FOREST MENSURATION

A Course for Trainees of the W.A.

Forests Department

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CHAPTER 1 - INTRODUCTION

Mensuration is the branch of mathematics which deals with the measurements of lengths, areas and volumes. When applied in forestry, this science is called Forest Mensuration which is concerned with the measurement of forest trees - standing or cut - and with the estimation of the growth and the future yields from forest stands.

The purpose of forest mensuration is to provide those measurements of the forest and forest products which are required by the forest manager.

What are the measurements which the forester requires? Basically they fall into three categories : (i) measurements of forest products to determine their sale value, or Measurement for the Purposes of Sale; (ii) measurements of forest trees and stands to determine their timber volume and rate of growth, or Measurements for Purposes of Management; and (iii) the measurements of differently treated forest stands or Measurement for the Purposes of Research.

This course deals with the methods used to make the above forest measurements. It is desirable therefore to look a little more closely at each category before proceeding to the course itself.

MEASUREMENT FOR THE PURPOSES OF SALE

In a primary industry where a producer sells his goods to a consumer, it is essential that the exact amount of the goods involved in the transaction be known. Both producer and consumer must have this information to ensure that the amount of goods sold is equal in value to the price paid for the goods.

In the timber industry transactions of two kinds take place. These are (i) the sale of logs and log materials by the Forest Department to the sawmilling companies and (ii) the sale of sawn timber and converted forest products by the sawmillers to the public.

Reliable measurements of the quantities of produce involved in each of these transactions must be made. The methods of making these measurements and the definition of standard units to describe the material measured, comprises an important field of forest mensuration.

MEASUREMENT FOR PURPOSES OF MANAGEMENT

Forest management in Western Australia has one primary objective : to manage our forests in such a way that a continuous supply of timber for all times is ensured. In other words, Western Australian foresters aim for what we call "Sustained Yield Production" from the forest.

To enable him to work and plan for sustained yield production, the forester must know the answers to four basic questions. These questions are :

1. How many acres of forest are there and where is it? The extent and location of the forest must be known.

2. How much timber is there standing in the forest? The standing volume must be known.

MEASUREMENT FOR PURPOSES OF MANAGEMENT(continued)

3. What quantity of timber is being removed from the forest each year? The depletion rate of the forest must be known.

4. What is the rate of production of timber in the forest? The growth rate or volume increment of the forest must be known.

When the answers to these questions are known the forester can then calculate the rate at which the forest can be cut, so that sustained yield production is possible.

The answer to the first question is supplied by forest Surveying, a subject which is covered in detail in the Foresters' Manual, Pamphlet 10; to supply the answers to the other three is the second important task of forest mensuration.

MEASUREMENT FOR PURPOSES OF RESEARCH

Foresters are continually working on the problem of making trees grow better and faster and of thus making every acre of forest a more productive unit. This work often involves the application of different methods of treating the forest.

To assess the value of various forest research projects it is necessary to compare the growth of the forest under each different treatment. To make these comparisons, measurements of the forest are required and the third important task of forest mensuration is to supply these measurements.

THE SCOPE OF THIS COURSE

This short course is written with the object of introducing the young forester to the basic techniques of forest mensuration. Three broad fields are covered :

1. The measurement of logs and forest products.

2. The measurement of the individual standing tree.

3. The measurement of the forest stand.

Since the course is of an introductory nature only, the mathematical theory behind many of the techniques has been kept to a bare minimum and emphasis has been placed only on those techniques which are applied in local forests. A list of publications on the subject of Forest Mensuration is included as an appendix, however, and where the reader feels he would like to look further into any aspect of the course he can refer to these books. All are available from the Forests Department Library in Head Office.

Enough emphasis cannot be placed on the necessity to follow up these notes with field practise and exercises. The correct use of the various instruments and techniques described herein can only be learnt in the field and the young forester must make every effort to become expert in their use.

THE SCOPE OF THIS COURSE (continued)

In addition the reader should commit to memory the common conversions given in Appendix II and should ensure that he can cope with the problems given in Appendix III.

Nearly every job the forester does requires some mensurational knowledge and the more efficiently he can do this part of the job, the better will be the job as a whole.

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CHAPTER 2 - THE UNITS OF WOOD MEASURE

The dimensions of logs sold by the Forest Department to the sawmillers and of forest products sold by the sawmillers to the public must be known to determine their sale value.

In this chapter we discuss the units which are used in the measurement of wood. These units are used to express the contents or volume of wood products of different sizes and shapes.

The basic units are the Cubic Foot, the Load and the Superficial Foot.

THE CUBIC FOOT

The basic unit used to express timber volume is the cubic foot (abbreviated Cu.ft.). This unit is represented by a block of wood 12" x 12" x 12".

To find the number of cubic feet in a piece of timber, the following formula is used :

$$\text{Volume (cu.ft.)} = T \times W \times L$$

where T is the thickness
W is the width
L is the length

When using this formula it is essential to express all dimensions in feet or parts of a foot. If inches are used the answer will be in cubic inches. This can be converted to cubic feet by dividing by 1,728 (which equals 12" x 12" x 12" or the number of cubic inches to one cubic foot.)

Example: Find the volume in cubic feet of a board 4" x 2", 24' long.

$$V = T \times W \times L$$

$$= \frac{4}{12} \times \frac{2}{12} \times 24 = 1.1/3 \text{ cubic feet.}$$

The cubic foot is a simple and exact measure and is taken as the basic unit of timber volume measurement.

THE LOAD

When dealing with big quantities of timber or timber of large dimensions it is convenient to use a unit larger than the cubic foot. In W.A. the load is used. This unit represents 50 cubic feet of timber volume.

Example: How many loads in 350 cubic feet of timber?

1 load = 50 cubic feet

therefore, Number of loads $= \frac{350}{50} = 7$ loads.

THE LOAD (continued)

The load can be used to describe the contents of trees, logs and sawn timber. To find the number of loads in pieces of sawn timber it is usual to first find the number of cubic feet and then to divide by fifty.

THE SUPERFICIAL FOOT

The superficial foot (or "super foot") is the most commonly used unit of measurement of sawn timber. One super foot is defined as the volume of timber in a board 12" wide, 1" thick and 12" long.

