growth per year actually produced, i.e., the total yield based on age of the stand. This has been the basis of most of the yield tables constructed in America, and might suffice were it not for the four other factors which modify the yields per acre independent of site; namely, form of stand, treatment, degree of stocking, and composition of stand.

The influence of these variable factors is tremendous, and it has usually been considered necessary to eliminate them by constructing yield tables for given fixed conditions only, such as for even-aged stands, artificially grown and thinned, of normal or full stocking, and of pure species. Where these conditions do not apply, as for instance in mixed stands of broken density in forests of all ages, it has often been considered impossible to determine the rate of growth per acre.

296. Height Growth a Basis for Site Qualities. Although it may be possible, by rigid selection, to eliminate these four variables and thus base the site qualities upon the rate of growth or the total yield per acre based on age, yet when it comes to reversing the process and applying this standard of site classes to the classification of lands on a larger area, the remaining variables are present and must be dealt with. This problem may be summed up as follows:

1. The factors of site, such as climate, and soil, are too complicated to be directly measured in the field as a means of site classification. Results expressed in forest growth, rather than causes, must be used as the indicator of site.

2. Volume as a site indicator is incomplete without the determination of age. For most conditions the relative volume based on age is too variable and difficult of determination to serve as a field basis of classification of large areas.

3. Dimensions of typical dominant trees in a stand may serve as the required indicator, since the tree unit is independent of the variables of age, form, composition and density which affect the stand.

4. The dimensions which may serve for this purpose are diameter and height. Of these, height alone is a reliable index of site quality since it is affected but little by varying density or degree of stocking, or by the treatment of the stand. Height based on age is a more reliable basis than volume on age for stands of varying degrees of stocking, and for both wild or unmanaged forests and thinned or managed stands. This reduces or eliminates two of the five variables, namely, treatment, and density of stand. Height growth is retarded by shade to a marked degree; hence in forests of all ages, and in mixed stands of several species, height based on total age ceases to be a reliable index, since the factor of economic age is introduced.

Total height or height at maturity remains, even in mixed stands, a distinguishing characteristic of different site qualities. The growth of dominant, unsuppressed trees, a few of which may be found in almost every stand, may be ascertained in a very few tests and will hold good for the stand or site. Thus the remaining two variables, form and composition, may be eliminated by selection of dominant trees or fully mature trees.

Site qualities, whether three or five in number, must be adapted to the range of actual yields of the species to be measured. Different species require a different range of site factors. The conifers thrive in soils too poor for hardwoods; hence quality I for pines may be quality II for oaks.

The adoption of a common standard of site index for species with the same range of soil requirements is desirable. One suggestion is to classify the trees of the country into groups, based on their total growth in height at a definite age. This principle is illustrated by the following table, in which four site classes are made for each group, based on even gradations of total height for dominant trees of the same age.

TABLE LX

STANDARDS OF SITE CLASSIFICATION BASED ON THE HEIGHT OF TREE AT 100 YEARS

Site	Standard *a*. Feet	Standard *b*. Feet	Standard *c*. Feet
I	110	90	70
II	90	75	60
III	70	60	50
IV	50	45	40

A standardization of this character serves the double purpose of coordinating the yield tables for species of similar growth habits, and furnishing the simplest basis for site classification during forest survey.

297. Other Possible Bases for Site Qualities. Medwiedew's Method. A method of site classification suggested by Medwiedew, a Russian, and applied by Hanzlik to Douglas fir is as follows:

A site factor is calculated by the formula,

$$\text{Site factor} = \frac{c \times h}{n},$$

when c = basal area on the average acre;
h = average height of stand;
n = age of stand.

These so-called site factors may then be grouped to represent different site qualities, all factors falling between certain limits indicating quality I, etc. This basis is not consistent as an indication of site, since it is nothing but the mean annual growth of the stand in a different form. If f = form factor, then, chf = total cubic volume, and $\frac{chf}{n}$ = mean annual growth of stand. As mean annual growth varies with age as well as site, it cannot be substituted for either volume or height as an absolute basis of classification.

A still more impracticable plan is to base site factors on the current annual growth of a stand.[1]

298. The Form of Stands. Even-aged versus Many-aged. There is an essential difference in the character of even-aged stands and those composed of all ages on the same area, and this difference constitutes one of the greatest difficulties in determining the rate of growth or yields. It has been shown (§ 274) that the competition between individual trees made necessary by the expansion of their crowns and growing space occurs in an even-aged stand between trees of the same age class. Except around the borders of this age class there can be no expansion of the areas occupied by the total stand belonging to this age class. The factor of area can therefore be standardized in yield tables. Since the yield of even-aged stands is composed of the volumes of trees which have remained dominant throughout the life of the stand, the rate of growth of the individual trees is a maximum both in height and diameter and the mean annual growth resulting on an acre is the maximum for the site when measured for the period required for the growth of the average tree from seedling to maturity.

The conditions are entirely different in many-aged stands, the difference being greatest for species which may be subjected to a long period of suppression and yet retain the power to survive and recover. In these stands several different age classes are brought into competition not merely with trees of their own age, but with older and younger trees. The older trees have the advantage of the younger in appropriating space vacated by the death of veterans or by the removal of trees for any cause. The young trees growing under partial shade are held back in height growth, diameter growth and consequent volume growth. The economic space occupied by the younger age classes growing under partial shade may be defined as the actual percentage of the total growing space as represented by the available light, moisture and soil fertility which is appropriated by these young trees to the exclusion of its use by other age classes. This proportion of space so used is exceedingly small and may be negligible, yet the reproduction may survive as scattered individuals for many years. When old trees die, the space released is not, as in the case of even-aged stands, occupied entirely by reproduction, but is distributed among all of the trees so placed that they may avail themselves of it by expanding their crowns. A portion only of released space is taken by additional reproduction.

[1] "Concerning Site," Carlos G. Bates, Journal of Forestry, XVI, 1918, p. 383. Not only is this basis impractical of measurement and classification in the field, but it varies with age of the stand to a much greater degree than does mean annual growth, hence is not trustworthy as a means of separating sites, though the postulate that the best sites are capable of yielding the largest current annual growth is perfectly true.

The result of these two factors is that the area of an age class is at first small, its growth retarded and mortality heavy, but with advancing age, the area or per cent of total area occupied by this class increases until it reaches a maximum at a period when the stand is at maturity and before the loss of veterans begins to leave holes in the canopy.

TABLE LXI

AVERAGE CROWN SPREAD OF LOBLOLLY PINE IN THE FOREST, AT VREDENBURGH. ALA.

Age. Years	Diameter of crown. Feet	Per cent of increase in diameter	Per cent of increase in area	Trees per acre
30	13.0			
40	15.5	19	42	140
50	19.0	46	113	116
60	22.0	69	186	88
70	24.5	88	255	70
80	27.0	108	332	59

This law of expansion is illustrated in Fig. 82.

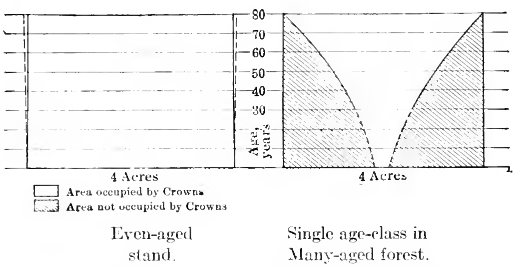

FIG. 82.—Possible expansion of area occupied by crowns of trees of a given age class in a many-aged forest, contrasted with limited expansion possible in crown area in an even-aged stand. Loblolly Pine, Ala. Dotted lines show possible expansion of 7 per cent in even-aged stand. Shaded area shows possible expansion of stand of 332 per cent in many-aged forest.

On the left, in Fig. 82 an even-aged stand occupies a square area of 4 acres, 417 feet square. During its growth, crown expansion is effected by a reduction in the number of trees from 140 at 40 years, to 59 at 80 years, with much more rapid reduction previous to 40 years. The only expansion of area possible for the age class is around the edges of the square. The trees can extend their crowns an average of 14 feet, or 7 feet on one side, in the 50-year period (27–13 feet). This gives a final area in square feet of 431^2 or an expansion of 7 per cent.

By increasing the area of the stand, this possible expansion of area becomes less. By reducing the area, the per cent of expansion possible becomes greater, since a greater per cent of the total number of crowns are so placed as to be able to utilize the increased space. The maximum possible expansion occurs when there are but 59 trees per acre at 30 years, equally spaced, and unobstructed by older age classes, in which case the area actually utilized by this age class expands 332 per cent or is 432 per cent of its original area, and the stand becomes fully stocked at 80 years. This expansion of actual are is shown on the right, in Fig. 82.

This second process is what takes place in a forest composed of stands of many different ages. In the case of even-aged stands, thinning or removal of trees simply permits the remainder to grow, with no change in area for the class, and the removal of the final crop is followed by reproduction which in turn occupies the entire original area. But with many-aged stands, when the final crop is removed, which takes place on any acre in several different cuttings, the area so released is reproduced only in part. The remainder is absorbed by the crown spread of the intermediate age classes which thus increase their total area in the manner shown by Fig. 82.

In the illustration, this stand at 30 years occupies but one-fourth of the total area of the 4 acres. The remainder can be occupied by older timber, which in the 50-year period is removed as it matures. By assuming this 4 acres to be but a part of a larger area, and to be distributed over the area coinciding with the distribution of the single age class in question, the conditions of a many-aged forest are visualized. This factor of crown expansion and competition between *different* age classes is the basis of the differences between the increment of many-aged and even-aged stands. It explains suppression, economic age, and increased growth after cutting. The actual amount of expansion and rate of increase due to this factor will be considerably less in all instances than the per cents given in table LXI since only a portion of the maximum space required by each tree of the class for expansion is available at all, and but a part of this can be taken from other age classes. Summed up, this factor represents an additional rate of increment to be added to that which an even-aged stand of like volume would show, and caused by the fact that the volume of the age class in the many-aged forest, while occupying only a certain per cent of the area of the forest, is thereby distributed over a much larger area into which its crowns can expand.

299. Annual Increment of Many-aged Stands. The rate of growth per year based on a unit of area for many-aged forests does not represent production of a single age class, but of the sum of all the age classes on the area, averaged for a long period. If desired for a single age class, this rate or yield per acre should not be based on the area occupied by the timber at maturity divided by the total ages of the trees composing this stand, for this would greatly under-estimate the rate of mean annual growth. The error can be expressed and corrected in one of three ways: (1) either the age used as a divisor must be shortened to represent the economic age of dominant trees growing in even-aged stands, or (2) the area occupied by the mature crop must be reduced to represent the average area for the stand during its life, which is practically impossible, or (3) to the yield for the period represented by the total life of the trees in the stand as actually shown by ring counts, must be added the additional yields from other crops of timber which this same area produced during the period when the final crop was only occupying a portion of it. The latter problem may be illustrated best by the yield or rate of growth per year of stands which have come up to spruce following poplar or white birch on a burn. In the period required to produce a mature crop of spruce, a crop of poplar and birch has also been produced. The mean annual growth for the whole period must include the total yield of both species.

Owing to the difficulty of adjusting these yields on one of these three bases, it is customary to employ a substitute method of determining the rate of growth, not for the total period by any of these adjustments, but for a partial period, measuring the current periodic growth based upon trees or stands which have already reached a given diameter or average age. This will be discussed in Chapter XXXI. Its effect is to eliminate most of the uncertainty attending the adjustment of the factor of competition in many-aged stands, but it introduces the question as to whether the current growth measured represents the true mean or average for the site over a complete period of crop production.

300. The Effect of Treatment on Growth. The fact that the growth of individual trees demands expansion of their crowns influences not merely the yield per acre which may be attained, but more especially the dimensions of the individual trees in the stand. Since the production of lumber and of certain piece products and the value of products grown on a given acre depend much more largely upon dimensions and sizes and upon quality than upon total cubic volume, yields attained in board feet are profoundly influenced by the number of trees brought to maturity in stands of equal degrees of crown density or stocking. It has been commonly assumed that a normal or fully stocked stand simply meant one which showed a complete crown density throughout its life regardless or independent of the number of trees which composed it. This conception neglects the fundamental idea of the tree as an individual. Stands which are fully stocked when young, so that crown density is early established, usually become overstocked almost immediately. The normal number of trees, to attain best results or highest yields, is least on good sites with strong growing species, rapid height growth and correspondingly rapid diameter growth, and increases as the sites become poorer. The danger of over-stocking and stagnation of both height and diameter growth increases with poor sites, even-aged stands, and tendency to abundant reproduction. These natural tendencies are affected tremendously by artificial control. All operations such as planting, in which the initial spacing is fixed, and subsequent thinning by which the resultant number of trees per acre at each decade is determined, have a direct effect upon the diameter growth of the remaining stand, which in stands continually under management may be maintained at an almost constant rate until the maturity of the stand.

It has been found that in stands originally stocked with only part of the normal number of trees for smaller ages, as the age of such stands advances and the number of trees required in a stand of maximum or normal density decreases, the poorly stocked stand tends to approach and to equal the yield per acre of the stand which has been normally stocked throughout its life. There is therefore a universal tendency under natural conditions for stands to approach a full crown cover as well as for the more densely stocked stands to become over-stocked. This tendency must be recognized in dealing with density factors or per cents in prediction of yield and forms a conservative factor in the prediction of growth for partly stocked empirical or average stands. Ideal conditions for growth are found in stands which have been maintained at a normal number of trees per acre as well as a normal crown density through repeated thinnings. Not only is the total volume produced per acre and the rate of growth greatly increased by a proper balance between thinnings and the remaining stand, but the maturity of the stand is hastened and its rotation may be reduced if desired.

301. Density of Stocking as Affecting Growth and Yields. In spite of the tendency of natural stands to approach normal density of stocking through the expansion of their crowns, the attainment of normality or full stocking under natural conditions of growth is seriously interfered with by many agencies. Natural spacing or stocking is largely a matter of chance and fails over extensive areas. Much of the reproduction may be destroyed during these early years by grazing, fires, frost or drought. Saplings and poles may be further destroyed by fire, insects and disease. Later on, insects, disease, fire and wind continue to make gaps in the age class and crown density. Most of these detrimental factors are reduced under protection and the average density greatly improved, yet forests covering wide areas ordinarily can not be brought to a perfect or full condition of crown cover or stocking, no matter how intensive the care which is bestowed upon them.

The yields of forests are desired on the basis of their actual average production and not upon the small per cent of stands showing maximum or perfect conditions of density and numbers per acre. This gives rise to the problem of applying tables of yield to these conditions, first as to the selection of areas or plots for the measurement of yields, and second, as to whether the area so selected shall be an average of all conditions of stocking within the site class or shall make no attempt to attain this empirical average.

It has been generally accepted that the best method of obtaining yields is to select plots which show a fairly complete crown density, not seriously reduced by avoidable factors of damage, and to construct the table of yields entirely from such plots. This is supposed to give the normal relation between yields at different ages for well-stocked stands. There remain many variable factors, the chief of which is the number of trees per acre in the plots measured. It has been suggested that the age or ages at which the final yield is to be harvested shall be taken to indicate the normal number of trees per acre and that stands of lesser age having this number or more trees, while not showing the full yield for these ages may be regarded as fully stocked, if not to be cut until the final age. The only difference between such stands and stands which remain fully stocked would be found in the thinnings in the interval and in the quality and limbiness of the timber.[1]

Yield tables based on a given standard such as described may be discounted to predict the average degree of stocking for average areas, which are known as empirical yields. In some instances efforts have been made, by collecting data on large areas, to obtain these empirical yields or averages directly in the field instead of by discount from yield tables. In either one or the other of these forms, the empirical or actual average is the final result desired, and the normal or standard yield table is but the means to this end. The arguments in favor of obtaining a normal or standard yield table by the selection of plots are that the variables represented in the average or empirical stocking by differences in form or mixed ages, differences in density and differences in composition of the forest, are eliminated from the table, which is confined to showing differences in yield based on site qualities and age. The relations of more than two variables can not be accurately set forth in a single table.

302. Composition of Stands as to Species. Stands composed of a mixture of species may vary in yield from pure stands. Species may differ considerably in their capacity for growth and yields even on the same site. They vary in height growth and consequently are affected differently by the factor of suppression when in mixed stands. The rate of survival and the dimensions vary so that the composition of the stand changes with its growth. Finally, the original composition, independent of these later changes, varies greatly. For these reasons the prediction of yields in stands of mixed species has always been regarded as extremely difficult. Approximate rather than accurate results must be accepted. Recent investigations indicate that for certain characteristic types and mixtures of species naturally growing together, yields

[1] The Use of Yield Tables in Predicting Growth, E. E. Carter, Proc. Soc. Am. Foresters, Vol. IX, No. 2, p. 177.

determined for the mixed stands do not differ very widely from those of pure stands (§ 314).

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CHAPTER XXVIII

NORMAL YIELD TABLES FOR EVEN-AGED STANDS

303. Definition and Purposes of Yield Tables. A yield table is intended to show the yields per acre which can be expected from stands of timber at given ages or for given periods, in terms of a given unit of volume or of product.

A complete yield table will show yields for successive decades or five-year periods covering the range of age of a species. Ordinarily, yield tables do not show the loss in yields per acre during the decadent period in over-mature stands, but they can be constructed so as to do so. In forests under management, the maximum ages shown are those of the oldest stands before cutting.

Yield tables are used primarily to predict the yield of existing stands, hence they are assumed to represent the actual development of individual or typical stands throughout their life cycle. This they do not always do, since naturally stocked areas tend constantly to pass from a condition of under-stocking to one of over-stocking. It follows that the most reliable yield tables are those constructed for stands grown under management, where thinnings have controlled the increment.

Yield tables are the fundamental data required for the determination of the value of forest lands and the profits of forestry, the appraisal of damages to forest property, the choice of a rotation or average age at which timber should be cut, the advisability of thinnings, the choice of species, and the relative profit from expenditures for all forestry operations on different sites. An accurate or even an approximate knowledge of yields per acre and the average rate of growth per year tends to place forestry on a business basis rather than one of blind speculation.

304. Standards for Yield Tables. Yield tables undertake to set standards in which the variables affecting yield are eliminated. The basis of all yield tables is a separation into site qualities, with separate average yields for each quality, since the fundamental variable is site quality.

Form of stand requires separate yield tables for even-aged stands, and many-aged stands (§ 252).

The factor of density of stocking (§ 273) separates yield tables into *Normal or Index* tables which are based on an average full or maximum stocking, and *Empirical* tables, which represent the actual average density of stocking on a given area including partially stocked and unstocked portions.

Composition of the forest is distinguished by constructing tables for pure stands (§ 314) separately from mixed stands.

The most important distinction is probably that made between natural stands and those grown under management. Owing to the great influence of treatment upon growth and yields, the standard of normality (see above) is entirely different for natural and for artificially grown stands, and yield tables based on the yields of planted, thinned and managed forests must be made to replace the present normal yield tables, when the material for such measurements becomes available in sufficient quantity to furnish a proper basis.

Normal or index yield tables serve their chief purpose as a *standard* of comparison, since most stands will produce either larger or smaller yields than those shown (§ 250). This function is better served if the standard of normality set by the table is not abnormally high, but is made to conform to the results possible of attainment on the average acre of the site class, with reasonably thorough protection from destructive agencies and reasonably full stocking.

305. Construction of Yield Tables, Baur's Method. There are two methods possible in the preparation of yield tables. The first, known as Baur's method [1] is based on the measurement of the present volume and age of numerous plots which are then classified as to site and age and form the basis of curves of average yields based on age for from three to four site classes. This method corresponds with the definition of a yield table cited in § 249 since it does not pretend to trace the past history of these individual stands; yet the use to which such a table is put is to predict from these average curves the growth of a given stand by decades. For original stands under natural conditions, this method is universally used. The second method is to re-measure established plots at stated intervals to determine the volume of growth, diminution in number of trees per acre and other changes in the stand. While more accurate, the collection of such data must await the growth of the timber and the method is best applied to stands under management.

Yield tables can be constructed by Baur's method on the basis of from 50 to 200 plots dependent on the range of site qualities and conditions of growth. The aim is usually to get at least 100 plots.

[1] Die Holzmesskunde, Franz Baur, Professor of Forestry, University of Munich, Bavaria, 1891.

306. Standard for "Normal" Density of Stocking. In selecting plots for a yield table, in natural stands, it is neither possible nor advisable to seek areas which show the maximum theoretical density of stocking, either as to crown canopy or number of stems per acre. Nor should any effort be made to select plots which represent the empirical average of stocking. The standard should be to exclude from the plots all larger blanks caused by destructive agencies or failure of stocking and to select areas reasonably well stocked, with comparatively complete crown canopy. This standard of selection should be such that a sufficient number of plots can be readily obtained from the larger areas, without refinements either in size or in location. If too high a standard is set, the plots conforming to this standard will be found to be either located exclusively on the better portions of each site, or the area of the plots will be too small for safe results. In natural stands this tendency will lead to the selection of plots containing too great a number of trees, which will result later in over-stocking.

The average yield obtained from plots selected on this basis is termed the normal yield, though it may be exceeded by the best plots, or by stands grown under management.

307. Age Classes. The area of a plot should include but one age class. Where stands are actually even-aged over considerable areas, plots are easily and rapidly located. Where there is difficulty in distinguishing the age classes, and in locating areas which exclude all trees but those belonging to the class desired, it may be necessary to include a few scattered trees of a different age class in order to obtain plots of a suitable size. The net area of the plot can then be found by deducting the space occupied by these trees, which can be based on the area covered by their crown spread, modified in open stands to include a proper proportion of the gaps in the crown cover.

Stands whose period of reproduction is from ten to thirty years, depending on site and climatic factors, but which may still be classed as even-aged stands (§ 259) will be measured as such and their average age determined.

308. Area of Plots. The value of a single plot in indicating normal yield increases with its size, within the limit which permits of securing a uniform stocking and crown cover conforming with the standard sought. Since one plot represents but a single age and one shade of site quality, and the cost of measurement increases with size, it is better to limit the size of plots for a yield table and obtain a greater number more widely distributed.

The size of plots should increase with the size and age of the trees to be measured. The greatest danger in measuring small plots is failure to coordinate the quantitative site factors utilized in producing the yield with the area measured. This error is best illustrated by the measurement of an isolated clump of trees with wide crown and root spread. A plot laid out to include their boles will have too small an area, and an excessive yield (Fig. 83).

In dry regions especially, root spread exceeds that of crowns and cannot be determined accurately. The effect of these errors is especially noticeable when the size of the plots is small, the yield per acre varying inversely with area of plots. By increasing the size of the plot, the proportional influence of a faulty location of its boundaries is lessened, and when coupled with care in making these boundaries inclusive of crown space and probable root space of the trees measured, the error is negligible. Just as for other sample plots (§ 243), it is better to have a smaller plot surrounded by a control strip of similar timber than to extend the boundaries to include the whole of a stand to be measured, and it is usually possible, in regions of average rainfall, to have such a control strip. The size of plots under the above principles will vary from $\frac{1}{16}$-acre, for dense young stands, to 5 acres for veteran scattered timber in dry regions. Ordinary sizes run from $\frac{1}{4}$ to 2 acres. Since these boundaries should be accurately run, plots should be square or rectangular, and since the area contributing to the growth of single trees is in theory a circle, rectangular plots should not be too narrow: their short dimension should be at least four times the average width of crowns of the trees measured. For the same reason plots should never be triangular or have sharp angles. Unless intended for permanent location and re-measurement, the corners of plots are marked temporarily by any convenient means, and their side lines blazed or marked so as to exclude all trees falling outside of the boundary.

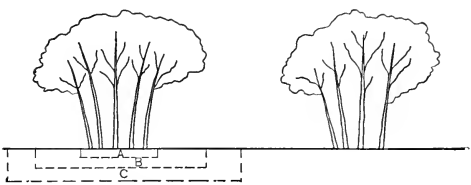

Fig. 83.—Relation between growing space occupied by crowns or roots of trees and size of plot measured to secure yield per acre.

A—Too small an area.
B—Correct for humid region or site.
C—Approximately correct for arid region.

309. Measurements Required on Each Plot. *Dimensions of Trees.* A diameter limit is determined, dependent on minimum merchantable sizes. All trees above this are measured at B.H. and recorded in diameter classes of 1 inch or 2 inches. Since these plots are for the purpose of measuring yields they are selected in stands which have reached merchantable sizes. Plots on which a portion only of the trees are merchantable may require the counting of the remaining stand and its classification as to size. Dead trees are recorded by diameter. Species are separately tallied.

The height of trees for a yield table should be taken separately on each plot. Several trees of different diameters, whose heights are average for the stand should be measured and recorded together with their diameters, the number varying with the stand, from 5 to 15. Where merchantable and not total height is desired, the satisfactory determination of heights for the plot is made much more difficult by the variation in top diameters and the danger of error in judging heights. Such a yield table, while practical, is less reliable than one based on total heights. Total height should always be recorded regardless of whether merchantable height is used, since it is required for a permanent standard of site quality.

Where the merchantable height unit is used it may be better to tally the merchantable length of every tree on the plot than to rely on a few trees measured by the hypsometer. This introduces the element of ocular guess.

Age and Volume of Stand. The age of each plot is separately determined by methods discussed in Chapter XXIII. The common method of determining the volume on the plot is by standard volume tables, based on diameter and height. This assumes that the variation of the trees on each plot as to shape or form quotients from the average form for this species or region, is not sufficient to require separate determination. Since trees must either be felled or cut into, to determine age, except when the increment borer will suffice, and since the trees selected for this purpose would be average in volume for the stand or for diameter groups within it, these sample trees are sometimes used to determine the volume of the stand. This method is useful when no reliable volume table exists, and when cubic volume is sought. The additional accuracy attained in measuring the volume of the sample trees for the plot itself is offset by the possibility that the trees cut may vary from the true average of the stand. The methods of determining the size of such sample trees for felling are described in § 241.

Crown Classes. Each tree on the plot is usually tallied in the crown class in which it falls, as classified in § 274.

Description of Plot or Site. Since in the preparation of a yield no effort is made to classify the plots into site qualities by inspection of the site factors in the field, the description of the plot should be brief, and serve merely to explain the results obtained and check their value. The points to be covered are the following:

1. Location of plot. Region, watershed or block, section or forty. Relocation is not contemplated from this description.

2. Density of crown cover. This has in some studies been used in an attempt to reduce the area to a fixed standard of density; e.g., a stand showing .9 crown density would be considered as the equivalent of but .9 of a full yield on the plot. The element of judgment thus introduced is dangerous and had best be omitted.

3. Altitude:
   Absolute—approximate.
   Relative—with respect to nearest stream, when it affects the quality of site.

4. Aspect—as affecting exposure.
5. Degree of slope.
6. Geological formation.
7. Soil, kind, depth, consistency and degree of moisture.
8. Origin of stand, whether from sprouts or from seed.
9. History of stand.
10. Condition of stand with respect to evidence of damage caused by fire, insects, wind or other agencies should be especially noted.
11. Exposure to winds, degree and character.
12. Amount and character of tree reproduction on the ground.
13. Herbaceous and shrubby vegetation under the timber.

Record of Data for each plot. The data of permanent value for each plot are,

1. Area, in acres.
2. Age.
3. Total number of living trees, by species.
4. Number of living trees above merchantable diameter limit, by species. (This may be shown for two diameter limits, as for cordwood and saw timber units.)
5. Average diameter (from diameter of tree of average basal area, or volume) (§ 242).
6. Height of dominant trees, or dominant height of stand; total; merchantable.
7. Total basal area at B. H. of trees per acre, in square feet. This is a valuable index to density of stocking.
8. Yield per acre, in cubic feet, total.
9. Yield per acre, in merchantable units, to given top diameters and stump heights.
10. Dead standing trees, number or per cent.
11. Density of crown cover.
12. Description of plot.

310. Construction of Yield Table with Site Classes Based on Height Growth. There are two possible bases on which to separate site quality, namely yields or rate of growth, and total height or height growth. In choosing between these as the basis of site quality, not only must the construction of the table be considered but also its later application in the field. Whichever basis is used, the range of growth for a species or region must be divided arbitrarily into site classes, once its maximum and minimum limits are determined. When volume or yield is chosen as the direct basis of site classes, regular and consistent results may be obtained by eliminating most of the variables in the choice of plots. But when these results are later used as a means of determining site qualities in the field on the basis of mean annual rate of growth per year or total yield based on age, the system breaks down.

On the other hand, if the division of plots into site qualities is based on height growth as indicated in § 296 not only are the original plots apt to be separated more accurately into their true site classes since variations in volume due to over- or under-stocking as reflected in the board foot or other unit are minimized, but the division of a large area in the field into site classes for the application of the growth data in predicting yields is made possible in strict conformity with the standard used in the table itself (§ 345).

While volume has been made the direct basis of many European yield tables, yet in these regulated and fully stocked stands most of the variables are reduced to reasonable proportions. Under our conditions of abnormal and accidental stocking, with the maximum of damage to the stands during growth, the variations from the factor of density of stocking due to variable number of trees per acre, even in stands of full crown cover, is so great as to discourage most investigators on first attempt.

The steps in the construction of a yield table based on height are as follows:

1. On cross-section paper on which age is plotted on the horizontal scale, and height on the vertical scale, place the average height for each plot above the age of the stand. These heights may be the heights of the dominant trees (§ 296). These points will fall in a comet-shaped band increasing with age.

2. Draw a curve indicating the maximum height growth, and one for minimum height growth as in Fig. 84.

3. Decide upon the number of site classes to use. These will depend largely on the total range of heights found for trees of a given age, and the possibility of convenient subdivisions not too small to be serviceable, i.e., large enough to overcome the slight variations in height based on age which may be due to density of stand instead of site.

4. Divide the space between the maximum and minimum curves, on each ordinate, into arbitrary spaces of equal magnitude, corresponding to the number of site classes established, and connect the points so found by curves.

5. The numbered plots whose height falls in each division of the chart are assigned to the indicated site quality. Owing to variables affecting yield, some of the plots in a lower site class may exceed the growth of plots whose site class is better.

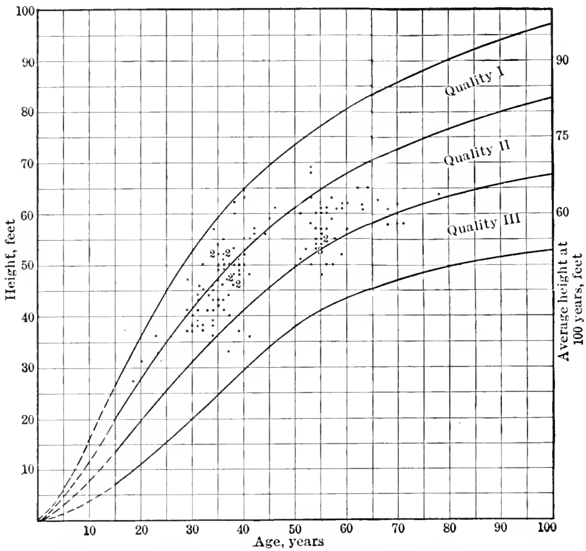

Fig. 84.—Method of separating plots into three site qualities based on the height attained by dominant trees in the stand, plotted on age of stand. Jack Pine, Minnesota.

The height of dominant trees on 131 plots of jack pine, plotted on the basis of age, is shown in Fig. 84. By this method (Baur's), the positions of the maximum and minimum curves determine that of the curves separating the site qualities. One or two plots with abnormally rapid or slow growth must not be permitted to influence unduly the position of these outer curves. With height, the true position of the boundary curves can be found with greater certainty than if volume is used originally as the basis of classification. In this figure, the average heights of qualities I, II and III at 100 years were taken as 90, 75 and

60 feet, following the suggestion of Roth as an example of class C in height classification (Table LV, § 296), and with these guiding points the curves limiting the three classes were drawn by Baur's method.

6. The yield of all plots in a single site class are then plotted on cross-section paper whose base or horizontal scale is age, and whose vertical scale is volume. From these data, a curve of average yield

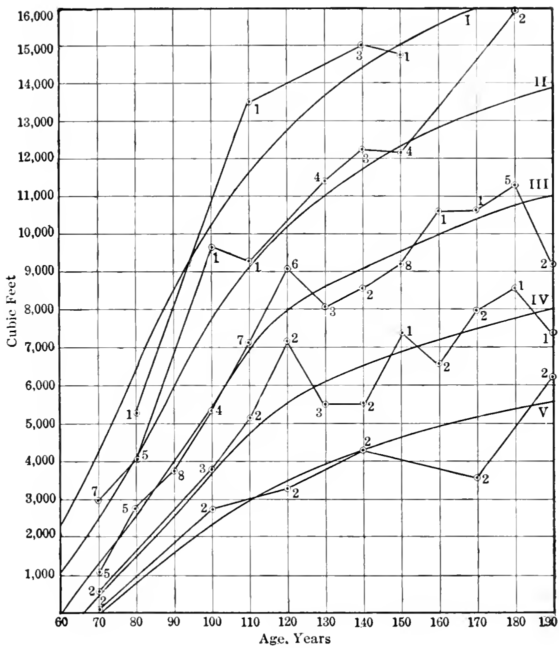

FIG. 85.—Curves of yield obtained by averaging the yields of plots whose height growth has placed them in the same site class. The final curves smooth off irregularities in these averages. Second growth Western Yellow Pine, California. S. B. Show.

based on age may be drawn from which the yields for the site class for each decade or five-year period are read. A separate curve is plotted for each site class. The yield table finally shows the average yields based on age for each separate site class.

When constructed on this basis, yields for different site classes increase at a greater ratio than do the indicating heights.

In drawing the curve of yield based on age for a single site class, it is best to first obtain the average yield for a given decade by arithmetical means and connect these averages by straight lines. Even if each plot were normal, the averages at different points might fall above or below the mean for the site as the plots happened to be on the better or poorer portions of this site class—and to this factor, the natural variation in density or yield is added.

7. For this reason, the average curves so constructed, for each site class, should now be assembled on a single sheet, as shown in Fig. 85. The curves of yield based on age can then be harmonized for all site classes by the same principle as used for volume tables (§ 140).[1]

311. Rejection of Abnormal Plots. As shown in § 304, the intent of this table is to establish a standard of yield, termed normal or index, with which the yields of any existing stand may be compared. After the separation based on height growth is effected, the yields of plots in the same site class will show great variation, due to the

Natural range of site quality within the arbitrary boundaries established;
Number of trees per acre in the natural stocking;
Completeness of the crown canopy.

The eccentric behavior of the averages plotted in Fig. 85 indicates the effect of these variations in yield. The question arises as to whether all of the plots should be included in these averages or certain plots rejected as abnormally stocked. A method of correcting the yields by a factor of density of crown has been generally rejected as unsatisfactory (§ 309). The area of plots is accepted as measured. There are, then, two possibilities of rejection; first, by ocular selection in the field, which eliminates those plots which are incompletely stocked; second, by further inspection of the plotted volumes based on age.

Baur's rule for rejection of plots is quoted by Graves as follows: "Stands which have the *same age and average height* are compared, and all are considered normal whose basal area lies within a range of 15 per cent; that is, the basal area of the best and poorest stocked stands must not differ more than 15 per cent." [2] The application of this rule rests upon the interpretation of the term "average height." Where from three to five site classes are made as in Fig. 85, and a curve of average height is found for each site class, which would fall midway of

[1] The yields shown in Fig. 85 are from an unpublished manuscript by S. B. Show, U. S. Forest Service, California, for second growth Western yellow pine.

[2] Graves' Forest Mensuration, p. 319.

the limits shown in the figure, the rule has been applied in this country to all plots whose heights classify them with a given site. The natural variation in volume for plots within one site class is greater than 15 per cent, *independent of abnormalities*—hence if all plots which vary $7\frac{1}{2}$ per cent above or below the average volume for the site at that age are rejected, about half of the plots, *although normal, may be thrown out.* If this rule is to be correctly applied as a test of normality, the arbitrary permitted variation of 15 per cent, *if used at all*, should first be corrected by finding what the normal yield of the particular plot should be, based on its actual height. If height for the plot is midway between quality I and II, normal yield is also midway between the averages for these qualities. The steps necessary would be as follows:

1. Draw curves of average height as shown in Fig. 84, and curves of average volume as shown in Fig. 85.

2. Determine the per cent of variation above or below average height, for each plot, and subtract or add the same per cent from the volume of the plot. This gives the corrected volume of the plot based on average height for the site.

3. Compare the corrected volume of the plot with the average volume for the site. If it falls above or below the calculated normal by more than the desired per cent of error the plot can be thrown out.

4. After testing the normality of all plots, re-compute the average, using only those plots accepted as conforming to the standard.

If 15 per cent is a proper standard of variation for forests under management, it is probable that even with the above method this per cent is too small as a criterion of normality for natural stands. It should be possible, by eye, to select plots of which at least 95 per cent will be suitable for inclusion in obtaining the average results for a standard yield table. With a range of basal area increased to 25 per cent *for plots of the same height* based on age as indicated, it is probable that only distinctly abnormal plots will be rejected.

In constructing volume tables it is not customary to reject trees after they have been measured for volume, since rejection can take place in the selection of the tree. With plots for yield tables, the desire to secure a theoretically normal or uniform standard may easily lead to too rigid a rejection of plots which are entirely suitable for the average sought. Maximum yields, on the basis of site alone, should never be sought by these average curves of yield, since the best portions of the site will exceed the average. Again, such tables, if made for natural stands, should show what can reasonably be expected in stands reproduced naturally and not thinned, on the average acre for site. A consistent average showing the probable progress of a fully or normally stocked acre by decades, and not an abnormal maximum yield, is the object sought both in field selection of plots and in their further sifting in the office for the preparation of normal yield tables for natural growth.

312. Construction of Yield Table with Site Classes Based Directly on Yields per Acre. The main objection to the direct classification of site on the basis of yield or volume on age by Baur's method is the impossibility of using this basis later as a means of classifying forest lands into site qualities from field examination. Furthermore, yield alone gives an unsatisfactory basis for correlating yield tables for given species when made for different regions, or for correlating the yields of different though similar species. It is this need of standardization that has led to the adoption of height growth rather than volume as the basic standard.

A further objection to the direct use of yields lies in the method of plotting, and the testing of plots for normal density. By this method, the volumes of all plots, based on age, are entered on the same sheet as shown in Fig. 86. The drawing of the maximum and minimum curves is the next step. There is no way by which the abnormality of the plots can be first tested as with heights. So the elimination consists wholly of drawing these boundary lines to exclude certain plots whose yield is so much greater or smaller than the remainder that their inclusion would unduly influence the position of these limiting curves.

The third step is to divide the space thus blocked off into equal bands by the method used for height, i.e., by dividing the distance on each ordinate into equal parts, and connecting the points so established.

Finally, a curve is drawn exactly midway of each space as described for height (§ 310), and the values are read from this curve at each decade to form the table of yield based on age.

By this method yields increase with site quality by exact intervals. No averages are attempted, and the result is entirely independent of height and is influenced principally by the maximum and minimum yields rather than the general weight of the plots studied.

Using as the basis the plots which have been classed as belonging to each separate site by either of the above methods, curves showing the average at different ages can also be prepared for the following additional data:

Number of trees per acre;
    Total,
    Above a minimum diameter
Average diameter.
Average height of dominant trees.
Total basal area.

313. Yield Tables for Stands Grown under Management. Normal yield tables for stands grown under management may be constructed by the above methods, whenever plots are available which have been under proper management, but may in the course of time be checked and finally supplemented entirely if desirable by the yields of plots which have been measured at intervals of from five to ten years.

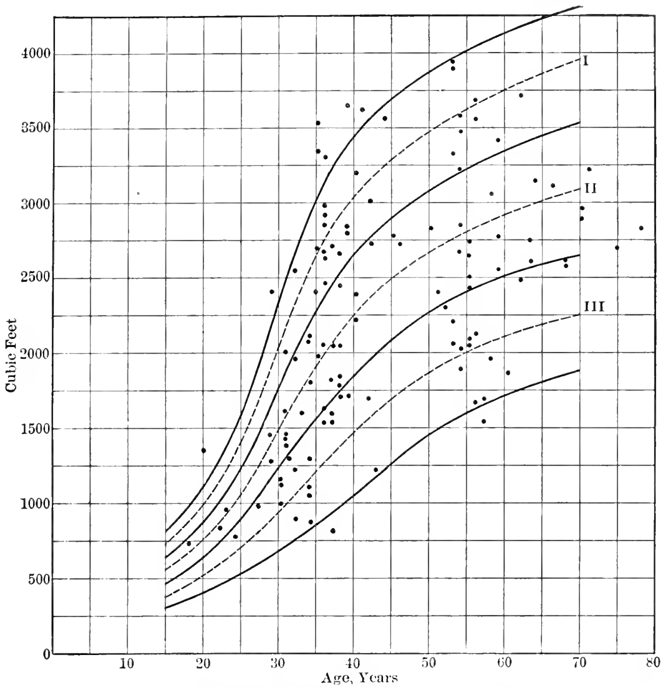

FIG. 86.—Curves of yield based directly on cubic volume plotted on age. Jack Pine, Minnesota.

Where a series of plots, differing in age by ten years, is available, the measurement a decade later on these plots will give fragments of a curve of growth which may be pieced together. The greater the period over which these re-measurements extend, the more nearly do these fragmentary curves form a complete series.

It may be expected that yields on areas under treatment will exceed the so-called normal yields used as a standard for natural growth.

The latter tables thus become the basis or minimum from which such increased yields may be computed for fully stocked areas.

314. Yield Tables for Stands of Mixed Species. Practically all stands are composed of more than one species, though some conifers as Western yellow pine and lodgepole pine grow in practically pure stands. So prevalent is the mixture that a stand which is composed of 80 per cent and over in volume for the given age class of a single species is termed a pure stand of that species. There may exist a large number of trees in an under-story of different species, and yet the volume of the trees of other species in the main stand may not exceed 20 per cent.

In even-aged stands composed of two or more species in mixture, two methods have been proposed for the determination of yields. One is to prepare yield tables for pure stands of each species, and then to determine the per cent of these species in the mixed stand. The further yield of such a stand is predicted by applying the per cent thus indicated, to each yield table, and taking the sum of the two partial yields as the yield of the mixed stand.

In applying these tables on this basis to get yields for the future from young stands, the question of survival may affect the result, in case one species tends to crowd out another. But when stands are even-aged, the association is apt to be of species which customarily grow in mixture and maintain their places in the stand. The yields, however, will be for the per cent of future, not of present mixture.

Where species differ radically in their characters, and grow in a mixed stand, such as a hardwood species with conifers, there is apt to be greater variation in yields, but with trees of similar habits, such as mixed sprout hardwoods or mixtures of two or more conifers, the stand behaves much as it would for pure stands.

For all such even-aged mixed stands, it is possible to prepare yield tables by disregarding the per cent of mixture, or recording it merely as a descriptive item, and proceeding as if the stand were pure.

An example[1] of a yield table for mixed stands of second-growth hardwoods in New England is given below. The conclusions based on this study were, first, that in spite of wide variation in percentages of species in mixture, for a given age, site, and density, the volumes in board feet, cubic feet and cords were constant, and, second, that the volumes of trees of given height and diameter in cords and cubic feet were the same, regardless of species.

[1] Bulletin of the Harvard Forest No. 1. Growth Study and Normal Yield Tables for Second-Growth Hardwood Stands in Central New England. By J. Nelson Spaeth, Cambridge, Mass., 1921.

TABLE LXII

NORMAL YIELD PER ACRE IN CUBIC FEET AND CORDS OF BETTER SECOND-GROWTH HARDWOOD STANDS IN CENTRAL NEW ENGLAND

SITE CLASS I

(All trees 2 inches in diameter and over)

Age in Years	Trees per acre	Basal area Sq. ft.	Height in Feet	D.B.H. in Inches	Volume per acre. Cu. ft.	Volume per acre. Cords	Forest form factor
20	1250	66.0	27.1	3.11	1041	15.80	0.582
25	1120	90.8	33.0	3.86	1625	23.71	.542
30	1010	107.2	37.5	4.41	2150	29.75	.501
35	900	119.9	41.5	4.94	2628	34.96	.503
40	800	130.2	45.0	5.46	3058	39.63	.520
45	700	139.7	48.2	6.05	3495	44.03	.520
50	610	148.0	50.7	6.69	3898	48.00	.520
55	525	155.7	53.1	7.37	4298	51.84	.520
60	450	162.5	55.4	8.14	4677	55.50	.520
65	390	169.0	57.8	8.91	5068	59.25	.520
70	340	175.1	59.8	9.72	5462	62.75	522
75	300	180.9	61.9	10.51	5833	66.18	.521
80	270	186.3	64.0	11.25	6200	69.50	.520

SITE CLASS II

(All trees 2 inches in diameter and over)

Age in Years	Trees per acre	Basal area. Sq. ft.	Height in Feet	D.B.H. in Inches	Volume per acre. Cu. ft.	Volume per acre. Cords	Forest form factor
25	1360	59.8	27.8	2.84	982	14.65	0.593
30	1235	77.9	31.8	3.40	1380	20.40	.557
35	1125	91.1	34.8	3.86	1798	25.48	.567
40	1030	101.6	37.4	4.25	2180	29.53	.574
45	940	110.3	39.8	4.66	2534	33.04	.577
50	855	117.9	41.5	4.94	2828	35.98	.580
55	775	124.6	42.8	5.43	3118	38.55	.584
60	700	130.7	44.2	5.85	3375	41.08	.584
65	630	136.6	45.3	6.31	3638	43.42	.587
70	565	142.2	46.3	6.79	3895	45.61	.592
75	500	147.7	47.0	7.36	4146	47.75	.598
80	440	153.0	47.6	7.78	4390	49.80	.601

The percentage of species in mixture in the stands comprising the above tables is shown in Table LXIII.

TABLE LXIII

Percentage of the Various Species in Mixture from Table LXII Classified as to Type and Site Class

Better Hwd	Oak, Red	Maple		Birch			Beech	Ch't-nut	Bass-wood	Pop-lar	Ash, white	Misc.*
		Red	Hard	Gray	Paper	Yel.						
Qual. I	27	15	3	0	2	8	2	6	9	7	15	6
Qual. II	20	12	6	0	8	10	7	5	3	8	14	7
Inf. Hwd.	2	24	2	38	3	4	0	1	0	15	1	10

* Under miscellaneous are included all species whose combined representation in the plots of any one type or site class is less than 5 per cent of the total number of trees. These species are: white oak, black cherry, pignut hickory, white pine, hemlock, elm, butternut, hop hornbeam, black birch, flowering dogwood, and shad bush.

By either of the above two methods of constructing yield tables for mixed stands, the yield of the entire stand is taken as the standard of yields.[1]

The classification of mixed stand may be greatly simplified by grouping together all plots in which 80 per cent or over of the merchantable volume is made up of certain species. In a study of the mixed conifer type on the Plumas National Forest in California, containing Western yellow pine, sugar pine, Douglas fir, white fir, and incense cedar, 75 per cent of 156 plots were found to contain but two principal species whose combined volume was over 80 per cent of the plot. The yields could be grouped as

1. Yellow pine—Douglas fir.
2. Yellow pine—Fir (Douglas or white).
3. Douglas fir—white fir.

As indicating the possibilities of simplifying the problem of yields of mixed stands, it was found in this study that the average basal areas, for plots showing the same standard of height growth (§ 296) was as follows:

Type	Basic plots	Per cents of yellow pine—Douglas fir type
Yellow pine—Douglas fir	43	100.0
Douglas fir—white fir	65	97.0
Yellow pine—fir	21	105.1

[1] A method by which the per cent of yields in plots of mixed species is recorded on the cross section paper, and the yield per acre expressed for different species which constitute different per cents of the total stand, is described in Graves' Forest Mensuration, Chapter XVII, p. 332.

This result strengths the conclusion that for species which form part of the same crown canopy, differences in total yield, of plots with different per cents of mixture, may not constitute a serious obstacle to the construction of yield tables based on age.[1]

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[1] A Preliminary Study of Growth and Yield of Mixed Stands, S. B. Show and Duncan Dunning, U. S. Forest Service, San Francisco, Cal., 1921. Unpublished manuscript.

CHAPTER XXIX

THE USE OF YIELD TABLES IN THE PREDICTION OF GROWTH IN EVEN-AGED STANDS, WITH APPLICATION TO LARGE AGE GROUPS

315. Factors Affecting the Probable Accuracy of Yield Predictions. If the average yield on Quality I site for a species is taken as 100 per cent, and but three qualities are distinguished, the relative yields shown for Qualities II and III may be as low as 72 and 45 per cent of that on Quality I, respectively.[1] This means gaps of 28 and 27 per cent in the series between the points arbitrarily marked by the average curves expressed in the yield table. The use of five qualities of site reduce these intervals to about 15 per cent. For young stands, or areas just growing up to timber, this is as close a prediction as can be expected. If the site is properly classified, its future yield if normally stocked will differ by an extreme of one-half of the above interval, either above or below the standard. Once the site is identified by the use of average height based on age, the future yields can be predicted by use of the yield table, either for bare land or for partly grown young stands, provided the degree of stocking agrees with that incorporated in the table.

The larger part of the area of any natural forest is not comparable with these conditions. The variables of density of stocking, form of age classes, and composition of species must all be dealt with before yields on any considerable area can be predicted within the desired margin of accuracy. The degree of accuracy attainable in prediction of yields in our wild forests is not yet known even approximately since for many-aged forests and mixed stands, yield tables based on age have not been attempted until recently (§ 314). This much can be said—the degree of accuracy attainable, and hence required, is greatest for short periods, i.e., for the current growth of a decade or two, and diminishes as the length of the period increases. But the relative importance of accuracy also diminishes with the length of the period, thus permitting the use of yield tables based on averages.

[1] Norway Pine in the Lake States, U. S. Dept. Agr., 1914, Bul. 139, p. 15.

316. Methods of Determining Actual or Empirical Density of Stocking. For even-aged, pure stands, but one variable is present in addition to site quality, that of the density of stocking. As this variable is the result, first, of the intrusion of small areas of unstocked land into the timbered area, which it may not pay to exclude in mapping (§ 306) and second, of the uninterrupted play of natural agencies of destruction operating on stands which are themselves originally the result of chance at the time of reproduction, the problem is to arrive at an average yield per acre which expresses not so much the capacity of the site as the accidental product of these various conditions. This average will in all cases be less than the standard or normal yields for the same area, sometimes by as much as 50 per cent. Evidently the determination of site quality is but the first step in predicting the yields of existing stands from such a standard table, and without correction these predictions may range from 50 to 100 per cent too high except on small tracts, such as plantations or managed forests, whose density factor is known to coincide closely with the yield table.

Use of Empirical Yield Tables. There are two methods of overcoming this difficulty. The first is an attempt to arrive directly at the average yields based on age for the larger area, or to make an empirical yield table (§ 303) which will reflect the degree of stocking present. This applies the principle used in timber estimating in determining the volume of the average acre (§ 209). But the operation is more difficult, as it involves the separation of the entire area into stands based on age, whose area is known, and the combining of these data into a yield table subnormal in character and representing a purely arbitrary percentage of standard yields. In the preparation of such a table, the curves of yield are affected by the varying per cents of stocking of different age classes and areas so that practically the entire area must be analyzed to obtain the true average, and then the table will be incorrect in its prediction of yield for any specific age class or stand which differs from this arbitrary average stocking. The table will be correct only for the tract on which it is made since empirical density varies with every forest and block. Empirical yield tables on this basis have the same drawbacks as volume tables for defective trees which express the net contents only (§ 151).

Use of Normal Yield Tables by Reduction. The better plan, and the one which will probably be universally used, is to depend upon a standard normal yield table (just as upon a volume table for sound trees only) and to ascertain the relation or percentage of deduction from this table, which applies to the specific stand or larger area for which yield is desired. For even-aged stands, the application of the yield table to the larger area involves the same steps for this area as are required in the construction of the normal yield table itself, or for the preparation of an average empirical yield table. These are as follows:

1. Determine the volume, the area occupied, and the age of each separate age class.

2. From these data in turn compute the volume per acre for the given age.

3. Determine the relative density by dividing this unit volume by the yield of an acre of the same age from the yield table; this is expressed as a per cent of the standard yield for that age. Per cent density can thus be found separately for each age class, or for each separate stand if desired.

317. Application of Density Factor in Prediction of Growth from Yield Tables. Future yield can now be predicted for all stands from the same yield table, by applying the reduction per cent to this table which is required by the stand or age class in question.

Influence of Number of Trees per Acre. There is one valid objection to this assumption that relative density as expressed at a given age in terms of volume will remain constant for future yields and that is that under the laws of growth of stands partially stocked this stand will tend to become fully stocked (§ 301). A knowledge of the number of trees per acre required for full stocking at the age of cutting is also obtained from a normal yield table, and this knowledge may be directly applied in determining the per cent of density in immature stands, not on the basis of crown cover existent but of the ultimate yield to be expected from the trees which will probably survive. In the same way, for older stands, when volume per acre is less than that in a normal stand, but the number of trees per acre is sufficient, the reduction can be lessened as applied to these partially stocked stands as long as the trees are so distributed as to utilize the area; e.g., in one case, a 50 per cent average stocking may represent 100 per cent stocking on 50 per cent of the area, with the rest blank. No correction should be made. In another case the entire area is covered with a stand whose volume is 50 per cent of normal, but trees are well placed. In this case the yield will probably be normal at the age at which the normal number of trees per acre drops to about the average number now present in the natural stand.

The former or simpler method is of course extremely conservative and allows a margin for the continuance of natural losses by fire, wind, insects and diseases, while the latter may be applied to more intensively managed and better protected forests.

This method is illustrated below based on a standard yield table, § 314.

SECOND-GROWTH HARDWOODS IN CENTRAL NEW ENGLAND

Site Class I

Area. Acres	Age. Years	Yield. Cords	Actual Yield per acre. Cords	Standard Yield per acre. Cords	Reduction. Per cent	Prediction of Yield 63 Per Cent of Standard in 10 Years. Cords	20 Years. Cords
10	25	150	15	23.71	63	22	27.7

This assumes no increase in the density factor with age and is the most conservative method.

Assuming that future yield will be influenced by the number of trees and their distribution, the future yields as shown may be increased as follows:

Number of trees per acre now	Normal number in 10 years	Reduction per cent in 10 years	Yield in 10 years. Cords	Normal number in 20 years	Reduction per cent in 20 years	Yield in 20 years. Cords
600	900	$66\frac{2}{3}$	23.3	700	86	37.8

This basis gives the maximum possible yields to be expected by contrast to the first method, since it does not contemplate the loss of any of the original six hundred trees, and assumes that these trees are distributed at equally spaced intervals over the area.

Somewhere between these two predictions the actual future yield will be found.

Use of Basal Areas. Basal area may be substituted for yields in determining the percentage relations, and as a basis for predicting yields in cubic feet. If in the above example the basal area at twenty-five years is 57.2 square feet per acre, the reduction per cent is 63 and the same prediction of future yield is obtained, which can be modified by comparing the number of trees per acre in the same way.

These illustrations bring out the function of a yield table as distinguished from that of merely stating the yields of stands. When the total age of any given stand is determined in addition to its volume, the rate of growth per year for that stand can then be found, or its past yield. But the whole purpose of a yield table is to predict the future yields of stands. A standard yield table gives a means of predicting this future yield, by indicating first the yield relation as to density of the stand in question with the standard yields, the second, the rate of growth for future decades, which can be reduced to fit the existing stand.

318. Separation of the Factors of Volume, Age and Area. The difficulties surrounding the prediction of yields lie in the fact that this requires for any stand the determination of three factors: volume, which can always be measured; age, which can be determined for a given tree but is difficult to find for an entire stand of mixed ages; and area, which can be measured, provided the boundaries of the age class are known or defined. The trouble arises entirely from the mixture of trees of different age classes on the same area, the overlapping of crowns and root spread, and the shifting of total areas occupied by each separate age class in successive periods (§ 298 and § 299). Thus two of the essential factors, age and area lose their clear definition. These two factors are interdependent in such forests. Age classes cannot be confined to stands of a single age but must include an age group. The area occupied by such a group will be influenced by the number of separate ages included in the group.

It has been shown previously in this chapter that the area occupied by a given age class, when determined by mapping, determines the relative density of stands whose age is known. The yield table expresses an arbitrary standard yield on 1 acre at a given age, representing 100 per cent density at each age. (This means that the table is accepted as standard, but does not necessarily represent the maximum yields possible on any acre, which may exceed this standard, by from 15 to 20 per cent.) When both area and age are determinable for a stand, the exact relation as to density or yield when compared with the standard can be found for each stand separately. When neither can be found with accuracy, they must be found by such means as is possible, and the results, while not as accurate, will be serviceable and worth attaining. The general method of solving this problem is to work from the known to the unknown, accepting averages and approximations when exact determination is impossible.

319. Determination of Areas from Density Factor. One of the simplest and most useful applications of this principle is in the determination of the area occupied by each of several age classes, *whose age and volume are known* but which have not been or cannot be mapped separately.

The total area of the tract can always be determined. If for any reason it is impossible to map the area of each age class, these areas may still be found *by proportion* if we are willing to assume that the *average density* of the entire stand *can be applied separately to each age class.* While admittedly less accurate than the separate determination of density by classes, yet the total error is probably very small. The method is as follows:

The standard density, or 100 per cent, as expressed in the yield table, calls for a definite volume per acre, differing with each age.

The total volume and age of each age class in the forest are known.

By dividing this volume by the standard volume on 1 acre of the required age from the yield table, the area which would be required by the age class if stocked at 100 per cent density is found.

The sum of the areas found in this manner for all the age classes would be the total area of the forest if the density of stocking were 100 per cent.

Since the total area actually stocked is known for this sum or total of age classes, but not for each age class separately, it follows that, Actual per cent of density for total area

$$=\left(\frac{\text{Area 100 per cent stocked}}{\text{Total area}}\right)100,$$

and, assuming this per cent for each class,

$$\text{Area in each age class}=\left(\begin{matrix}\text{Area 100 per cent}\\ \text{stocked in age class}\end{matrix}\right)\frac{100}{\text{per cent of density}}.$$

ILLUSTRATION

SECOND-GROWTH HARDWOODS IN CENTRAL NEW ENGLAND

Age.	Volume. Cords	Yield of 1 acre from table. Cords	Area of 100 per cent stocked. Acres
20	1738	15.80	110
30	5593	29.75	188
40	3854	39.63	97
50	1008	48.00	21
		Total.	416 acres

Actual area 624 acres.

Density per cent $\frac{416}{624}=66\frac{2}{3}$ which will be assumed to apply to each of the four age classes represented.

To determine the area in each age class;

Ratio to fully stocked area $\frac{100}{66\frac{2}{3}}=1.5.$

Age class. Years	Area 100 per cent stocked. Acres	Actual area in age class. Acres
20	110	165
30	188	282
40	97	145.5
50	21	31.5
Total.	416	624

This method of obtaining the area of separate age classes makes possible the prediction of yields from yield tables based on age for long periods with considerable accuracy, where without such separation this would not be possible and yields could be predicted only for the current decade or two.

320. Application to Forests Having a Group Form of Age Classes. Forests composed of species which are intolerant and fire-resistant tend to form groups of approximately even age. A yield table based on age can be obtained for such species, which will serve as a 100 per cent standard. But it is very difficult to separate the forest itself into its component age classes by mapping the areas which they occupy, and equally difficult to determine in a practical manner the average actual age of the stand on such areas even if mapped. But the forest can still be separated into these age classes based on area and age, permitting the application of this yield table to predict its growth, provided proper use is made of the laws of averages. (In timber estimating, it is permissible to employ averages known to be subject to error because it is not practicable to attain mathematical accuracy on account of expense.)

The problem here is,

1. To determine the trees which belong to each age class so that the volume of the class may be found.

2. To determine the age of the age class.

3. To find its area. Given the first two of these elements, the method of finding the third has already been shown (§ 319).

By reference to § 275 it is seen that diameter is an indicator of the age of trees, but that a given age class will include a wide range of diameters. Where stands are composed of trees of many different ages so that it is not possible to ascertain the age of a given stand by felling one or two trees, nor to map the separate areas in the forest which are occupied by these age classes, the only alternative in obtaining age is through the use of average diameters. The diameters can be measured. In timber estimating, a stand table can be made giving the range and distribution of diameters in the stand. The substitution of diameters for ages thus furnishes a means of separating age classes in forests of mixed ages.

Choice of Methods. There are three gradations in the possible applications of this method.

1. Diameter is used merely to determine the age of an average tree, but the forest is separated into actual age classes as nearly as possible, rather than diameter classes (§321).

2. Diameter is used as the basis of separation into classes, whose average age is then determined on the basis of these diameters (§ 323). These, as shown (§275), are not true age classes since they do not include all the trees of a given age.

3. Diameter is substituted altogether for age, and the total age of trees is not determined for these classes, but current growth is predicted merely for trees of given diameters for short periods. This method is discussed in Chapter XXXII.

The use of diameter to indicate total age is most reliable when applied to large areas and numbers and to forests of many age classes, for species and stands whose actual and economic age agree, i.e., which usually do not show a period of suppression.

321. Determination of Volume and Area for Two Age Groups on Basis of Average Age. While the method to be described is limited in its application to two age groups, yet even this subdivision will be found of great value in Mensuration and Regulation. In the French many-aged forests, but two groups are made in timber above exploitable size. In our forests, when under management, the subdivision into two groups will be equally effective.

In natural stands containing decadent timber, three groups are needed instead of two, for timber above the minimum diameter. These may be termed " young merchantable," " mature " and " veteran."

In the Western yellow pine stands for which this method was developed, it was possible to separate the young merchantable timber by the appearance of bark into a class termed " Blackjack," leaving the remaining yellow pine timber for separation into mature and veterans. In forests where this cannot be done, it is possible to first separate the young merchantable timber on a diameter class basis, leaving the larger mature and veteran timber for division by this method. Where the forest is cut over, and but two age classes are required, the method will separate the young merchantable from the mature timber. The three steps in this method are as follows:

1. A standard yield table based on age for even-aged stands can be made the basis of separation of the forest into two age groups. This

yield table can be constructed by standard methods from selected plots in the groups of which the forest is composed. From this yield table two ages are chosen, representing respectively the younger and the older age class. The development of the normal stand as indicated by its current and its mean annual growth is the basis for this choice of ages.

2. The ages thus chosen from the yield table must then be correlated with a given diameter since it is impossible, in the forest, to determine either the age or area of age classes directly.

This requires a table of diameter growth *on the basis of age*, for the species and site (§ 267 to § 269) based on a sufficient number of trees to insure a reliable average. Age is the direct basis of this curve, and not diameter (§ 275). From this table, the diameter sought is indicated, for each of the two age classes.

3. The total volume on the area contained in the two age classes can be separated into the volume in each age class, by means of these two trees of average diameter, representing average age of each class. This requires:

(*a*) That the average volume contained in a tree of this average diameter be found. For this purpose, a curve of average height based on diameter is constructed for the site (§ 209). With the height of a tree of the required diameter thus indicated, its volume is found from the standard volume table for the species and region.

(*b*) That the number of trees with this average volume be found for each age class, which is required to make up the total volume of the combined group. This number, multiplied by the average volume will give the volume of each age class.

This solution is simple, when the total number of trees and their total volume are known. Deducting a given number of trees of a given average volume from the group leaves a residual volume, which is equivalent to a fixed number of trees of the average volume for the remaining group; i.e., with total number, total volume, and the average volume of each tree of two groups fixed, there can be but one solution by which the number in each group, and consequently the sum of their volumes equals the required or existing estimate or total in the stand.

If x = number of trees in younger group;
y = number of trees in older group;
a = volume of average younger tree;
b = volume of average older tree.

Then

$$x+y=\text{total number of trees in stand, } c$$

and

$$ax+by=\text{total volume of stand, } d.$$

If all the trees c had the volume a then instead of a total volume d,

$$ax+ay=ac.$$

The difference between this volume and the total actual stand is $d-ac$ and represents the surplus volume in the older trees, of which there are y. The difference in volume for each tree is $b-a$, and for all of the older trees is $(b-a)y$.
Then

$$(b-a)y=d-ac;$$

and

$$y=\frac{d-ac}{b-a},$$

while

$$x=c-y.$$

Having the values, or number, of each group x and y, the total volume is obtained by multiplying this number by the volume of the average tree for the group.

Illustration, Western Yellow Pine.

Total volume in group (d) = 27,042,800 feet B.M.
Total number of trees (c) = 44,423.
Age of older trees, veterans, chosen as 300 years.
Age of younger trees, mature, chosen as 200 years.
Diameter, from curve of growth, veterans, 27 inches.
mature, 20.7 inches.
Volume of average tree of this size, veterans 805 feet B.M.
mature, 340 feet B.M.

Then

(1) $340x+805y=27{,}042{,}800$ feet B.M.
(2) $340x+340y=340\ c.$
$=15{,}103{,}820$ feet B.M.

Subtracting (2) from (1)

$465y=11{,}938{,}980$ feet B.M.
$y=25{,}675$ trees;
$x=18{,}748$ trees.
Volume of younger class = 6,374,320 feet B.M.
Volume of older class = 20,668,375 feet B.M.

322. Application of Results to Forest by Use of Stand Table and Per Cent. It is not necessary that a 100 per cent tally of the number of trees, and total volume for the site be obtained, but only that the stand table (§ 188) from which the determination is made be representative of the total area.

If in the timber survey, 5 per cent of the area is covered and assumed to represent the average stand, the total count of trees on this 5 per cent and the total estimate on the strip, give the data needed. If, in turn, but 10 per cent of the strip itself or $\frac{5}{10}$ of 1 per cent of the total area is tallied, and this per cent gives the *run of sizes* of the timber without reference to its density of stocking, the data are still sufficient.

To obtain the separation of the total stand by means of the data from the smaller area counted, the volume of each age class is first expressed as a per cent of the total. These per cents are then applied to the total estimated volume on the entire area.

In the above case, the per cents are:

Veterans 76.4
Mature 23.6

The total stand is 2,583,940,000 feet B.M.
The stand of veterans is then 1,974,130,000 feet B.M.
and of mature is 609,810,000 feet. B.M.

To secure this division, a little over 1 per cent of the total stand was tallied and estimated for the basic data, while the total estimate was secured by ocular means (§ 205) (Coconino National Forest).

323. Determination of Volume and Area for Age Groups on Basis of Diameter Groups. Where the second alternative is chosen (Method 2, § 320) to obtain the separation of age classes, namely, diameter rather than age, the following changes in procedure are necessary.

1. The volume of the so-called age classes is directly obtained from a stand table, in which the number of trees *of each diameter class* must be shown.

2. The diameter of the average tree is obtained by first finding the average volume for the group, and second, the tree of this volume from a local volume table based solely on diameter, which is obtained from a curve of average heights and a standard volume table.

3. The age of a tree of this average diameter is then found, not from the yield table as before, but from the *curve of growth based on diameter*, which gives directly the ages of trees of given diameters. The ages indicated will be those of the respective age groups into which the forest has been separated. As indicated, this method works back from diameters to age, while the first is based on age directly.

By either of these methods, the area in each age class may now be found by following the precedure described in § 319. The age, and consequent normal yields for 1 acre at these ages, have been determined for each age class. The total normally or 100 per cent stocked area can be found, and from this the reduction per cent and the area in each age class. From the reduction per cent an empirical yield table can be computed, which will be used as the basis for predicting the yields of the forest or site class as a whole (§ 250).

Since the above-described methods of determining areas of age groups are based primarily on the factor of relative density of the stands as determined by volume, they apply only to the age groups which have already grown to merchantable sizes. The problem of determining the area of immature age classes is treated in § 348, and must be considered in working out a plan for growth predictions for any large area, in connection with the above methods.

324. The Construction of Yield Tables Based on Crown Space, for Many-aged Stands. The above methods depend upon the construction of yield tables from plots whose average age is determined, so that the yields are given as for even-aged stands. Since it is seldom that any species is so distributed in age classes and so free from major sources of damage as never to be found in stands of even age, plots based on age can be obtained under a greater range of conditions than is commonly admitted.

But when this method is apparently impracticable, there remains one possibility for constructing a yield table based on age, which although far from being accurate, is based on a fundamental law of growth of stands. It was shown in § 274 that as trees develop, they require increased crown space, and that this expansion of crown can be attained only by the reduction of numbers of trees per acre.

The diameters of crowns of trees is an index of the growing space which they require though it seldom exactly measures this space. But if it can be shown that the space occupied by trees of different diameters is *proportional* to the diameter of their crowns, the *relative* number of trees per acre of different diameters which can stand on an acre can be determined.

To obtain such data, crowns can be assumed as circular in shape, (though the actual shape varies according to the light and growing space available, especially in hardwoods), and that the space occupied by each crown is in proportion to the square of its diameter or width in feet.

Measurement of Width of Crowns. To determine the average width of crown for trees of different diameters, two men may work together. One stations himself behind a plumb-bob suspended from a pole so to hang clear from a height of about 8 feet. He lines in the second man at a point below the outer edge of the crown of the tree, whose width is then measured on the ground to the point intersecting the opposite edge of crown. For this purpose a pole, marked in feet, can be used. The distance measured must be at right angles to the lines of sight. A record is made of the D.B.H. and crown width.[1]

Areas of Crowns. To obtain a true average of crown area, each crown width must be squared. The sum of the areas so obtained for each diameter class is divided by the number of trees in the class, to get the average area of the square for that class. The square root, or side of this square is the average width of the crown for the class. Now, if it be assumed that the space occupied by this diameter squared represents the actual growing space required by the tree, the number of trees per acre for the diameter class is found by dividing the area

[1] No effort need be made to obtain the area of each crown by two or more measurements or by plotting the projected area of the crown. Reliance is placed on a large number of measurements of one diameter, rapidly and accurately taken, to obtain the true average diameter of crowns for each D.B.H. class.

of one acre, 43,560 square feet, by this area. This method is employed in finding the number of trees per acre required to plant an acre, if spacing is 4, 6, 8 or 10 feet apart in both directions.

Density of Crown Cover. In actual stocking, the absolute number of trees cannot be so simply determined. As crowns tend to adjust themselves to light, they depart from a circular form, and the circular spacing itself may permit of more trees per acre than the square. The relation of the area of an inscribed circle to a square is .7854. That of an inscribed circle to a hexagon is .9018.

If either of these relations is consistently maintained, the *total* number of trees per acre for full crown cover may differ, but the *relative* number, for trees of different diameters will remain constant. From the number so found, a curve of number of trees per acre based on diameter can be plotted. This is a standard, intended to show relative, not absolute, numbers. For instance, if the number per acre from such a table for a given diameter is 400 trees, a stand of 200 trees per acre of this average diameter would be 50 per cent of the standard.

Two factors interfere to prevent the satisfactory application of such a table in predicting yields. First, the number of trees in fully stocked stands does not always decrease in direct proportion to their increase in crown space. In tolerant species, a great over-lapping and suppression of crowns occurs, doubling the number of trees per acre over the theoretical number indicated by the spread of crown, while in over-mature stands, the increasing demand for light and moisture reduces the stand per acre below that indicated by the crowns. The relation is therefore not consistent except within rather narrow limits of age and species; and yields based on this assumption will be excessively large for over-mature age classes.

The second factor tends to offset the first in stands not fully stocked—this is the tendency (§ 301 and § 316) to improve the degree of stocking with age. When a stand of a given age has only the number of trees required for one twice this age, its rate of mortality will be very much less since each tree has more than enough room to survive. Hence the assumption, in stands not fully stocked, that the growth of a stand can be predicted by determining the per cent which the number of trees now in the age class bears to the normal number, will not be borne out, but better results will be obtained.

Method of Construction of the Yield Table. In stands which possess a full crown cover, but whose age classes are distributed in many-aged form, the rate of mortality may be assumed to hold for all classes. An illustration of the above method of constructing a yield table for yellow poplar in Tennessee is given below.[1]

[1] Based on data collected by W. W. Ashe.

TABLE LXIV

TREES PER ACRE BASED ON CROWN SPACE

D.B.H. Inches	Diameter of crown. Feet	Area of crown based on D^2. Square feet	Trees per acre. Number
7	11.0	121	360
8	11.6	134	325
9	12.4	154	283
10	13.3	177	246
11	13.7	187	233
12	14.4	207	210
13	15.1	228	191
14	15.8	249	175
15	16.5	272	160
16	17.2	295	148
17	17.9	320	136
18	18.6	346	126
19	19.4	376	116
20	20.0	400	109
21	20.7	428	102
22	21.3	453	96

The above data must now be correlated with age. The steps are as follows:

1. From a curve of age based on diameter, the diameters at each five-year period are found, and the number of trees per acre, formerly based on diameter, are then interpolated for the fractional diameters corresponding to these exact ages.

2. From a curve of height growth based on age the height of the average tree is found.

3. From diameter and height, the volume of each tree is taken from a standard volume table (§ 288).

4. The yield per acre at each age is the product of the number of trees per acre and this average volume.

The application of this method is shown in Table LXV, p. 426.

325. Application of Method to Many-aged Stands. To apply this standard table to the many-aged forest for the prediction of yield, the same principles are used as were described in § 316. But in this case, *the number of trees in given diameter classes* is the basis of comparison to determine the reduction per cent or density factor.

It makes no material difference whether the standard table above illustrated exactly represents the true or actually possible normal yield of a pure, even-aged fully stocked stand, provided it approximately indicates the *proportional yields* at different ages, correlated with the proportional falling off in numbers of trees per acre at these ages, both factors correlated with diameter of the average trees, for it is evident that in such a forest no stands will be found which are pure, even-aged or fully stocked over any large area; hence the use to which the table is put must be solely as a *standard to be discounted by a reduction per cent.*

TABLE LXV

YIELDS OF CORDWOOD, FOR YELLOW POPLAR IN TENNESSEE—BASED ON CROWN SPACE AND VOLUMES OF TREES OF GIVEN AGES

Age. Years	D.B.H. Inches	Average Height. Feet	Volume * in cords of 160 cord feet. Cords	Trees per acre	Yield per acre. Long cords
40	10.5	78	0.148	237	35.1
45	11.8	83	.198	214	42.6
50	13.0	87	.254	191	48.5
55	14.2	91	.317	172	54.5
60	15.4	94	.381	155	59.0
65	16.5	97	.445	141	62.7
70	17.5	101	.511	130	66.4
75	18.4	104	.569	121	68.8
80	19.3	107	.630	114	71.8
85	20.2	110	.693	108	74.8
90	21.0	113	.755	102	77.0
95	21.8	115	.825	97	80.0
100	22.5	117	.880	94	82.7

* From volume table 5, p. 22, Bulletin 106, Yellow Poplar in Tennessee, W. W. Ashe, State Geological Survey of Tennessee, 1913.

The age of stands, by this method, is assumed as the age of trees of given diameters. To determine this age, for each diameter class, a curve of growth is required in which ages are averaged on the basis of diameter (§ 276). Otherwise the ages of trees of the larger classes will be over-estimated.

To apply this yield table for the prediction of yield in the forest, a large area must be considered; otherwise the assumed correlation between age and diameter will not hold good. The stand table (§ 188) for this area must show the number of trees of each diameter class in the forest.

One of the principal services rendered by such a table is its indication of the probable rate of loss of numbers, which is a most difficult problem to solve by any other method.

In applying such a table, it can be assumed that the mortality in the forest will be at the proportional rate indicated by the table. The prediction of yields will then be based on a stand table giving the number of trees in each diameter class. Several methods of applying the standard table are possible, as

1. Base the prediction upon the total number of trees in each diameter class or group. The per cent of reduction in numbers is obtained from the table. This per cent is applied to the stand in the forest, and the future growth obtained by computing the future volume of the remaining trees, as shown in the illustration.

2. Base the prediction upon yields. The number of trees in each diameter class is divided by the number per acre in the standard table. This gives the area normally stocked by that class, from which its future yield is taken directly from the standard yield table. This area forms, of course, but a small per cent of the forest, and is the total area occupied by trees of the diameter class.

The forest can be divided into age classes, based on diameter, and the area occupied by each of these age classes obtained as described in § 316.

At best, it can be seen that this substitution of standard yields based on growing space per tree is a makeshift compared with determining these relations from even-aged plots in which the factors of site, tolerance and soil at different ages are directly measured.