Thus a board which is 12" wide, 1" thick and 16 feet long will contain 16 super feet.

To find the number of super feet in a piece of timber the following formula is used :

$$\text{Volume (s.ft.)} = \frac{T'' \times W'' \times L\ (\text{ft.})}{12}$$

or :

$$2\ (\text{s.ft.}) = \frac{T'' \times W'' \times L''}{144}$$

Example: Find the number of super feet in a board 4" x 2" x 20' long.

$$V = \frac{T'' \times W'' \times L'}{12}$$

$$= \frac{4 \times 2 \times 20}{12} = 13.3 \text{ super feet.}$$

Since by definition the cubic foot is equivalent to a board 12" x 12" x 12", and the super foot is equivalent to a board 12" x 1" x 12" then it follows that the super foot is one/twelth of a cubic foot.

Similarly if :

	1 cubic foot	=	12 super feet,
then	50 cubic feet	=	50 x 12 super feet,
or	1 load	=	600 super feet.

Sawn timber sold to the public is usually quoted on a cost basis as "so much" per 100 super feet.

OTHER UNITS

There are several other units of measure applied to timber and forest products. The most important of these are :

1. The Cord. The cord is a unit applied to stacked round or split wood of specified dimensions. The actual dimensions of the wood may vary so long as the dimensions of the stack remain constant.

The cord is generally defined as a pile of wood 4 feet high by 8 feet long and 4 feet wide, occupying 128 cubic feet of space.

OTHER UNITS (continued)

The measure is usually applied to small size, bulk wood products such as pulp-wood or chip-wood products. The individual pieces in the stack are known as billets and these may vary in size and form, but must be of uniform length (8').

Cords are not commonly used in Western Australia at the present.

2. The Bin. Small size bulk wood may also be measured by the bin. This is a variable measure calculated on the basis of the loading capacity of a specific truck. Bin Measure is discussed in more detail in Chapter 3.

3. The Ton. For irregularly shaped rough wood products such as firewood or branchwood it is more convenient and more economical to measure by weight rather than by volume. When this is done, the ton is the most commonly used unit.

Some common weight conversions are :

Species	Weight (lbs.) per Load (50 cu.ft.)	
	Green	Dry (16% M.C.)
Jarrah	3,400	2,750
Karri	3,600	2,900
Wandoo	3,950	3,550
P.radiata	2,800	1,450

4. The Running Foot. Sawn or round timber of a specific dimension can be sold by the running or "Lineal" foot. The number of running or lineal feet in a number of pieces of timber of the same dimensions is found by adding together the lengths of the pieces.

The value of poles and piles of certain specified top diameter are calculated on the basis of the number of running feet in the member. This measure is also applied to mouldings and dressed timber of small dimensions. In such cases the basis for costing is "per 100 lineal feet".

5. The Square Foot. Where wood products such as plywood, particle board etc., are sold by the sheet, it is customary to express their dimensions in square feet. The number of square feet in a sheet is found by multiplying its breadth by its length.

Prices in these cases are usually quoted on a "100 sq.ft." basis, or when sold as standard sizes as "so much" per sheet.

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CHAPTER 3 - THE MEASUREMENT OF LOGS

The consideration of the measurement of logs on the ground to determine their cubic contents, or volume, is a convenient place to commence our study of forest mensuration.

In this chapter we will briefly examine the theory behind log volume determination and then describe some of the common methods used to determine the volume of logs.

THE THEORY OF LOG VOLUME DETERMINATION

There are many problems attached to the determination of the volume of logs, for logs are large, irregular objects which do not lend themselves to simple measurement.

There is only one way by which the volume of a log may be determined with absolute exactness : by the technique of "water displacement". In this method the log is submerged in a large water-filled vessel (called a Xylometer). By doing this a certain amount of water will be displaced out of the xylometer by the log. From our knowledge of Archimedes Principle we know that the volume of water displaced will exactly equal the volume of the log, so that by measuring the volume of water displaced we will have in fact measured the volume of the log. (For instance if the log displaces 51 cubic feet of water, then the volume of the log is 51 cubic feet).

Clearly in normal forestry or sawmilling practice, we could not carry out a water displacement test every time we wanted to find the volume of a log. We must therefore look for a simpler method which will give the most accurate results from the most simple and direct measurements of the log.

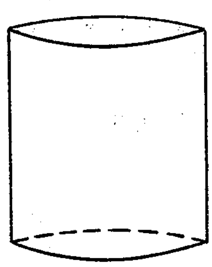
The methods we use are the so-called mathematical, or "formula" methods. These methods sacrifice absolute accuracy for speed and simplicity of measurement, but they are nevertheless precise enough for most purposes.

The Formula Methods. The basis of the formula methods of log volume determination is that they attempt to relate the form (or shape) of the log to the form of some simple geometric solid. If this can be done, then the volume of the log can be simply calculated.

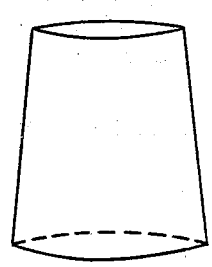
Many theories have been put forward to define the type of geometric solid to which the log most closely corresponds. For the purpose of this course we will take the simplest of these, the cylinder.

If we assume that the form of a log corresponds closely to the form of a cylinder, then the volume of the log may be calculated as if the log were cylindrical.

But how closely does the form of a log correspond to the form of a cylinder? Examine the diagrams below.



Cylinder



Log

We see that the cylinder and the log correspond very closely - but there is one discrepancy : the cylinder has the same cross-sectional area at the top as it does at the base, while the log has a smaller cross-sectional area at the top (the "crown") than it does at the base (the "butt"). In other words, the log is tapered.

Therefore if we are to calculate the volume of a log as if the log were cylindrical, the effect of taper must somehow be taken into account.

In other words the formula for calculating the volume of a cylinder,

Volume = Cross-sectional area x length

can be used to calculate the volume of logs, only if the effect of log taper is accounted for.

We shall see in the following pages that this formula provides the basis for our methods of calculating the volume of logs.