326. Yield Tables for Stands Grown under Management. European experience with stands grown under management has shown, first, that the best results and heaviest total yields per acre are obtained by several thinnings at frequent intervals, in which not only the trees which would otherwise die before the next cutting are removed, but the remaining crowns are freed from competition.

Second, that the proportion of the total yield removed as thinnings under this system may equal one-third or more of the total yield.

Third, that the diameter growth of the surviving trees can by proper thinnings be sustained at a uniform rate until the final crop is cut. The development of each tree in the stand proceeds actually at the rate of growth of a dominant tree which maintains its crown spread throughout its life.

Even where second-growth stands have sprung up, in this country, and reached sizes suitable for logging, they have usually received no care in the form of thinnings. Stagnation sets in on many of these stands, especially with conifers on old fields, and the diameter growth of the whole stand suffers. This occurs even in plantations on which thinnings have been neglected.

The actual yields and sizes which may be grown on such stands under sustained management and thinnings may be roughly approximated by measurements taken on natural stands not under management, by the method just discussed, of computing the number of trees per acre for given diameters. The rate of diameter growth *should be that of trees now dominant in the stand.* This gives the age of the diameter classes. The approximate amount of material yielded by thinnings in such a forest may also be roughly predicted by noting the number of trees which drop out of the stand at each decade, and computing their average diameter and volume.

By establishing permanent plots, re-measured at intervals of 5 or 10 years, and properly thinned, data will finally become available showing not merely the yield of stands grown under management, at final cutting, but the total yield including thinnings. The absence of such stands precludes the construction of yield tables on this basis at present and justifies efforts to predict such yields by means of crown spread and number of trees per acre in normal stands. The nearest approach to such yield tables is found in tables constructed from second-growth stands, or plantations, but it is seldom that these stands have been repeatedly and properly thinned, hence the yields shown merely indicate a normal possibility for fully stocked, wild stands.

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Yield in Uneven-aged Stands, Barrington Moore, Proc. Soc. Am. Foresters, Vol. IX, 1914, p. 216.

CHAPTER XXX

THE DETERMINATION OF GROWTH PER CENT

327. Definition of Growth per Cent. *Growth per cent* is an expression of the relation between growth and volume.

Current growth per cent is the relation of growth during a given year to the volume at the beginning of the year.

Periodic growth per cent is the relation of the growth during a period, to a basic volume, which may be taken as the mean or average volume for the period (§ 328), but is usually that at the beginning of the period.

Mean annual growth per cent is the per cent which the mean annual growth (§ 245) for a given age bears to the total volume at that age, and represents the average rate of growth per year, at which this volume has been produced. Growth per cent requires for its determination a knowledge of two factors, the growth for a period and the volume upon which this growth was laid. The primary purpose for which growth per cent is utilized is to test the maturity or ripeness of individual trees and of stands of timber. Those trees or stands which show the lowest per cent of increment on their present volume compared with other trees or stands, should be selected for cutting. The object of such selection is to withdraw from the forest the greatest possible volume of wood capital, while at the same time reducing the volume of expected growth by the smallest possible amount. If carried out, the effect is to transform the forest capital from a condition in which the ratio of growth to volume is low, to one in which this ratio is materially increased for the forest as a whole.

On individual trees the difference in volume or growth for the decade may be found by analysis (§ 287 and § 288). For stands, the difference is taken from yield tables for the decade. In each case one year's growth is one-tenth of the growth for a decade. The growth per cent of average test trees is frequently assumed to be that of the stand.

328. Pressler's Formula for Volume Growth Per Cent. To determine growth per cent as a means of judging the ripeness or maturity of stands or trees, the same methods apply whether the unit is the tree or the stand. Since volume growth is measured for periods of a decade, the growth for one year is found by division. Let n equal the period representing a decade. This may be a longer or shorter period if necessary. Let V equal volume at present, and v equal volume n years ago. Then growth for one year equals $\frac{V-v}{n}$. If it is assumed that this growth for n years is laid on in equal annual installments, then the growth so obtained is considered that of the current year or for any year during the period.

If the growth per cent is obtained on this basis, the result will vary according to the year in which the volume of the stand is taken as the basis. If for ten years ago, then the formula is,

$$\text{Growth per cent}=\left(\frac{V-v}{vn}\right)100.$$

But if the per cent is desired for the last or present year,

$$\text{Growth per cent}=\left(\frac{V-v}{Vn}\right)100.$$

For an average year midway of the period, the capital or volume is

$$\frac{V+v}{2},$$

and growth per cent is

$$\frac{\frac{V-n}{n}}{\frac{V+v}{2}}100=\left(\frac{V-v}{V+v}\right)\frac{200}{n}.$$

This is known as Pressler's formula.

329. Pressler's Formula Based on Relative Diameter. Further modifications of this formula by Pressler are intended to reduce it to terms of diameter so that it may be applied to measurements on standing trees taken at B.H. If height and form factor do not change, then

$$p=\left(\frac{D^2-d^2}{D^2+d^2}\right)\frac{200}{n}.$$

In this formula D is the present D.B.H. and d is the diameter n years ago. $D-d$ is then designated as a and $\frac{D}{a}$ is called the relative diameter. By making $\frac{D}{a}=q$, and substituting aq for D, and $a(q-1)$ for d, he reduced the formula thus to

$$p=\left(\frac{q^2-(q-1)^2}{q^2+(q-1)^2}\right)\frac{200}{n},$$

for which expressions values are computed in a table.

To use this table the present diameter D is divided by twice the width of the rings in the period n, thus indicating the relative diameter. The values in the table give the per cent of volume growth *for the period*. This is then divided by the number of years in the period to get the current annual growth per cent.[1]

[1] This table is given in Principles of American Forestry, Samuel B. Green, John Wiley & Sons, N. Y., 1903, p. 178.

Further modifications of this formula are discussed in Graves' Mensuration, pp. 306–7.

330. Schneider's Formula for Standing Trees. The most convenient formula for testing the growth per cent of standing trees is known as Schneider's formula, developed in 1853 by Professor Schneider, Eberswalde. This formula is applied at B.H. and requires the determination of diameter, D, at that point, and the number of rings in the last inch of radius, n. Then

$$p=\frac{400}{nD}.$$

The following description of the derivation of the formula is taken from Graves' Mensuration, p. 308.

If n represents the number of rings in the last inch of radius at breast-height, then the periodic annual growth during n years is $\frac{1}{n}$ inches. Let the present diameter be represented by D, then the diameter last year was $D-\frac{2}{n}$ and the diameter at the end of one year from now will be $D+\frac{2}{n}$.

The present volume of the tree is $\frac{\pi D^2hf}{4}$, that of one year ago was

$$\frac{\pi}{4}\left(D-\frac{2}{n}\right)^2hf.$$

The growth for the last year is then

$$\frac{\pi D^2hf}{4}-\frac{\pi}{4}\left(D-\frac{2}{n}\right)^2hf=\frac{\pi hf}{4}\left(\frac{4D}{n}-\frac{4}{n^2}\right).$$

The growth per cent is:

$$\frac{\pi D^2hf}{4}:\frac{\pi hf}{4}\left(\frac{4D}{n}-\frac{4}{n^2}\right)=100:p.$$

$$p=\frac{400}{nD}-\frac{400}{n^2D^2}.$$

If the growth be calculated on the basis of $d+\frac{2}{n}$ instead of $d-\frac{2}{n}$, then the following formula will result:

$$p=\frac{400}{nD}+\frac{400}{n^2D^2}.$$

The average between the two formulæ is taken, namely,

$$p=\frac{400}{nD}.$$

Inasmuch as Schneider's formula assumes that there is no change in height and nor change in form factor, the results are very conservative.

An attempt has been made to adapt the formula to rapid-growing trees by substituting other values for 400, but the resulting formulæ have little practical value.

331. Use of Growth Per Cent to Predict Growth of Stands. Growth per cent is sometimes used to determine the growth of trees or stands, by both the standard methods, that of prediction, and of comparison. It is not well adapted to secure accurate results by either method. Owing principally to the variability of the per cent relation, and its direct dependence on and derivation from the two factors, volume and increment, the problem of reversing this process and deriving increment from growth per cent is apt to lead to error through a mistake either in choosing the basis of volume for deriving the per cent figure, or in applying this figure in turn to the wrong volume basis.

The method of prediction of growth by means of growth per cent consists of determining this per cent for a stand, either from sample trees (§ 241) or by direct use of yield tables or other methods of measuring the past growth for a decade.

Schiffel states, "If in any period of life the current annual increment per cent of a tree is to be calculated, it would be contrary to nature and incorrect to relate the increment to any former dimensions or volume, but it must be related to the dimensions or volume of the previous year."

The formula, growth per cent $=\left(\frac{V-v}{V+v}\right)\frac{200}{n}$ when $n=10$ years, bases growth per cent on volume five years ago, and is correct as an average per cent of the past ten-year period. If applied to the next decade, and based on V, or present volume, it assumes an increase in growth for this period. When this per cent is applied only to the current year, and is based on V the per cent is more conservative.

While individual trees are growing rapidly in diameter, as dominant trees, their growth per cent for a time falls less rapidly than that of slower-growing trees. In even-aged stands, growth on individual trees is proportional to their diameters. Growth per cent in area is about twice the per cent of diameter growth. If determined for the trees which will be retained under management, this relation of growth to volume may be fairly consistent in such even-aged, thinned stands. Hence sample or average trees may give a close indication of the growth per cent or present status of the stand. But the assumption that this *growth per cent* will continue to be laid on annually breaks down at once; hence the real assumption and the only one possible, if growth per cent is to be applied for predictions, is that the *volume* indicated by this per cent will continue to be laid on annually. And this in turn is inaccurate.

The sources of inaccuracy in this method are:

1. Predicting the volume growth of a stand from that of one or two selected or average trees. The growth per cent of a stand is practically always less than that of the average trees which survive, due to loss of numbers and falling growth rate of the suppressed class.

2. Applying a growth per cent obtained from a past period on a smaller volume, to the present volume of tree or stand, under the assumption that not only will the rate of growth in volume continue the same but the per cent will remain unchanged, when, as shown, growth per cents always fall as wood capital increases.

3. Assuming that the growth per cent as derived from average trees, or even from sample plots, will apply to larger areas and to different proportions of age classes in mixture, when in fact, so doubly sensitive is this per cent relation, that any difference in average age and volume between the forest and the sample areas will result in a large error in determining the true weighted per cent by this means.

The possible errors may be illustrated as follows:
From a yield table for White Pine [1] the actual known yields are,

At 30 years	3750 cubic feet
40 years	6590 cubic feet
50 years	8035 cubic feet
60 years	9075 cubic feet

By Pressler's formula, the current annual growth per cent for these decades is,

30 to 40 years	5.5 per cent
40 to 50 years	2.0 per cent
50 to 60 years	1.2 per cent

If the growth for the decade from thirty to forty years be taken to indicate the current growth in the fortieth year, of 284 board feet, this gives a current growth per cent for that year on 6590 board feet, of 4.3 per cent. Assuming that this growth per cent will continue for the next decade, we have a total increase of 43 per cent or 2834 board feet. The actual growth is 1445 board feet. The error is 96 per cent excess.

Such errors are the result of use of the growth per cent, even when the basic data are correct. The errors may be greatly increased when growth per cent is obtained from single trees and the losses in the stand are ignored, since too high a current growth per cent will be obtained.

332. Use of Growth Per Cent to Determine Growth of Stands by Comparison with Measured Plots. The only merit which growth per cent has as a method of determining growth lies in the possibility of using it as a means of *comparison*. Since per cent does not express

[1] Forest Mensuration of the White Pine in Mass., H. O. Cook, Office of State Forester, 1908, p. 21.

absolute quantity but a relation, the assumption is that this relation once established for a given stand will apply to other stands of a similar character but differing in area and total volume. Growth per cent on sample plots could for instance be applied to determine the annual growth on the stand within which they are located.

In so far as it can be known that the relation between the volume of the larger area and the growth on this area is the same as on the stand sampled, the method is obviously correct. The error lies in applying such growth per cent figures to stands or areas on which this relation is *not* the same, because the average age, thrift, or other conditions, differ from the sample area. The simplicity of assuming that growth per cent for a sample tree, or for a sample plot, can be applied to large areas has led to its use as a substitute for sound growth data in many instances. No such short cut will actually measure the growth on a forest comprising many stands of different ages, site qualities, and densities of stocking.

333. Use of Growth Per Cent in Forests Composed of All Age Classes. Growth per cent is a direct expression of *current growth* in its relation to past or total volume. Hence it varies with the current growth curve. Current growth per cent is equal to mean annual growth per cent in the year in which the mean annual growth culminates (§ 245).

In a forest composed of stands of all ages, or in a stand composed of trees of all ages, equally proportioned as to area or ultimate yield, and under management, the current growth per cent for the whole forest or the whole stand, when weighted by volume of each age or tree class, will be equal to the mean annual growth per cent for every year, since there is no change from year to year in either of the two factors, total volume or increment, which determine it.

For such a forest the average growth per cent can be found separately for each diameter class. By weighting each per cent according to the volume of the trees in this class for the stand, a composite per cent is obtained which shows the present status of the forest, and is applicable in predicting its growth. But accurately to determine this per cent, the growth itself must first be found on the trees or plots measured. If in determining this growth, the future factors are really considered, the numbers reduced, and the rate of diameter growth and probable suppression taken into account, the result is a quantitative statement of growth for the next decade or two instead of for the past decade. This prediction of growth, on a few acres or a small per cent of the stand, can then be reduced to the form of a per cent of present volume, and applied, in this form, to the remaining stand as a convenient means of computing growth on the total area.

334. Growth Per Cent in Quality and Value. Growth in money value of a stand is treated in Forest Valuation.[1] This depends upon the three factors mentioned in § 244, namely, increase in volume, in quality, and in unit price independent of the other two factors. The growth in quality differs from that in volume, since it tends in a measure to raise the value of the previous growth, especially when this increased quality is due to increased dimensions. Per cent increase in value is usually computed as an annual per cent found by dividing the periodic per cent by the years in the period, and is applied to the volume at the beginning of the period, thus showing simple interest on the initial value. When thus expressed, the per cent of increase is made up of the sum of the per cents due to each of the three separate factors. For young and immature timber, growth per cent in volume forms the chief element of increase, but as the trees reach maturity this diminishes, and is greatly exceeded by per cent increase in price due to quality, and to unit prices—so that the per cent of increment in value may continue for a much longer time than that of volume.

The growth in quality of a stand can be measured by the use of graded log tables (§74) or graded volume tables (§165) provided it is carefully ascertained that these tables apply to the trees in the stands to be measured, at the successive ages.

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[1] Forest Valuation, H. H. Chapman. John Wiley & Sons, N. Y., 1915.

CHAPTER XXXI

METHODS OF MEASURING AND PREDICTING THE CURRENT OR PERIODIC GROWTH OF STANDS

335. Use of Yield Tables in Prediction of Current Growth. The current growth of stands for short periods can always be predicted with greater accuracy than for long periods. Not only can the present condition of the stand be gaged, as to species, numbers, crown density, form, thrift and rate of growth in immediate past, and this information applied in predicting the rate at which growth will continue, but the inevitable changes, some of them unforeseen, which will occur in the future to modify this rate of growth, take place at a rate which bears a close relation to the length of the period of prediction.

Only when the net results of all the various factors which produce yields have been measured on stands after they have passed through the period is an approximate degree of accuracy obtained for long periods, hence the use of yield tables based on age. It follows that for the prediction of current growth for short periods on existing stands, the net current growth shown by the above yield tables, reduced on the basis of age and relative density to apply to the stand in question, is the best basis of growth prediction even for these short periods.

336. Method of Prediction Based on Growth of Trees, with Corrections for Losses. In endeavoring to use these yield tables for stands which differ greatly from the normal in number of trees per acre, density of crown cover, form or distribution of age classes, and composition of species, it is often difficult to find or make a table which will apply to the stand even when corrected for density. In such cases, a direct measurement of the stand may be resorted to instead of a comparison with a standard yield. The growth of any stand of whatever character, for the next decade, will be the sum of the growth in volume of the trees which survive till the end of this period minus the loss of the total volume of the trees which do not survive (§ 252). The elements which give stability to this method are a knowledge of the exact present number and diameter of the trees in the stand, which may be supplemented by a classification of crowns to indicate those now dominant, intermediate or already suppressed, and by a tabulation of past growth in diameter, by diameter classes (§ 278). The elements of uncertainty are probable loss of numbers in the next period, and future rate of diameter, height and volume growth of the survivors. At best, owing to the great difficulty of predicting for a given stand the loss in numbers and the rate at which diameter growth will be maintained, for long future periods, the method can be used only for periods of ten to twenty years, except for slow-growing or long-lived species where the factors of change are slowed down correspondingly.

To apply this method of predicting tree growth to obtain current growth of stands, the steps are,

1. Prepare a stand table of the forest or area (§ 188).

2. As an aid in determining mortality, tally or estimate the number or per cent of each diameter class which is suppressed or will probably die within ten or twenty years.

3. Decide upon the method to be applied in predicting diameter growth (§ 278 and § 279) and prepare table of growth by diameter classes to conform to the requirements of the method.

4. Obtain data and construct a curve of average height growth (§ 248), which will probably be best expressed as current height growth based on height, for the last decade or two.

5. Obtain volume tables giving the volume of trees of each diameter and average height. A standard volume table classified by heights is needed for best results.

6. From present number of trees in each diameter class, deduct the per cent or number which will probably die within the period.

7. Compute the average diameter which surviving trees of each diameter class will attain at end of period.

8. Compute the increase in height for each diameter class. (The false method described in § 285 is frequently used as a substitute for a curve of height growth.)

9. The volume of the present stand is calculated from the stand table and volume table.

10. The volume of the surviving stand at end of period is obtained from the future diameter and height of the surviving trees of each diameter class, and volumes taken from the standard volume table.

11. The difference in volume thus found is the net growth for the period, in stands which have not been thinned and in which no salvage of dying or dead timber is possible. The volume of the trees which die is thus deducted from the growth on the survivors, and only the net growth is represented in increased volume of the stand.

In stands which are thinned, this prospective loss in numbers is not lost nor deducted, but is expressed in the form of thinnings. Where thinnings are marked and will be made in such stands, they will commonly include more trees than will actually die during the period, since the suppression of diameter growth is to be avoided, and this begins considerably in advance of the death of the tree and may affect the entire stand if too crowded.

By this method, neither a full volume analysis of current growth of trees is needed on the one hand, nor a yield table based on area and age on the other. Nor is it necessary to compute the average tree of the stand, and by predicting the growth of this tree for the next decade, seek to determine that of the stand (§ 275) since all the trees in the stand are given their proper weight in predicting growth. Only for very regular stands can average trees be used safely, and for such stands yield tables are better.

337. Increased Growth of Stands after Cutting. The method of predicting diameter and volume growth of trees after release by cutting is shown in § 280. The problem of predicting growth of stands left on cut-over lands is one of properly combining the growth data for the different classes of trees left on the area.

That diameter growth of individual trees should increase when their crowns and roots are given increased growing space is a natural law of growth of stands. The question is, "What is the total net current growth per acre on such lands?"

The first result of cutting should be to tremendously increase the *growth per cent* on the remaining stand, or change its status, by removing large, old and slow-growing trees with a low growth per cent, and leaving small, young and more vigorous trees with a larger growth per cent. *This change would occur even if no increased growth followed the cutting.*

The total growth per acre laid on after cutting is the sum of the current increments on the residual trees. In spite of change in growth per cent or status, and of possible increased growth on the trees left, the total net volume increase may be less than on the original stand. If the number of trees is greatly reduced this is usually the case. But if the stand cut over is many-aged, and only the decadent and suppressed trees are taken, the combination of a large number of trees left on the area, an increased rate of growth on these trees, and especially the prevention, by cutting, of a loss of volume by death of trees which would otherwise have to be deducted from current growth, may result in a larger actual net increase per acre from the cut-over stand than before it was cut, as well as a greater growth per cent.

This expansion of diameter and volume growth of the residual stand after cutting, is, for even-aged stands, a response to increased light, soil, moisture and space in which to expand. In many-aged stands it may mean, as well, an expansion of the total area of the age class (§ 253).

The method of determining the growth of individual trees in the stand to obtain the growth of the stand (§ 277), is favored in studies of cut-over lands, first, because such studies are usually made in many-aged stands of mixed species, second, because the difficulty of separating the age classes by area and age is even greater than on stands before cutting; hence the application to these stands of yield tables based on age is very difficult.

The stimulation of growth on the trees left after logging is similar in character to the beneficial effects of repeated thinnings on stands under management. It undoubtedly increases the rate of yield per acre over that realized if the natural processes of selection are not interfered with.

Two factors must be considered in analyzing this growth; first, to what extent have the trees left on the area been liberated or given increased growing space?—second, to what extent can they utilize or monopolize the area released by cutting? The maximum of increased growth would be found in a stand, either even- or many-aged, in which the cutting was so evenly distributed as to affect all of the remaining trees, and so light that the space released could all be absorbed by these trees.

When cutting is either too light or too poorly distributed to affect all trees, the trees showing increased growth will be only a certain per cent of the total number. This per cent of each diameter class which will be released, as affected by the increased rate, will give the net actual increase over the previous rate of growth.

Table LXVI illustrates the data required in a study of increased growth after cutting (p. 440).

From a table of this character the average increase in growth may be computed by weighting the rate of increase by the per cent of trees affected; e.g., since 18 per cent of the trees are affected, an average increase of 18 per cent of the difference between the two classes of trees, those not affected and thus growing faster, can be added to the slower or original rate to get the new average for the forest.

338. Reduced Growth of Stands after Cutting. In heavier cuttings, even on parts of the same cut-over area, openings may easily occur from cutting even-aged or mature groups, which affect but few of the remaining trees. These clear-cut spots will result in a net reduction of current increment per acre for the forest, just as would the clear cutting of a larger area. There is no possibility of increased growth because there is no timber left on which to lay this growth. In even-aged stands cut clear, the growth for *the forest* occurs on separate areas of maturing timber, not on the areas cut over; the growth on cut-over areas must result from reproduction of a new crop and come along in time. Thus on heavily cut-over areas, in mixed age classes, a heavy reduction of growth per acre will occur for the present regardless of increase on the residual trees or stand.

TABLE LXVI

ADIRONDACK SPRUCE

Average Rate of Growth in Diameter on the Stump of 1593 Trees on Cut-over Land at Santa Clara, New York

Diameter. Inches	No. of trees	Current annual growth in diameter just before first cutting. Inches	Current annual growth in diameter since first cutting. Inches	Current annual growth in diameter since first cutting. Values made regular by a curve. Inches	No. of years required to grow 1 inch in diameter	No. of trees showing increased growth	Current annual growth in diameter since first cutting. Inches
5	8	0.095	0.095	0.09	11	1	0.100
6	158	.080	.100	.10	10	16	.180
7	329	.090	.110	.109	9	63	.185
8	350	.105	.125	.125	8	77	.205
9	277	.120	140	.140	7	59	.205
10	226	.135	.150	.150	7	50	.215
11	135	.130	.145	.160	7	18	.210
12	64	.165	.175	.170	6	7	.240
13	30	.165	.170	.178	6	2	.170
14	11	.150	.150	.185	6	1	.200
15	1	.080	.080	.192	6		
16	4	.200	.200	.200	5		
Average.........		0.112	0.137	....	.....	.....	0.20
No. years to grow 1 inch.......		9	.....	.....	7	.....	5

Total number of trees, 1593.
Number of trees showing increased growth, 294, or 18 per cent.

The condition of such cut-over areas would be more accurately gaged if it were possible to separate the age classes in the cut-over stand on the basis of the actual area which they occupy. Thus, in a stand on which the timber cut formerly occupied 90 per cent of the growing space, it is not reasonable to expect that the trees which occupy the remaining 10 per cent of space will be able to expand sufficiently to absorb nine times their former crown space, even if properly distributed so as to make this possible. The increment on this area for any considerable period into the future depends on securing reproduction to fill the gaps.

The method of measuring increment on cut-over lands solely by the growth expected on the trees left after cutting is best adapted to typical many-aged or "selection"[1] forests, and the more closely the conditions both as to distribution of cutting and of the residual stand resemble a many-aged forest, the better the results obtained. This method gives best results also on areas under intensive management, where if trees die or are blown over, their volume is not lost, and when the danger of reduction or loss in numbers is at a minimum.

The necessity for reducing the number of trees for loss during the period remains, and applies to all stands on cut-over lands as well as elsewhere. Neglect of this factor means over-estimation of probable net growth.

339. Application of Yield Tables Based on Age, to Cut-over Areas. Where stands in the original forest can be or have been separated by area and age by any method, and a yield table based on age exists, a more conservative method of calculating growth on cut-over lands can be used, which bases this growth not on the theory of the many-aged forest and crown expansion of the age class, but on that of even-aged stands (§ 298). If age classes are on separate areas and cut clean, the cutting of one stand has no effect on the growth of another. If the forest is divided into age classes, and part is cut over, it can be assumed that this cutting removes an age class without stimulating the growth on the remainder, and that this area cut over is to be reproduced to young timber rather than absorbed by existing age classes.

To determine the area which is cut over, and that which remains stocked, the density or reduction per cent already determined for the original forest (§ 317) *is assumed to apply to the residual stand.* The area stocked to this degree of density can be found by dividing the volume in each age class left on the cut-over area, *by that of the empirical yield table* for the given age which has been prepared for the original forest previous to cutting (§ 304). The sum of these areas, including that stocked already by young or immature age classes, subtracted from the total area, gives the area actually cut over. The *actual* yields of the age classes left on the cutover area will be in proportion to the *per cent of the total area which they occupy, plus the degree of expansion or increased growth which they put on.* The growth to be expected in the absence of any such expansion will be predicted by the empirical yield table from the net area or per cent of area stocked. This fixes

[1] Selection—A term applied to forests in which the entire series of age classes is intermingled over the whole area and not separated by areas.

the minimum expectancy and is safe for a long future period (§ 248). Studies of growth on the individual trees and on permanent sample plots as stimulated by release will in time indicate the maximum growth possible on the same area. The actual growth will be somewhere between these two extremes, dependent on the balance between the forces tending to expand the crown area, and the destructive agencies tending to reduce the numbers in the stand, as shown in Fig. 87 by the lines;

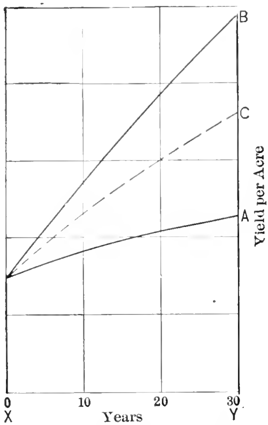

Fig. 87.—Possibilities of Growth on Cut-over Areas.

A. Based on average growth per acre in original stand, with normal loss of numbers.

B. Based on increased growth after cutting and no loss of numbers.

C. Probable rate somewhere between *A* and *B*, based on increased growth of a part of the stand and a reduced rate of loss in numbers.

Probably the safest basis for growth prediction for long periods on cut-over lands is not the current growth study based on diameters, but, where possible, yields based on age, at the rate produced in the past on virgin forests, and figured for the net areas stocked, to which a percentage of increase may be added to represent expansion of crowns due to release and stimulus following cutting.

An illustration of this principle of growth prediction is as follows:

The empirical yield table for Western yellow pine, Coconino National Forest, Arizona, gives 66.2 per cent of the normal or index yield.

The stand of timber left on the cut-over areas, separated into three age classes by the method given in § 321 is found.

By dividing the stand for each age class by the yield per acre from the empirical yield table, the area which is stocked with timber, for each age class, is determined.

The area reproduced to poles and saplings is estimated. The total area of cut-over land is known. The remaining area, not shown as stocked either with mature timber or young timber is the area cut clean and awaiting restocking. The results are given in Table LXVII.

The prediction of growth is now made by applying the empirical yield table to the areas and ages represented in the table.

With the area and age of each age class indicated, the future yields on cut-over lands may be predicted by applying the empirical yield table, increased by the per cent of expansion agreed upon.

TABLE LXVII

AREAS REMAINING STOCKED ON CUT-OVER LANDS

Class	Age. Years	Yield per acre. Board feet	Stand, total M. Board feet	Empirical area equivalent acres	Per cent of 70,654 acres; also per cent of 1 acre
Veteran	300	12,050	27,900	2,315	3.2
Mature	200	16,750	9,702	579	0.8
Blackjack	100	7,480	70,908	9,493	13.4
Poles	50	......	......	6,006	8.5
Saplings	20	......	......	17,663	25.0
Not restocked	0	......	......	34,598	49.1
	....	Totals....	108,510	70,654	100.0

340. Permanent Sample Plots for Measurement of Current Growth. The best method of measuring the current growth of a stand is by means of permanent sample plots, established in stands which are typical of the conditions to be studied, and re-measured at intervals of from five to ten years. Methods of establishing and measuring such plots are described in § 243. In this way, just as for yield tables the actual net results of all factors which affect the current growth of the stand as a whole, such as wind, insects, disease, suppression, or increased growth, are measured, rather than either compared or predicted. The only precautions to observe on re-measurement of plots are that the diameters and heights of the trees must be taken in successive measurements in such a way as to give exact comparisons, whose difference indicates growth rather than discrepancies in re-measurements.

Krauch has pointed out that the height of trees should be measured on such plots from the same position or point at each measurement, to avoid discrepancy due to the departure of the tree from the perpendicular (§ 199). The diameter tape insures consistency in re-measurement of diameters (§ 190). The same volume table should be used in calculating successive volumes for trees of each size class. These precautions insure the isolation of the current growth in successive measurements.

341. Measurement of Increment of Immature Stands as Part of the Total Increment of a Forest or Period. The increment of a forest or large area, just as in the case of a single stand, may be expressed as the total growth over a definite period, or yield, the average annual growth or mean for this period, or the actual volume laid on each year or current annual growth. A forest resembles more closely a many-aged stand than one composed of a single age class. In such a stand or forest, it is not possible to separate one period which coincides with the complete cycle of production for a crop of timber, as can be done in the even-aged stand. The total production of the many-aged area or of the forest, for a period equal to that required to grow one crop from seed to maturity, may equal that of the even-aged stand, but it is laid on in many stands.

In a regular many-aged forest the current growth for one year is the growth in volume of each stand, including those which are as yet unmerchantable. This is true of the forest, whatever its form. The current growth on the mature timber is but part of the total; that which represents the younger stands is equally important. Growth is not usually measured, on either trees or stands, until a size is attained which is merchantable for some form of product. Another reason for postponing the measurement of young stands is that a very large per cent of the existing trees in such stands will never reach maturity, and the total volume at any period previous to an age at which it can be used is misleading and serves no useful purpose, while by contrast the natural selection of surviving trees in stands measured at merchantable age has already occurred and the results are accurately gaged.

When the volume is finally measured on a young stand for the first time, it represents the growth for the entire preceding period. Perhaps but 10 per cent of the trees are large enough to measure at this time. After another decade, the stand is again measured. By this time 50 per cent of the trees may be merchantable. The growth for this decade now includes the current growth, for ten years, on the original 10 per cent, plus the growth since germination on the remaining 40 per cent. At the third measurement, all trees which survive may be merchantable and are measured, but a portion of them have entered the merchantable class after being missed for the two previous decades. What happens is that although current increment by decades is sought, yet for trees which mature and are measured for the first time, total growth is substituted for current growth since there is no other way to handle it.

If this example is now applied to a forest composed of a series of even-aged stands, the same thing is seen to occur. For the forest, the current increment is the increase in merchantable cubic volume of stands already partly merchantable; but to this is added, in each decade, stands measured for the first time, whose volume though added as current increment is in reality the total growth of several periods instead of one. It follows that for a stand just becoming merchantable, the apparent current growth will be very rapid during this process while its actual average or mean annual growth, which takes in the true period required, is much less.

But in a many-aged stand, or on a forest composed of stands of all ages, these elements counterbalance each other. As growth cannot be measured on stands below merchantable age or size, it is not measured on the areas covered by such young stands, or on the portion occupied by immature trees in mixed stands. But as soon as these stands or trees mature, the growth is measured all at once and greatly exceeds the actual current rate on the areas measured or for the trees in these age classes. Whenever the age classes are distributed evenly, the excess of current growth so caused is balanced for the area or forest by the neglect of the current growth on the younger stands. It follows, first, that in forests with well distributed age classes, the total current annual growth actually laid on in stands of all ages should be about equal to the current growth obtained by measuring only the merchantable stands, provided the maturing volumes of young timber are included as current growth. For a single even-aged stand, or a forest devoid of younger age classes, this premise does not hold good, and the current growth for the period of early maturity will greatly exceed the real rate for the area or total period. On such stands or forests this rate will not be maintained, and the true yield must be found by dividing by age, in the form of mean annual growth.

342. Comparative Value of Current Growth versus Yield Tables and Mean Annual Growth. The relative value and utility of the methods of studying the increment on forests or large areas may be summed up as follows:

Increment or growth is always desired for areas of land rather than individual trees.

The rate of growth per year on an average acre is the object sought.

Where forestry is a permanent land policy, the rate of growth desired is that which represents the average for the life of a crop of timber, and which can be maintained, in consequence, indefinitely.

This rate can be found most accurately whenever growth can be measured directly on the basis of area and total age, as in yield tables for even-aged stands, and applied to the forest by the necessary reduction per cents.

The current growth on stands or forests is best obtained from these same yield tables.

But where it is not possible or practicable to construct such yield tables, current growth for short periods only can be measured directly on merchantable trees, and applied in predicting growth of the stand and forest.

This method gains in accuracy over yield tables, by measuring directly the density of the stand, and by predicting growth on basis of actual volume and conditions. It loses in comparison, because it measures only one current section of the growth curve for the stand or forest, which may be above or below the mean, and because the basis, the individual tree, while accurate to start with, rapidly loses its reliability, while by contrast, yield tables retain a fair degree of reliability over long future periods.

Current growth, if it is actually measured in terms of volume, and the errors of using growth per cent are avoided, is well adapted to answer questions regarding the immediate future growth of specific stands, but is poorly adapted to growth predictions covering long periods.

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CHAPTER XXXII

COORDINATION OF FOREST SURVEY WITH GROWTH DETERMINATION FOR THE FOREST

343. Factors Determining Total Growth on a Large Area. The solution of the problem of determining the amount or volume of wood which will be grown on a forest or area of forest land in a given period depends upon six factors:

1. An analysis or classification of the forest into the areas included in each of the site qualities present.
2. The areas occupied by stands of given type and mixture of species.
3. The actual present density of stocking, volume and number of trees per acre, and size of diameters of the present stand on the forest.
4. The actual age classes present, and the area which each occupies.
5. The length of the period for which growth is desired, whether for a short current period, or for permanent management and a rotation.
6. The rate of growth, to be determined by whatever method can best be applied to the forest as a whole by obtaining the actual growth on the stands which compose it.

344. Data Required from the Forest Survey. The first four of these elements require the collection of data in connection with the forest survey. Studies of the rate of growth (6) for the period determined (5) will not solve this problem in the absence of quantitative data to tie this growth study to the tract in question.

Unless a forest is to be cleared for farms, the prediction of future growth is a basic consideration of its future management. A forest survey that is so conducted as to fail to obtain the necessary data on which growth for the forest can be determined must later be repeated to obtain this data, or supplemented in some way, while if the need were recognized at the start, the information could be obtained in final form with trivial extra cost.

The character of this data depends upon the form of the forest as to its age classes. It may be itemized as,

1. Site classification.
2. Age of stands.
3. Area of stands.
4. Volume of stands.

When these factors cannot be directly ascertained, the requisite basis must be obtained for calculating them. The most fundamental and useful basis is,

5. Diameter of trees in stand by species, or a stand table.

Finally, because of its inadequate handling, special emphasis must be placed on obtaining

6. The area stocked by immature age classes.

345. Site Qualities—Separation in Field. Site qualities in the forest should be separated by area. Where several types exist, such as cove, lower slope, upper slope and ridge, which correspond closely with difference in site, the division by types goes a long way toward separating the site qualities (§ 228).

Where site qualities must be determined directly, there are but two methods possible of which the first is direct judgment based on observation of site factors, such as soil, altitude, slope, rock, moisture (as swamps) and general character of the timber growth. This method is subject to serious errors (§ 226). The second method[1] is based on the height growth of dominant trees (§ 227). But to determine directly the site class indicated by trees of different heights, their age must be known. When the forest is composed of a few large age classes of even age, direct determination of a few ages may give this basis.

But where the age classes are mixed, the age of individual dominant trees, rather than age of stand, must be relied on to indicate site quality. If we could assume that diameter growth did not decrease for the average tree, on poor sites, and that average trees of a given diameter were as old on Quality I site as on Quality III, diameter could be substituted for age; but average diameter growth varies with the site quality itself, which prevents this substitution.

To obtain the basis of field classification of site, the heights of different trees based on age are plotted and divided into site qualities based on the standard chosen, as illustrated in Fig. 84 (§ 310) except that in this case the data are obtained by plotting individual trees, and by analysis of the height growth of trees, rather than from plots.

To apply this table or set of curves, in determining the quality of a given site, a selected tree or two is measured for height. If fully matured, total height may indicate directly the site quality. If the stand is young, age must always be ascertained. The average height for the given age is then looked up on the chart. The trees chosen should preferably be dominant and must never be suppressed. The position of the height with reference to the curves or table indicates the site quality.

The unit of area on which sites are separated should be that used

[1] Journal of Forestry, Vol. XV, 1917, p. 552.

in separating stands or units of volume estimating, such as small legal subdivisions, e.g., 10 acres, except where, by the aid of topography, the site qualities can be mapped to conform more closely with natural boundaries. Types are commonly separated in the forest survey by mapping the areas, and the estimate is usually separated to coincide with the divisions thus made (§ 221) though on forties this is not always done.

346. Relation between Volume and Age of Stands. Density of stocking, as shown, is not determined by the total merchantable volume of a stand, but by a comparison of the existing volume with the index volume which stands should have *at given ages*. Density when determined by comparison of volumes, is therefore a function not solely of area but also of age. To determine density for large areas, therefore, a basis of separation of the volume into age classes is required. This means either the direct mapping of areas of separate age classes, or a tally of diameters and a stand table for diameter classes in the stand. Methods of forest survey which utilize diameter tallies to obtain volumes (§ 207 and § 209) naturally lend themselves to the securing of such a stand table. The use of such tallies for determining age groups and average ages are shown in § 320 and § 323. In general, density of stocking for mature age classes will be found not in the field, but after the volumes have been computed or stand tables prepared, and by means of a comparison of volumes with the yield table, on the basis of similar ages.

Age classes and their actual ages may be determined directly during timber survey only when the areas which they occupy are separate, large and easily distinguished, and when time permits of the testing of trees for age. In intensive management, this method will be followed on small areas; but for large areas of mixed ages, the general method of depending upon diameters to indicate age should be relied on; hence the stand table is the basis of this age class division, both for age and area (§ 318 to § 323.)

347. Averaging the Site Quality for the Entire Area. Site qualities, when not correlated with type, present difficulties in classification, so much so that on large extensive projects site qualities may for the time have to be waived and an average yield table obtained for all sites. (This method was adopted in the preliminary working plan for the Coconino National Forest, Arizona.) A composite stand table, including stands on all sites, is best for this purpose. Its application to the average site will depend on the average density or reduction per cent found for the area. Only when the divisions of the total area into site qualities can be coordinated with similar divisions of the estimate and stand can these divisions be made the basis of separate growth predictions for the forest. Wherever possible, this division must be made.

348. Growth on Areas of Immature Timber. The growth on any large area, whether the form of forest is even-aged in pure stands, or many-aged in mixed stands (§ 314) must include that of the young, unmerchantable stands. This growth is a prediction of future volume, and as such, may be obtained, not by measuring the present volume of the stand, nor by counting the number of trees in very young stands, but by the method of comparison with older stands. The yield table based on area and age gives this comparison. But to utilize the table, the one thing necessary to determine is the area which is stocked with the immature timber. Its age is more easily determined than for old timber, either by cutting or by counting whorls. Based on area and age, the future yield is a matter of density of stocking. The rate of growth per year may be taken as the mean annual growth, shown by the reduced or empirical yield table, for the age at which the stand will be cut.

The density per cent for young stands is practically independent of the density of crown cover, and depends instead upon the number of trees per acre as compared with the normal number required at maturity, the distribution of these trees over the area, and the chance of survival (§ 316). Mortality in scattered stands where each tree has room to grow is much less than in crowded stands; and if the spacing of the reproduction is such that, allowing for a reasonable rate of loss from insects and causes other than suppression, the stand will reach full stocking at least a decade before maturity, it can be considered as fully stocked now.

If a large area is being measured and an average density per cent is found for this area, resulting in an empirical yield table somewhat lower in values than the normal table, a conservative plan is to assume that the ultimate yield of young stands will not exceed this density, and to use the empirical yield table as the basis for calculating their future yields.

That area and yield per acre is the only possible basis of prediction of yield for immature stands must become evident by considering the difficulties of the opposite plan, that of counting numbers of trees on snall plots. In tallying or counting reproduction or immature sizes, it is customary to lay off the plots at fixed intervals, comprising from one-tenth of the estimated strip, down to less than 1 per cent of the strip, and to count the seedlings and saplings upon these plots. The only way in which these data can be used to predict growth on such small timber is by predicting the percentage of this count which will survive. The method of comparison by numbers of trees is useless, first, because number of trees per acre at these ages does not in any way indicate the future yield, since this is determined by the number that survive; second, because the area rather than the number will determine the future yield. On a plot of 100 square feet there may be one hundred seedlings; yet if fully stocked at maturity not more than one tree would be able to survive from this number. Such counts on plots serve only to determine the extent to which reproduction is becoming established and do not give the data needed for growth predictions.

Age Classes Based on Size. Immature timber may be divided into at least three classes for purposes of growth study; seedlings, saplings and poles. Seedlings are trees under 3 feet high.[1] Saplings include trees from 3 feet high to 4 inches D.B.H. Poles are trees from 4 to 12 inches D.B.H.

Saplings may be divided into
- Small—from 3 to 10 feet high.
- Large—from 10 feet high to 4 inches D.B.H.

Poles may be divided into
- Small—from 4 to 8 inches D.B.H.
- Large—from 8 to 12 inches D.B.H.

Methods for Seedlings and Saplings. In determining the quantity of reproduction and immature timber present on an area, in order to predict its growth by comparison with a yield table, the procedure will depend upon the form of the forest. In even-aged stands, areas stocked with seedlings in sufficient numbers can be entered by mapping them as fully stocked. Danger of destruction is chiefly by fire, and for this, correction can be made when fires occur. But in many-aged stands, suppression must be considered. Depending upon the silvical characteristics of the species and the behavior of the seedlings, the object should be to record only the area of mature forest which will result from the present stocking. Seedlings which are suppressed will be ignored. Those which grow in openings and are thrifty will be regarded as probable survivors. In rather open, group-selection[2] forests like yellow pine, the areas stocked in this manner are easily distinguished. With species such as spruce, seedlings starting under shade and not in openings should be disregarded altogether, both because of suppression, and because their age will be prolonged by this cause and they will not become an economic factor in the stand till a later period (§ 263).

With saplings, the establishment of the stand in many-aged forests

[1] Standard definitions, Society of American Foresters.

[2] Group-selection, a forest composed of trees of all ages intermingled in small fairly even-aged groups.

is more certain, and the area so stocked with trees which will probably survive can be better determined.

For both these classes of timber, the best method of determining the area, and consequent future growth, during the forest survey, is to record on each strip the per cent of total area on the strip which is stocked with young timber, on the basis of probable survival to maturity. This per cent is then reduced to acres for the strip. The average size and age can also be noted. Seedlings and saplings can be separately noted, or thrown together, depending on the intensiveness of the work and size of area.

A second method of record on the basis of area, formerly used in the Southwest, was to note the reproduction in general terms, based on whether the stocking was sufficient to replace the present stand. If so it was termed excellent. Different per cents less than this were termed good, fair, poor, and none. This system does not distinguish between the areas of mature and young timber or consider the relation which one bears to the other.

To supplement the per cent method of ocular guessing at areas restocked, plots may be laid out at given intervals, on which the areas stocked can be mapped, and computed in terms of acres. The per cent of the plot thus shown as reproduced serves to correct the ocular work and to check the results.

Methods for Poles. With poles, the area method can still be applied directly in even-aged stands, by mapping. In many-aged stands, a choice of two methods is offered. Either the area per cent can be used as for saplings, but separately, and the number of trees in this class ignored as before, in which case merely the average size and age of the poles on each strip is recorded with the per cent of area occupied, or instead, the poles may be counted.

The purpose of the count is to obtain a second basis of comparison with the empirical yield table. The latter should show the number of trees per acre required at different ages. The yield table data may be made to include pole sizes, by including plots of this age in constructing the normal tables of yield. In case this has been done, the area occupied by poles can be very roughly determined by means of the numerical comparison with the empirical table. For instance, if poles, averaging sixty years old and 7 inches in diameter run 120 per acre in the normal table, and the reduction per cent is $66\frac{2}{3}$, the empirical stocking is 80 poles per acre. A count of 8000 poles on the area indicates an area of 100 acres stocked with pole sizes.

A definite plan for the determination of the stocking with poles must be made preliminary to undertaking the timber survey. Trees which are part of an even-aged mature stand, but which are not yet merchantable or are suppressed, are not considered, since the yield table for the stand takes care of them. Only in many-aged stands must poles be counted, or their area determined by per cent of the total, the former method to be used if the yield table permits of direct comparison of numbers, the later, if only the mature classes are shown in the table.

349. Effect of Separation of Areas of Immature Timber on the Density Factor for Mature Stands. The separation by area of the immature age classes accomplishes more than the determination of future yield for these age classes. In the many-aged forest, the mature timber is not segregated as it is in even-aged stands, but is intermingled with areas of reproduction, saplings, and poles. In the attempt to separate this mature timber into two or more age classes, either based on diameter classes, or by age groups (§ 320 and § 323) it is necessary to begin with a knowledge of the total area occupied by all the mature age classes. If the area actually stocked with seedlings, saplings and poles to the exclusion of mature timber is neglected, then the area apparently required by the mature timber is greater than that actually required, by just the amount of this error. In the even-aged forest no such mistake is possible, and *by analogy, its correction for the many-aged forest must be undertaken.*

The effect of not separating the area of immature stands is to lower the reduction per cent or apparent density factor for the mature age class. E.g., a reduction per cent of 40 is found for mature timber when it is assumed to occupy the entire area. Segregation of young timber shows that one-half or 50 per cent of the area is occupied by these age classes. The total area is 10,000 acres. The actual area occupied by mature timber is now 5000 acres, which doubles its density, and gives a density per cent of 80 instead of 40.

At first glance it would appear that no difference is made in the calculation of yield of these mature age classes by either assumption since reduced area and increased density are reciprocal and refer to the same actual stocking and volume and presumably the same future yield. The benefit lies in the fact that the corrected density factor *more nearly indicates the rate of growth per year for the forest or on the average acre,* which is the information most needed in permanent management. By separating the yield and area of the young timber, it is possible to predict the total actual yield of the forest over a long period, instead of for the shorter period required to harvest timber now mature. Instead of an extremely low per cent of density for mature timber and for the forest, which would indicate the need of considerable reduction in yields from the standard table (§ 316), the true conditions are revealed. Finally, it gives the same data as to age classes for the many-aged forests as are obtained by mapping for even-aged stands.

350. Stand Table by Diameters for Poles and Saplings: When Required. When diameter is definitely substituted for age and area, the growth of the forest for a period of from ten to twenty years into the future will include not only the increase on existing merchantable trees, but the volume of all young trees which grow during the period to a size which brings them into the merchantable class (§ 277).

The number of diameter classes which will become merchantable will be determined by the length of the period and the rate of growth in diameter. At a rate of 1 inch in five years, trees now 4 inches below the minimum diameter will reach the required size in 20 years.

In order to predict the growth of the stand for this period, the number of trees of each diameter class included in the group which will mature within the period must be recorded during the forest survey. Either all of the trees of these sizes must be calipered or counted, and the average diameter approximated, or these sizes may be calipered on a part of the area, distributed mechanically to obtain an average for the whole. This again indicates the need for correlation of the method to be used in predicting growth with the timber survey, before the latter is undertaken.

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APPENDIX A

A. LUMBER GRADES AND LOG GRADES

351. Purpose of Log Grades. The most useful purpose of timber estimating and log scaling is to determine the value of the logs and standing timber. This value depends upon the amount or per cent of lumber of different qualities which can be obtained from the logs or timber to be valued. In § 87 it was shown that for this purpose logs are separated into grades, usually three in number, but that the specifications for and value of each log grade depend upon the contents of logs as expressed in grades of lumber, and in resultant average value or price per 1000 board feet.

352. Grades of Lumber. Wood varies in texture or closeness of grain, difference between heart- and sapwood, uniformity of texture and freedom from knots, number, size, placement and character of knots, and presence of or freedom from various defects which lower the value of the piece by altering its appearance, strength, surface or suitability for the purposes for which it may be used. Pieces which are entirely free from all defects are suitable for the highest uses and possess the greatest value. At the opposite extreme are found pieces with defects so numerous or serious that they are unfitted for any useful purpose, hence possess no market value and are disposed of as refuse to the burner or as fuel. Certain "cull" grades, formerly refuse, are now generally handled as merchantable, but the practice of scaling has not been altered and such grades are still excluded from the scale as unsound.

The output of a mill in lumber, if separated according to the quality and value of each board, would form an unbroken series from the most perfect pieces descending through an increasing per cent of more and more serious defects until the poorest merchantable boards are passed, and refuse only is left.

For practical purposes, this series must be separated by arbitrary standards into groups termed lumber grades, so defined that any piece may be assigned by its appearance to its proper classification or grade. These grades are then made the basis of lumber prices and lumber trade.

The specifications for a grade are intended to define the poorest piece which will be accepted in the grade, thus excluding all lumber whose quality and defects are such as to unfit it for this grade. The average quality of lumber in any grade will therefore be better than the minimum specifications. Lumber which would qualify for a given grade is sometimes included in a lower grade, but this is not in the interest of the seller and tends to destroy the standards of grading.

353. Basis of Lumber Grades. The requirements of a lumber grade are, that it be generally adopted in a region or for the trade which handles the lumber from this species or region; that it be consistently applied throughout this region; that it be capable of definition and application in grading; and that it conform to the requirements for certain definite uses of lumber. To use lumber for a given purpose, when it is better than is necessary and is suitable for a higher use, is wasteful, but to admit lumber to a grade intended for a given use, when it possesses defects which unfit it for this use, destroys the basis of sound business.

Again, a grade, as applied to the lumber of a given species or region, must be so defined as to permit of securing a sufficient volume of output qualifying for the grade to make it a commercial or market product. No purpose is served in making grades for clear lumber, to apply to second-growth stands which produce little if any lumber of this grade.

Defects characteristic of one species but absent or rare in others call for modifications of grading rules to suit the species in order to prevent the rejection of too large a percentage of the output for grades for which it is otherwise suited.

To secure uniformity in both definition and application, grades of lumber are established by regional associations of lumber manufacturers and dealers, which frequently employ a corps of grading inspectors acting under a central head. These grading rules are modified from time to time as market conditions change. The latest specifications for any region or species should be obtained from the local associations. Not only do specifications change, but there is considerable fluctuation in their application as a whole, and in individual mills, which it is the purpose of inspection and standardization to avoid as far as possible.

354. Grades for Remanufactured and Finished versus Rough Lumber. For the purpose of valuing logs and standing timber, only those grades of lumber are serviceable which can be applied with some degree of accuracy directly to the log. Lumber is finally sold on the basis of its grade when finished or remanufactured. But these final grades are made the basis of the grading of the rough boards on the sorting table, with the modification that the better grades of rough lumber may be split up into several special grades, including lumber intended for specific uses. In all such cases, the general grade of the rough lumber is the basis of log grading.

Structural and dimension lumber calls for a different basis of grading, as do sawed cross ties. Where a considerable proportion of the output is in these forms, the basis of log grading is affected. While a system based on this form of products could be worked out for logs, it has not been attempted, but the basis of log grades has been confined to 1-inch rough lumber. The average value of each standard grade of lumber may be obtained from that of the grades of remanufactured lumber which it produces.

It is always possible to recognize and estimate separately the quantity and value of trees containing unusual or special dimensions, in the nature of piece products.

355. General Factors which Serve to Distinguish Lumber Grades. *Face.* Lumber is graded on the appearance of the poorest face for certain uses and in certain regions. For other uses and in other regions, the appearance of the best face determines the grade. The specific practice is in each case determined by the local grading rules.

Defects. With respect to perfect pieces, all departures from standard as defined in § 352 constitute defects. With regard to each specific grade, the defects which disqualify the piece and throw it into lower grade are defined. Defects which disqualify in one grade may be accepted in the grade below.

The principal defects are caused by,

1. Knots, sound or unsound, encased, firm or loose, and knot holes.
2. Rot.
3. Shake, season checks, seams and cracks.
4. Pitch.
5. Worm holes.
6. Stain, either as blue sap or red heart.

7. Mechanical defects, as splits, torn grain.
8. Wane, or round edges.

These defects or any combination of them may reduce grade by affecting the utility and value of the piece through its appearance, surface, texture, or strength.

356. Grouping of Grades of Rough Lumber. Even when standard grades of rough lumber only are considered, it is best not to attempt to base log grades or quality of standing timber on the determination of given per cents of each of these standard grades supposed to be contained in the logs. Instead, these grades should be combined into a few groups with similar characteristics conforming to the grading rules for the species and region. Three such groups may be distinguished in softwoods, namely, finishing grades, factory or shop grades, and common grades. Based on the practice of "sound" scaling, a fourth group may be made to include grades which contain rot or other defects in sufficient quantity to cause their rejection in scaling logs.

Finishing grades include all of the so-called upper grades of lumber, characterized by freedom from all but a few small defects. These grades are suitable for use without being cut up, for purposes requiring appearance as the prime factor, combined with definite and sometimes considerable width and length.

These grades are used for outside and inside finish and for many purposes of manufacture. The entire piece is graded as a unit, any defect serving to reduce its grade as a whole.

Factory or Shop Grades. Boards suitable for factory or shop grades are such as will yield smaller pieces of upper grade material when ripped or cut up as to exclude or cull out disqualifying defects. In these grades, therefore, the piece is not graded as a unit but on the basis of the per cent of its volume that can be utilized. The remainder is rejected as refuse and may therefore contain defects of any character without affecting the grade of the piece.

Common Grades. As applied to lumber cut from conifers or "softwoods," common lumber is distinguished from the other two groups by a general coarseness of appearance caused by various defects or combinations of defects, such as numerous large or small knots, which not only render it unsuitable for the upper grades but prevent cuttings being made from it which would qualify it for factory grades.

Common lumber of this class is graded for the entire piece and finds its principal use in construction. Owing to the large volume of common lumber, in conifers, which constitutes from 60 to 95 per cent of the total output, this group may be subdivided in each given region. These specific common grades are not always given identical names any more than are the grades in the other two groups. The most widely accepted nomenclature is,

No. 1 Common,
No. 2 Common,
No. 3 Common.

357. Example of Grading Rules. *Southern Yellow Pine.—Finishing, or Upper Grades.* "A" Finishing, inch, $1\frac{1}{4}$, $1\frac{1}{2}$ and 2-inch, dressed one or two sides, up to and including 12 inches in width, must show one face practically clear of all defects, except that it may have such wane as would dress off if surfaced four sides.

13-inch and wider "A" finishing will admit two small defects or their equivalent.

"B" Finishing, inch, $1\frac{1}{4}$, $1\frac{1}{2}$ and 2-inch, dressed one or two sides, up to and including 10 inches in width, in addition to the equivalent of one split in end which should not exceed in length the width of the piece, will admit any two of the following or their equivalent of combined defects: slight torn grain, three pin knots, one standard knot, three small pitch pockets, one standard pitch pocket, one standard pitch streak, 5 per cent of sap stain, or firm red heart; wane not to exceed 1 inch in width, $\frac{1}{4}$-inch in depth and $\frac{1}{6}$ the length of the piece; small seasoning checks.

11-inch and wider " B " Finishing will admit three of the above defects or their equivalent, but sap stain or firm red heart shall not exceed 10 per cent.

Select Common Finishing, up to and including 10-inch in width will admit, in addition to the equivalent of one split in end which should not exceed in length the width of the piece, any two of the following, or their equivalent of combined defects: 25 per cent of sap stain, 25 per cent firm red heart, two standard pitch streaks, medium torn grain in three places, slight shake, seasoning checks that do not show an opening through, two standard pitch pockets, six small pitch pockets, two standard knots, six pin knots, wane 1 inch in width, $\frac{1}{2}$ inch in depth and one-third the length of the piece. Defective dressing or slight skips in dressing will also be allowed that do not prevent its use as finish without waste.

11 and 12-inch " C " Finishing will admit one additional defect or its equivalent. Pieces wider than 12 inches will admit two additional defects to those admitted in 10-inch or their equivalent, except sap stain, which shall not be increased.

Pieces otherwise as good as " B " will admit of twenty pin-worm holes.

Common Grades. No. 1 Common boards, dressed one or two sides, will admit any number of sound knots. The mean or average diameter of any one knot should not be more than 2 inches in stock 8 inches wide, nor more than $2\frac{1}{2}$ inches in stock 10 and 12 inches wide; two pith knots; the equivalent of one split, not to exceed in length the width of the piece; torn grain, pitch, pitch pockets, slight shake, sap stain, seasoning checks, firm redheart; wane $\frac{1}{2}$ inch deep on the edge not exceeding 1 inch in width and one-third the length of the piece, or its equivalent; and a limited number of pin-worm holes well scattered; or defects equivalent to the above.

No. 2 Common boards, dressed one or two sides; No. 2 Shiplap, Grooved Roofing, D. & M. and Barn Siding will admit knots not necessarily sound; but the mean or average diameter of any one knot shall not be more than one-third of the cross section if located on the edge, and shall not be more than one-half of the cross section if located away from the edge; if sound may extend one-half the cross section if located on the edge, except that no knot, the mean or average diameter of which exceeds 4 inches should be admitted; worm holes, splits one-fourth the length of the piece, wane 2 inches wide or through heart shakes, one-half the length of the piece; through rotten streaks $\frac{1}{2}$ inch wide one-fourth the length of the piece, or its equivalent of unsound red heart; or defects equivalent to the above.

A knot hole 2 inches in diameter will be admitted, provided the piece is otherwise as good as No. 1 Common.

Miscut 1-inch common boards which do not fall below $\frac{3}{4}$-inch in thickness shall be admitted in No. 2 Common, provided the grade of such thin stock is otherwise as good as No. 1 Common.

No. 3 Common boards, No. 3 Common Shiplap, D. & M. and Barn Siding is defective lumber, and will admit of coarse knots, knot holes, very wormy pieces, red rot, and other defects that will not prevent its use as a whole for cheap sheathing, or which will cut 75 per cent of lumber as good as No. 2 Common.

358. Relation between Grades of Lumber and Cull in Log Scaling. From the standpoint of the lumber trade, lumber which is merchantable, no matter what the extent and character of defects it contains, is placed in a recognized grade, while cull lumber is lumber which is not merchantable. Grades of common lumber below No. 3 are sawed from unsound or defective portions of logs, which would be culled in scaling. In mill-scale studies and in determining log grades, it is proper, therefore, to throw all grades under No. 3 Common into the group termed cull. In addition, the grade designated as No. 3 Common may in certain regions contain unsound material which would not be scaled on the basis of sound scale. Hence a portion of the No. 3 grade, if so constituted, plus all of the cull grades of lumber, when utilized, go to increase the amount of over-run secured in manufacture.

From one to three grades of lumber below No. 3 Common may be recognized, according to the species and region.

Common Grades Culled in Sound Scale of Logs. Southern Yellow Pine. No. 4 Common boards shall include all pieces that fall below the grade of No. 3 Common, excluding such pieces as will not be held in place by nailing, after wasting one-fourth the length of the piece by cutting into two or three pieces; mill inspection to be final.

359. Log Grades. Determination. The purpose of defining log grades is to furnish a basis for separating the logs into groups whose average value or price per 1000 board feet can be determined, instead of attempting to arrive at an average price for the entire run of logs. Three such groups permit of a sufficient differentiation for this purpose.

Where logs are not bought or sold, but standing timber is manufactured by the purchaser, log grades (§ 87) form the best basis for appraising the value of this timber.

The specification for determining the grade of logs must apply to the external appearance and dimensions of the log. In application, logs on the border line between two grades are usually thrown to the grade below, since a part of the surface is invisible. Log grades are based on

1. Minimum diameters and lengths.
2. Surface appearance, and presence of knots or visible defects.
3. Judgment of scaler, based on 1 and 2 as to the minimum per cent of upper or better grades of lumber contained therein.

The specifications for log grades are more elastic than for lumber grades, since the presence of a small per cent of high grade lumber may serve to offset serious defects and give the log the value of a grade from which it would be excluded if based solely on quantity or scale. These specifications should be drawn in such a manner as to furnish the most serviceable basis of subdivision of the existing range of quality found for the species and region, which object may be secured by modifying the requirements as to size and per cent of upper grades required for logs of first and second grades.

Log grades should be established only after thorough mill-scale studies, and by some agency similar to that of the United States Forest Service or a Lumber Manufacturers' Association, so as to secure uniformity over as wide an area as possible.

Within the limits of a log grade a certain variation in average quality will occur in different quantities of logs, owing to the preponderance of higher or lower grades of lumber within the limits set. The quality of the logs which form the basis of the mill-scale study may be better or poorer than the average, even after classification into grades. But as logs and timber stumpage are worth considerably less than lumber, it is unnecessary to attempt a greater refinement, nor could it be practically applied.

Diameter For logs of the best grade, diameter is a reliable guide. Up to a certain size, trees retain the branches, either alive or dead, and the central bole of the tree is filled with these knots. Stunted, slow-growing, and consequently small trees still have these knots, and during their growth, have made very little clear lumber. Large trees, on the other hand, even if no older, have laid on much clear wood outside of the knots.

The minimum diameter for the highest grade can be fixed to include practically all logs of this class, not barred by knots or defects. This diameter will vary with the same species in different regions, and for different species.

Effect of Defect upon Grades of Logs. The defect most easily seen, both in logs and standing timber, is a knot. In grading hardwood logs, one sound, bright knot, with a maximum diameter of 4 inches is taken as a standard defect. Other defects are compared with this knot, on the basis of an equal amount of damage to quality. These may be worm holes, smaller or larger knots, shake, rot, cat faces or fire scars. The maximum number of standard defects, or their equivalent, is prescribed for each grade of logs.

For conifers, a different system is employed, and the specifications lay stress on the possible percentage of yield of certain grades, with indication as to the general appearance and character of defect in logs which will yield this ratio.

Defects are of two classes, those which cause loss of grade, but no discount in total scale, i.e., sound defects, and those which require elimination from the scale of the defective part. To the first class belong sound knots, stain, firm red heart and pitch. In the second class fall rot, shake, fire scars, cat faces, and crook or sweep. Worm holes may be in either class, according to size and frequency.

In the grading of hardwood logs, no distinction is made, and the presence of more than two " standard " defects serves to throw the log into the lowest class, or No. 2, except when over 24 inches in diameter, when it must cut at least 75 per cent of No. 1 common and better lumber.

With conifers, the presence of either class of defect will not reduce the grade of a log as long as the minimum percentage of upper grades can still be secured. But in reality, the value of the log is greatly lessened by such defects. With increasing amounts of defect, the log is de-graded either to second or third grade, and finally is rejected as cull.

360. Examples of Log Grades. Hardwoods—National Hardwood Lumber Association, 1916 Oak, White and Red.

No. 1 logs. 2 inches of bright sap is no defect. Sap in excess of 2 inches is one standard defect.

No. 1 logs must be 24 inches and over in diameter.

24 to 29 inches inclusive will admit of one standard defect or its equivalent.

30 inch and over will admit of two standard defects or their equivalent.

Select. Select logs must be 18 inches and over in diameter.

2 inches of bright sap is no defect. Sap in excess of 2 inches is one standard defect.

18 to 21 inches wide inclusive must have ends and surface clear.

22 and 23 inches will admit of one standard defect or its equivalent.

24 inches and over will admit of one more standard defect than is admitted in No. 1 logs of same size.

No. 2 logs. No. 2 logs must be 16 inches and over in diameter.

Bright sap is not a defect in this grade.

16- and 17-inch will admit of one standard defect or its equivalent.

18 to 23 inches inclusive will admit of two standard defects or their equivalent.

24 inches and over must cut 75 per cent or more into No. 1 common and better lumber.

The grades for other species are similar.

Softwoods—Columbia River Log Scaling and Grading Bureau, Washington and Oregon, 1920.

No. 1 Logs. No. 1 logs shall be logs which, in the judgment of the scaler, will be suitable for the manufacture of lumber in the grades of No. 2 clear or better to an amount of not less than 50 per cent of the scaled contents.

No. 1 logs shall contain not less than six annual rings to the inch in the outer portion of the log equal to one-half of the log content; and No. 1 logs shall be straight grained to the extent of a variation of not more than 2 inches to the lineal foot for a space of 2 lineal feet equidistant from each end of the log.

Rings, rot, or any defect that may be eliminated in the scale, are permitted in a No. 1 log, providing their size and location do not prevent the log producing the required amount of No. 2 clear or better lumber.

A No. 1 log may contain a few small knots or well scattered pitch pockets as permitted in grades of No. 2 clear or better lumber; or may contain a very few grade defects so located that they do not prevent the production of the required amount of clear lumber.

No. 2 Logs. No. 2 logs shall be not less than 12 feet in length, having defects which prevent their grading No. 1, but which, in the judgment of the scaler, will be suitable for the manufacture of lumber, principally in the grades of No. 1 common or better.

No 3 Logs. No. 3 logs shall be not less than 12 feet in length, having defects which prevent their grading No. 2 but which, in the judgment of the scaler, will be suitable for the manufacture of inferior grades of lumber.

Cull Logs. Cull logs shall be any logs which do not contain $33\frac{1}{3}$ per cent of sound lumber.

Logs which contain considerable clear lumber but not sufficient to grade No. 1, and contain also large coarse knots or other grade defects of No. 3 quality, will be classed as No. 2 if the average value of the lumber falls in this class, regardless of its actual grade. Logs which are on the border line between two grades should be graded alternately or in equal amount in the upper and the lower grade.

361. Mill-Grade or Mill-scale Studies. In § 81 and § 82 it was shown that the log scale should make no attempt to measure the actual sawed contents, which is the sum of the scale, plus this over-run. It is equally impossible for the scaler to separate his scale into grades, for in doing so he would be compelled to substitute judgment for facts; yet the actual value of logs can be determined only by a knowledge of both of these factors.

When the sawed output of a run of logs has been tallied and totaled separately by grades, its comparison with the log scale shows for *the entire quantity scaled*, the average over-run per thousand board feet of scale, and the per cent represented by each grade produced. The value of the product of an average thousand feet B. M. log scale in terms of sawed lumber is determined by first multiplying the price of each grade of lumber sawed by the per cent of the grade in one thousand board feet, adding the by-products, and multiplying by the total per cent of over-run.

This general check, applied to an average run of logs, and termed the mill run, will serve to determine the value of similar average sizes and quality. But for timber averaging larger or better, or smaller, knottier and poorer, the true value can be obtained, by this method, only after sawing.

But individual logs of similar sizes possessing certain distinctive features, as shown by surface indications such as clearness, knots and other defects, will cut out about the same per cent of grades and values wherever found.

By using the log as the standard, it is possible to apply the results of mill-scale studies of separate logs to stands whose average quality may be entirely different from that which is being sawed, provided only that *some logs of all qualities* are analyzed. For this reason, mill-scale studies should be based on the separate analysis of the product of individual logs, by grades of lumber. Such studies determine, for logs of each diameter, length and grade, first, the over-run in sound lumber, and in all merchantable grades; second, the amount of each standard grade of rough boards, expressed in per cent of the total scale of the log, net and gross.

362. Method of Conducting Mill-scale Studies. A tabulation, classification and summary of the logs so analyzed permits, first, a correlation between logs of given sizes, appearance and defects, and the actual sawed contents in grades which these logs will produce, hence their actual value; second, the adoption of arbitrary specifications for separating the logs themselves into log classes or grades; third, a comparison of the value of logs of each size and grade with the cost of logging them, enabling both owner of stumpage and operator to determine both the lower limits of merchantability as to minimum size and per cent of sound lumber in a log which warrants its removal and manufacture, and in case only a portion of the merchantable stand is removed, to know the relative value and profit of removing certain definite classes and sizes of material and leaving others (§ 96).

The steps in a mill-scale study are:

1 Decision as to the exact number and designation of the grades of rough lumber to be tallied.

2. Scale and record of each log, on the deck. If log grades have already been adopted, the scaler assigns each log to its apparent grade. A full record would embrace the following items: number of log (serial); length, in feet and inches; position in tree, as butt, middle, top; species; average diameter inside bark at small end; at large end; width of sapwood; thickness of bark; scale, by standard log rule, full and net after deductions for cull defects; estimated log grade; description of defects, preferably graphic, on a diagram showing large and small ends, and both sides of logs. This record requires one man, an experienced log scaler, who will place a number on each log to coincide with his record. Logs scaled sound are given a special mark, and separated in the final tables.

3. Identification of this product of separate logs. A marker standing behind the head saw marks with crayon each piece sawed from a log. The number of the log is placed on the first few pieces. Different-colored crayons are used for alternate logs. A count may be made of the total number of pieces from a log, as a check on the tally. This work is made quite difficult by a resaw, which tends to mix the products of consecutive logs on the chains and requires the marking of both sides of the piece. Gang saws further complicate the study. The marker can also check logs scaled as sound for unseen defects appearing in sawing, and make final record of the logs which saw up sound.

4. Record of grades and sizes. An expert grader, familiar with the standard for the species and locality, will grade each piece. The record, kept on a separate sheet for each log, and given the log number, will show length, width, and grade, by pieces, and a recapitulation or summary for the log, giving in addition to the data copied from the scales, the total board-foot contents in each grade, and the per cent of the sound scale which this equals. This tally requires the services of a tallyman, making a crew of four men.

5. Additional data needed. (*a*) Data on per cent of total contents utilized embrace the measurement of the cubic contents of a log, and the analysis of the volume which goes into slabs, edgings, and sawdust.

(*b*) Data on sawing practice include gage of saws, actual widths and lengths of lumber sawed, efficiency of sawyers, methods of sawing, and the output or performance of mill.

(*c*) Data on the character of the timber and logs measured, to indicate the comparison with other tracts. whether of higher or lower quality.

6. Tables or compilation of results. The logs can be classified, first, into sound

and defective. Where log grades are used, these grades are also separated. Next, the logs in each separate class are sorted into diameter classes, 1-inch or 2-inch (volume based on differences of 100 board feet was used in the studies conducted in District 1, Missoula, Montana). As a result of this tabulation, the logs when originally classed by the scaler into grades by judgment, can be re-graded in accordance with actual specifications for the grades. A sample form of tabulation would be, by columns:

Diameter class.
Number of logs as a basis.
Average lengths of logs.
Per cent and value per 1000 board feet of each grade, represented in the product obtained.
Total lumber tally, excluding cull lumber sawed.
Over-run, excluding cull lumber sawed.
Tally of cull lumber sawed.
Over-run, including cull lumber sawed.
Net scale.
Per cent of total net scale in each class of logs.
Value per 1000 board feet, based on net tally.
Value per 1000 board feet, based on net scale.
Gross scale.
Per cent deducted for defect.

These data, shown thus for each class of logs, can be totaled for all logs, and averaged.

7. Deductions or summaries. Irregularities are sure to occur in the final summaries. These can frequently be evened off by means of curves. The final curves and tables should show, for each separate log grade, the per cent of each grade of lumber obtained for logs of each diameter class, and the value of the average log for the class.

Effect of Waste or Cull. Such studies indicate the effect of increasing amounts of waste or cull upon the value of the gross scale or log. Cull lumber may not reduce the sale value of the residual lumber cut from the log, but the cost of logging is based upon the actual size of the log, which is best measured by its gross scale. The value of the product divided by this total scale gives a more correct gage of the value of the whole log in terms of price per 1000 board feet, for the purpose of determining whether the log is merchantable.

A crew of five men can usually tally two hundred logs per day of average sizes. A single mill-scale study requires from one thousand to two thousand logs for best results

Instructions for Recording Data, U. S. Forest Service. Logs should be lettered A, B, C, etc., A being the butt log. The species may be written out or the atlas number may be used, thus: "Loblolly pine" or "P76." The log length should be measured to the nearest tenth of a foot. The crook may be measured by noting the distance in inches between a straight line connecting the ends of the log on the concave side and the log itself. If relative terms such as "V" (very crooked), "M" (moderately crooked), and "S" (slightly crooked) are used, they should be carefully defined. Thus, if the crook is more than one-half the diameter of the log the term "V" might be applied; if one-quarter to one-half the diameter it would be "M"; while less than one-quarter it would be "S." If practically straight indicate this by "O" after heading "Crook."

Form of Record for Mill-scale Studies, U. S. Forest Service

FORM 234
Revised July 1, 1912

Tree. . . . . *Log*. . . . .
(Number.) (Letter.)

Species. . . . .

Log length. . . . . *Crook*. . . . . *Knots*. . . . .

	LARGE END.	SMALL END.
D. i. b.,		
Width of bark,		
D. o. b.,		
Width of sap,		
Rings,		

Cubic feet — Peeled,	
Cubic feet — With bark,	
Full scale,	
Net scale,	
Sawed out,	

1	2	3

4	5	6	7

1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	

8	9	10	11	12

Remarks:. . . . .

. . . .

. . . . *Date*. . . . ., *191*

Knottiness may not always be of importance, but if it is recorded letters may be used, as for crook. Two diameters inside bark at right angles should be measured and the average recorded to the nearest tenth inch. The average width of bark, measured on a radius, should be recorded, care being taken to make the measurements where bark is not partly worn off. The width of sap, in case desired, should be measured along an average radius. In case the age at either end of the log is found it can be inserted opposite " Rings." If the cubic content of a log is found in the office it may be entered opposite " Cubic feet." " Full scale " means the number of board feet that would be tallied by the log scaler if the log were straight and sound. " Net scale " is the number of board feet tallied by the scaler after deducting for defects of any kind. " Sawed out " is the number of board feet of lumber actually sawed out.

The large spaces are for the dimensions of boards sawed out, each space being for a separate grade. The name of the grade may be written or stamped in at the head of the column. The total number of board feet of each grade sawed out should be entered opposite the proper grade number in the small spaces under " Sawed out," which is the grand total of these grade totals. The boards may be tallied thus: " $1 \times 3 \times 16$," meaning a board 1 inch thick, 3 inches wide, and 16 feet long. Fractions may be indicated thus: $3^1 \times 3^2 \times 12$ ($3\frac{1}{4}'' \times 3\frac{1}{2}'' \times 12'$). As a rule the thickness should be recorded to the nearest even quarter inch below, the width to the nearest inch below, and the length to the nearest foot below the actual measurement. In some cases it may be preferable to tally the number of board feet direct. This means that the number of board feet in a board is read from a rule and entered at once. Thus for a board $1'' \times 3'' \times 12'$, the figure 3 would be tallied.

APPENDIX B

THE MEASUREMENT OF PIECE PRODUCTS

363. Basis of Measurement. Any finished products of uniform or standard dimensions, manufactured or cut from trees or logs may be measured by tallying or counting the pieces. The size or contents of the standard piece determines its value, either directly or by conversion to cubic or board-foot contents. The relative value of pieces of different sizes is seldom directly proportional to their cubic volume, though for such products as mining timbers this may be true. But for piling and poles, value per cubic foot increases with increased length. The contents of sawed or hewn pieces of rectangular shape is easily computed in board feet. Finished pieces may be classed as round, hewn, or manufactured products. Squares and bolts intended for further manufacture may be sold by count (§ 9).