THE MEASUREMENT OF LOGS

Before examining the methods of determining log volume, let us quickly look at the measurements which must be made on the log before such determinations can be made.

To find the volume of a log, measurements of two dimensions of the log must be made : the length of the log and its cross-sectional area at various points.

Measurement of log length is readily done with a cloth or metal tape. When measuring butt logs, allowance for sloven must be made (always measure from the top of the sloven).

The cross-sectional area of the log can be found from measurement of either the radius, the diameter or the circumference (girth) of the log.

1. If the radius is measured, sectional area is given by

$$S.A. = \pi r^2.$$

2. If the diameter is measured, sectional area is given by

$$S.A. = \frac{\pi d^2}{4}$$

3. If the girth is measured, sectional area is given by

$$S.A. = \frac{G^2}{4\pi}$$

In W.A. it is traditional to calculate the cross-sectional area of logs as follows :

(a) With pines, measure the diameters across the large and small axes of the end of the log and use the mean of these figures to compute sectional area.

(b) With hardwoods, use the girth to compute sectional area.

METHODS OF CALCULATING LOG VOLUME

There are four methods commonly used to calculate the volumes of logs. These are :

1. The Mid-girth Method (or "Huber's Method").

2. The Mean of Crown and Butt Girth Method (or Smalian's Method).

3. The Sectional Method.

4. The Form Factor Method.

Each of these methods is based on the principle outlined above: the volume of a log can be calculated by using the formula for the volume of a cylinder so long as the effect of log taper is accounted for in some way.

The methods are now described.

1. The Mid-girth Method.

In this method the effect of log taper is overcome by making the measurement of log cross-sectional area at a point mid-way between the butt end and the crown end of the log. The assumption is that by measuring at this point, the average cross-sectional area of the log is found. The formula is as follows:

Log Volume = S.A. at mid-lenth x log length.

or:

$$V = \frac{cG^2}{4\pi} \times L$$

(where cG is the centre girth of the log).

Example : A log 44' long has a centre girth of 8'. Find its volume.

$$V = \frac{cG^2}{4\pi} \times L$$

$$= \frac{8 \times 8}{4} \times \frac{7}{22} \times 44$$

$$= 224 \text{ cubic feet or } 4.48 \text{ loads.}$$

The Mid-girth method (also called Huber's method after the forester who first recommended its use) is the standard method used in Western Australia for measuring log volumes for the purpose of royalty assessments. The method will give reasonably accurate results so long as

(i) the log has an even rate of taper from one end to the other, and

(ii) there are no irregularities in the shape of the log at the mid-length point.

2. The Mean of Crown and Butt Girth Method

This method is similar to the Mid-girth method, but instead of using the sectional area at mid-length to overcome the effect of taper, the mean (or average) of the sectional areas at the crown end and the butt end of the log is used. Log volume is given by :

$$V = \frac{(\text{S.A. at crown} + \text{S.A. at butt})}{2} \times \text{Length}$$

The sectional areas at the crown and at the butt are calculated separately from the girths at these points.

Example : Find the volume of a log 44 ft. long which has a crown girth of 8 ft. and a butt girth of 12 ft.

$$\text{Sectional area at Crown} = \frac{(8)^2}{4\pi} = 5.1 \text{ sq.ft.}$$

$$\text{Sectional area at Butt} = \frac{(12)^2}{4\pi} = 11.5 \text{ sq.ft.}$$

$$\text{Therefore Volume} = \frac{(5.1 + 11.5)}{2} \times 44$$

$$= 365 \text{ cubic ft.}$$

The Mean of Crown and Butt Girth method (sometimes known as Smalian's Method after the forester who suggested its use) is no more accurate than the Mid-girth method and requires an additional measurement and more complicated calculation. It is only used when

(i) a gross irregularity (such as a hole or a swelling) at the mid-length point makes measurement there impossible, or

(ii) on quarterly assessment when logs have been removed, but crown and stump remain.

3. The Sectional Method

In this method the effect of taper between the ends of long logs is allowed for by measuring the log into a series of sections, each ten feet long. The volume of each ten foot log is then calculated separately by the Mid-girth method. These sectional volumes are then added together to give the total volume of the log.

When a log is not evenly divisible into ten foot sections (for example, a log 36 feet long has three ten foot sections and one six foot section), the volume of the top log - or "odd-log" - is calculated separately by the Mid-girth method.

Example : a log is 36 feet long. Find its volume by the Sectional Method.

Divide the log into ten foot sections. Then

Log 1. Centre girth at 5', $V = \frac{(CG)^2}{4\pi} \times 10 = $ "a"

Log 2. Centre girth at 15', $V = \frac{(CG)^2}{4\pi} \times 10 = $ "b"

Log 3. Centre girth at 25', $V = \frac{(CG)^2}{4\pi} \times 10 = $ "c"

Odd-log, Centre girth at 33', $V = \frac{(CG)^2}{4\pi} \times 6 = $ "d"

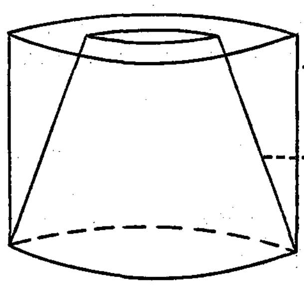
The volume of the log then = a + b + c + d.

3. The Sectional Method (continued)

The Sectional Method is the most accurate of the formula methods for determining log volumes, but it is also the most time-consuming and the most complicated. It is normally used only in research work or for the compilation of log volume tables.

4. The Form Factor Method

The term "form factor" describes the ratio between the form of a cylinder and the form of a tapering log which has the same cross-sectional area at its base as does the cylinder. The following diagram illustrates the relationship between these two figures :



The ratio of the volume of the log to the volume of the cylinder is termed the form factor (ff) of the log. Since the volume of the log is always smaller than the volume of the cylinder (due to taper), the form factor of a log is always less than one.

Thus : Volume of log = Volume of cylinder x form factor.

or : Log V = S.A. at butt end x ff.

Form factors are very variable - they can vary between different species and between individual logs of the same species. (Average form factors of 0.66 for Karri and 0.8 for Jarrah are sometimes used). Consequently the form factor method for calculating log volume is not a very accurate method and should not be used when other methods are available.