364. Round Products. Round products include poles, piling, posts, mine timber, and certain lesser products such as hop poles and converter poles. Practically all round pieces are intended for uses requiring durability against atmospheric and soil moisture, and strength to support weight or strains. Peeling reduces weight for transportation.

Durability differs markedly with different species; hence whenever two or more species are available, at least two classes of product are recognized, the first containing the more durable or resistant species, the second, those which decay more rapidly or require preservative treatment.

Round products are classed by length and diameter. Both minimum and maximum specifications are quoted for length. For diameter, the minimum is given for each grade, since an excess adds to strength of piece. Prices are fixed by grades.

Straightness is a quality necessary to strength, in poles and especially in piling. The degree of crook or sweep permitted in such products is always specified.

A minimum taper is desired in poles and piles, especially when long, in order to diminish weight in handling. The diameter or circumference at both ends of poles and piling is specified, and both minimum and maximum limits given, corresponding to specified top diameters. Such limitations must correspond to the average shape of the material available, both to insure strength and prevent rejection of too large a percentage of pieces.

Defects which will weaken the piece or decrease its durability serve to reject products of this character. The specifications are remarkably similar whether for poles, piles, mining timbers or cross ties. Such defects are shake, checks, splits, large coarse or rotten knots which weaken the piece, and rot. When the qualities of the piece for the use for which it is intended permit of knots, or of a certain amount of center or pipe rot, these defects may be permitted, especially if their exclusion would cause the rejection of a large percentage of the output. For poles, the presence of center rot requires an increased diameter at the butt, for acceptance of piece.

Round products as a class give almost complete utilization of the bolt or log, and of the tree. The ends of piling, cross ties, and butts of poles are cut square with a saw, and the only waste is the bark. Where there is a market for posts or small mine props, the tops are also utilized down to 3 or 4 inches. These small round products also permit the utilization of suppressed trees and small timber, thus reducing total per cent of waste in a stand to a minimum.

365. Poles. Standard poles are 20 feet or more in length, and are used principally for telegraph or telephone lines. Specifications are based usually on circumference rather than diameter. Since the ratio between the two measurements for a circle is 3.1416 to 1, and this is exceeded for eccentric cross sections, specifications, especially for large sizes, call for ¼ to 1 inch greater circumference than the proportion of 3 to 1 for dry poles and an extra ½ to ¾ inch for green or water-soaked poles.

White cedar, which furnishes the larger part of the poles utilized, is measured either by circumference or diameter. The specified relation of these measurements for peeled poles is,

TABLE LXVIII

Relation between Circumference and Diameter for White Cedar Poles

Seasoned poles, Top diameter. Inches	Seasoned poles, Circumference at top. Inches	Green or water-soaked poles, Circumference at top. Inches
4	12	12½
5	15	16
6	18½	19½
7	22	22¾

An excess of 6 inches in length is permitted, or 1 half-inch scant for every 5 feet in length.[1]

The standard specifications for Eastern white cedar poles, (American Telephone and Telegraph Company), are given below:

All poles shall be reasonably straight, well proportioned from butt to top, shall have both ends squared, the bark peeled, and all knots and limbs closely trimmed.

The dimensions of the poles shall be in accordance with the following table, the " top " measurement being the circumference at the top of the pole and the " butt " measurement the circumference, six (6) feet from the butt. The dimensions given are the minimum allowable circumferences at the points specified for measurement and are not intended to preclude the acceptance of poles of larger dimensions.

When the dimension at the butt is not given, the poles shall be reasonably well proportioned throughout their entire length. No pole shall be over six (6) inches longer or three (3) inches shorter than the length for which it is accepted. If any pole is more than six (6) inches longer than is required, it shall be cut back.

Quality and Defects of Timber. The wood of a dead pole is grayish in color. The presence of a black line on the edge of the sapwood (as seen on the butt) also shows that a pole is dead. No dead poles, and no poles having dead streaks covering more than one-quarter of their surface, shall be accepted under these specifications. Poles having dead streaks covering less than one-quarter of their surface shall have a circumference greater than otherwise required. The increase in the circumference shall be sufficient to afford a cross-sectional area of sound wood equivalent to that of sound pieces of the same class.

[1] Northwestern Cedarmen's Association.

TABLE LXIX

Minimum Dimensions of White Cedar Poles in Inches

Length of poles (Feet)	Classes A Top	A 6 feet from butt	B Top	B 6 feet from butt	C Top	C 6 feet from butt	D Top	D 6 feet from butt	E Top	F Top	G Top
	Circumference, Inches										
20	23½	33	21½	30	18¾	28½	18¼	26	17	15½	12½
22	23½	34	21½	31	18¾	29½	18¼	27	17	15½	12½
25	23½	36	21½	33	18¾	31½	18¼	28½	17	15½	12½
30	23½	40	21½	36	18¾	34½	18¼	31½	17	15½	12½
35	23½	43	21½	40	18¾	37½	18¼	34½	17	15½	
40	23½	47	21½	43	18¾	40	18¼	37½	17	15½	
45	23½	50	21½	46	18¾	43	18¼	40			
50	23½	53	21½	49	18¾	46	18¼	43			
55	23½	56	21½	52							
60	23½	59	21½	54							

No dark red or copper-colored poles, which when scraped do not show good live timber, shall be accepted under these specifications.

No poles having more than one complete twist for every twenty (20) feet in length, no cracked poles and no poles containing large season checks shall be accepted under these specifications.

No poles having " cat faces," unless they are small and perfectly sound and the poles have an increased diameter at the " cat face," and no poles having " cat faces " near the six (6) foot mark or within ten (10) feet of their tops, shall be accepted under these specifications.

No shaved poles shall be accepted under these specifications.

No poles containing sap rot, evidence of internal rot as disclosed by a careful examination of all black knots, hollow knots, woodpeckers' holes, or plugged holes; and no poles showing evidences of having been eaten by ants, worms or grubs shall be accepted under these specifications except that poles containing worm or grub marks below the six (6) foot mark will be accepted.

No poles having a short crook or bend, a crook or bend in two planes or a reversed curve shall be accepted under these specifications. The amount of sweep, measured between the (6) foot mark and the top of the pole, that may be present in poles acceptable under these specifications, is shown in the following tables:

35-foot poles shall not have a sweep of over 10½ inches.
40-foot poles shall not have a sweep of over 12 inches.
45-foot poles shall not have a sweep of over 9 inches.
50-foot poles shall not have a sweep of over 10 inches.
55-foot poles shall not have a sweep of over 11 inches.
60-foot poles shall not have a sweep of over 12 inches.

Poles having tops of the required dimensions must have sound tops. Poles having tops one (1) inch or more above the requirements in circumference may have one (1) pipe rot not more than one-half ($\frac{1}{2}$) inch in diameter. Poles with double tops or double hearts shall be free from rot where the two parts or hearts join.

No poles containing ring rot (rot in the form of a complete or partial ring) shall be accepted under these specifications. Poles having hollow hearts may be accepted under the conditions shown in the following table:

Average diameter or rot	Add to Butt Requirements		
	of 25 and 30-foot poles	of 35-, 40- and 45-foot poles	of 50-, 55-, 60- and 65-foot poles
2 inches	Nothing	Nothing	Nothing
3 inches	1 inch	Nothing	Nothing
4 inches	2 inches	Nothing	Nothing
5 inches	3 inches	1 inch	Nothing
6 inches	4 inches	2 inches	1 inch
7 inches	Reject	4 inches	2 inches
8 inches	Reject	6 inches	3 inches
9 inches	Reject	Reject	4 inches
10 inches	Reject	Reject	5 inches
11 inches	Reject	Reject	7 inches
12 inches	Reject	Reject	9 inches
13 inches	Reject	Reject	Reject

Scattered rot, unless it is near the outside of the pole, may be estimated as being the same as heart rot of equal area.

Poles with cup shakes (checks in the form of rings) which also have heart or star checks may be considered as equal to poles having hollow hearts of the average diameter of the cup shakes.

Western Red Cedar forms the main source of supply of poles in the West. The specifications for these poles permit a much smaller taper than for Eastern timber since the tree form is more cylindrical.

The specifications (American Telephone and Telegraph Company) are given in Table LXX, p. 470.

For *Southern Yellow Pine* poles for creosoting, the required dimensions are given in Table LXXI, p. 471.

Chestnut has been a standard pole timber but is rapidly disappearing in Eastern states because of the ravages of the chestnut blight. The specifications differ only slightly from those for white cedar, and are as follows:

Dimensions. Length. Poles shall not be over six (6) inches shorter or twenty-four (24) inches longer than the length specified in the order.

Circumference. Poles shall be classified with respect to their circumferences at six (6) feet above the butt and at their top in accordance with Table LXXII, p. 472. This table gives the minimum allowable circumference at six (6) feet above the butt and at the top for poles of each class and length listed and shall not preclude the acceptance of poles having greater circumferences at those points of measurement than those given in the table.

TABLE LXX

(Minimum Dimensions of Western Red Cedar Poles in Inches)

Length of poles (Feet)	A (Minimum top circumference 28). Circumference 6 feet from butt	B (Minimum top circumference 25). Circumference 6 feet from butt	C (Minimum top circumference 22). Circumference 6 feet from butt	D (Minimum top circumference $18\frac{1}{2}$). Circumference 6 feet from butt	E (Minimum top circumference 15)	F (Minimum top circumference 12)
	Inches					
20	30	28	26	24	No butt requirement	No butt requirement
22	32	30	27	25		
25	34	31	28	26		
30	37	34	30	28		
35	40	36	32	30		
40	43	38	34	32		
45	45	40	36	34		
50	47	42	38	36		
55	49	44	40	38		
60	52	46	41	39		
65	54	48	43			

(*Chestnut poles, continued*) *Shape.* No poles shall contain short crooks.

With respect to other deviations from straightness, poles required in the order to be of the "town" class shall be free from all deviations from straightness except sweep in one plane only. The amount of sweep between the top and the butt of these poles shall not be greater than that specified for their length in the Table LXXIII, p. 472.

Poles required by the order to be of "country" class may have sweep in two planes or sweep in two directions in one plane provided that a straight line connecting the center of the butt with the center of the top does not, at any intermediate point, pass through the external surfaces of the pole. Where sweep is in one plane and one direction only, the amount between the top and the butt shall not be greater than that specified for the length of the pole in Table LXXIV, p. 473.

366. Piling. All piles are peeled before measuring. Piling should show close grain or slow growth, and be straight, with a minimum taper. If a straight line drawn between the centers of the butt and top falls outside the peeled pile at any point the piece is usually rejected. Hence long piling brings a proportionally higher price. Specifications for piling prescribe minimum and maximum diameters for the butt, and a minimum top diameter. Examples of such specifications are shown in Table LXXV, p. 473.

Piling is sold by the linear foot, but the price per foot increases with length of stick. In Southern pine, piling is frequently measured by log scale, by taking the diameter at the middle of the log.

TABLE LXXI

MINIMUM DIMENSIONS OF SOUTHERN YELLOW PINE POLES IN INCHES—CLASSES

Length of poles (Feet)	A		B		C		D		E	
	Top	6 feet from butt	Top	6 feet from butt	Top	6 feet from butt	Top	6 feet from butt	Top	6 feet from butt
	Circumference, Inches									
20	22	29½	20	27	18	26	16	24	14	21
22	22	30½	20	28	18	27	16	25	14	22
25	22	32½	20	29½	18	28½	16	26	14	23
30	22	35	20	32	18	30½	16	28½	14	24½
35	22	38	20	34	18	32½	16	30	14	26
40	22	40	20	36	18	34½	16	32	14	27½
45	24	42½	22	38	20	36	18	33½		
50	24	44½	22	40	20	38	18	35		
55	24	47	22	42½	20	40				
60	24	49	22	44½	20	42				
65	24	51	22	47						
70	24	53	22	49						
75	24	55	22	51						
80	24	57								
85	24	59								
90	24	61								

Defects. Defects in piling are rot, loose or rotten knots, wind shake, twisted grain, checks or other defects which interfere with driving or durability.

367. Posts, Large Posts and Small Poles. *Standard fence posts* are cut, 7, 7½ or 8 feet long. Dimensions up to 10 feet are termed large posts, while lengths of 12 to 18 feet inclusive are small poles; the distinction being based partly on the uses to which they are put. Standard cedar posts may be 2 inches short, and ¼ inch scant in diameter when seasoned, but must be full if green or water-soaked.

Posts are graded by inch classes measured at top or small end. They will permit knots and other defects which will not weaken the piece for the purpose of a post. Cedar may contain a certain amount of center or pipe rot. White cedar posts may have a sweep of 4 inches. Western juniper and red cedar posts may have much greater sweep, provided it lies in one plane or "crooks one way."

Post material in round bolts whose diameter exceeds 6 to 7 inches, when not needed for corner or gate posts, is usually split into two or more fence posts whose cross-sectional area will equal or exceed that of round posts of the standard dimensions.

Posts must be cut from live timber and, in white cedar, rot or other defects are permitted which do not impair the strength of the post for uses of a fence post.

TABLE LXXII

Minimum Circumferences of Chestnut Poles in Inches

Length (Feet)	A		B		C		D		E		F		G
	Top	6 feet from butt	Top	6 feet from butt	Top	6 feet from butt	Top	6 feet from butt	Top	6 feet from butt	Top	6 feet from butt	Top
	Inches												
20	24	34	22	31	20	29	18	27	16	24	15	22	15
25	24	37	22	34	20	32	18	29	16	27	15	24	15
30	24	40	22	37	20	35	18	32	16	29	15	27	15
35	24	43	22	40	20	37	18	35	16	32	15	29	15
40	24	46	22	43	20	40	18	37	16	35	15	32	15
45	24	49	22	46	20	43	18	40	16	37			
50	24	52	22	49	20	46	18	43					
55	24	55	22	52	20	49							
60	24	58	22	55									
65	26	60	22	58									
70	26	62	22	60									
75	26	64	22	62									
80	26	66	22	64									
85	26	68	22	66									
90	26	70	22	68									

TABLE LXXIII

Maximum Sweep, Poles, Standard

Length of pole. Feet	Maximum sweep. Inches	Length of pole. Feet	Maximum sweep. Inches	Length of pole. Feet	Maximum sweep. Inches
20	4	45	9	70	14
25	5	50	10	75	15
30	6	55	11	80	16
35	7	60	12	85	17
40	8	65	13	90	18

Small cedar poles up to and including 18 feet in length may have a sweep of 4 inches, which for lengths of 16 to 18 feet is measured from a point 4 feet from the butt, in the manner prescribed for long poles.

Fire-killed lodgepole pine is accepted for poles and posts in the Rocky Mountains.

TABLE LXXIV

MAXIMUM SWEEP, POLES, COUNTRY

Length of pole. Feet	Maximum sweep. Inches	Length of pole. Feet	Maximum sweep. Inches	Length of pole. Feet	Maximum sweep. Inches
20	6	45	13½	70	21
25	7½	50	15	75	22½
30	9	55	16½	80	24
35	10½	60	18	85	25½
40	12	65	19½	90	27

TABLE LXXV

DIMENSIONS FOR PILING

Species, region or purchaser	Length. Feet	Minimum top diameter—Inches Not less than	Diameter limits, butt—Inches
Hardwoods—Eastern	20–35	6	12 and over
	40–50	6	14 and over
Panama Canal	Under 30	6	12 to 16
	30–50	6	12 to 18
California	Under 60	9	13 to 17
Southern Pacific R.R.	Over 60	9	13 to 20
A., T. & S. F. R.R.	Under 30	9	13 to 18
	30–40	9	14 to 18
	40–69	8	14 to 18
	70 and over	8	16 to 18

All classes of poles and posts are usually seasoned to decrease weight for transportation.

Fence stays are round or split pieces about 2 inches in diameter and 5 to 6 feet long. They are used between posts for wire fences as upright pieces not set in the ground, to which the wires are stapled to prevent their being spread apart by stock, and to reduce the number of posts required.

Converter poles, called also furnace poles and brands, are consumed in the process of refining copper. The Montana specifications call for poles with a top diameter of 3 to 4 inches and length of 24 feet. They should have as little taper as possible. Eastern brass mills use poles 25 to 40 feet long, 2 inches and over at top, and 5 inches and over at butt. The bark is not removed and poles must be green.

Standard California *hop poles* are made from split pieces 2 by 2 inches by 8 feet. In the East hop poles are usually made from round pieces of approximately the same dimensions.

368. Mine Timbers. Mine timber can be classed as stulls and props, lagging, shaft timbers and lumber, and mine ties. Stulls include round props used as posts, caps to connect pairs of opposite posts, and girts to connect posts lengthwise of the gallery. Their dimensions depend on size of galleries. Diameters vary from $5\frac{1}{2}$ to 24 inches. Square props are used for similar purposes. Small round props used principally in coal mines are termed mine props and run from 4 inches up in diameter and from 4 to 10 feet in length. These timbers are used to support the ground and must be straight, sound and free from knots that will impair the strength of the piece, or from defects affecting strength or durability.

Mine timber is bought by the linear foot, by classes based on top diameter. Split props must have a cross-sectional area in square inches equal to that of a round post of minimum specified diameter.

Pole lagging varies from $1\frac{1}{2}$ to 5 inches in diameter at small end and averages 16 feet in length. Four- to five-inch poles may be split. Lodgepole pine is the principal species used. Lagging is bought by the piece.

Mine Ties. Cross ties for mine tramways are usually 5 to $5\frac{1}{2}$ feet long but may be from 3 feet to 6 feet in length, and vary for individual mines, from 3 by 4 inches to 5 by 6 inches in diameter. Their small size makes a market for very small timber, which can be grown in 20 to 30 years. Ties are bought by count, and on basis of specifications.

Round mine timber of these classes and mine ties not only utilize the entire stick, but permit the almost complete utilization of the felled tree and of the stand. In fact, the tendency is to exploit young second-growth stands while still too small to bear seed, and under private management forests in mining regions are rapidly destroyed. The same conditions permit of thinnings in dense stands, the removal of small diseased trees and a short rotation, and under forest management offer very favorable conditions for profitable production of timber.

369. Cross Ties. Standard railroad cross ties are either hewn, with two parallel faces, or sawed to specified dimensions. Switch ties are sawed in sets of graduated lengths. Hewn ties, termed also pole ties, are made from round bolts hewn on two sides to produce parallel faces. Bolts 14 inches and over in diameter are usually split into two or more ties, hewn on four sides. Hewn ties are preferred to sawed ties as they are said to be more durable.

The standard specifications for cross ties of the U. S. Railroad Administration have since March, 1920, been adopted with slight changes by over two-thirds of the railroad mileage of the country. These specifications are shown graphically in Fig. 88. The specifications of the Pennsylvania Railroad System, based on the above, are as follows:

All ties shall be free from any defects that may impair their strength or durability as cross ties, such as decay,[1] splits, shakes, large or numerous holes [2] or knots,[3] or oblique fiber with slope greater than one in fifteen.

Ties from needle-leaved trees shall be of compact wood with not less than one-

[1] Ties must be rejected when decayed in the slightest degree, except that the following may be allowed: in cedar, "pipe or stump rot" up to $1\frac{1}{2}$ inches diameter and 15 inches deep; in cypress, "peck" up to the limitations as to holes; and, in pine, "blue sap stain."

[2] A large hole in woods other than cedar is one more than $\frac{1}{2}$ inch in diameter and 3 inches deep within, or one more than 1 inch in diameter and 3 inches deep outside the sections of the tie between 20 and 40 inches from its middle. Numerous holes are any number equaling a large hole in damaging effect.

[3] A large knot is one exceeding in width more than $\frac{1}{4}$ of the width of the surface on which it appears; but such a knot may be allowed if it occurs outside the sections of the tie between 20 and 40 inches from its middle. Numerous knots are any number equaling a large knot in damaging effect.

third summerwood when averaging five or more rings of annual growth per inch, or with not less than one-half summerwood in fewer rings, measured along any radius from the pith to the top of the tie. Ties of coarse wood, with fewer rings or less summerwood, will be accepted when specially ordered.

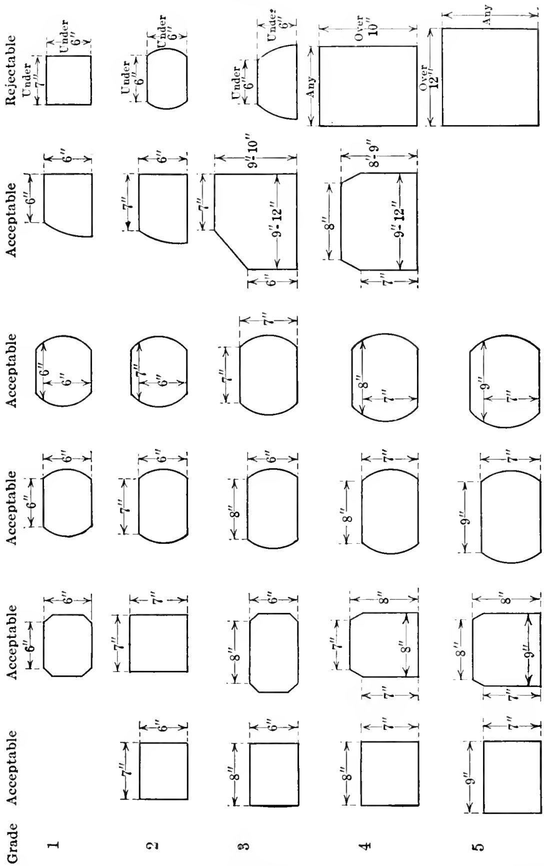

Fig. 88.—Standard sizes for cross ties accepted under U. S. Railway administration specifications.

Ties for use without preservative treatment shall not have sapwood wider than one-fourth the width of the top of the tie between 20 and 40 inches from the middle, and will be designated as " heart " ties. Those with more sapwood will be designated as " sap " ties.

Manufacture. Ties should be made from trees which have been felled not longer than one month.

All ties shall be straight, well manufactured,[1] cut square at the ends, have bottom and top parallel, and have bark entirely removed.

Dimensions. Before manufacturing ties, producers should ascertain which of the following grades will be accepted.

All ties shall be eight (8) feet six (6) inches long.

All ties shall measure as follows throughout both sections between 20 and 40 inches from the middle of the tie.

Grade	Sawed or hewn top, bottom and sides	Sawed or hewn top and bottom
1	None accepted	6″ thick×6″ wide on top
2	6″ thick×7″ wide on top	6″ thick×7″ wide on top 7″ thick×6″ wide on top
3	6″ thick×8″ wide on top	7″ thick×7″ wide on top 6″ thick×8″ wide on top
4	7″ thick×8″ wide on top	7″ thick×8″ wide on top
5	7″ thick×9″ wide on top	7″ thick×9″ wide on top

The above are minimum dimensions. Ties over one (1) inch more in thickness, over three (3) inches more in width, or over two (2) inches more in length will be degraded or rejected.

The top of the tie is the plane farthest from the pith of the tree, whether or not the pith is present in the tie.

CLASS U—TIES WHICH MAY BE USED UNTREATED

Group U*a*	Group U*b*	Group U*c*	Group U*d*
"Heart" Black Locust "Heart" White Oaks "Heart" Black Walnut	"Heart" Douglas Fir "Heart" Pines	"Heart" Cedars "Heart" Cypress "Heart" Redwood	"Heart" Catalpa "Heart" Chestnut "Heart" Red Mulberry "Heart" Sassafras

CLASS T—TIES WHICH SHOULD BE TREATED

Group T*a*	Group T*b*	Group T*c*	Group T*d*
Ashes Hickories "Sap" Black Locust Honey Locust Red Oaks "Sap" White Oaks "Sap" Black Walnut	"Sap" Cedars "Sap" Cypress "Sap" Douglas Fir Hemlock Larches "Sap" Pines "Sap" Redwood	Beech Birches Cherries Gums Hard Maples	"Sap" Catalpa "Sap" Chestnut Elms Hackberry Soft Maples "Sap" Mulberries "Sap" Sassafras Spruces Sycamore White Walnut

[1] A tie is not well manufactured when its surfaces are cut into with score-marks more than ½ inch deep or when its surfaces are not even.

370. Inspection and Measurement of Piece Products. Piece products, while graded on basis of dimensions, may be rejected either because of scant length, thickness or width, below requirements for lowest grade, or because of disqualifying defects. As these products are usually hauled to track or landing before being graded, considerable losses are occasioned by failure to conform to these specifications.

Although the character and amount of defect disqualifying a piece is usually prescribed as exactly as possible in the specifications, yet there is always considerable latitude exercised by the inspector, and the closeness or laxity of inspection may vary under instructions according to the demand for the product. This method of regulating supply supplements price adjustments and is open to serious objections. Good inspectors are thoroughly familiar with the qualities required of product and display a certain leniency in judging pieces which almost conform to specifications, provided the general run of the product is of good quality and workmanship. An inspector must command respect for his integrity and reputation for giving both parties a square deal.

The contents of various classes of piece products may be desired in terms of either cubic feet or board feet, in order to reduce different kinds of products to terms of a common standard or to simplify terms of payment or of record. Since most of these products are exposed to decay, and their value is measured by their resistance to fungus attacks, wood preservation is becoming more prevalent. Creosoting plants base their charges upon the cubic contents of such pieces as are treated as a whole.

The volume in cubic feet of poles of different dimensions is obtained by the formulæ given in § 27 by applying the values for cubic volumes of cylinders shown in Table LXXVII, Appendix C. The middle diameter measurement is the most accurate method for long poles, owing to the errors resulting from large butts.

For short poles, piling or mining stulls, the middle diameter measurement is probably the most satisfactory, and the table of cylindrical contents, or Humphrey caliper cordwood rule will suffice as a standard. Prices for mining stulls of different lengths and diameters sold by the U. S. Forest Service in Montana, are based upon the cubic contents of pieces of each standard size.

Smaller material such as fence posts or other round pieces may be converted to cubic feet by the same means.

Cross ties, on account of uniformity of size, are converted into their equivalent in board feet, and expressed either by average contents per tie, or by the number of ties per 1000 feet B. M. The average contents of hewn ties may be obtained by scaling a large number as logs 8 feet long. Or their cubic contents may be calculated from the thickness and face and reduced to board feet. The first method deducts for sawdust, and the second for squaring the tie. By either method a 6- by 8- inch tie scales about 32 board feet, or 30 ties per 1000 feet B.M. Ties $8\frac{1}{2}$ feet long, 7 inches thick by 9- inch face may average 40 to 44 board feet, or 25 to 23 per 1000 board feet.

Ratios are easily worked out on the basis of specifications and actual scale, and, once determined, may be substituted for measurement and applied to the count of ties, separately for each size class or grade of tie.

To reduce piling to board feet, pieces are sometimes scaled directly by a log rule. For small poles, posts or mining timbers the best method of conversion is to apply a converting factor to the cubic contents of pieces of given dimensions. Where total or actual cubic contents is measured, the best ratio is probably 5.5 board feet per cubic foot. If cubic contents includes only the cylinder measured at small end, a larger ratio is required.

The following table gives converting factors adopted by the U. S. Forest Service for products of various classes and dimensions:

TABLE LXXVI

Converting Factors, Piece Products to Board Feet

Product	Assumed dimensions	Equivalent in board feet
Long cord (acid wood, pulpwood, and distillation wood)	4′ × 5′ × 8′	625
Cord (spruce pulpwood)	4′ × 4′ × 8′	560
Cord (shingle bolts)	4′ × 4′ × 8′	600
Cord (fuel material averaging 5 inches or less in middle diameter)	4′ × 4′ × 8′ 4′ × 4′ × 8′	333⅓ 500
Cord (fuel material averaging 6 inches or more in middle diameter)	4′ × 4′ × 8′	
Load (in the rough)*	1 cord	333⅓
Pole (telephone)	7″ × 30′	60
Pole (telephone)	9″ × 30′	100
Pile	7″ × 30′	60
Stull	10″ × 16′	60
Tie (standard)	6″ × 8″ × 8′	30
Tie (2d class)	6″ × 7″ × 8′	20
Tie (narrow gauge)	6″ × 7″ × 6′	15
Tie (narrow gauge)	7″ × 8″ × 6½″	25
Tie (narrow gauge)	6″ × 7″ × 6½′	15
Tie	7″ × 8″ × 8′	30
Tie	7″ × 9″ × 8′	35
Derrick pole	7″ × 30′	60
Derrick set (11 pieces)	....	480

Product	Assumed dimensions	Equivalent in board feet
Trestle timber	10″ × 20′	70
Trestle timber	7″ × 12′	20
House log	8″ × 16′	30
House log	7″ × 16′	30
House log	7″ × 10′	15
Mining timber	6″ × 10′	10
Prop	6″ × 10′	10
Converter pole	4″ × 20′	10
Pole (fence)	16′	8
Pole (fence)	4″ × 20′	10
Lagging (6 pieces)	3″ × 6′	10
Cubic foot (round)	....	6
Rail (split)	½ pole	5
Piece	6″ × 7′	7
Stick	6″ × 7′	7
Slab	2″ × 6″ × 16′	2
Post	6″ × 7′	7
Post (circumference, 18 inches)	5.7″ × 7′	6
Post	5″ × 7′	5
Linear foot	10″ × 1′	3
Brace	4″ × 6′	2
Stay (fence)	2″ × 6′	½
Stay	4″ × 6′	2
Shake (roof)	⅜″ × 6″ × 2′	⅓
Shake (fruit tray)	3/16″ × 5″ × 32″	⅕
Picket	3″ × 5′	1
Stake (fence)	3″ × 5′	1

* This refers to small irregular pieces of wood and not to material that can be ricked for measurement.

APPENDIX C

TABLES USED IN FOREST MENSURATION

TABLE LXXVII

Cubic Contents of Cylinders and Multiple Table of Basal Area

This table serves a double purpose. It shows, in the first place, the contents of cylinders of different diameters and lengths. It may be used to determine the contents of logs whose diameters are measured at the middle. The table shows also the sums of the basal areas of different numbers of trees. Thus the total basal area of fifty-one trees 9 inches in diameter is 22.53 square feet. This table will be found very useful in computing the total basal area of different diameter classes in forest surveys.

The values given in this table are practically identical with those of the Humphrey Caliper Cordwood Rule (§ 121) for which it may be substituted. By multiplying the values in the table by 1.28 the contents of logs will be found in terms of stacked cubic feet of cordwood, p. 480.

TABLE LXXX

The International Log Rule for Saws Cutting a $\frac{1}{4}$ inch Kerf

This log rule is derived from the values of the International log rule for saws cutting a $\frac{1}{8}$-inch kerf, by applying the factor .904762 to the values in the former rule, computing to the third decimal place, and then rounding off the resultant values to the nearest 5 board feet. The values were computed and checked by Judson F. Clark in 1917, p. 493.

TABLE LXXXI[1]

Values in square feet for .16 and for .66 of the area of circles of different diameters, for computing the cubic volume of trees by the Schiffel formula, $V = (.16\ B + .66b)\ h$, p. 494.

[1] Computed by the U. S. Forest Service.

TABLE LXXVII

Cubic Contents of Cylinders and Multiple Table of Basal Areas

Length Feet, or Number of Trees.	Diameter in Inches.						
	2	3	4	5	6	7	8
	Contents of Cylinders in Cubic Feet, or Basal Areas in Square Feet.						
1	0.02	0.05	0.09	0.14	0.20	0.27	0.35
2	0.04	0.10	0.17	0.27	0.39	0.53	0.70
3	0.07	0.15	0.26	0.41	0.59	0.80	1.05
4	0.09	0.20	0.35	0.55	0.79	1.07	1.40
5	0.11	0.25	0.44	0.68	0.98	1.34	1.75
6	0.13	0.29	0.52	0.82	1.18	1.60	2.09
7	0.15	0.34	0.61	0.95	1.37	1.87	2.44
8	0.17	0.39	0.70	1.09	1.57	2.14	2.79
9	0.20	0.44	0.79	1.23	1.77	2.41	3.14
10	0.22	0.49	0.87	1.36	1.96	2.67	3.49
11	0.24	0.54	0.96	1.50	2.16	2.94	3.84
12	0.26	0.59	1.05	1.64	2.36	3.21	4.19
13	0.28	0.64	1.13	1.77	2.55	3.47	4.54
14	0.31	0.69	1.22	1.91	2.75	3.74	4.89
15	0.33	0.74	1.31	2.05	2.95	4.01	5.24
16	0.35	0.79	1.40	2.18	3.14	4.28	5.59
17	0.37	0.83	1.48	2.32	3.34	4.54	5.93
18	0.39	0.88	1.57	2.45	3.53	4.81	6.28
19	0.41	0.93	1.66	2.59	3.73	5.08	6.63
20	0.44	0.98	1.75	2.73	3.93	5.35	6.98
21	0.46	1.03	1.83	2.86	4.12	5.61	7.33
22	0.48	1.08	1.92	3.00	4.32	5.88	7.68
23	0.50	1.13	2.01	3.14	4.52	6.15	8.03
24	0.52	1.18	2.09	3.27	4.71	6.4	8.38
25	0.55	1.23	2.18	3.41	4.91	6.68	8.73
26	0.57	1.28	2.27	3.55	5.11	6.95	9.08
27	0.59	1.33	2.36	3.68	5.30	7.22	9.42
28	0.61	1.37	2.44	3.82	5.50	7.48	9.77
29	0.63	1.42	2.53	3.95	5.69	7.75	10.12
30	0.65	1.47	2.62	4.09	5.89	8.02	10.47
31	0.68	1.52	2.71	4.23	6.09	8.28	10.82
32	0.70	1.57	2.79	4.36	6.28	8.55	11.17
33	0.72	1.62	2.88	4.50	6.48	8.82	11.52
34	0.74	1.67	2.97	4.64	6.68	9.09	11.87
35	0.76	1.72	3.05	4.77	6.87	9.35	12.22
36	0.79	1.77	3.14	4.91	7.07	9.62	12.57
37	0.81	1.82	3.23	5.05	7.26	9.89	12.92

TABLE LXXVII—*Continued*

Length, Feet, or Number of Trees.	Diameter in Inches.						
	2	3	4	5	6	7	8
	Contents of Cylinders in Cubic Feet, or Basal Areas in Square Feet.						
38	0.83	1.87	3.32	5.18	7.46	10.16	13.26
39	0.85	1.91	3.40	5.32	7.66	10.42	13.61
40	0.87	1.96	3.49	5.45	7.85	10.69	13.96
41	0.89	2.01	3.58	5.59	8.05	10.96	14.31
42	0.92	2.06	3.67	5.73	8.25	11.22	14.66
43	0.94	2.11	3.75	5.86	8.44	11.49	15.01
44	0.96	2.16	3.84	6.00	8.64	11.76	15.36
45	0.98	2.21	3.93	6.14	8.84	12.03	15.71
46	1.00	2.26	4.01	6.27	9.03	12.29	16.06
47	1.03	2.31	4.10	6.41	9.23	12.56	16.41
48	1.05	2.36	4.19	6.54	9.42	12.83	16.76
49	1.07	2.41	4.28	6.68	9.62	13.10	17.10
50	1.09	2.45	4.36	6.82	9.82	13.36	17.45
51	1.11	2.50	4.45	6.95	10.01	13.63	17.80
52	1.13	2.55	4.54	7.09	10.21	13.90	18.15
53	1.16	2.60	4.63	7.23	10.41	14.16	18.50
54	1.18	2.65	4.71	7.36	10.60	14.43	18.85
55	1.20	2.70	4.80	7.50	10.80	14.70	19.20
56	1.22	2.75	4.89	7.64	11.00	14.97	19.55
57	1.24	2.80	4.97	7.77	11.19	15.23	19.90
58	1.27	2.85	5.06	7.91	11.39	15.50	20.25
59	1.29	2.90	5.15	8.04	11.58	15.77	20.60
60	1.31	2.95	5.24	8.18	11.78	16.04	20.94
61	1.33	2.99	5.32	8.32	11.98	16.30	21.29
62	1.35	3.04	5.41	8.45	12.17	16.57	21.64
63	1.37	3.09	5.50	8.59	12.37	16.84	21.99
64	1.40	3.14	5.59	8.73	12.57	17.10	2[illegible].[illegible]4
65	1.42	3.19	5.67	8.86	12.76	17.37	[illegible].69
66	1.44	3.24	5.76	9.00	12.96	17.64	23.04
67	1.46	3.29	5.85	9.14	13.16	17.91	23.39
68	1.48	3.34	5.93	9.27	13.35	18.17	23.74
69	1.51	3.39	6.02	9.41	13.55	18.44	24.09
70	1.53	3.44	6.11	9.54	13.74	18.71	24.43
71	1.55	3.49	6.20	9.68	13.94	18.97	24.78
72	1.57	3.54	6.28	9.82	14.14	19.24	25.13
73	1.59	3.58	6.37	9.95	14.33	19.51	25.48
74	1.61	3.63	6.46	10.09	14.53	19.78	25.83
75	1.64	3.68	6.54	10.23	14.73	20.04	26.18

TABLE LXXVII—*Continued*

Length, Feet, or Number of Trees.	Diameter in Inches.						
	9	10	11	12	13	14	15
	Contents of Cylinders in Cubic Feet, or Basal Areas in Square Feet.						
1	0.44	0.55	0.66	0.79	0.92	1.07	1.23
2	0.88	1.09	1.32	1.57	1.84	2.14	2.45
3	1.33	1.64	1.98	2.36	2.77	3.21	3.68
4	1.77	2.18	2.64	3.14	3.69	4.28	4.91
5	2.21	2.73	3.30	3.93	4.61	5.35	6.14
6	2.65	3.27	3.96	4.71	5.53	6.41	7.36
7	3.09	3.82	4.62	5.50	6.45	7.48	8.59
8	3.53	4.36	5.28	6.28	7.37	8.55	9.82
9	3.98	4.91	5.94	7.07	8.30	9.62	11.04
10	4.42	5.45	6.60	7.85	9.22	10.69	12.27
11	4.86	6.00	7.26	8.64	10.14	11.76	13.50
12	5.30	6.55	7.92	9.42	11.06	12.83	14.73
13	5.74	7.09	8.58	10.21	11.98	13.90	15.95
14	6.19	7.64	9.24	11.00	12.90	14.97	17.18
15	6.63	8.18	9.90	11.78	13.83	16.04	18.41
16	7.07	8.73	10.56	12.57	14.75	17.10	19.63
17	7.51	9.27	11.22	13.35	15.67	18.17	20.86
18	7.95	9.82	11.88	14.14	16.59	19.24	22.09
19	8.39	10.36	12.54	14.92	17.51	20.31	23.32
20	8.84	10.91	13.20	15.71	18.44	21.38	24.54
21	9.28	11.45	13.86	16.49	19.36	22.45	25.77
22	9.72	12.00	14.52	17.28	20.28	23.52	27.00
23	10.16	12.54	15.18	18.06	21.20	24.59	28.23
24	10.60	13.09	15.84	18.85	22.12	25.66	29.45
25	11.04	13.64	16.50	19.64	23.04	26.73	30 68
26	11.49	14.18	17.16	20.42	23.97	27.79	31.91
27	11.93	14.73	17.82	21.21	24.89	28.86	33.13
28	12.37	15.27	18.48	21.99	25.81	29.93	34.36
29	12.81	15.82	19.14	22.78	26.73	31.00	35.59
30	13.25	16.36	19.80	23.56	27.65	32.07	36.82
31	13.70	16.91	20.46	24.35	28.57	33.14	38.04
32	14.14	17.45	21.12	25.13	29.50	34.21	39.27
33	14.58	18.00	21.78	25.92	30.42	35.28	40.50
34	15.02	18.54	22.44	26.70	31.34	36.35	41.72
35	15.46	19.09	23.10	27.49	32.26	37.42	42.95
36	15.90	19.64	23.76	28.27	33.18	38.48	44.18
37	16.35	20.18	24.42	29.06	34.10	39.55	45.41

TABLE LXXVII—*Continued*

Length, Feet, or Number of Trees.	Diameter in Inches.						
	9	10	11	12	13	14	15
	Contents of Cylinders in Cubic Feet, or Basal Areas in Square Feet.						
38	16.79	20.73	25.08	29.85	35.03	40.62	46.63
39	17.23	21.27	25.74	30.63	35.95	41.69	47.86
40	17.67	21.82	26.40	31.42	36.87	42.76	49.09
41	18.11	22.36	27.06	32.20	37.79	43.83	50.31
42	18.56	22.91	27.72	32.99	38.71	44.90	51.54
43	19.00	23.45	28.38	33.77	39.64	45.97	52.77
44	19.44	24.00	29.04	34.56	40.56	47.04	54.00
45	19.88	24.54	29.70	35.34	41.48	48.11	55.22
46	20.32	25.09	30.36	36.13	42.40	49.17	56.45
47	20.76	25.63	31.02	36.91	43.32	50.24	57.68
48	21.21	26.18	31.68	37.70	44.24	51.31	58.90
49	21.65	26.73	32.34	38.48	45.17	52.38	60.13
50	22.09	27.27	33.00	39.27	46.09	53.45	61.36
51	22.53	27.82	33.66	40.06	47.01	54.52	62.59
52	22.97	28.36	34.32	40.84	47.93	55.59	63.81
53	23.41	28.91	34.98	41.63	48.85	56.66	65.04
54	23.86	29.45	35.64	42.41	49.77	57.73	66.27
55	24.30	30.00	36.30	43.20	50.70	58.80	67.49
56	24.74	30.54	36.96	43.98	51.62	59.86	68.72
57	25.18	31.08	37.62	44.77	52.54	60.93	69.95
58	25.62	31.63	38.28	45.55	53.46	62.00	71.18
59	26.07	32.18	38.94	46.34	54.38	63.07	72.40
60	26.51	32.73	39.60	47.12	55.31	64.14	73.63
61	26.95	33.27	40.26	47.91	56.23	65.21	74.86
62	27.39	33.82	40.92	48.69	57.15	66.28	76.09
63	27.83	34.36	41.58	49.48	58.07	67.35	77.31
64	28.27	34.91	42.24	50.27	58.99	68.42	78.54
65	28.72	35.45	42.90	51.05	59.91	69.49	79.77
66	29.16	36.00	43.56	51.84	60.84	70.55	80.99
67	29.60	36.54	44.22	52.62	61.76	71.62	82.22
68	30.04	37.09	44.88	53.41	62.68	72.69	83.45
69	30.48	37.63	45.54	54.19	63.60	73.76	84.68
70	30.93	38.18	46.20	54.98	64.52	74.83	85.90
71	31.37	38.72	46.86	55.76	65.44	75.90	87.13
72	31.81	39.27	47.52	56.55	66.37	76.97	88.36
73	32.25	39.82	48.18	57.33	67.29	78.04	89.58
74	32.69	40.36	48.84	58.12	68.21	79.11	90.81
75	33.13	40.91	49.50	58.91	69.13	80.18	92.04

TABLE LXXVII—*Continued*

Length, Feet, or Number of Trees.	Diameter in Inches.						
	16	17	18	19	20	21	22
	Contents of Cylinders in Cubic Feet, or Basal Areas in Square Feet.						
1	1.40	1.58	1.77	1.97	2.18	2.41	2.64
2	2.79	3.15	3.53	3.94	4.36	4.81	5.28
3	4.19	4.73	5.30	5.91	6.54	7.22	7.92
4	5.59	6.31	7.07	7.88	8.73	9.62	10.56
5	6.98	7.88	8.84	9.84	10.91	12.03	13.20
6	8.38	9.46	10.60	11.81	13.09	14.43	15.84
7	9.77	11.03	12.37	13.78	15.27	16.84	18.48
8	11.17	12.61	14.14	15.75	17.45	19.24	21.12
9	12.57	14.19	15.90	17.72	19.63	21.65	23.76
10	13.96	15.76	17.67	19.69	21.82	24.05	26.40
11	15.36	17.34	19.44	21.66	24.00	26.46	29.04
12	16.76	18.92	21.21	23.63	26.18	28.86	31.68
13	18.15	20.49	22.97	25.60	28.36	31.27	34.32
14	19.55	22.07	24.74	27.57	30.54	33.67	36.96
15	20.94	23.64	26.51	29.53	32.72	36.08	39.60
16	22.34	25.22	28.27	31.50	34.91	38.48	42.24
17	23.74	26.80	30.04	33.47	37.09	40.89	44.88
18	25.13	28.37	31.81	35.44	39.27	43.30	47.52
19	26.53	29.95	33.58	37.41	41.45	45.70	50.16
20	27.93	31.53	35.34	39.38	43.63	48.11	52.80
21	29.32	33.10	37.11	41.35	45.82	50.51	55.44
22	30.72	34.68	38.88	43.32	48.00	52.92	58.08
23	32.11	36.25	40.64	45.29	50.18	55.32	60.72
24	33.51	37.83	42.41	47.25	52.36	57.73	63.36
25	34.91	39.41	44.18	49.22	54.54	60.13	66.00
26	36.30	40.98	45.95	51.19	56.72	62.54	68.64
27	37.70	42.56	47.71	53.16	58.90	64.94	71.27
28	39.10	44.14	49.48	55.13	61.09	67.35	73.91
29	40.49	45.71	51.25	57.10	63.27	69.75	76.55
30	41.89	47.29	53.01	59.07	65.45	72.16	79.19
31	43.28	48.86	54.78	61.04	67.63	74.56	81.83
32	44.68	50.44	56.55	63.01	69.81	76.97	84.47
33	46.08	52.02	58.32	64.98	71.99	79.37	87.11
34	47.47	53.59	60.08	66.94	74.18	81.78	89.75
35	48.87	55.17	61.85	68.91	76.36	84.18	92.39
36	50.27	56.75	63.62	70.88	78.54	86.59	95.03
37	51.66	58.32	65.38	72.85	80.72	89.00	97.67

TABLE LXXVII—*Continued*

Length, Feet, or Number of Trees.	Diameter in Inches.						
	16	17	18	19	20	21	22
	Contents of Cylinders in Cubic Feet, or Basal Areas in Square Feet.						
38	53.06	59.90	67.15	74.82	82.90	91.40	100.31
39	54.45	61.47	68.92	76.79	85.08	93.81	102.95
40	55.85	63.05	70.69	78.76	87.27	96.21	105.59
41	57.25	64.63	72.45	80.73	89.45	98.62	108.23
42	58.64	66.20	74.22	82.70	91.63	101.02	110.87
43	60.04	67.78	75.99	84.66	93.81	103.43	113.51
44	61.44	69.36	77.75	86.63	95.99	105.83	116.15
45	62.83	70.93	79.52	88.60	98.17	108.24	118.79
46	64.23	72.51	81.29	90.57	100.36	110.64	121.43
47	65.62	74.08	83.06	92.54	102.54	113.05	124.07
48	67.02	75.66	84.82	94.51	104.72	115.45	126.71
49	68.42	77.24	86.59	96.48	106.90	117.86	129.35
50	69.81	78.81	88.36	98.45	109.08	120.26	131.99
51	71.21	80.39	90.12	100.42	111.26	122.67	134.63
52	72.61	81.97	91.89	102.39	113.45	125.07	137.27
53	74.00	83.54	93.66	104.35	115.63	127.48	139.91
54	75.40	85.12	95.43	106.32	117.81	129.89	142.55
55	76.79	86.69	97.19	108.29	119.99	132.29	145.19
56	78.19	88.27	98.96	110.26	122.17	134.70	147.83
57	79.59	89.85	100.73	112.23	124.35	137.10	150.47
58	80.98	91.42	102.49	114.20	126.54	139.51	153.11
59	82.38	93.00	104.26	116.17	128.72	141.91	155.75
60	83.78	94.58	106.03	118.14	130.90	144.32	158.39
61	85.17	96.15	107.80	120.11	133.08	146.72	161.03
62	86.57	97.73	109.56	122.07	135.26	149.13	163.67
63	87.96	99.30	111.33	124.04	137.44	151.53	166.31
64	89.36	100.88	113.10	126.01	139.63	153.94	168.95
65	90.76	102.46	114.86	127.98	141.81	156.34	171.59
66	92.15	104.03	116.63	129.95	143.99	158.75	174.23
67	93.55	105.61	118.40	131.92	146.17	161.15	176.87
68	94.95	107.19	120.17	133.89	148.35	163.56	179.51
69	96.34	108.76	121.93	135.86	150.53	165.96	182.15
70	97.74	110.34	123.70	137.83	152.72	168.37	184.79
71	99.13	111.91	125.47	139.80	154.90	170.77	187.43
72	100.53	113.49	127.23	141.76	157.08	173.18	190.07
73	101.93	115.07	129.00	143.73	159.26	175.59	192.71
74	103.32	116.64	130.77	145.70	161.44	177.99	195.35
75	104.72	118.22	132.54	147.67	163.62	180.40	197.99

TABLE LXXVII—*Continued*

Length, Feet, or Number of Trees.	Diameter in Inches.						
	23	24	25	26	27	28	29
	Contents of Cylinders in Cubic Feet, or Basal Areas in Square Feet.						
1	2.89	3.14	3.41	3.69	3.98	4.28	4.59
2	5.77	6.28	6.82	7.37	7.95	8.55	9.17
3	8.66	9.42	10.23	11.06	11.93	12.83	13.76
4	11.54	12.57	13.64	14.75	15.90	17.10	18.35
5	14.43	15.71	17.04	18.44	19.88	21.38	22.93
6	17.31	18.85	20.45	22.12	23.86	25.66	27.52
7	20.20	21.99	23.86	25.81	27.83	29.93	32.11
8	23.08	25.13	27.27	29.50	31.81	34.21	36.70
9	25.97	28.27	30.68	33.18	35.78	38.48	41.28
10	28.85	31.42	34.09	36.87	39.76	42.76	45.87
11	31.74	34.56	37.50	40.56	43.74	47.04	50.46
12	34.62	37.70	40.91	44.24	47.71	51.31	55.04
13	37.51	40.84	44.31	47.93	51.69	55.59	59.63
14	40.39	43.98	47.72	51.62	55.67	59.86	64.22
15	43.28	47.12	51.13	55.31	59.64	64.14	68.80
16	46.16	50.27	54.54	58.99	63.62	68.42	73.39
17	49.05	53.41	57.95	62.68	67.59	72.69	77.98
18	51.93	56.55	61.36	66.37	71.57	76.97	82.56
19	54.82	59.69	64.77	70.05	75.55	81.24	87.15
20	57.71	62.83	68.18	73.74	79.52	85.52	91.74
21	60.59	65.97	71.59	77.43	83.50	89.80	96.33
22	63.48	69.11	74.99	81.11	87.47	94.07	100.91
23	66.36	72.26	78.40	84.80	91.45	98.35	105.50
24	69.25	75.40	81.81	88.49	95.43	102.63	110.09
25	72.13	78.54	85.22	92.18	99.40	106.90	114.67
26	75.02	81.68	88.63	95.86	103.38	111.18	119.26
27	77.90	84.82	92.04	99.55	107.35	115.45	123.85
28	80.79	87.96	95.45	103.24	111.33	119.73	128.43
29	83.67	91.11	98.86	106.92	115.31	124.01	133.02
30	86.56	94.25	102.27	110.61	119.28	128.28	137.61
31	89.44	97.39	105.67	114.30	123.26	132.56	142.20
32	92.33	100.53	109.08	117.98	127.23	136.83	146.78
33	95.21	103.67	112.49	121.67	131.21	141.11	151.37
34	98.10	106.81	115.90	125.36	135.19	145.39	155.96
35	100.98	109.96	119.31	129.05	139.16	149.66	160.54
36	103.87	113.10	122.72	132.73	143.14	153.94	165.13
37	106.75	116.24	126.13	136.42	147.11	158.21	169.72

TABLE LXXVII—*Continued*

Length, Feet, or Number of Trees.	Diameter in Inches.						
	23	24	25	26	27	28	29
	Contents of Cylinders in Cubic Feet, or Basal Areas in Square Feet.						
38	109.64	119.38	129.54	140.11	151.69	162.49	174.30
39	112.52	122.52	132.94	143.79	155.07	166.77	178.89
40	115.41	125.66	136.35	147.48	159.04	171.04	183.48
41	118.30	128.81	139.76	151.17	163.02	175.32	188.06
42	121.18	131.95	143.17	154.85	167.00	179.59	192.65
43	124.07	135.09	146.58	158.54	170.97	183.87	197.24
44	126.95	138.23	149.99	162 23	174.95	188.15	201.83
45	129.84	141.37	153.40	165.92	178.92	192.42	206.41
46	132.72	144.51	156.8[illegible]	169.60	182.90	196.70	211.00
47	135.61	147.65	160.22	173.29	186.88	200.97	215.59
48	138.49	150.80	163.62	176.98	190.85	205.25	220.17
49	141.38	153.94	167.03	180.66	194.83	209.53	224.76
50	144.26	157.08	170.44	184.35	198.80	213.80	229.35
51	147.15	160.22	173.85	188.04	202.78	218.08	233.93
52	150.03	163.36	177.26	191.72	206.76	222.35	238.52
53	152.92	166.50	180.67	195.41	210.73	226.63	243.11
54	155.80	169.65	184.08	199.10	214.71	230.91	247.69
55	158.69	172.79	187.49	202.79	216.68	235.18	252.28
56	161.57	175.93	190.90	206.47	222.66	239.46	256.87
57	164.46	179.07	194.30	210.16	226.64	243.73	261.46
58	167.34	182.21	197.71	213.85	230.61	248.01	266.04
59	170.23	185.35	201.12	217.53	234.59	252.29	270.63
60	173.12	188.50	204.53	221.22	238.56	256.56	275.22
61	176.00	191.64	207.94	224.91	242.54	260.84	279.80
62	178.89	194.78	211.35	228.59	246.52	265.12	284.39
63	181.77	197.92	214.76	232.28	250.49	269.39	288.98
64	184.66	201 06	218.17	235.97	254.47	273.67	293.56
65	187.54	204.20	221.57	239.66	258.45	277.94	298.15
66	190.43	207.34	224.98	243.34	262.42	282.22	302.74
67	193.31	210.49	228.39	247.03	266.40	286.50	307.32
68	196.20	213.63	231.80	250.72	270.37	290.77	311.91
69	199.08	216.77	235.21	254.40	274.35	295.05	316.50
70	201.97	219.91	238.62	258.09	278.33	299.32	321.09
71	204.85	223.05	242.03	261.78	282.30	303.60	325.67
72	207.74	226.19	245.44	265.46	286.28	307.88	330.26
73	210.62	229.34	248.85	269.15	290.25	312.15	334.85
74	213.51	232.48	252.25	272.84	294.23	316.42	339.43
75	216.39	235.62	255.66	276.53	298.21	320.70	344.02

TABLE LXXVII—*Continued*

Length, Feet, or Number of Trees.	Diameter in Inches.						
	30	31	32	33	34	35	36
	Contents of Cylinders in Cubic Feet, or Basal Areas in Square Feet.						
1	4.91	5.24	5.59	5.94	6.30	6.68	7.07
2	9.82	10.48	11.17	11.88	12.61	13.36	14.14
3	14.73	15.72	16.76	17.82	18.92	20.44	21.21
4	19.63	20.97	22.34	23.76	25.22	26.73	28.27
5	24.54	26.21	27.93	29.70	31.53	33.41	35.34
6	29.45	31.45	33.51	35.64	37.83	40.09	42.41
7	34.36	36.69	39.10	41.58	44.14	46.77	49.48
8	39.27	41.93	44.68	47.52	50.44	53.45	56.55
9	44.18	47.17	50.27	53.46	56.75	60.13	63.62
10	49.09	52.41	55.85	59.40	63.05	66.81	70.69
11	54.00	57.66	61.44	65.34	69.36	73.49	77.75
12	58.90	62.90	67.02	71.27	75.66	80.18	84.82
13	63.81	68.14	72.61	77.21	81.97	86.86	91.89
14	68.72	73.38	78.19	83.15	88.27	93.54	98.96
15	73.63	73.62	83.78	89.09	94.58	100.22	106.03
16	78.54	83.86	89.36	95.03	100.88	106.90	113.10
17	83.45	89.10	94.95	100.97	107.18	113.58	120.17
18	88.36	94.35	100.53	106.91	113.49	120.26	127.23
19	93.27	99.59	106.12	112.85	119.80	126.95	134.30
20	98.17	104.83	111.70	118.79	126.10	133.63	141.37
21	103.08	110.07	117.29	124.73	132.41	140.31	148.44
22	107.99	115.31	122.87	130.67	138.71	146.99	155.51
23	112.90	120.55	128.46	136.61	145.02	153.67	162.58
24	117.81	125.79	134.04	142.55	151.32	160.35	169.65
25	122.72	131.04	139.63	148.49	157.63	167.03	176.71
26	127.63	136.28	145.21	154.43	163.93	173.71	183.78
27	132.54	141.52	150.80	160.37	170.24	180.40	190.85
28	137.44	146.76	156.38	166.31	176.54	187.08	197.92
29	142.35	152.00	161.97	172.25	182.85	193.76	204.99
30	147.26	157.24	167.55	178.19	189.15	200.44	212.06
31	152.17	162.48	173.14	184.13	195.45	207.12	219.13
32	157.08	167.73	178.72	190.07	201.76	213.80	226.19
33	161.99	172.97	184.31	196.01	208.06	220.48	233.26
34	166.90	178.21	189.89	201.95	214.37	227.17	240.33
35	171.81	183.45	195.48	207.88	220.68	233.85	247.40
36	176.71	188.69	201.06	213.82	226.98	240.53	254.47
37	181.62	193.93	206.65	219.76	233.28	247.21	261.54

TABLE LXXVII—*Continued*

Length, Feet, or Number of Trees.	Diameter in Inches.						
	30	31	32	33	34	35	36
	Contents of Cylinders in Cubic Feet, or Basal Areas in Square Feet.						
38	186.53	199.17	212.23	225.70	239.59	253.89	268.61
39	191.44	204.42	217.82	231.64	245.89	260.57	275.67
40	196.35	209.66	223.40	237.58	252.20	267.25	282.74
41	201.26	214.90	228.99	243.52	258.50	273.93	289.81
42	206.17	220.14	234.57	249.46	264.81	280.62	296.88
43	211.08	225.38	240.16	255.40	271.11	287.30	303.95
44	215.98	230.62	245.74	261.34	277.42	293.98	311.02
45	220.89	235.86	251.33	267.28	283.72	300.66	318.09
46	225.80	241.11	256.01	273.22	290.03	307.34	325.15
47	230.71	246.35	262.50	279.16	296.33	314.02	332.22
48	235.62	251.59	268.08	285.10	302.64	320.70	339.29
49	240.53	256.83	273.67	291.04	308.94	327.39	346.36
50	245.44	262.07	279.25	296.98	315.25	334.07	353.43
51	250.35	267.31	284.84	302.92	321.55	340.75	360.50
52	255.25	272.55	290.42	308.86	327.86	347.43	367.57
53	260.16	277.80	296.01	314.80	334.16	354.11	374.63
54	265.07	283.04	301.59	320.74	340.47	360.79	381.70
55	269.98	288.28	307.18	326.68	346.77	367.47	388.77
56	274.89	293.52	312.76	332.62	353.08	374.15	395.84
57	279.80	298.76	318.35	338.56	359.38	380.84	402.91
58	284.71	304.00	323.93	344.50	365.69	387.52	409.98
59	289.62	309.24	329.52	350.43	371.99	394.20	417.05
60	294.52	314.49	335.10	356.37	378.30	400.88	424.11
61	299.43	319.73	340.69	362.34	384.61	407.54	431.21
62	304.34	324.97	346.27	368.28	390.91	414.22	438.28
63	309.25	330.21	351.86	374.22	397.22	420.80	445.35
64	314.16	335.45	357.44	380.16	403.52	427.58	452.42
65	319.07	340.69	363.03	386.07	409.82	434.29	459.46
66	323.98	345.93	368.61	392.04	416.13	440.95	466.55
67	328.89	351.18	374.20	397.98	422.44	447.63	473.62
68	333.79	356.42	379.78	403.92	428.74	454.31	480.69
69	338.70	361.66	385.37	409.86	435.05	460.99	487.76
70	343.61	366.90	390.95	415.77	441.35	467.69	494.80
71	348.52	372.14	396.54	421.74	447.66	474.35	501.90
72	353.43	377.38	402.12	427.68	453.96	481.03	508.97
73	358.34	382.62	470.71	433.62	460.27	487.61	516.04
74	363.25	387.87	413.29	439.56	466.57	494.39	523.11
75	368.16	393.11	418.88	445.47	472.87	501.10	530.14

TABLE LXXVIII

Areas of Circles or Table of Basal Areas for Diameters to Nearest $\frac{1}{10}$ Inch

Diameter, Inches.	Area, Square Feet.	Diameter, Inches.	Area, Square Feet.	Diameter, Inches.	Area, Square Feet.	Diameter, Inches.	Area, Square Feet.	Diameter, Inches.	Area, Square Feet.	Diameter, Inches.	Area, Square Feet.
1.0	.006	2.0	.022	3.0	.049	4.0	.087	5.0	.136	6.0	.196
.1	.007	.1	.024	.1	.052	.1	.092	.1	.142	.1	.203
.2	.008	.2	.026	.2	.056	.2	.096	.2	.147	.2	.210
.3	.009	.3	.029	.3	.059	.3	.101	.3	.153	.3	.216
.4	.011	.4	.031	.4	.063	.4	.106	.4	.159	.4	.223
1.5	.012	2.5	.034	3.5	.067	4.5	.110	5.5	.165	6.5	.230
.6	.014	.6	.037	.6	.071	.6	.115	.6	.171	.6	.238
.7	.016	.7	.040	.7	.075	.7	.120	.7	.177	.7	.245
.8	.018	.8	.043	.8	.079	.8	.126	.8	.183	.8	.252
.9	.020	.9	.046	.9	.083	.9	.131	.9	.190	.9	.260
7.0	.267	8.0	.349	9.0	.442	10.0	.545	11.0	.660	12.0	.785
.1	.275	.1	.358	.1	.452	.1	.556	.1	.672	.1	.799
.2	.283	.2	.367	.2	.462	.2	.567	.2	.684	.2	.812
.3	.291	.3	.376	.3	.472	.3	.579	.3	.696	.3	.825
.4	.299	.4	.385	.4	.482	.4	.590	.4	.709	.4	.839
7.5	.307	8.5	.394	9.5	.492	10.5	.601	11.5	.721	12.5	.852
.6	.315	.6	.403	.6	.503	.6	.613	.6	.734	.6	.866
.7	.323	.7	.413	.7	.513	.7	.624	.7	.747	.7	.880
.8	.332	.8	.422	.8	.524	.8	.636	.8	.759	.8	.894
.9	.340	.9	.432	.9	.535	.9	.648	.9	.772	.9	.908
13.0	.922	14.0	1.069	15.0	1.227	16.0	1.396	17.0	1.576	18.0	1.767
.1	.936	.1	1.084	.1	1.244	.1	1.414	.1	1.595	.1	1.787
.2	.950	.2	1.100	.2	1.260	.2	1.431	.2	1.614	.2	1.807
.3	.965	.3	1.115	.3	1.277	.3	1.449	.3	1.632	.3	1.827
.4	.979	.4	1.131	.4	1.294	.4	1.467	.4	1.651	.4	1.847
13.5	.994	14.5	1.147	15.5	1.310	16.5	1.485	17.5	1.670	18.5	1.867
.6	1.009	.6	1.163	.6	1.327	.6	1.503	.6	1.689	.6	1.887
.7	1.024	.7	1.179	.7	1.344	.7	1.521	.7	1.709	.7	1.907
.8	1.039	.8	1.195	.8	1.362	.8	1.539	.8	1.728	.8	1.928
.9	1.054	.9	1.211	.9	1.379	.9	1.558	.9	1.748	.9	1.948

TABLE LXXVIII—*Continued*

Diameter Inches.	Area, Square Feet.	Diameter, Inches.	Area, Square Feet.	Diameter, Inches.	Area, Square Feet.	Diameter, Inches.	Area, Square Feet.	Diameter Inches.	Area, Square Feet.	Diameter Inches.	Area, Square Feet.
19.0	1.969	20.0	2.182	21.0	2.405	22.0	2.640	23.0	2.885	24.0	3.142
.1	1.990	.1	2.204	.1	2.428	.1	2.664	.1	2.910	.1	3.168
.2	2.011	.2	2.226	.2	2.451	.2	2.688	.2	2.936	.2	3.194
.3	2.032	.3	2.248	.3	2.474	.3	2.712	.3	2.961	.3	3.221
.4	2.053	.4	2.270	.4	2.498	.4	2.737	.4	2.986	.4	3.247
19.5	2.074	20.5	2.292	21.5	2.521	22.5	2.761	23.5	3.012	24.5	3.275
.6	2.095	.6	2.315	.6	2.545	.6	2.786	.6	3.038	.6	3.301
.7	2.117	.7	2.337	.7	2.568	.7	2.810	.7	3.064	.7	3.328
.8	2.138	.8	2.360	.8	2.592	.8	2.835	.8	3.089	.8	3.355
.9	2.160	.9	2.382	.9	2.616	.9	2.860	.9	3.115	.9	3.382

Diameter, Inches.	Area, Square Feet.	Diameter, Inches.	Area, Square Feet.	Diameter, Inches.	Area, Square Feet.	Diameter, Inches.	Area, Square Feet.	Diameter, Inches.	Area, Square Feet.
25.0	3.409	26.0	3.687	27.0	3.976	28.0	4.276	29.0	4.587
.1	3.436	.1	3.715	.1	4.006	.1	4.307	.1	4.619
.2	3.464	.2	3.744	.2	4.035	.2	4.337	.2	4.650
.3	3.491	.3	3.773	.3	4.065	.3	4.368	.3	4.682
.4	3.519	.4	3.801	.4	4.095	.4	4.399	.4	4.714
25.5	3.547	26.5	3.830	27.5	4.125	28.5	4.430	29.5	4.746
.6	3.574	.6	3.859	.6	4.155	.6	4.461	6	4.779
.7	3.602	.7	3.888	.7	4.185	.7	4.493	.7	4.811
.8	3.631	.8	3.917	.8	4.215	.8	4.524	.8	4.844
.9	3.659	.9	3.947	.9	4.246	.9	4.555	.9	4.876
30.0	4.909	31.0	5.241	32.0	5.585	33.0	5.940	34.0	6.305
35.0	6.681	36.0	7.069	37.0	7.467	38.0	7.876	39.0	8.296
40.0	8.727	41.0	9.168	42.0	9.621	43.0	10.085	44.0	10.559
45.0	11.045	46.0	11.541	47.0	12.048	48.0	12.566	49.0	13.095
50.0	13.635	51.0	14.186	52.0	14.748	53.0	15.321	54.0	15.904
55.0	16.499	56.0	17.104	57.0	17.721	58.0	18.348	59.0	18.986
60.0	19.635								

TABLE LXXIX

TABLES FOR THE CONVERSION OF THE METRIC TO THE ENGLISH SYSTEM AND VICE VERSA.

Hectares to Acres.	Acres to Hectares.
1= 2.47109	1= .40467
2= 4.94213	2= .80934
3= 7.41327	3=1.21401
4= 9.88436	4=1.61868
5=12.35545	5=2.02335
6=14.82654	6=2.42802
7=17.29763	7=2.83269
8=19.76872	8=3.23736
9=22.23981	9=3.64203

Kilos to Pounds.	Cubic Meters per Hectare to Cubic Feet per Acre.
1= 2.20462	1= 14.291
2= 4 40924	2= 28.582
3= 6.61386	3= 42.873
4= 8.81848	4= 57.164
5=11.02310	5= 71.455
6=13.22772	6= 85.746
7=15.43234	7=100.037
8=17.63696	8=114.328
9=19.84158	9=128.619

Centimeters to Inches.	Kilometers to Miles.
1= .39370423	1= .62137676
2= .78740846	2=1.24275352
3=1.18111269	3=1.86413028
4=1 57481692	4=2.48550704
5=1.96852115	5=3.10688380
6=2.36222538	6=3.72826056
7=2.75592961	7=4.34963732
8=3.14963384	8=4.97101408
9=3.54333807	9=5.59239084

Meters to Feet.	Cubic Meters to Cubic Feet.
1= 3.280869	1= 35.315617
2= 6.561738	2= 70.631234
3= 9.842607	3=105.946851
4=13.123476	4=141.262468
5=16.404345	5=176.578085
6=19.685214	6=211.893702
7=22.966083	7=247.209319
8=26.246952	8=282.524936
9=29.527821	9=317.840553

TABLE LXXX

The International Log Rule for Saws Cutting a $\frac{1}{4}$-inch Kerf.

Standard scale for seasoned lumber with $\frac{1}{16}$-inch shrinkage per 1-inch board, and saws cutting a $\frac{1}{4}$-inch kerf, or for green lumber, for saws cutting a $\frac{5}{16}$-inch kerf.

Diam.	Length of Log in Feet													Diam.
	8	9	10	11	12	13	14	15	16	17	18	19	20	
4	...	...	5	5	5	5	5	5	5	5	5	10	10	4
5	5	5	5	5	10	10	10	10	10	15	15	15	15	5
6	10	10	10	10	15	15	15	20	20	20	25	25	25	6
7	10	15	15	15	20	20	25	25	30	30	35	35	40	7
8	15	20	20	25	25	30	35	35	40	40	45	50	50	8
9	20	25	30	30	35	40	45	45	50	55	60	65	70	9
10	30	35	35	40	45	50	55	60	65	70	75	80	85	10
11	35	40	45	50	55	65	70	75	80	85	95	100	105	11
12	45	50	55	65	70	75	85	90	95	105	110	120	125	12
13	55	60	70	75	85	90	100	105	115	125	135	140	150	13
14	65	70	80	90	100	105	115	125	135	145	155	165	175	14
15	75	85	95	105	115	125	135	145	160	170	180	195	205	15
16	85	95	110	120	130	145	155	170	180	195	205	220	235	16
17	95	110	125	135	150	165	180	190	205	220	235	250	265	17
18	110	125	140	155	170	185	200	215	230	250	265	280	300	18
19	125	140	155	175	190	205	225	245	260	280	300	315	335	19
20	135	155	175	195	210	230	250	270	290	310	330	350	370	20
21	155	175	195	215	235	255	280	300	320	345	365	390	410	21
22	170	190	215	235	260	285	305	330	355	380	405	430	455	22
23	185	210	235	260	285	310	335	360	390	415	445	470	495	23
24	205	230	255	285	310	340	370	395	425	455	485	515	545	24
25	220	250	280	310	340	370	400	430	460	495	525	560	590	25
26	240	275	305	335	370	400	435	470	500	535	570	605	640	26
27	260	295	330	365	400	435	470	505	540	580	615	655	690	27
28	280	320	355	395	430	470	510	545	585	625	665	705	745	28
29	305	345	385	425	465	505	545	590	630	670	715	755	800	29
30	325	370	410	455	495	540	585	630	675	720	765	810	860	30
31	350	395	440	485	530	580	625	675	720	770	820	870	915	31
32	375	420	470	520	570	620	670	720	770	825	875	925	980	32
33	400	450	500	555	605	660	715	765	820	875	930	985	1045	33
34	425	480	535	590	645	700	760	815	875	930	990	1050	1110	34
35	450	510	565	625	685	745	805	865	925	990	1050	115	1175	35
36	475	540	600	665	725	790	855	920	980	1045	1115	1180	1245	36
37	505	570	635	700	770	835	905	970	1040	1110	1175	1245	1315	37
38	535	605	670	740	810	885	955	1025	1095	1170	1245	1315	1390	38
39	565	635	710	785	855	930	1005	1080	1155	1235	1310	1390	1465	39
40	595	670	750	825	900	980	1060	1140	1220	1300	1380	1460	1 40	40
41	625	705	785	870	950	1030	1115	1200	1280	1365	1450	1535	1620	41
42	655	740	825	910	995	1085	1170	1260	1345	1435	1525	1615	1705	42
43	690	780	870	955	1045	1140	1230	1320	1410	1505	1600	1695	1785	43
44	725	815	910	1005	1095	1195	1290	1385	1480	1580	1675	1775	1870	44
45	755	855	955	1050	1150	1250	1350	1450	1550	1650	1755	1855	1960	45
46	795	895	995	1100	1200	1305	1410	1515	1620	1730	1835	1940	2050	46
47	830	935	1040	1150	1255	1365	1475	1585	1695	1805	1915	2030	2140	47
48	865	975	1090	1200	1310	1425	1540	1655	1770	1885	2000	2115	2235	48
49	905	1020	1135	1250	1370	1485	1605	1725	1845	1965	2085	2205	2330	49
50	940	1060	1185	1305	1425	1550	1675	1795	1920	2045	2175	2300	2425	50
51	980	1105	1235	1360	1485	1615	1745	1870	2000	2130	2265	2395	2525	51
52	1020	1150	1285	1415	1545	1680	1815	1945	2080	2215	2355	2490	2625	52
53	1060	1195	1335	1470	1605	1745	1885	2025	2165	2305	2445	2590	2730	53
54	1100	1245	1385	1530	1670	1815	1960	2100	2245	2395	2540	2690	2835	54
55	1145	1290	1440	1585	1735	1885	2035	2185	2330	2485	2640	2790	2945	55
56	1190	1340	1495	1645	1800	1955	2110	2265	2420	2575	2735	2895	3050	56
57	1230	1390	1550	1705	1865	2025	2185	2345	2510	2670	2835	3000	3165	57
58	1275	1440	1605	1770	1930	2100	2265	2430	2600	2770	2935	3105	3275	58
59	1320	1490	1660	1830	2000	2170	2345	2515	2690	2865	3040	3215	3390	59
60	1370	1545	1720	1895	2070	2250	2425	2605	2785	2965	3145	3325	3510	60

Formula: $\{(D^2 \times 0.22) - 0.71D\} \times 0.904762$ for 4-foot sections.

Taper allowance: $\frac{1}{2}$ inch per 4 feet lineal.

TABLE LXXXI

Tables for Values in Schiffel's Formula for Cubic Volumes of Entire Stems.

This table is for use in calculating the cubic contents of trees by a short method (Schiffel's formula):

$$V = H(0.16B + 0.66b).$$

The field measurements necessary for this calculation are the diameter breast-high and the diameter at the middle height of the tree. To find the volume look up 0.16 of the area corresponding to the D.B.H. of the tree. Add to this 0.66 of the area corresponding to the diameter at the middle height. The sum of the two multiplied by the height of the tree equals the total volume of the tree in cubic feet. Thus, if the total height of the tree is 62.5 feet, the diameter breast-high 10.4 inches, and the diameter at the middle 8.1 inches, from tables $0.16B$ and $0.66b$ it is found that the areas corresponding ot these diameters are 0.094 and 0.236, respectively. Their sum, 0.330, multiplied by the height, 62.5, equals the volume, 20.6 cubic feet.