THE USE OF LOG VOLUME TABLES

To save time spent in the calculation of log volumes, the Forests Department has prepared a booklet of log volume tables called the "Cubic Contents of Logs and Associated Tables".

In these tables the average volumes of logs for all centre girths up to 25' and all lengths up to 55' are given. The preamble to the booklet describes the correct procedures for measuring logs and the method of log table compilation. This should be carefully read by anyone using the tables.

THE BIN MEASURE OF LOGS

The Bin, as defined on page 6, is a variable log volume measure based on the loading capacity of a given vehicle.

This technique was devised to save time wasted on the laborious measurement of small logs of the same length (such as casewood or pulpwood material).

The basis of this method is the knowledge that if a given truck is always loaded in exactly the same way with approximately the same sized material, the volume of the load will be more or less constant. If this constant volume is worked out for a particular vehicle, loaded with material of a given size, the figure obtained can be applied each time the truck is similarly loaded.

To find the Bin Measure of a Truck : the truck is loaded to its correct capacity with the particular material used (e.g., casewood logs). The volume of each log is then individually calculated. Individual volumes are then added together to give the total log volume of the load. This procedure is repeated three or four times until the Bin measure of the vehicle is established. It can later be checked at irregular intervals to ensure that the bin remains constant.

The essential points in the use of this convenient measure are:

1. The truck must always be loaded to the same marks on the tailboard and the headboard.

2. The measure must not be applied to logs which are a different size or of a different species to those on which the Bin was calculated.

FIELD EXERCISES ON CHAPTER 3

1. Select two logs on a local mill landing. Measure the length, centre girth, crown girth and butt girth of each log. Find their volumes by Hubers method and by Smalians method.

2. Select a long log and having made the appropriate measurements calculate its volume by the sectional method.

3. Use the average form factors quoted on page 11 to find the volumes of the two logs measured in Exercise 1.

4. Prepare a table as follows :

	Volume		
Log Number	Hubers	Smalians	Form factor
1.			
2.			

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CHAPTER 4 - THE MEASUREMENT OF THE STANDING TREE

Measurements of standing trees can be made for many purposes, but the most important is for the determination of the tree bole volume. The volumes of trees cannot be measured directly, for trees are both inaccessible and variable in shape. Tree volumes are therefore indirectly derived from tree variables which can be directly measured. The three variables measured are :

1. The sectional area of the bole at a point near the ground.

2. The height of the tree, or the length of the bole.

3. The taper of the bole, or the rate at which sectional area decreases up the bole.

In this chapter we describe the techniques used to measure these tree variables and in the next chapter show how these measurements are used to determine tree volume.

MEASUREMENT AT BREAST HEIGHT

To find dimensions near the base of the standing tree, direct measurements of the bole must be made. It is conventional in forest practice to always make such measurements at a specific height from the ground. This height is known as Breast Height and is 4'3" from the ground.

The use of this measurement rather than stump height is supported by three facts :

(i) Stumps are never cut at the same height.

(ii) When measurements of many trees have to be made, measurement at breast height causes less fatigue than measurement at stump height.

(iii) Breast height is generally high enough to avoid the butt-swell or fluting commonly found at the base of the tree.

There are several prescriptions to be followed when making tree measurements at breast height. These are :

1. On sloping ground, always measure to the breast height point from the uphill side of the tree.

2. When there is a mound of soil or litter at the base of the tree, displace if loose but otherwise measure from the highest point.

3. If the tree forks below breast height, treat as two stems; if above breast height treat as one stem.

4. Before making a measurement at breast height, remove all material which is not an actual living part of the tree (for example - mosses, vines, loose bark etc.)

5. If the breast height point is not representative (i.e., there is a whorl of knots, or a swelling, or a hole at that point), then take two measurements equi-distant above and below breast height and use the average of these two measurements.

MEASUREMENT AT BREAST HEIGHT (continued)

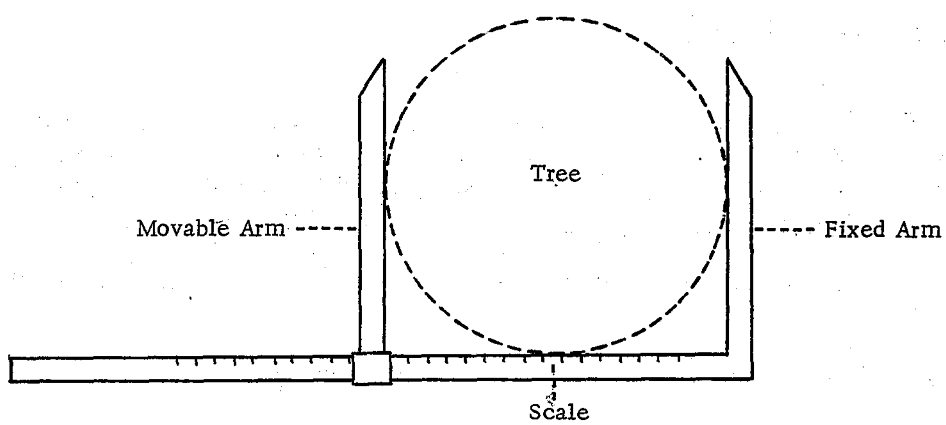
6. Measurements must always be made at right angles to the long axis of the tree bole.

Measurement to the breast height point from the ground (4'3") is generally done with a tape, but when a large number of measurements are being made (for example in an assessment) it is often more convenient to carry a stick marked at 4'3".

MEASUREMENT OF GIRTH OR DIAMETER AT BREAST HEIGHT

Girth or diameter at breast height (known as GBH and DBH respectively) are measured directly on the tree stem. The two instruments most commonly used for this measurement are (i) the calipers and (ii) the girth/diameter tape.

The Calipers. A pair of calipers is a simple wooden or light metal instrument comprising two arms, one fixed and the other able to be moved along a graduated scale.



When the two arms of the calipers are fitted tightly around the tree bole, a direct measurement of the diameter of the bole at that point is obtained. (see diagram above).

For the correct use of the calipers, the following rules must be adhered to :

1. Always take two readings, one across the largest and one across the smallest axis of the tree and use the average of these readings as the diameter.