Diameter.	0.16 of the Area of a Circle at Breast Height (0.16*B*)									
Inches	0.0 Sq. ft.	0.1 Sq. ft.	0.2 Sq. ft.	0.3 Sq. ft.	0.4 Sq. ft.	0.5 Sq. ft.	0.6 Sq. ft.	0.7 Sq. ft.	0.8 Sq. ft.	0.9 Sq. ft.
1	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.003	0.003	0.003
2	.003	.004	.004	.005	.005	.005	.006	.006	.007	.007
3	.008	.008	.009	.010	.010	.011	.011	.012	.013	.013
4	.014	.015	.015	.016	.017	.018	.018	.019	.020	.021
5	.022	.023	.024	.025	.025	.026	.027	.028	.029	.030
6	.031	.032	.034	.035	.036	.037	.038	.039	.040	.042
7	.043	.044	.045	.047	.048	.049	.050	.052	.053	.054
8	.056	.057	.059	.060	.062	.063	.065	.066	.068	.069
9	.071	.072	.074	.075	.077	.079	.080	.082	.084	.086
10	.087	.089	.091	.093	.094	.096	.098	.100	.102	.104
11	.106	.108	.109	.111	.113	.115	.117	.119	.122	.124
12	.126	.128	.130	.132	.134	.136	.139	.141	.143	.145
13	.147	.150	.152	.154	.157	.159	.161	.164	.166	.169
14	.171	.173	.176	.178	.181	.183	.186	.189	.191	.194
15	.196	.199	.202	.204	.207	.210	.212	.215	.218	.221
16	.223	.226	.229	.232	.235	.238	.240	.243	.246	.249
17	.252	.255	.258	.261	.264	.267	.270	.273	.276	.280
18	.283	.286	.289	.292	.295	.299	.302	.305	.308	.312
19	.315	.318	.322	.325	.328	.332	.335	.339	.342	.346
20	.349	.353	.356	.360	.363	.367	.370	.374	.378	.381
21	.385	.389	.392	.396	.400	.403	.407	.411	.415	.419
22	.422	.426	430	.434	.438	.442	.446	.450	.454	.458
23	.462	.466	.470	.474	.478	.482	.486	.490	.494	.498
24	.503	.507	.511	.515	.520	.524	.528	.532	.537	.541
25	.545	.550	.554	.559	.563	.567	.572	.576	.581	.585
26	.590	.594	.599	.604	.608	.613	.617	.622	.627	.631
27	.636	.641	.646	.650	.655	.660	.665	.670	.674	.679
28	.684	.689	.694	.699	.704	.709	.714	.719	.724	.729
29	.734	.739	.744	.749	.754	.759	.765	.770	.775	.780
30	.785	.791	.796	.801	.806	.812	.817	.822	.828	.833
31	.839	.844	.849	.855	.860	.866	.871	.877	.882	.888
32	894	.899	.905	.910	.916	.922	.927	.933	.939	.945
33	.950	.956	.962	.968	.974	.979	.985	.991	.997	1.003
34	1.009	1.015	1.021	1.027	1.033	1.039	1.045	1.051	1.057	1.063
35	1.069	1.075	1.081	1.087	1.094	1.100	1.106	1.112	1.118	1.125

TABLE LXXXI—*Continued*

Diameter.	0.16 of the Area of a Circle at Breast Height (0.16*B*)									
Inches	0.0 Sq. ft.	0.1 Sq. ft.	0.2 Sq. ft.	0.3 Sq. ft.	0.4 Sq. ft.	0.5 Sq. ft.	0.6 Sq. ft.	0.7 Sq. ft.	0.8 Sq. ft.	0.9 Sq. ft.
36	1.131	1.137	1.144	1.150	1.156	1.163	1.169	1.175	1.182	1.188
37	1.195	1.201	1.208	1.214	1.221	1.227	1.234	1.240	1.247	1.254
38	1.260	1.267	1.273	1.280	1.287	1.294	1.300	1.307	1.314	1.321
39	1.327	1.334	1.341	1.348	1.355	1.362	1.368	1.375	1.382	1.389
40	1.396	1.403	1.410	1.417	1.424	1.431	1.438	1.446	1.453	1.460
41	1.467	1.474	1.481	1.488	1.496	1.503	1.510	1.517	1.525	1.532
42	1.539	1.547	1.554	1.561	1.569	1.576	1.584	1.591	1.599	1.606
43	1.614	1.621	1.629	1.636	1.644	1.651	1.659	1.667	1.674	1.682
44	1.689	1.697	1.705	1.713	1.720	1.728	1.736	1.744	1.751	1.759
45	1.767	1.775	1.783	1.791	1.799	1.807	1.815	1.823	1.831	1.839
46	1.847	1.855	1.863	1.871	1.879	1.887	1.895	1.903	1.911	1.920
47	1.928	1.936	1.944	1.952	1.961	1.969	1.977	1.986	1.994	2.002
48	2.011	2.019	2.027	2.037	2.044	2.053	2.061	2.070	2.078	2.087
49	2.095	2.104	2.112	2.121	2.130	2.138	2.147	2.156	2.164	2.173
50	2.182	2.190	2.199	2.208	2.217	2.226	2.234	2.243	2.252	2.261
51	2.270	2.279	2.288	2.297	2.306	2.315	2.324	2.333	2.342	2.351
52	2.360	2.369	2.378	2.387	2.396	2.405	2.414	2.424	2.433	2.442
53	2.451	2.461	2.470	2.479	2.488	2.498	2.507	2.516	2.526	2.535
54	2.545	2.554	2.564	2.573	2.583	2.592	2.602	2.611	2.621	2.630
55	2.640	2.649	2.659	2.669	2.678	2.688	2.698	2.707	2.717	2.727
56	2.737	2.746	2.756	2.766	2.776	2.786	2.796	2.806	2.815	2.825
57	2.835	2.845	2.855	2.865	2.875	2.885	2.895	2.905	2.915	2.926
58	2.936	2.946	2.956	2.966	2.976	2.986	2.997	3.007	3.017	3.027
59	3.038	3.048	3.058	3.069	3.079	3.089	3.100	3.110	3.121	3.131
60	3.142	3.152	3.163	3.173	3.184	3.194	3.205	3.215	3.226	3.237
61	3.247	3.258	3.269	3.279	3.290	3.301	3.311	3.322	3.333	3.344
62	3.355	3.365	3.376	3.387	3.398	3.409	3.420	3.431	3.442	3.453
63	3.464	3.475	3.486	3.497	3.508	3.519	3.530	3.541	3.552	3.563
64	3.574	3.586	3.597	3.608	3.619	3.630	3.642	3.653	3.664	3.676
65	3.687	3.698	3.710	3.721	3.733	3.744	3.755	3.767	3.778	3.790
66	3.801	3.813	3.824	3.836	3.848	3.859	3.871	3.882	3.894	3.906
67	3.917	3.929	3.941	3.953	3.964	3.976	3.988	4.000	4.012	4.023
68	4.035	4.047	4.059	4.071	4.083	4.095	4.107	4.119	4.131	4.143
69	4.155	4.167	4.179	4.191	4.203	4.215	4.227	4.239	4.252	4.264
70	4.276	4.288	4.301	4.313	4.325	4.337	4.350	4.362	4.374	4.387
71	4.399	4.412	4.424	4.436	4.449	4.461	4.474	4.486	4.499	4.511
72	4.524	4.536	4.549	4.562	4.574	4.587	4.600	4.612	4.625	4.638
73	4.650	4.663	4.676	4.689	4.702	4.714	4.727	4.740	4.753	4.766
74	4.779	4.792	4.805	4.818	4.831	4.844	4.857	4.870	4.883	4.896
75	4.909	4.922	4.935	4.948	4.961	4.975	4.988	5.001	5.014	5.027
76	5.041	5.054	5.067	5.080	5.094	5.107	5.120	5.134	5.147	5.161
77	5.174	5.187	5.201	5.214	5.228	5.241	5.255	5.269	5.282	5.296
78	5.309	5.323	5.337	5.350	5.364	5.378	5.391	5.405	5.419	5.433
79	5.446	5.460	5.474	5.488	5.502	5.515	5.529	5.543	5.557	5.571
80	5.585	5.599	5.613	5.627	5.641	5.655	5.669	5.683	5.697	5.711

TABLE LXXXI—*Continued*

Diameter.	0.66 of the Area of a Circle at the Middle Height of the Tree (0.66*B*)									
Inches	0.0 Sq. ft.	0.1 Sq. ft.	0.2 Sq. ft.	0.3 Sq. ft.	0.4 Sq. ft.	0.5 Sq. ft.	0.6 Sq. ft.	0.7 Sq. ft.	0.8 Sq. ft.	0.9 Sq. ft.
1	0.004	0.004	0.005	0.006	0.007	0.008	0.009	0.010	0.012	0.013
2	.014	.016	.017	.019	.021	.023	.024	.026	.028	.030
3	.032	.035	.037	.039	.042	.044	.047	.049	.052	.055
4	.058	.061	.064	.067	.070	.073	.076	.080	.083	.086
5	.090	.094	.097	.101	.105	.109	.113	.117	.121	.125
6	.130	.134	.138	.143	.147	.152	.157	.162	.166	.171
7	.176	.182	.187	.192	.197	.202	.208	.213	.219	.225
8	.230	.236	.242	.248	.254	.260	.266	.273	.279	.285
9	.292	.298	.305	.311	.318	.325	.332	.339	.346	.353
10	.360	.367	.375	.382	.389	.397	.405	.412	.420	.428
11	.436	.444	.452	.460	.468	.476	.484	.493	.501	.510
12	.518	.527	.536	.545	.554	.563	.572	.581	.590	.599
13	.608	.618	.627	.637	.646	.656	.666	.676	.686	.696
14	.706	.716	.726	.736	.746	.757	.767	.778	.788	.799
15	.810	.821	.832	.843	.854	.865	.876	.887	.899	.910
16	.922	.933	.945	.956	.968	.980	.992	1.004	1.016	1.028
17	1.040	1.053	1.065	1.077	1.090	1.102	1.115	1.128	1.140	1.153
18	1.166	1.179	1.192	1.205	1.219	1.232	1.245	1.259	1.272	1.286
19	1.299	1.313	1.327	1.341	1.355	1.369	1.383	1.397	1.441	1.426
20	1.440	1.454	1.469	1.483	1.498	1.513	1.528	1.542	1.557	1.572
21	1.587	1.603	1.618	1.633	1.649	1.664	1.680	1.695	1.711	1.726
22	1.742	1.758	1.774	1.790	1.806	1.822	1.839	1.855	1.871	1.888
23	1.904	1.921	1.937	1.954	1.971	1.988	2.005	2.022	2.039	2.056
24	2.073	2.091	2.108	2.126	2.143	2.161	2.178	2.196	2.214	2.232
25	2.250	2.268	2.286	2.304	2.322	2.341	2.359	2.378	2.396	2.415
26	2.433	2.452	2.471	2.490	2.509	2.528	2.547	2.566	2.585	2.605
27	2.624	2.644	2.663	2.683	2.703	2.722	2.742	2.762	2.782	2.802
28	2.822	2.842	2.863	2.883	2.903	2.924	2.944	2.965	2.986	3.006
29	3.027	3.048	3.069	3.090	3.111	3.133	3.154	3.175	3.197	3.218
30	3.240	3.261	3.283	3.305	3.327	3.349	3.371	3.393	3.415	3.437
31	3.459	3.482	3.504	3.527	3.549	3.572	3.595	3.617	3.640	3.663
32	3.686	3.709	3.732	3.756	3.779	3.802	3.826	3.849	3.873	3.896
33	3.920	3.944	3.968	3.992	4.016	4.040	4.064	4.088	4.112	4.137
34	4.161	4.186	4.210	4.235	4.260	4.285	4.309	4.334	4.359	4.385
35	4.410	4.435	4.460	4.486	4.511	4.537	4.562	4.588	4.614	4.639
36	4.665	4.691	4.717	4.743	4.769	4.796	4.822	4.848	4.875	4.901
37	4.928	4.955	4.981	5.008	5.035	5.062	5.089	5.116	5.143	5.171
38	5.198	5.225	5.253	5.280	5.308	5.336	5.363	5.391	5.419	5.447
39	5.475	5.503	5.532	5.560	5.588	5.616	5.645	5.673	5.702	5.731
40	5.760	5.788	5.817	5.846	5.875	5.904	5.934	5.963	5.992	6.022
41	6.051	6.081	6.110	6.140	6.170	6.200	6.230	6.260	6.290	6.320
42	6.350	6.380	6.411	6.441	6.471	6.502	6.533	6.563	6.594	6.625
43	6.656	6.687	6.718	6.749	6.780	6.812	6.843	6.874	6.906	6.937
44	6.969	7.001	7.033	7.064	7.096	7.128	7.160	7.193	7.225	7.257
45	7.290	7.322	7.354	7.387	7.420	7.452	7.485	7.518	7.551	7.584
46	7.617	7.650	7.683	7.717	7.750	7.784	7.817	7.851	7.884	7.918
47	7.952	7.986	8.020	8.054	8.088	8.122	8.156	8.190	8.225	8.259
48	8.294	8.328	8.363	8.404	8.433	8.467	8.502	8.537	8.573	8.608
49	8.643	8.678	8.714	8.749	8.785	8.820	8.856	8.892	8.927	8.963
50	8.999	9.035	9.072	9.108	9.144	9.180	9.217	9.253	9.290	9.326

TABLE LXXXII

Breast-high Form Factors

For Various Heights and Form Classes

Total Cubic Volume of Stem

Height in feet (5-foot classes)	Form Class													Height in feet (5-foot classes)
	0.50	0.525	0.55	0.575	0.60	0.625	0.65	0.675	0.70	0.725	0.75	0.775	0.S0	
	Breast-high Form Factor													
20	0.524	0.532	0.541	0.548	0.559	0.569	0.581	0.592	0.607	0.620	0.641	0.661	0.683	20
25	472	482	494	504	517	530	545	560	577	595	614	635	657	25
30	443	454	466	478	494	508	524	541	559	579	598	621	643	30
35	424	436	449	464	478	494	511	528	547	568	588	611	635	35
40	409	422	437	452	468	483	501	518	537	559	580	603	628	40
45	398	412	427	442	459	474	493	510	530	552	574	597	623	45
50	389	404	420	435	451	468	487	504	524	546	569	592	619	50
55	583	397	414	429	445	463	482	499	519	542	565	588	615	55
60	378	392	409	424	441	459	477	495	515	538	562	584	612	60
65	373	388	405	420	437	455	473	492	512	535	559	581	609	65
70	369	385	401	417	434	452	470	489	509	532	556	579	606	70
75	366	382	398	415	431	449	467	487	507	529	553	577	604	75
80	364	380	395	412	429	446	465	485	505	527	550	575	603	80
85	361	378	393	410	427	444	463	483	503	525	548	573	601	85
90	359	376	392	409	425	442	461	481	501	523	546	571	600	90
95	357	374	390	407	424	441	460	479	500	522	545	570	598	95
100	356	373	389	405	423	440	459	478	499	521	544	569	597	100
105	354	371	387	404	421	439	457	477	498	520	543	568	596	105
110	353	370	386	403	420	437	456	476	497	519	542	567	595	110
115	352	368	385	402	419	436	455	475	495	518	541	566	594	115
120	350	367	384	401	417	434	453	474	494	516	540	565	593	120

* From table, Massatabeller für Träduppskattning. Tor Jonson, Stockholm, Sweden, 1918, p. 66, by conversion of height in meters to height in feet.

TABLE LXXXIII *

Weights per Cord of Timber of Various Species—7- to 8-inch Wood

Hardwoods

Species	Pounds, green	Pounds, seasoned	Species	Pounds, green	Pounds, seasoned
Alder, red	4150	2600	Hackberry	4500	3500
Ash, Biltmore	4050	3650	Haw, pear	5650	4550
Ash, black	4700	3300	Hickory, bigshellbark	5650	4800
Ash, blue	4150	3800	Hickory, butternut	5750	4550
Ash, green	4300	3800	Hickory, mockernut	5750	4900
Ash, Oregon	4150	3600	Hickory, nutmeg	5500	4000
Ash, pumpkin	4150	3450	Hickory, pig nut	5750	5050
Ash, white (forest growth)	4150	3750	Hickory, shagbark	5750	4850
			Hickory, water	6200	4300
Ash, white (second growth)	4600	4300	Holly, American	5150	3750
			Hornbeam	5400	4900
Aspen	4250	2500	Laurel, California	4850	3650
Aspen, large tooth	3850	2500	Laurel, mountain	5600	4550
Basswood	3700	2450	Locust, black	5200	4550
Beech	4950	4050	Locust, honey	5850	4750
Birch, paper	4600	3550	Madrona	5400	4000
Birch, sweet	5300	4400	Magnolia, evergreen	5600	3250
Birch, yellow	5200	4100	Maple, Oregon	4250	3200
Bird's eye, yellow	4400	2350	Maple, red	4600	3450
Buckthorn, cascara	4500	3350	Maple, silver	4150	3200
Butternut	4150	2500	Maple, sugar	5050	4100
Cherry, black	4150	3350	Oak, burr	5600	4200
Cherry, wild red	2950	2600	Oak, California, black	5900	3650
Chestnut	4850	2850			
Chinquapin, Western	5500	3000	Oak, canyon live	6400	5200
Cottonwood, black	4150	2250	Oak, chestnut	5600	4300
Cucumber tree	4500	3200	Oak, cow	5850	4650
Dogwood, flowering	5850	5050	Oak, laurel	5850	4400
Dogwood, Western	4950	4400	Oak, Pacific post	6100	
Elder, pale	5850	3450	Oak, post	5650	4500
Elm, cork	4750	4250	Oak, red	5750	4100
Elm, slippery	5050	3500	Oak, Spanish highland	5600	3900
Elm, white	4700	3250	Oak, Spanish lowland	6050	4600
Gum, black	4050	3350	Oak, water	5650	4200
Gum, blue	6300	4900	Oak, white	5600	4500
Gum, cotton	5950	3450	Oak, willow	6050	4300
Gum, red	4150	3250	Oak, yellow	5650	4100

* From General Orders No. 63, War Department, p. 4.

TABLE LXXXIII—*Continued*

HARDWOODS—*Continued*

Species	Pounds, green	Pounds, seasoned	Species	Pounds, green	Pounds, seasoned
Poplar, yellow	3400	2600	Sumach, staghorn	3700	3200
Rhododendron, great	5600	3750	Sycamore	4700	3400
Sassafras	3950	3000	Umbrella, Fraser	4250	2900
Service berry	5500	4900	Willow, black	4600	2400
Silver-bell tree	3950	3000	Willow, Western black	4600	2900
Sourwood	4750	3750	Witch hazel	5300	4300

CONIFERS

Species	Pounds, green	Pounds, seasoned	Species	Pounds, green	Pounds, seasoned
Cedar, incense	4150	2400	Pine, jack	4500	2800
Cedar, Port Orford	3500	2900	Pine, Jeffrey	4250	2600
Cedar, Western red	2450	2100	Pine, lobloily	4750	3600
Cedar, white	2500	1950	Pine, lodgepole	3500	2700
Cypress, bald	4300	3200	Pine, longleaf	4550	3950
Cypress, yellow	3150		Pine, Norway	3800	3200
Douglas fir, Pacific Northwest	3400	3250	Pine, pitch	4850	3200
			Pine, pond	4400	3750
Douglas fir, mountain type	3100	2900	Pine, shortleaf	4500	3500
			Pine, sugar	4500	2500
Fir, Alpine	2500	2050	Pine, Table Mountain	4850	3450
Fir, amabilis	4250	2700	Pine, Western white	3500	2800
Fir, balsam	4050	2350	Pine, Western yellow	4150	2650
Fir, Noble	2800	2600	Pine, white	3500	2500
Fir, white	5050	2400	Spruce, Englemann	3500	2200
Hemlock, black	4050	3000	Spruce, Sitka	3250	2400
Hemlock, Eastern	4350	3100	Spruce, white	3300	2650
Hemlock, Western	4200	2900	Tamarack	4250	3550
Larch, Western	4300	3500	Yew, Western	4850	4200
Pine, Cuban	4750	4200			

Two pounds of air-dried wood are equivalent to 1 pound of average hard coal. The above table indicates the comparative fuel value of different species of wood compared with coal. For anthracite, the equivalent is 2.5 pounds of dry wood to 1 pound of coal, or $3\frac{1}{3}$ pounds green wood to 1 pound coal.

TABLE

THE TIEMANN LOG RULE FOR SAWS

This log rule is applied to the diameter inside bark at middle of

on mill tallies, for 1-inch boards, but conforms to the formula,

TABLE

TIEMANN

Middle diameter, Inches	Length of									
	4	5	6	7	8	9	10	11	12	13
	Contents—									
3	...	...	...	...	...	...	...	1	1	1
4	1	1	2	2	2	2	2	3	3	3
5	2	3	3	4	4	5	5	6	7	7
6	4	5	6	7	8	8	9	10	11	12
7	6	7	9	10	11	13	14	16	17	18
8	8	10	12	14	16	18	20	22	24	26
9	11	13	16	19	21	24	27	29	32	35
10	14	17	21	24	28	31	34	38	41	45
11	17	21	26	30	34	39	43	47	52	56
12	21	26	32	37	42	47	52	58	63	68
13	25	31	38	44	50	57	63	69	76	82
14	30	37	45	52	60	67	74	82	89	97
15	35	43	52	61	69	78	87	95	104	113
16	40	50	60	70	80	90	100	110	120	130
17	46	57	69	80	91	103	114	126	137	148
18	52	65	78	91	104	116	129	142	155	168
19	58	73	87	102	116	131	145	160	175	189
20	65	81	98	114	130	146	162	179	195	211
21	72	90	108	126	144	162	180	199	217	235
22	80	100	120	140	160	179	199	219	239	259
23	88	110	132	153	175	197	219	241	263	285
24	96	120	144	168	192	216	240	264	288	312
25	105	131	157	183	209	236	262	288	314	340
26	114	142	171	199	228	256	284	313	341	370
27	123	154	185	216	246	277	308	339	370	400
28	133	166	200	233	266	299	332	366	399	432
29	143	179	215	251	286	322	358	394	430	465
30	154	192	231	269	308	346	384	423	461	500
31	165	206	247	288	329	371	412	453	494	535
32	176	220	264	308	352	396	440	484	528	572

LXXXIV

Cutting a $\frac{3}{16}$-inch Kerf

log, by caliper scale with deduction of widths of bark. It is based

$$B.M. = (0.75D^2 - 2D)\frac{L}{16}.$$

LXXXIV

Log Rule

Log—Feet

14	15	16	17	18	19	20	21	22	23	24
Board Feet										
1	1	1	1	1	1	1	1	1	1	1
4	4	4	4	4	5	5	5	6	6	6
8	8	9	9	10	10	11	11	12	13	13
13	14	15	16	17	18	19	20	21	22	22
20	21	23	24	26	27	28	30	31	33	34
28	30	32	34	36	38	40	42	44	46	48
37	40	43	45	48	51	53	56	59	61	64
48	52	55	58	62	65	69	72	76	79	82
60	64	69	73	77	82	86	90	95	99	103
74	79	84	89	94	100	105	110	116	121	126
88	94	101	107	113	120	126	132	139	145	151
104	112	119	126	134	141	149	156	164	171	178
121	130	139	147	156	165	173	182	191	199	208
140	150	160	170	180	190	200	210	220	230	240
160	171	183	194	206	217	228	240	251	263	274
181	194	207	220	233	246	259	272	285	298	310
204	218	233	247	262	276	291	305	320	335	349
228	244	260	276	292	309	325	341	358	374	390
253	271	289	307	325	343	361	379	397	415	433
279	299	319	339	359	379	399	419	439	459	478
307	329	351	373	395	417	438	460	482	504	526
336	360	384	408	432	456	480	504	528	552	576
366	393	419	445	471	497	523	550	576	602	628
398	427	455	483	512	540	569	597	626	654	682
431	462	493	524	554	585	616	647	678	708	739
466	499	532	565	598	632	665	698	732	765	798
501	537	573	609	644	680	716	752	788	823	859
538	577	615	653	692	730	769	807	846	884	922
576	618	659	700	741	782	823	865	906	947	988
616	660	704	748	792	836	880	924	968	1012	1056

TABLE LXXXV

Tiemann Log Rule

Reduced to end measurement assuming a taper of 1 inch to 8 feet.

Small end diameter, Inches	Length of Log—Feet: 6	8	10	12	14	16
	Contents of Log—Board Feet					
4	2	3	4	6	7	9
5	4	6	8	10	12	15
6	7	9	12	16	19	23
7	10	14	18	22	27	32
8	13	19	24	30	36	43
9	18	24	31	39	47	55
10	22	31	40	49	59	69
11	28	38	49	60	72	84
12	34	46	59	72	86	101
13	40	55	70	86	102	119
14	47	64	82	100	119	139
15	55	75	95	116	138	160
16	63	86	109	133	157	183
17	72	98	124	151	178	207
18	81	110	139	170	201	233
19	91	123	156	190	224	260
20	101	137	174	211	249	289
21	112	152	192	233	276	319
22	124	167	212	257	303	351
23	136	184	232	282	332	384
24	149	201	253	307	363	419
25	162	218	276	334	394	455
26	176	237	299	362	427	493
27	190	256	323	392	461	532
28	205	276	348	422	497	573
29	221	297	374	453	533	615
30	237	318	401	486	572	659
31	253	341	429	519	611	704
32	271	364	458	554	652	751

TABLE LXXXVI

Scribner Decimal C Log Rule for Saws Cutting a $\frac{1}{4}$-inch Kerf

This log rule disregards taper, and is applied at small end of log, inside bark. It is based on diagrams of 1-inch boards, values not made regular by curves, and deduction for slab too large above 28 inches.

The Decimal form is given, with values of the original rule rounded off to the nearest 10 board feet and the cipher dropped. To read in board feet, add the cipher. Decimal C values are given, as in Table XII, § 68. Values above 44 inches adopted by the U. S. Forest Service.

TABLE LXXXVI

Scribner Decimal C Log Rule

Diameter, Inches	Length—Feet 6	7	8	9	10	11	12	13	14	15	16	Diameter, Inches
	Contents—Board Feet											
6	0.5	0.5	0.5	0.5	1	1	1	1	1	1	2	6
7	0.5	1	1	1	1	2	2	2	2	2	3	7
8	1	1	1	1	2	2	2	2	2	2	3	8
9	1	2	2	2	3	3	3	3	3	3	4	9
10	2	2	3	3	3	3	3	4	4	5	6	10
11	2	2	3	3	4	4	4	5	5	6	7	11
12	3	3	4	4	5	5	6	6	7	7	8	12
13	4	4	5	5	6	7	7	8	8	9	10	13
14	4	5	6	6	7	8	9	9	10	11	11	14
15	5	6	7	8	9	10	11	12	12	13	14	15
16	6	7	8	9	10	11	12	13	14	15	16	16
17	7	8	9	10	12	13	14	15	16	17	18	17
18	8	9	11	12	13	15	16	17	19	20	21	18
19	9	10	12	13	15	16	18	19	21	22	24	19
20	11	12	14	16	17	19	21	23	24	26	28	20
21	12	13	15	17	19	21	23	25	27	28	30	21
22	13	15	17	19	21	23	25	27	29	31	33	22
23	14	16	19	21	23	26	28	31	33	35	38	23
24	15	18	21	23	25	28	30	33	35	38	40	24
25	17	20	23	26	29	31	34	37	40	43	46	25
26	19	22	25	28	31	34	37	41	44	47	50	26
27	21	24	27	31	34	38	41	44	48	51	55	27
28	22	25	29	33	36	40	44	47	51	54	58	28
29	23	27	31	35	38	42	46	49	53	57	61	29
30	25	29	33	37	41	45	49	53	57	62	66	30
31	27	31	36	40	44	49	53	58	62	67	71	31
32	28	32	37	41	46	51	55	60	64	69	74	32
33	29	34	39	44	49	54	59	64	69	73	78	33
34	30	35	40	45	50	55	60	65	70	75	80	34
35	33	38	44	49	55	60	66	71	77	82	88	35
36	35	40	46	52	58	63	69	75	81	86	92	36
37	39	45	51	58	64	71	77	84	90	96	103	37
38	40	47	54	60	67	73	80	87	93	100	107	38
39	42	49	56	63	70	77	84	91	98	105	112	39
40	45	53	60	68	75	83	90	98	105	113	120	40
41	48	56	64	72	79	87	95	103	111	119	127	41
42	50	59	67	76	84	92	101	109	117	126	134	42
43	52	61	70	79	87	96	105	113	122	131	140	43
44	56	65	74	83	93	102	111	120	129	139	148	44
45	57	66	76	85	95	104	114	123	133	143	152	45
46	59	69	79	89	99	109	119	129	139	149	159	46
47	62	72	83	93	104	114	124	134	145	155	166	47
48	65	76	86	97	108	119	130	140	151	162	173	48
49	67	79	90	101	112	124	135	146	157	168	180	49
50	70	82	94	105	117	129	140	152	164	175	187	50

TABLE LXXXVII

Index to Standard Volume Tables

Standard volume tables (§ 140) have been constructed by the U. S. Forest Service, by state forestry departments, by forest schools, and in some instances by private corporations, or individuals.

This index is intended to include such of these tables as are of value for future timber estimating, and can be obtained in published form, or from the U. S. Forest Service. The index briefly describes each table under the standard headings to enable the estimator to decide whether or not it is suitable for his purposes. The final column gives the Forest Service designation of such tables as have not so far been published.

TABLE

HARDWOODS

Species	Locality	Tree class	Unit of measurement	Log rule
Aspen	New Hampshire	25–50 yrs.	Cubic ft. peeled merch.	....
Aspen	Maine	....	Cubic ft. peeled merch.	....
Aspen	Maine	....	Cords	....
Aspen	Utah	....	Board ft.	Scribner Dec C.
Ash, black	General	Over 75 yrs.	Cu. ft., peeled total	....
Ash, black	General	Over 75 yrs.	Cords	....
Ash, black	General	Over 75 yrs.	Board feet	Scribner Dec. C.
Ash, green	General	Under 75 yrs.	Cu. ft., peeled total	....
Ash, green	General	Over 75 yrs.	Cu. ft., peeled total	....
Ash, green	General	Under 75 yrs.	Cords	....
Ash, green	General	Over 75 yrs.	Cords	....
Ash, green	General	Under 75 yrs.	Board feet	Scribner Dec. C.
Ash, green	General	Over 75 yrs.	Board feet	Scribner Dec. C.
Ash, white	General	Under 75 yrs.	Cu. ft., peeled total	....
Ash, white	General	Over 75 yrs.	Cu. ft., peeled total	....
Ash, white	General	Under 75 yrs.	Cords	....
Ash, white	General	Over 75 yrs.	Cords	....
Ash, white	General	Under 75 yrs.	Board feet	Scribner Dec. C.
Ash, white	General	Over 75 yrs.	Board feet	Scribner Dec. C.
Ash, white	Eastern U. S.	....	Cu. ft. of branch wood	....
Ash, white	Vermont	Second growth	Cu. ft., with limbs	....
Ash, white	Vermont	Second growth	Bd. ft. and cu. ft. in tops	....
Basswood..........	Lake States	....	Board feet	Scribner Dec. C
Beech	Vermont	....	Cu. ft., with limbs	....
Beech	Vermont	....	Bd. ft. and cu. ft. in tops	....
Beech	Michigan	....	Cubic feet	....
Beech	Pennsylvania	....	Cubic feet	....
Beech	New Hampshire	....	Board feet	Scribner Dec. C.
Beech.............	Pennsylvania	....	Board feet	Scribner Dec. C.
Beech.............	Michigan	....	Board feet	Scribner Dec. C.
Birch, paper.......	New Hampshire	45–60 yrs.	Cubic ft., merch.	....
Birch, paper.......	New Hampshire	45–60 yrs.	Board feet	Mill tally
Birch, paper.......	Maine, N. Hamp.	....	Cu. ft., total	....
Birch, paper.......	Maine, N. Hamp.	....	Cubic ft., merch.	....
Birch, paper.......	Maine, N. Hamp.	....	Board feet	New Hampshire
Birch, paper.......	Maine, N. Hamp.	....	Cubic ft., merch.	....
Birch, paper.......	Maine, N. Hamp.	....	Board feet	New Hampshire
Birch, yellow......	Vermont	Second growth	Cu. ft., total with limbs	....
Birch, yellow......	Vermont	Second growth	Board feet	....
Birch, yellow......	New Hampshire	....	Board feet	Scribner Dec. C.
Birch, yellow......	Lake States	....	Board feet	Scribner Dec. C.
Chestnut..........	Connecticut	Second growth	Cu. ft., merch. O.B.	....
Chestnut..........	Connecticut	Second growth	Board feet	International ¼" kerf
Chestnut..........	Connecticut	Second growth	Cubic feet merch.	....
Cottonwood.......	Mississippi Valley	Second growth	Cu. ft., peeled total	....
Cottonwood......	Mississippi Valley	Second growth	Board feet	Scribner Dec. C.

LXXXVII

HARDWOODS

D.B.H. (Inches)	Height. (Feet)	Top diameter. (Inches)	Basis. Trees	Date	Publication	U. S. F. S. designation
5–13	50– 80	......	289	1905	Bul. 36, U. S. Forest Service	
5–20	30– 90	4	362	1911	Bul. 93, U. S. Forest Service	
5–20	30– 90	4	362	1911	"	
10–27	1–4 log	9	675	1913	....	W5-V10
6–30	60–110	......	116	1915	Bul. 299, U. S. Dept. Agr.	
6–30	60–110	......	116	1915	"	
8–30	2–6 log	6–12	116	1915	"	
4–24	40–100	......	278	1915	"	
8–44	60–130	......	918	1915	"	
4–24	40–100	......	278	1915	"	
8–44	60–130	......	918	1915	"	
......	40–100	6–10	223	1915	"	
8–44	60–130	6–10	918	1915	"	
2–22	20– 90	......	806	1915	"	
6–36	50–150	......	488	1915	"	
4–22	20– 90	......	696	1915	"	
6–32	50–120	......	487	1915	"	
8–24	1½–5 log	......	423	1915	"	
......	....	6–18	475	1915	"	
......	....	2	....	1915	"	
3–21	40– 90	......	285	1914	Bul. 176, Vt. Agr. Exp. Sta.	
3–20	40– 90	......	285	1914	"	
8–40	2–4½	6–24	319	1915	Bul. 285, U. S. Dept. Agr.	
3–14	30– 70	......	102	1914	Bul. 176, Vt. Agr. Exp. Sta.	
3–14	30– 70	......	102	1914	"	
4–26	40–100	6–15	289	1915	Bul. 285, U. S. Dept. Agr.	
8–30	70–110	6–21	120	1909	"	
7–24	½–3½ log	6–17	376	1915	"	
10–30	2–4 log	6–21	118	1915	"	
......	1–4½ log	6–15	285	1915	"	
......	10–50 used	4–10	427	1905	Bul. 36, U. S. Forest Service	
6–16	10–50 used	4–10	427	1905	"	
4–16	50– 90	......	443	1909	Circ. 163, U. S. Forest Service	
5–14	12–60 used	......	396	1909	"	
5–14	12–60 used	......	396	1909	"	
5–18	50– 90					
5–18	50– 90	3.3–6.1	396	1909	Circ. 163, U. S. Forest Service	
3–15	40– 70	......	....	1914	"	
3–14	40– 70	......	....	1914	"	
7–32	½–3½ log	6–21	651	1915	Bul, 285, U. S. Dept. Agr.	
8–30	1½–3½ log	6–17	237	1915	"	
2–25	20– 90	2	218	1912	Bul. 96, U. S. Forest Service	
9–25	50– 90	7–12	118	1912	"	
7–20	50– 90	......	517	1905	N. H. Forestry Com. Report	
5–30	50–150	......	409	1910	....	W94–V8
11–30	80–150	7–19	267	1910	....	W94–V8

TABLE LXXXVII

HARDWOODS—*Continued*

Species	Locality	Tree class	Unit of measurement	Log rule
Eucalyptus (Blue gum)	California	Plantations	Cubic feet	....
Eucalyptus (Blue gum)	California	Plantations	Board feet	Scribner Dec. C.
Gum, red	Southern States	Under 75 yrs.	Board feet	Scribner Dec. C.
Gum, red	Southern States	Over 75 yrs.	Board feet	Scribner Dec. C.
Gum, red	Southern States	Over 75 yrs.	Board feet	Scribner Dec. C.
Hickories	Eastern States	....	Cubic ft., merch.	....
Hickories	Eastern States	....	Cubic ft., total	....
Maple, red.......	Massachusetts	Second growth	Cubic ft., merch.	....
Maple, red	Massachusetts	Second growth	Cords	....
Maple, sugar.....	Vermont	Second growth	Cu. ft., with limbs	....
Maple, sugar ..	Vermont	Second growth	Bd. ft., cu. ft. in tops	....
Maple, sugar......	Lake States	....	Cu. ft., merch. O.B.	....
Maple, sugar ...	Pennsylvania	....	Cu. ft., merch. O.B., cu. ft. in tops	....
Maple, sugar ...	Pennsylvania	....	Board feet	Scribner Dec. C.
Maple, sugar ...	New Hampshire	....	Board feet	Scribner Dec. C.
Maple, sugar	Lake States	....	Board feet	Scribner Dec. C.
Maple, sugar.......	Lake States	....	Board feet	Scribner Dec. C.
Maple, sugar ...	Lake States	....	Board feet	Scribner Dec. C.
Oak, chestnut	S. Appalachians	Over 75 yrs	Board feet	Scribner Dec. C.
Oak, chestnut	S. Appalachians	Over 75 yrs.	Board feet	Scribner Dec. C.
Oak, red..........	New Hampshire	Second growth	Cubic ft., merch.	....
Oak, red..........	New Hampshire	Second growth	Board feet	Mill tallies
Oak, red..........	S. Appalachians	Under 75 yrs.	Board feet	Scribner Dec. C.
Oak, red..........	S. Appalachians	Over 75 yrs.	Board feet	Scribner Dec. C.
Oak, red..........	S. Appalachians	Over 75 yrs.	Board feet	Scribner Dec. C.
Oak, red, scarlet and black	Connecticut	Second growth	Cubic ft., merch.	....
Oak, red, scarlet and black	Connecticut	Second growth	Board feet	International ¼″ kerf
Oak, white.......	Connecticut	Second growth	Cu. ft., merch. O.B.	....
Oak, white........	Connecticut	Second growth	Board feet	International kerf
Oak, white.......	New York	Second growth	Cu. ft., merch. O.B.	....
Oak, white.........	S. Appalachians	....	Board feet	Scribner Dec. C.
Poplar, yellow.....	S. Appalachians	1–50 yrs.	Board feet	Scribner Dec. C.
Poplar, yellow.....	S. Appalachians	51–100 yrs.	Board feet	Scribner Dec. C.
Poplar, yellow.....	S. Appalachians	Under 100 yrs.	Board feet	Mill tallies
Poplar, yellow.....	S. Appalachians	Over 100 yrs.	Board feet	Mill tallies
Poplar, yellow.....	Virginia	Second growth	Cubic feet, total	....
Poplar, yellow.....	Virginia	Second growth	Board feet	Scribner Dec. C.