2. Always ensure before use that the movable arm of the calipers is adjusted so that it is perpendicular to the graduated arm and parallel to the fixed arm.

Calipers find their best use in making rapid diameter measurements of small trees or of small logs (such as pine logs). They are never used in research work. The main disadvantage of the calipers is that they can not be used on large trees such as mature Jarrah or Karri. For this reason they are not used in local hardwood forests.

MEASUREMENT OF GIRTH OR DIAMETER AT BREAST HEIGHT (continued)

Girth/Diameter Tapes. Girth/diameter tapes are metal tapes which are graduated on one side to read girth (circumference) and on the other to read the diameters corresponding to each girth. These instruments are in common use in W.A.

Tapes have the following advantages over calipers :

1. They are smaller and easier to carry.

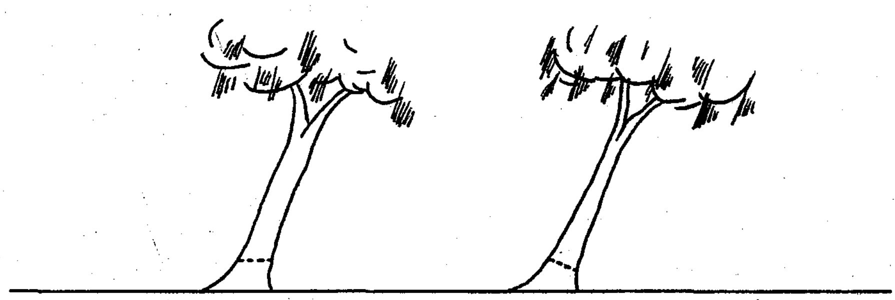
2. Only one measurement is required.

3. They do not tend to get out of adjustment with age.

4. They can be easily carried up the tree when measurements above 4'3" are required.

5. They can be used on large trees.

There are two very important points to remember when using girth/diameter tape: (i) always take care that the tape does not lodge on any obstructions at the back of the tree such as branch stubs or overgrowths and (ii) always hold the tape horizontal to the long axis of the bole (see diagram):



If these points are not observed, incorrect readings will result.

MEASUREMENT OF SECTIONAL AREA OF A TREE

The sectional area of a tree (S.A.) is its cross-sectional area at breast height. This dimension is obtained by measurement of girth or diameter at breast height and conversion of this figure.

The following formula are used:

(i) to convert diameter (ft.) to sectional area (sq.ft.)

$$S.A. = \frac{\pi d^2}{4}$$

(ii) to convert girth (ft.) to sectional area (sq.ft.)

$$S.A. = \frac{G^2}{4\pi}$$

When a large number of sectional areas have to be calculated it is normal to use Sectional Area Tables. These tables have been published by the Forests Department in the booklet "Pine Volume Yield and Log Tables", table 16, page 42.

MEASUREMENT OF SECTIONAL AREA OF A TREE (continued)

Unrepresentative Breast Height Point. If the breast height point is unrepresentitive, sectional area must be found from two measurements taken equi-distant above and below the breast height point. It is very important to remember to use the mean of the two sectional areas at the points above and below breast height, and not the sectional area corresponding to the mean of the two girths or the two diameters.

Basal Area. The "basal area" of a stand of trees is found by adding together the sectional areas of each tree in the stand. For instance if there are 25 trees in the stand and the sum of the sectional areas of each tree is 155 square feet, then that stand is said to have a basal area of 155 square feet. Basal area is usually expressed on a per acre basis, so that if these 25 trees occured on an area of half an acre, the stand basal area would be quoted as 310 square feet per acre. (Stand basal area is further discussed in Chapter 6).

THE MEASUREMENT OF BARK THICKNESS

The purpose in measuring bark thickness is to derive an underbark dimension from an overbark one. The bark of a tree (particularly that of a young tree) may often represent as much as 15 to 35% of the volume of the tree and this fact has to be taken into account in management planning.

Bark thickness is defined as the distance from the external surface of the tree to the true wood beneath the cambium. There are two ways of measuring this distance :

1. By the use of Bark Gauges. There are three types of bark gauge used in local forests - the Swedish Bark Gauge (mainly used in pines), the Forests Department Bark Gauge and the "Icepick" Bark Gauge (used on hardwoods). All three instruments work on the same principle : a graduated metal probe is pushed into the tree until stopped by the wood beneath the cambium; the distance the instrument entered the tree is then read off on the graduated scale. The reader should ensure that he has the correct method of using these instruments demonstrated to him in the field.

2. By chopping out a wedge on the tree at the measurement point and making a direct measurement on the exposed surface with a rule. This method should only be used when no bark gauges are available; it should never be used on pines or in re-measurement plots.

When Bark thickness (B.T.) is known, overbark dimensions may be converted to underbark as follows :

(i) Radius under bark RUB = ROB - BT

(ii) Diameter under bark, DUB = DOB - 2BT

(iii) Girth under bark, GUB = GOB - 2πBT

Points to remember when measuring bark thickness with a bark gauge are :

(a) When finding Diameter under bark, take two measurements and use the mean of them in the calculation.

THE MEASUREMENT OF BARK THICKNESS (continued)

For example : Diameter over bark = 6.75 inches

1st B.T. measurement = 0.46 inches

2nd B.T. measurement = 0.50 inches

Mean = 0.48 inches

Therefore D.UB. = 6.75 - 2.(0.48) inches

= 6.75 - 0.96 inches

= 5.79 inches.

(b) When finding Girth under bark, take four measurements at right angles to each other round the tree and use the mean of these four measurements.

For example : Girth over bark = 25.88 inches

Bark thickness measurements = 0.68
0.59
0.70
0.71

Mean = 0.67 inches

Therefore G.U.B. = GOB - 4πBT

= 25.88 - 4π(0.67)

= 25.88 - 8.42

= 17.46 inches.

MEASUREMENT OF TREE TAPER

Taper is the decrease in cross-sectional area of a tree bole with increased height from the ground.

Taper is found by measuring sectional areas at different points up the bole of the tree and comparing these measurements. Sometimes the points of measurement of sectional area are specified. For instance in the Cromer-McIntyre-Lewis Volume Table for P.radiata, (see page 26) taper is derived from measurement of sectional area at points 5 feet and 15 feet from the ground.