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HARDWOODS—*Continued*

D.B.H. (Inches)	Height. (Feet)	Top diameter. (Inches)	Basis. Trees	Date	Publication	U. S. F. S. designation
2-23	30-160	......	2611	1906	....	G93-V2-3
7-24	50-160	......	685	1906	....	G93-V1
8-32	1-6 log	6-13	332	1904	....	G71-V5
8-48	1-7 log	6-23	1740	1904	....	G71-V7
8-48	80-140	6-23	1740	1904	....	G71-V8
5-28	5-65 used	4-20	630	1910	Bul. 80, U. S. Forest Service	
5-18	40- 90	......	365	1910	Bul. 80	
2-17	20- 80	2	397	1915	Bul. 285, U. S. Dept. Agr.	
3-17	20- 80	2	397	1915	"	
2-15	40 -80	......	222	1914	Bul. 176, Vt. Agr. Exp. Sta.	
7-14	40- 80	......	222	1914	"	
6-30	50-100	6-17	305	1915	Bul. 285, U. S. Dept. Agr.	
10-28	70-110	6-16	41	1915	"	
10-28	2½-4 log	6-16	41	1915	"	
7-32	½-4 log	6-21	360	1915	"	
8-30	1½-4 log	6-17	278	1915	"	
8-30	2-5 log	6-13	278	1915	"	
8-30	1-1½ log	7-22	278	1915	"	
8-40	1-5 log	6-20	2232	1913	....	Q68-V19
8-40	40-110	6-20	2232	1913	Bul. 285, U. S. Dept. Agr.........	Q68-V20
5-20	10-50 used	5- 9	683	1905	N.H. Forestry Com. Report	
5-20	10-50 used	5- 9	683	1905	" and Bul. 36, U. S. For. Serv.	
8-25	40-100	6-13	198	1914	....	Q61-V18
8-44	1-5 log	6-22	1300	1914	....	Q61-V15
8-44	40-130	6-22	1300	1914	....	Q61-V16
2-19	20- 80	2	441	1913	Bul. 96, U. S. Forest Service	
9-19	50- 80	7-10	175	1913	"	
2-16	20- 80	2	293	1913	"	
9-16	50- 70	6	26	1913	"	
2-13	20- 60	1	349	1905	Bul. 36, U. S. Forest Service	
10-40	1-5 log	......	1436	1903	....	Q82-V1
7-26	1-5 log	6- 8	489	1913	....	W82-V24
9-30	1-6 log	6-14	102	1913	....	W82-V25
7-26	1-5 log	6- 8	489	1913	....	W82-V26
10-40	2-6 log	6-17	407	1913	....	W82-V28
5-20	50-100	......	491	1907	Bul. 36, U. S. Forest Service	
7-20	40-100	5.9-7.2	480	1907	"	

TABLE LXXXVII

CONIFERS

Species	Locality	Tree class	Unit of measurement	Log rule
Cedar, incense	California	.....	Cubic feet, total	....
Cedar, incense	California	....	Board feet	Scribner Dec. C.
Cedar, incense	California	....	Board feet	Scribner Dec. C.
Cedar, western red.	Puget Sd., Wash.	.....	Board feet	Scribner Dec. C.
Cedar, western red.	Idaho	...	Board feet	Scribner Dec. C.
Cedar, western red.	Idaho	.....	Board feet	Scribner Dec. C.
Cypress	South Carolina	....	Board feet	Scribner Dec. C.
Cypress	South Carolina	.	Board feet	Scribner Dec. C.
Douglas fir	Washington, Oregon	Second growth	Cu. ft., peeled total	....
Douglas fir	Washington, Oregon	....	Board feet	Scribner Dec. C.
Douglas fir	Oregon	....	Board feet	Scribner Dec. C.
Douglas fir	California	....	Board feet	Scribner Dec. C.
Douglas fir	California	......	Board feet	Scribner Dec. C.
Douglas fir	New Mexico	..	Board feet	Scribner Dec. C.
Douglas fir	Montana, Idaho	....	Board feet	Scribner Dec. C.
Douglas fir	Montana, Idaho	....	Board feet	Scribner Dec. C.
Fir, Amabilis	Washington, Oregon	....	Board feet	Scribner Dec. C.
Fir, balsam	New York, Maine	....	Cubic feet, total	....
Fir, balsam	New York	....	Cubic feet, peeled merch.	....
Fir, balsam	Maine	....	Cubic feet, peeled merch.	....
Fir, balsam	New Hampshire	....	Cubic feet, peeled merch.	....
Fir, balsam	New York, Maine	....	Cords	....
Fir, balsam	New Hampshire	....	Cords	....
Fir, balsam	Northeast	....	Board feet	Scribner Dec. C.
Fir, balsam	Northeast	....	Board feet	Maine
Fir, balsam	Quebec	....	Board feet	Quebec
Fir, balsam, western.	Idaho, Montana	....	Board feet	Scribner Dec. C.
Fir, red	California	....	Cubic feet, total	....
Fir, red	California	....	Cubic feet, cords	....
Fir, red	California	....	Board feet	Scribner Dec. C.
Fir, red	California	....	Board feet	Scribner Dec. C.
Fir, white	California	....	Cubic feet	....
Fir, white	California	....	Board feet	Scribner Dec. C.
Fir, white	California	....	Board feet	Scribner Dec. C.
Fir, white	California	....	Board feet	Scribner Dec. C.
Fir, white	California	....	Board feet	Scribner Dec. C.
Hemlock	New Hampshire	....	Cubic feet, merch.	....
Hemlock	Mich., Wis.	....	Cu. ft., merch. O.B.	....
Hemlock	New Hampshire	....	Board feet	Mill tally
Hemlock	Wis., Mich.	....	Board feet	Scribner Dec. C.
Hemlock	Wis., Mich.	....	Board feet	Scribner Dec. C.
Hemlock	Wis., Mich.	....	Board feet	Scribner Dec. C.
Hemlock	Wis., Mich.	....	Board feet	Scribner Dec. C.
Hemlock	Wis., Mich.	....	Board feet	Vermont
Hemlock, western	Washington	....	Board feet	Scribner Dec. C.
Hemlock, western.	Washington	....	Cubic feet, total	....
Juniper	Utah, Arizona	....	Cubic feet, total	....
Juniper	Utah, Arizona	....	Cords with branches	....
Larch, western	Montana	....	Cubic feet, total	....

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CONIFERS

D.B.H. (Inches)	Height. (Feet)	Top diameter. (Inches)	Basis. Trees	Date	Publication	U. S. F. S. designation
16–62	60–150	......	1054	1918	Bul. 604, U. S. Dept. Agr.	
14–60	2–9 log	8–11	1054	1918	"	
16–60	40–200	8–11	1084	1918	"	
10–50	Short, medium, tall	......	1230	....	....	T6–V3
8–31	1–6 log	6–7	1890	1910	....	T6–V3
10–42	1–9 log	......	186	1914	Manual for Timber Reconnaisance, Dist. 1, U. S. Forest Service	
6–30 at 20 ft.	1–5 log	6–24	441	1915	Bul. 272, U. S. Dept. Agr.	
8–30	1–6 log	6–25	437	1915	"	
2–44	20–220	......	1747	1911	Circ. 175, U. S. Forest Service	
12–46	2–10 log	8	967	1911	"	
10–76	2–15 log	10	1394	1905	....	D1–V18
10–60	40–200	7–11	880	1913	....	D4–V32
10–60	1–10 log	7–11	880	1913	Circ. 175, U. S. Forest Service	D4–V31
10–60	1–9 log	7	1048	1917	....	D1–V35–36
7–37	1–7 log	6	855	....	....	D1–V29
8–40	1–9 log	......	....	1914	Manual for Timber Reconnaisance, Dist. 1, U. S. Forest Service	A8–V2
12–50	1–5½ log	10	372	1917	....	A–35–V2
3–14	20–80	......	2173	1904	....	
6–16	40–80	4	947	1914	Bul. 55, U. S. Dept. Agr.	
8–15	50–90	4	330	1914	"	
6–15	40–60	6	100	1914	"	
3–14	20–80	4	2171	1914	"	
6–15	40–60	6	100	1914	"	
7–16	40–80	5.8–6.8	....	1914	"	
7–16	40–90	5.9–6.4	....	1914	"	
6–22	39–91	4	1866	1911	For Quar., IX, 593	
8–30	1–9 log	......	33	1914	Manual for Timber Reconnaissance, Dist. 1, U. S. Forest Service	
10–40	40–150	......	677	1909	....	A1–V4
10–50	40–150	......	750	1912	....	A1–V6–7
10–50	40–150	7–10	752	1912	....	A1–V2
10–50	1–8 log	7–10	800	1912	....	A1–V3
7–40	40–170	......	597	1905	....	A2–V3
7–44	40–180	5.7–6.6	639	1905	....	A2–V2
18–60	3–10 logs	8.7–14.5	366	....	....	A2–V5
12–60	90–220	9–15	1114	1913	....	A2–V15
11–40	2–8 logs	6–9	322	1913	For. Quar., XI, 362	A2–V17
6–17	30–70	4.4–6.5	317	1905	For. Com. N. H., 1905; Bul. 152, U. S. Dept. Agr.	
5–36	30–100	4	....	1915	Bul. 152, U. S. Dept. Agr.	
6–17	30–70	4.4–6.5	317	1905	"	
8–38	30–100	6–12	542	1915	"	
8–38	1–5 log	6–12	542	1915	"	H65–V20
10–50	50–120	7–26	1402	1915	"	
8–50	1–7 log	6–17	1370	1915	"	
8–30	4–100	......	320	1910	Bul. 161, Vt. Agr. Exp. Sta.	
12–60	2–11 log	8	1440	1912	....	H6–V5
6–40	50–200	......	335	1900	....	H6–V4
3–23	10–20	......	495	1900	Circ. 137, U. S. Forest Service	
3–23	10–20	......	495	1900	"	
11–44	80–160	......	1324	1907	....	L7–V3

TABLE LXXXVII

CONIFERS—*Continued*

Species	Locality	Tree class	Unit of measurement	Log rule
Larch, western	Montana		Board feet	Scribner Dec. C.
Larch, western	Montana		Board feet	Scribner Dec. C.
Larch, western	Montana		Board feet	Scribner Dec. C.
Pine, Jack	Minnesota		Cu. ft., peeled total	
Pine, Jack	Minnesota		Cu. ft., merch. O.B.	
Pine, Jack	Minnesota		Board feet	Scribner Dec. C.
Pine, Jack	Minnesota		Board feet	Scribner Dec. C.
Pine, Jeffrey	California		Board feet	Scribner Dec. C.
Pine, loblolly	Maryland, Virginia		Cu. ft., merch. O.B.	
Pine, loblolly	Maryland, Virginia		Peeled	
Pine, loblolly	Maryland, Virginia		Board feet	Scribner Dec. C.
Pine, loblolly	Maryland, Virginia		Board feet	Mill tallies
Pine, loblolly	North Carolina		Cu.ft.,peeled merch.	
Pine, loblolly	North Carolina	Under 75 yrs.	Board feet	Mill tallies
Pine, loblolly	North Carolina	Over 75 yrs.	Board feet	Mill tallies
Pine, loblolly	North Carolina	Under 75 yrs.	Board feet	Scribner Dec. C.
Pine, loblolly	North Carolina	Over 75 yrs.	Board feet	Scribner Dec. C.
Pine, loblolly	North Carolina	Under 75 yrs.	Board feet	Tiemann
Pine, loblolly	North Carolina	Over 75 yrs.	Board feet	Tiemann
Pine, lodgepole	Montana		Cubic feet, merch.	
Pine, lodgepole	Montana		Board feet	Scribner Dec. C.
Pine, lodgepole	Montana		Board feet	Scribner Dec. C.
Pine, lodgepole	Montana		Cubic ft., total O.B.	
Pine, lodgepole	Montana		Board feet	Scribner Dec C.
Pine, lodgepole	Oregon		Board feet	Scribner Dec. C.
Pine, lodgepole	Oregon		Poles	
Pine, lodgepole	Oregon		Ties	
Pine, lodgepole	Oregon		Board feet	Scribner Dec. C.
Pine, lodgepole	Colorado, Wyoming		Board feet	Scribner
Pine, longleaf	Alabama		Board feet	Scribner Dec. C.
Pine, red	Minnesota		Cu. ft., peeled total	
Pine, red	Minnesota		Board feet	Scribner Dec. C.
Pine, red	Minnesota		Board feet	Scribner Dec. C.
Pine, red	Minnesota		Cubic feet, total	
Pine, red	Minnesota	Under 130 yrs.	Board feet	Scribner
Pine, red	Minnesota	Over 200 yrs.	Board feet	Scribner
Pine, scrub	Maryland	Second growth	Cords O.B.	
Pine, scrub	Maryland	Second growth	Cords, peeled	
Pine, scrub	Maryland	Second growth	Cu. ft., total O.B.	
Pine, shortleaf	North Carolina		Cubic feet, merch.	
Pine, shortleaf	North Carolina		Board feet	Scribner Dec. C.
Pine, shortleaf	Arkansas		Board feet	Scribner Dec. C.
Pine, shortleaf	Arkansas		Board feet	Scribner Dec. C.
Pine, sugar	California		Board feet	Scribner Dec. C.
Pine, sugar	California		Board feet	Scribner Dec. C.
Pine, sugar	California		Cubic feet, merch.	
Pine, white	New Hampshire	Second growth	Cu. ft., total O.B.	
Pine, white	Massachusetts	Second growth	Cu. ft., merch O. B.	
Pine, white	Massachusetts	Second growth	Cords	
Pine, white	New Hampshire	Second growth	Board feet	Mill tallies
Pine, white	Massachusetts	Second growth	Board feet	Mill tallies
Pine, white	Minnesota	Original	Board feet	Scribner
Pine, white	Minnesota	Original	Board feet	Scribner Dec. C.
Pine, white	Minnesota	Original	Board feet	Scribner Dec. C.
Pine, white	New Hampshire	Second growth	Cubic feet, merch.	
Pine, white	S. Appalachians	Under 75 yrs.	Board feet	Scribner Dec. C.

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CONIFERS—*Continued*

D.B.H. (Inches)	Height. (Feet)	Top diameter. (Inches)	Basis. Trees	Date	Publication	U. S. F. S. designation
12–42	80–160	7.3–10.8	1388	1907	Bul. 36, U. S. Forest Service	L7–V2
12–42	3–8 log	7.3–10.8	1394	1907	"	L7–V4
8–40	1–9 log	......	233	1914	Manual for Timber Reconnaissance, Dist. 1, U. S. Forest Service	
2–20	20– 80	......	658	1920	Bul. 820, U. S. Dept. Agr.	
4–20	20– 80	3	615	1920	"	
8–20	20– 80	5.5	288	1920	"	
8–20	1–4 log	5.5	288	1920	"	
14–54	40–130	6–16.4	413	1907	....	P7–V1
3–20	15– 80	1½	372	1914	Bul. 11, U. S. Dept. Agr.	
3–20	15– 80	1½	372	1914	"	
7–20	40– 80	5.5	372	1914	"	
4– 8	30– 70	2.5	Tapers	1914	"	
6–30	20–120	3–5	....	1915	Bul. 24, N. Car. Geol. Survey	
7–22	40–120	5–11	....	1915	"	P76–V24
14–36	90–140	7–15	....	1915	"	P76–V28
8–22	40–120	5–11	....	1915	"	P76–V23
14–36	90–140	7–15	....	1915	"	P76–V27
7–22	40–120	5–11	....	1915	"	P76–V21
14–36	90–140	7–15	....	1915	"	P76–V25
3–20	30–100	2 –3	....	1915	Bul. 234, U. S. Dept. Agr.	
7–24	1–5 log	6	555	1915	"	
10+	1–5 log	6.2–6.6	1808	1915	"	
4–22	30– 90	......	644	1907	Circ. 126, U. S. Forest Service	
10–24	50–100	6	1817	1907	"	
7–22	½–4½ log	6	549	1913	....	P0–V13
......	30– 70	3–4	255	1913	....	P0–V14
8–18	0–6 log	9	2000	....	....	P0–V12
9–18	½–3½ log	8	....	1913	....	P0–V11
8–25	½–5 log	8	1971	1915	....	P0–V28
7–36	40–120	6–18	614	1904	Bul. 36, U. S. Forest Service	
5–20	40–100	......	303	1914	Bul. 139, U. S. Dept. Agr.	
8–34	30–120	6	4282	1914	"	
8–34	1–7 log	6	4282	1914	"	
7–30	40–120	......	613	1905	....	P31–V11
7–18	60–100	6	259	1909	Bul. 36, U. S. Forest Service	
10–27	70–100	......	964	1909	"	
2–12	10– 75	......	228	1911	Bul. 94, U. S. Forest Service	
4–12	30– 75	......	228	1911	"	
2–12	20– 70	......	228	1905	Bul. 36, U. S. Forest Service	
6–20	40– 90	6–8	317	1915	Bul. 308, U. S. Dept. Agr.	
6–20	40– 90	6–8	317	1915	"	
8–34	40–120	6–13	3206	1915	"	
8–34	1½–6 log	6–13	3206	1915	"	
10–80	40–220	8–16	910	1917	Bul 426, U. S. Dept. Agr.	
10–80	1–12 log	8–16	910	1917	"	
10–80	60–240	8–16	773	1913	....	P3–V13
5–26	30–120	5	1578	1905	Bul. 13, U. S. Dept. Agr.	
5–25	30– 90	4	2000	1908	"	
5–27	30– 90	4	2000	1908	"	
5–26	30–120	5	1578	1905	" and Bul. 820, U. S. Dept. Agr.	
5–27	30– 90	4	2000	1908	Bul. 13, U. S. Dept. Agr.	
8–40	40–140	6–14	3899	1910	"	
8–42	40–110	6	1834	1913	....	P32–V40
8–42	1½–7 log	6	1834	1913	....	P32–V39
5–26	30–120	5	1578	1905	....	P32–V25
8–20	40– 90	6	260	1913	....	P32–V42

TABLE LXXXVII

CONIFERS—*Continued*

Species	Locality	Tree class	Unit of measurement	Log rule
Pine, white	S. Appalachians	Under 75 yrs.	Board feet	Scribner Dec. C.
Pine, western white	Idaho	....	Board feet	Scribner Dec. C.
Pine, western white	Idaho	....	Board feet	Scribner Dec. C.
Pine, western white	Idaho	....	Board feet	Scribner Dec. C.
Pine, western white	Idaho	....	Cubic feet	....
Pine, western yellow	Black Hills, S. Dak.	....	Cubic feet, total	....
Pine, western yellow	California	....	Cubic feet, total	....
Pine, western yellow	Black Hills, S. Dak.	....	Board feet	Scribner
Pine, western yellow	Klamath, Ore.	....	Board feet	Scribner Dec. C.
Pine, western yellow	Blue Mts., Ore.	....	Board feet	Scribner Dec. C.
Pine, western yellow	Arizona	....	Board feet	Scribner Dec. C.
Pine, western yellow	Arizona	....	Board feet	Scribner Dec. C.
Pine, western yellow	Arizona	....	Board feet	Scribner Dec. C.
Pine, western yellow	Arizona	....	Board feet	Scribner Dec. C.
Pine, western yellow	California	....	Board feet	Scribner Dec. C.
Pine, western yellow	S. Dakota, Idaho	....	Board feet	Scribner Dec. C.
Pine, western yellow	Montana	....	Board feet	Scribner Dec. C.
Pine, western yellow	Montana	....	Board feet	Scribner Dec. C.
Pine, western yellow	Montana	....	Board feet	Scribner Dec. C.
Pine, western yellow	Montana	....	Board feet	Scribner Dec. C.
Pine, western yellow	Colorado	....	Board feet	Scribner
Redwood	California	Sprouts	Cu. ft., total O.B.	....
Redwood	California	Sprouts	Board feet	Scribner Dec. C.
Redwood	California	Original	Board feet	Spaulding
Spruce, black	Quebec	....	Cubic feet	....
Spruce, black	Quebec	....	Board feet	Quebec
Spruce, red	Maine	....	Cubic feet, merch.	....
Spruce, red	New Hampshire	Old field	Cubic ft. total O.B.	....
Spruce, red	New Hampshire	Old field	Cu. ft., merch. O.B.	....
Spruce, red	New Hampshire	Original	Cu. ft., merch. O.B.	....
Spruce, red	New Hampshire	Original	Cubic feet, peeled	....
Spruce, red	New York	Original	Cu. ft., merch. O.B.	....
Spruce, red	West Virginia	Original	Cu. ft., merch. O.B.	....
Spruce, red	New York	Original	Standards	Dimick
Spruce, red	New York	Original	Standards	Dimick
Spruce, red	Maine	....	Board feet	Maine
Spruce, red	Maine	....	Board feet	Maine
Spruce, red	Maine	....	Board feet	Scribner Dec. C.
Spruce, red	Maine	....	Board feet	Scribner Dec. C.
Spruce, red	New Hampshire	....	Board feet	New Hampshire
Spruce, red	New Hampshire	....	Board feet	New Hampshire
Spruce, red	New Hampshire	....	Board feet	Scribner Dec. C.
Spruce, red	New Hampshire	....	Board feet	Scribner Dec. C.
Spruce, red	New York	....	Board feet	Scribner Dec. C.
Spruce, red	New York	....	Board feet	Scribner Dec. C.
Spruce, red	West Virginia	....	Board feet	Scribner Dec. C.
Spruce, red	West Virginia	....	Board feet	Scribner Dec. C.
Spruce, Englemann	Colorado, Utah	....	Cubic feet, merch. peeled	....
Spruce, Englemann	Colorado, Utah	....	Board feet	Scribner Dec. C.
Spruce, Englemann	Colorado, Utah	....	Board feet	Scribner Dec. C.
Spruce, Englemann	Colorado, Utah	....	Board feet	Scribner
Spruce, Englemann	Idaho, Montana	....	Board feet	Scribner Dec. C.
Spruce, white	Quebec	....	Cubic feet, merch.	....
Spruce, white	Quebec	....	Board feet	Quebec
Tamarack	Minnesota	....	Cubic feet, total	....

—*Continued*

CONIFERS—*Continued*

Diameter. (Inches)	Height. (Feet)	Top diameter. (Inches)	Basis. Trees	Date	Publication	U. S. F. S. designation
8–20	1½–3½ log	6	260	1913	....	P32–V41
8–36	30–160	6–8	1791	1908	Bul. 36, U. S. Forest Service	P2–V3
8–36	2–10 log	6–8	1791	1908	"	P2–V4
8–60	1–9 log	......	306	1914	Manual of Timber Reconnaissance, Dist. 1, U. S. Forest Service	
8–44	80–190	......	1790	1914	Bul. 36, U. S. Forest Service	P2–V5
8–25	30– 90	......	1004	1908	Circ. 127, U. S. Forest Service	
12–48	50–160	......	710	1908	"	
8–25	40–100	......	1419	1910	....	P4–V31
12–50	2–8½ log	6–14	823	1917	Bul. 418, U. S. Dept. Agr.	
10–42	2–8½ log	6–16	1536	1917	"	
10–50	30–150	8	6099	....	....	P4–V43
10–50	1–8 log	8	6099	....	....	P4–V41
12–40	40–120	8.3–17	1822	1911	Bul. 101, U. S. Forest Service	
12–40	1–6 log	8.3–17	1822	1911	"	
12–70	60–220	8–14	2396	1911	....	P4–V39
12–50	2–10 log	8	1193	1913	....	P4–V42
10–40	1–8 log	6–10	427	1913	....	P4–V5
10–40	30–140	6–10	427	1913	....	P4–V36
8–40	1¼–8 log	......	2822	1916	....	P4–V37
8–40	30–140	6–18	2438	1916	....	P4–V38
12–43	1–6½ log	6.1–10.6	2167	1916	....	P4–V61
6–24	30– 90	......	883	1900	....	R1–V3
7–24	30– 90	6–7	763	1900	....	R1–V2
20–112	55–180	......	503	1917	Timberman, Dec., 1917, p. 38	
7–20	46– 89	4	317	1911	For. Quar., Vol. IX, p. 591	
6–20	13– 84	4	317	1911	"	
6–25	40– 90	4–5	246	1920	Bul. 544, U. S. Dept. Agr.	
6–14	40– 70	......	711	1920	"	
6–18	40– 80	5	711	1920	"	
5–28	40– 90	4	1226	1920	"	
6–14	40– 70	4–6	711	1920	"	
6–26	30–100	4–5	1591	1920	"	
6–34	50–100	4.5	417	1920	"	
8–26	1–5 log	6	1507	1920	"	
8–26	30–100	6	1507	1920	"	
7–25	40– 90	6	241	1920	"	
7–25	1–4½ log	6	241	1920	"	
7–25	40– 90	6–9	241	1920	"	
7–25	1–5 log	6–9	241	1920	"	
8–26	30– 80	6	668	1920	"	
8–26	1–4 log	6	668	1920	"	
8–26	30– 80	6	668	1920	"	
8–26	1–4 log	6	668	1920	"	
8–26	30–100	6	1507	1920	"	
8–26	1–5 log	6	1507	1920	"	
8–34	50–110	6	416	1920	"	
8–34	1½–6 log	6	416	1920	"	
7–36	40–120	6–8	676	1910	Circ. 170, U. S. Forest Service	S2–V4
8–30	40–120	6–8	676	1910	"	S2–V1
8–30	1–6 log	6–8	671	1910	"	S2–V5
7–26	35–115	6	2380	1915	....	S2–V10
8–40	1–9 log	......	189	1914	Manual for Timber Reconnaissance, Dist. 1, U. S. Forest Service	
7–25	51–100	4	441	1911	For. Quart., Vol. IX, p. 590	
6–25	44–112	4	1351	1911	" p. 592	
7–15	60–100	......	246	1905	....	L35–V4

TABLE LXXXVIII

Index to Yield Tables

Species	Locality	Unit of measurement	Log rule	Ages. Years	Lowest diameter, B.H. Inches	Basis. Plots	Date	Publication
Ash..............	General	Cubic ft.	....	20–80	3	63	1915	Bul. 299, U. S. Dept. Agr.
		Cords	....	20–80	3	63	1915	Bul. 299, U. S. Dept. Agr.
		Board ft.	Scribner Dec. C.	20–80	7	63	1915	Bul. 299, U. S. Dept. Agr.
Aspen............	Utah	Cords	....	40–150	..	91	1913	U. S. Forest Service, W5–Y3
		Board ft.	Scribner Dec. C.	40–150	..	91	1913	U. S. Forest Servi e, W5–Y3
		Linear ft.	....	40–150	..	91	1913	U. S. Forest Servi e, W5–Y3
Birch, paper......	Northeast	Cubic ft.	....	15–70	2	46	1909	Circular 163, U. S. Forest Service
		Cords	....	15–70	2	46	1909	Circular 163, U. S. Forest Service
Cottonwood......	Miss. Valley	Cubic ft.	....	5–50	..	100	1913	Bul. 24, U. S. Dept. Agr.
		Board ft.	Scribner Dec. C.	13–50	..	100	1913	Bul. 24, U. S. Dept. Agr.
			Doyle	12–50	..	100	1913	Bul. 24, U. S. Dept. Agr.
Chestnut.........	Connecticut	Cubic ft.	....	15–75	2	187	1912	Bul. 96, U. S. Forest Service
Chestnut.........	Tennessee	Long cords	....	25–60	4.5	117	1910	U. S. F. S., N89–Y9
		Board ft.	Mill tally Doyle-Scribner	25–60				
		Ties						
Douglas fir.......	Pacific Northwest	Cubic ft.	....	10–140	..	361	1911	Circular 175, U. S. Forest Service
		Board ft.	Scribner Dec. C.	10–140	12	361	1911	Circular 175, U. S. Forest Service
Gum, blue........	California	Cubic ft.	Scribner Dec. C.	2–30	..	..	1906	U. S. F. S.
		Cords	....	2–30	..	..	1906	G93–Y1 to 7 incl.
		Board ft.	....	3–30	..	..	1906	

Hickories.........	General	Cubic ft.	....	30–200	4	30	1910	Bul. 80, U. S. Forest Service
Oaks.............	Connecticut	Cubic ft.	....	15–75	2	187	1912	Bul. 96, U. S. Forest Service
Pine, Jack........	Minnesota	Cubic ft.	....	20–70	5	128	1920	Bul. 820, U. S. Dept. Agr.
		Cords	....	20–70	5	128	1920	Bul. 820, U. S. Dept. Agr.
		Board ft.	Mill tally	20–70	5–8	128	1920	Bul. 820, U. S. Dept. Agr.
			Scribner Dec. C.	20–70	8–10	128	1920	Bul. 820, U. S. Dept. Agr.
Pine, loblolly.....	Maryland	Cubic ft.	....	10–50	3	..	1914	Bul. 11, U. S. Dept. Agr.
		Board ft.	....	10–50	5–7	..	1914	Bul. 11, U. S. Dept. Agr.
		Grades of lumber	Mill tally	10–50	5	..	1914	Bul. 11, U. S. Dept. Agr.
Pine, loblolly.....	Texas	Cubic ft.	....	10–70	..	12	1905	Bul. 64, U. S. Forest Service
		Board ft.	Herring	10–70	..	12	1905	Bul. 64, U. S. Forest Service
Pine, lodgepole....	Rocky Mountains	Cubic ft.	....	10–220	3	..	1915	Bul. 154, U. S. Dept. Agr.
		Board ft.	Scribner	30–220	6–8	..	1915	Bul. 154, U. S. Dept. Agr.
Pine, longleaf.....	Florida	Cubic ft.	....	15–70	3	78	1920	U. S. Forest Service, F54–Y15
	Georgia	Cords	....	15–70	3	78	1920	U. S. Forest Service, F54–Y15
	S. Carolina	Board ft.	Doyle	15–70	7	78	1920	U. S. Forest Service, F54–Y15
			Scribner Dec. C.	15–70	7	78	1920	U. S. Forest Service, F54–Y15
Pine, red or Norway	Minnesota	Board ft.	Scribner	40–200	..	85	(1902) 1920	Bul. 139, U. S. Dept. Agr.
Pine, scrub.......	Maryland	Cubic ft.	....	10–50	..	39	1911	Bul. 94, U. S. Forest Service
		Cords	....	10–50	..	39	1911	Bul. 94, U. S. Forest Service
		Board ft.	Mill tally	15–50	5–10	39	1911	Bul. 94, U. S. Forest Service
Pine, shortleaf....	North Carolina	Cubic ft.	....	10–80	6	80	1915	Buls. 244 and 308, U. S. Dept. Agr.
		Board ft.	Doyle	10–80	6	80	1915	Buls. 244 and 308, U. S. Dept. Agr.
			Scribner	10–80	6	80	1915	Buls. 244 and 308, U. S. Dept. Agr.
Pine, shortleaf....	Arkansas	Cubic ft.	....	20–80	6	38	1915	Bul. 308, U. S. Dept. Agr.
		Board ft.	Doyle	20–80	6	38	1915	Bul. 308, U. S. Dept. Agr.
			Scribner	20–80	6	38	1915	Bul. 308, U. S. Dept. Agr.

TABLE LXXXVIII—*Continued*

Species	Locality	Unit of measurement	Log rule	Ages. Years	Lowest diameter, B.H. Inches	Basis. Plots	Date	Publication
Pine, sugar and western yellow	California	Board ft.	Scribner Dec. C.	10–640	..	..	1916	Bul. 426, U. S. Dept. Agr.
Pine, slash	Florida	Cubic ft.	....	10–60	3	28	1920	U. S. Forest Service, F58–Y4
	Georgia	Cords	....	10–60	3	28	1920	U. S. Forest Service, F58–Y4
	South Carolina	Board ft.	Doyle	10–60	7	28	1920	U. S. Forest Service, F58–Y4
			Scribner Dec. C.	10–60	7	28	1920	U. S. Forest Service, F58–Y4
Pine, western yellow	South Dakota	Board ft.	Scribner	30–300	..	35	1914	U. S. Forest Service, P4–Y9–10
Pine, white	Minnesota	Board ft.	Scribner Dec. C.	50–180	..	..	(1902) 1914	Bul. 13, U. S. Dept. Agr.
Pine, white	New England	Cords	....	25–60	4	..	1905 (1908)	Bul. 63, Bureau of Forestry
Pine, white	Massachusetts	Cubic ft.	....	25–65	5	177	1914	Bul. 13, U. S. Dept. Agr.
		Cords	....	25–65	5	177	1914	Bul. 13, U. S. Dept. Agr.
		Board ft.	Mill tally	25–65	5	177	1914	Bul. 13, U. S. Dept. Agr.
Pine, western white	Idaho	Board ft.	Scribner	30–160	4	24	1909	U. S. Forest Service, P2Y–1–8
Poplar, yellow	Virginia	Cubic ft.	....	......	5	..	1907	U. S. Forest Service, W82–Y1–2
		Board ft.	Scribner	10–50	7	..	1907	U. S. Forest Service, W82–Y1–2
Poplar, yellow	Tennessee	Board ft.	....	......	10	..	1912	Bul. 10-C, Tenn. Geol. Survey
		Long cords	....	......	5	..	1912	U. S. Forest Service, W82–Y4
Spruce, red, Old-field	New England	Cubic ft.	....	20–100	4	59	1917	Bul. 544, U. S. Dept. Agr.
		Cords	....	20–100	6	59	1917	Bul. 544, U. S. Dept. Agr.
		Board ft.	New Hampshire	20–100	7	59	1917	Bul. 544, U. S. Dept. Agr.

TABLE LXXXIX

Index to Taper Tables

Species	Locality	D.B.H. classes. Inches	Height classes. Feet	Taper interval. Feet	Ages of trees. Years	Basis. Trees	Publication in	Mss. U. S. Forest Service
Ash, black	General	6–30	60–110	8.15	75–300	....	Bul. 299, U. S. Dept. Agr.	
Ash, green	Ark., S. Car.	4–24	40–100	8.15	Under 75	....	Bul. 299, U. S. Dept. Agr.	
Ash, green	Ark., S. Car.	8–44	60–130	8.15	75–149	....	Bul. 299, U. S. Dept. Agr.	
Ash, white	General	2–22	20– 90	8.15	Under 75	....	Bul. 299, U. S. Dept. Agr.	
Ash, white	General	6–36	50–120	8.15	75–149	....	Bul. 299, U. S. Dept. Agr.	
Aspen	Maine	4–18	30– 80	5	......	184	....	W5–F1–2
Basswood	Mich., Wis.	2–40	30–120	8.15	......	....	Bul. 285, U. S. Dept. Agr.	Z89–F1–7
Beech	Michigan	2–26	40–100	8.15	......	295	Bul. 285, U. S. Dept. Agr.	V86–F2–4
Birch, white	Maine	6–14	60– 80	5	......	354	Circ. 163, U. S. F. S.	Y89–F1–4
Birch, yellow	Lakes States	4–30	50– 90	8.15	......	259	Bul. 285, U. S. Dept. Agr.	Y64–F2–3
Chestnut	Eastern States	6–44	40–120	8.15	......	2999	....	N89–F3–6
Fir, balsam	New York	2–16	20– 80	10	......	1109	....	A35–F8
Fir, balsam	Maine	6–16	40– 90	10	......	885	Bul. 55, U. S. Dept. Agr.	A35–F2
Fir, balsam	New York (swamp)	2–13	20– 70	....	......	341	....	A35–F6
Fir, Douglas	Idaho, Wyoming	9–40	60–110	10	......	900	....	D1–F3
Fir, white	California	11–28	60–140	10	......	276	....	A2–F1–5
Hemlock	Mich., Wis.	4–38	30–160	8.15	......	614	Bul. 152, U. S. Dept. Agr.	H65–F5–8
Hemlock	Appalachian	2–50	20–140	8.15	......	1504	Bul. 152, U. S. Dept. Agr.	H65–F9
Maple, sugar	Mich., Wis.	4–30	50–100	8.15	......	307	Bul. 285, U. S. Dept. Agr.	M84–F2–4
Oak, chestnut	South Appalachians	8–40	40–110	8.15	......	2020	....	Q68–F3–5
Oak, red	South Appalachians	10–42	50–120	8.15	Over 75	1293	....	Q61–F3–6

TABLE LXXXIX—*Continued*

Species	Locality	D.B.H. classes. Inches	Height classes. Feet	Taper interval. Feet	Ages of trees. Years	Basis. Trees	Publication in	Mss. U. S. Forest Service
Oak, red	South Appalachians	4–28	40–100	8.15	Under 75	249	....	Q61–F7–9
Oak white	South Appalachians	10–40	50–120	....	......	1358	....	Q82–F3–5
Pine, Jack	Minnesota	2–20	20 –80	8	......	658	....	P30–F3–5
Pine, loblolly	Maryland	3–20	30– 80	4	......	372	....	P76–F1
Pine, loblolly	N. Car. and Virginia	4–22	40–120	8.15	Under 75	377	....	P76–F3–5
Pine, loblolly	N. Car. and Virginia	14–36	90–140	8.15	Over 75	197	....	P76–F6–7
Pine, lodgepole	Montana	7–22	50– 90	5	......	1024	Bul. 234, U. S. Dept. Agr.	
Pine, longleaf	Alabama	3–36	30–120	5–10	......	820	....	P54–F1–5 and 6
Pine, red	Minnesota	2–34	30–120	8.15	......	4539	Bul. 139, U. S. Dept. Agr.	P31–F6–9
Pine, shortleaf	North Carolina	4–20	40– 90	8.15	......	382	Bul. 308, U. S. Dept. Agr.	P74–F4–5
Pine, shortleaf	Arkansas	6–34	40–120	8.15	......	3211	Bul. 308, U. S. Dept. Agr.	P74–F6–9
Pine, western yellow								
Pine, white	Massachusetts	5–27	30– 90	5–10	......	....	....	P32–{F9–15, F2– 8}
Pine, white	South Appalachians	2–18	20– 80	8.15	Under 75	....	....	P32–F19–20
Poplar, yellow	South Appalachians	4–26	40–100	8.15	1–50	502	....	W82–F11–13
Poplar, yellow	South Appalachians	9–30	70–130	8.15	50–100	102	....	W82–F6–7
Poplar, yellow	South Appalachians	10–40	70–140	8.15	Over 100	397	....	W82–F8–10
Spruce, red								
Tamarack	Minnesota	6–20	50–100	8.15	......	528	....	
Willow, black	....	8–36	60–130	8.15	......	252	....	S80–F1–3
Willow, crack	....	2–22	20– 80	8.15	......	64	....	S66–F1–3

APPENDIX D

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