Measurements of bole dimension at heights up the tree are generally obtained by climbing the tree (or using ladders) and making a direct measurement with a tape. Optical devices, which enable upper diameters to be read by an observer on the ground, have been developed but these are not in use in W.A.

MEASUREMENT OF TREE HEIGHT

The accurate measurement of tree height is essential to enable the accurate determination of tree volume.

The forester is interested in two different tree heights :

1. Total height : the perpendicular distance from the ground to the tree crown tip; and

2. Merchantable height : the perpendicular distance from the ground (or the stump) to the point on the bole above which the timber is not merchantable.

When height measurements of trees are made it must always be stated whether total or merchantable height was measured.

Methods of measuring tree heights are either direct or indirect, depending on whether the height is measured directly on the tree or indirectly by an observer with an instrument standing back from the tree. Direct methods are generally said to give the most accurate results but they are slow, and therefore uneconomical, and are seldom used in W.A.

1. Direct Methods

The most accurate direct method is to climb the tree carrying a long tape measure; when the topmost point of the tree is reached, an observer on the ground reads off the height reached. This method has two drawbacks : (i) it is dangerous and (ii) it does not lend itself to trees which are very difficult to climb.

Another direct method is to use Height Rods. These are lightweight metal rods, each five feet long, which can be fitted together and threaded up through the branches until the tree tip is reached. The number of sections used is counted as the rods are dismantled.

Height rods give accurate height measurements on small trees, but are unweildy, and thus less reliable, on trees taller than 40 to 50 feet.

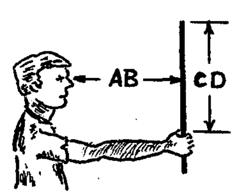
2. Indirect Methods

These methods involve the use of Hypsometers which are instruments used for determining the height of standing trees. These methods are based on the principles of geometry and trigonometry.

A description of some common hypsometers follows. (Readers interested in the mathematical proofs of the methods used should consult the reference texts listed in the appendix.)

(i) The Pole Hypsometer. This is a simple, hand-made instrument which can be used to give quick and reasonably accurate estimates of tree heights.

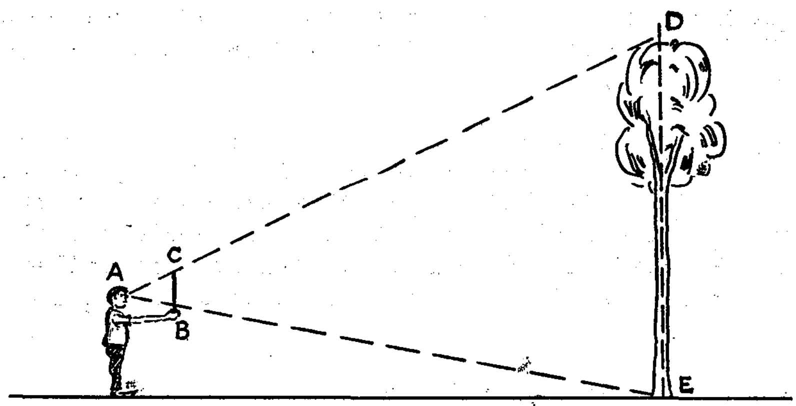
A short, straight stick (the "pole hypsometer") is grasped so that the distance from the top of the fist to the top of the stick exactly equals the distance from the out-stretched fist to the eye.



i.e. AB = CD

2. Indirect Methods (continued)

The observer then walks back from the tree until his line of sight to the top of the stick cuts the top of the tree and to the top of his fist cuts the base of the tree, thus :



Now, since AB = BC,

then AE = DE.

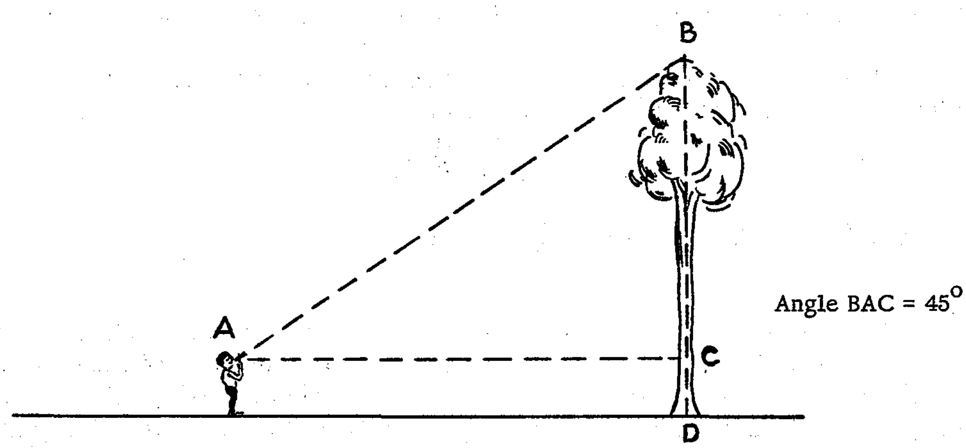
(Theoretical principle : triangles ACB and ADE are similar).

Therefore the height of the tree (DE) equals the distance from the observer to the base of the tree (AE). This distance is measured. (It is sufficient to pace this ground distance, as the crudeness of the instrument does not warrant more accurate measurement.)

To get the best results from this method it is essential that the pole is held vertically and the arm horizontal to the ground.

(ii) The Abney Level. The topographic Abney Level used in survey work can be used as a highly accurate hypsometer. The method is called the 45 Degree Method.

The Abney is set on 45 degrees. The observer then walks back from the tree until the line of sight through the level cuts the top of the tree. He then marks his position of the ground. The Abney is then set on 0 degrees (level) and aimed at the tree stem. An assistant marks the point on the tree at which the 0 degree line of sight cuts. To illustrate :



AC and CD are measured. Therefore height of tree, BD = AC + CD

(Theoretical principle : triangle ABC is a rightangled isosceles triangle; therefore AC = BC).

2. Indirect Method (continued)

The Abney level has one serious disadvantage as a hypsometer : the line of sight through the tube is very narrow and in dense stands, it is frequently difficult to pick out the right crown on which to sight.

(iii) The Haga Meter. This is a Scandanavian instrument specifically designed as a hypsometer. It is a quick and accurate instrument and is commonly used in W.A.

The Haga is a pistol-shaped instrument which has five scales : 15, 20, 25, 30 and %. These different scales give the Haga an important advantage as a Hypsometer : tree height can be measured at a variety of distances from the tree. Unlike the Abney level which employs a floating bubble, levels are indicated in the Haga by a "gravity controlled damped pivoted pointer" the movement of which is controlled by a release mechanism and a trigger clamp.

To use the instrument the observer selects a suitable scale depending on the height of the tree to be measured. He then :

(1) Measures back (with a tape or chain band) the required distance from the tree. This distance will be the same as, or a multiple of the scale used - for instance, he would measure back 30 feet for the 30 scale or 100 feet (or 200 feet) for the % scale.

(2) "Shoots" at the top and then at the base of the tree and notes the reading in each case. Both measurements are repeated as a check.

(3) Uses these two readings to find the height of the tree as follows:

   (a) If the base of the tree is lower than the observer's eye (so that the Haga reading to this point is negative) the two readings are added to give total tree height.

   (b) If the base of the tree is higher than the observer's eye (so that the reading to that point is positive) then this reading is subtracted from the other to give total tree height.

The height of the tree is then expressed in the same units as those used to measure the horizontal ground distance back from the tree. For instance, if the 30 scale is used and the observer measures back 30 yards from the tree, then the final height of the tree must be expressed in yards. If he measured back 30 feet, the height would be in feet, and so on.

The Haga is a very useful and practical instrument and is simple to use after a little practice in the field.

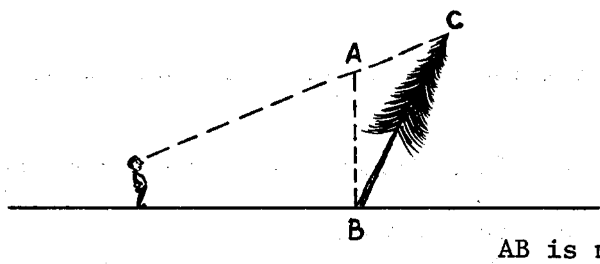
MEASUREMENT OF THE HEIGHT OF LEANING TREES

The mathematical principles upon which the above methods are based assume that the tree measured is straight and standing vertically. Unfortunately few trees grow straight and stand vertically. Therefore the effect of lean on tree height measurement must be taken into account if serious errors are to be avoided.

MEASUREMENT OF THE HEIGHT OF LEANING TREES (continued)

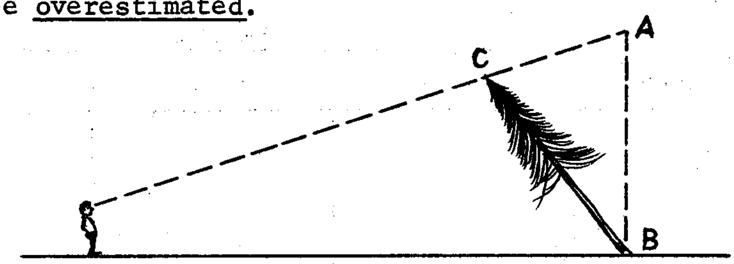
The effect of lean on height measurements is shown in the following diagrams :

1. When the tree leans away from the observer, tree height will be underestimated.



AB is measured instead of CB

2. When the tree leans towards the observer, tree height will be overestimated.

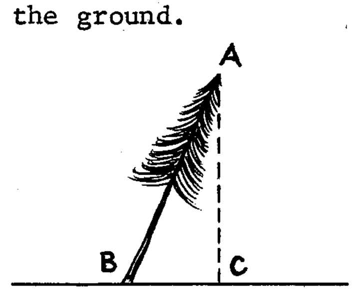


AB is measured instead of CB

To overcome the effect of lean on tree height measurements, the following procedure should be adopted:

1. Always take instrument sightings at right angles to the direction of the lean of the tree.

2. Use a plumbob to find the true vertical line from the top of the tree to the ground.



3. Mark the position of C on the ground. Measure AC with a hypsometer and BC with a tape.

4. Then the true height of the tree (or bole length) is given by

$$AB = \sqrt{AC^2 + CB^2}$$

(Theoretical principle : the theorem of Pythagorus which says - The hypotenuse is equal to the square root of the sum of the square of the other two sides of the right angled triangle)

FIELD EXERCISES ON CHAPTER 4

1. Using a girth/diameter tape, measure the DBH and GBH (over bark) of six trees. Convert each measurement to Sectional Area over bark.

2. Use a bark gauge to find diameter at breast height under bark and girth at breast height under bark of the above six trees.

3. Select three trees (about 100 feet tall) and measure the height of each using :

   (a) A pole hypsometer (construct your own)

   (b) An Abney Level.

   (c) A Haga Meter.

   Make up a table as follows to compare the measurements made :

	Height		
Tree Number	Pole	Abney	Haga
1.			
2.			
3.			

4. Select an obviously leaning tree and find the length of its bole using the correct procedure for leaning trees.

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CHAPTER 5 - TREE VOLUME

The determinations of the volume of timber in the bole of the standing tree is the next important step we must take in the study of forest mensuration, for to be able to find the volume of forest stands we must first be able to find the volume of the individual trees which comprise those stands.

Tree volume can be found in two ways :

1. By direct measurement of the tree followed by some specific method of calculation, or

2. By the use of Tree Volume Tables.

For most forestry work, Tree Volume Tables can be used, but when no volume tables exist, or where they are being compiled, tree volume can only be found by direct measurement of the tree.

In this chapter we will examine two common methods of calculating tree volume and then discuss the different types of tree volume tables and their use.

METHODS OF CALCULATING TREE VOLUME

The bole of a tree, like the log cut from it, is an irregularly shaped object which does not conform to any simple geometric shape. The problems in tree volume determination are therefore the same as those encountered in log volume determination.

The problem once again is one of taper. Two approaches to overcoming this problem can be used :

1. By assuming a form factor (see page 11) for the tree and using the formula

   $$V = S.A. \times HT \times FF. \qquad \text{or,}$$

2. By measuring the tree into a number of short sections, calculating the volume of each section separately and then finding tree volume by summing the sectional volumes.

The form factor method has one advantage : it is speedy and thus economical. Only two measurements are required (Sectional Area at Breast Height and Height) and the tree does not have to be climbed. However, the method has one serious weakness : form factors for individual trees vary considerably and the use of a standard form factor (e.g., 0.6 for Karri) will often incur a serious error.

The second type of tree volume determination is less economical than the form factor method, but provides accurate and reliable volume figures. Two common methods of this type are the Sectional Method and the Graphical (or "Tasmanian") Method.

These methods will now be examined.

METHODS OF CALCULATING TREE VOLUME (continued)

1. The Sectional Method. The Sectional method described earlier for the determination of log volumes can be applied to the standing tree. The tree is assumed to consist of a series of ten foot log sections standing one on top of the other. A measurer climbs the tree and measures the mid-girth of each ten foot log and the mid-girth of the odd-log.

Hubers formula (the Mid-girth method) is then used to find the volume of each sectional log. The volume of the tree is then found by adding together the volumes of the sectional logs.

Field technique : The measurer climbing the tree takes with him a 66' or 100' cloth tape (to determine heights of measurement above ground), a girth/diameter tape and a bark gauge (if U.B. measurements are required). His assistant crouches at the base of the tree and (i) steadies the base of the cloth tape and (ii) records the measurements shouted down to him.

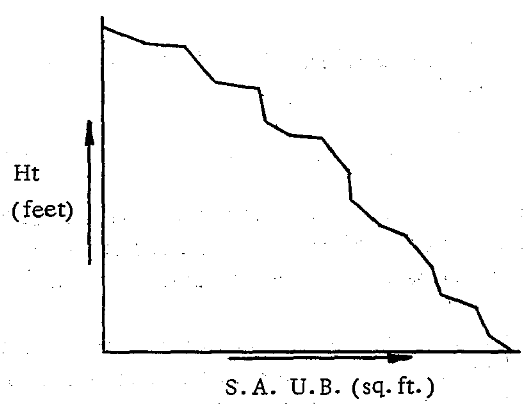
Note : When the mid-girth point of a ten foot section falls on a branch whorl or other disfigurement, the measurer must select for measurement a representative point above or below the mid-girth point.

2. The Graphical Method. An extremely accurate method of finding tree volume is the Graphical or "Tasmanian" method. The procedure is as follows :

(i) The tree is climbed and girth underbark is measured every three or four feet up the bole.

(ii) Girths underbark are then converted to sectional area under bark (use S.A. tables or SA = $\frac{G^2}{4\pi}$

(iii) A graph is then constructed on square-inch graph paper by plotting each sectional area against the height from the ground at which that sectional area occured.



Now, since 1 sq.ft. of SA x 1 ft. of height = 1 cu.ft. of volume, then the area enclosed by the graph line represents the volume of the tree.

The area enclosed by the graph is found either by counting the squares on the graph paper or by using a planimeter (an instrument for measuring areas in square inches).

The graphical method gives very accurate results, but requires tedious and time-consuming measurement and calculation - it is not therefore used in general forest work.

However the method (or a variant of it called the "Taper-line Method", which uses fewer points of measurement) is occasionally used by management officers for research work and for the compilation of tree volume tables.

THE USE OF TREE VOLUME TABLES

A Volume Table is a table which shows the average cubic contents of trees of different sizes. They are generally compiled for a single species and for a specific locality of occurence of that species.

General Volume Tables for Karri and Jarrah, for Pinus radiata and for Pinus pinaster are in use in Western Australia.

Tree Volume Tables can be of three types, depending on the number of tree measurements required to use them. These are One-way volume tables, Two-way volume tables and Three-way volume tables.

1. One-Way Volume Tables. These are so constructed that only one measurement of the tree is required to find volume from the table. This measurement is usually girth (or diameter), but may sometimes be height.

A One-way volume table based on diameter at breast height over bark might read as follows :

Volume Table for SQ IV P, radiata at Age 10

DBHOB"	Vol. cu.ft.
5	2.33
6	3.53
7	4.71
8	6.21
9	7.73

One-way volume tables are only applicable to even-aged stands where the age and the site quality (and therefore, approximately, the height) are known.

They are rarely used in Western Australia.

2. Two-Way Volume Tables. These are the most commonly used type of volume table. Two measurements of the tree are required; girth (or diameter) and height are generally used.

A two-way volume table might read as follows :

Volume Table - Jarrah

GBHOB	Heights						
	25'	30'	35'	40'	45'	50'	
7'0	67	76	86	93	102		)
7'6	77	88	97	105	115	etc	) Volumes
8'0	86	95	110	124	129		) in
8'6	95	110	124	134	147		) cubic feet
9'0	107	123	126	152	163		
		etc					

Example: a tree has a girth of 8'0 and bole height of 45'
The volume will be 129 cubic feet.

THE USE OF TREE VOLUME TABLES (continued)

3. Three-Way Volume Tables. These are the most accurate type of tree volume table. Three measurements of the tree are required. They are generally diameter at breast height, taper and merchantable height. An example of this type of table is the "Cromer-McIntyre-Lewis Volume Table for P.radiata."

Three-Way Volume Tables are more difficult to use than are One-Way or Two-Way Tables but they are correspondingly more accurate.

At the time of writing these notes, a Three-Way Volume Table for P.pinaster is in the early stages of compilation.

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CHAPTER 6 - THE MEASUREMENT OF FOREST STANDS

In previous chapters we have been concerned with the measurement of the individual forest tree and the derivation of tree volume from these measurements.

The next step is the measurement of numbers of individuals, or the measurement of forest stands.

Stand measurements are made for three purposes:

1. For the determination of stand Basal Area.

2. For the determination of stand volume.

3. For the determination of stand growth rate.

In this chapter we will firstly examine stand measurement in general, and then show how determinations of stand basal area, stand volume and stand growth can be made.

METHODS OF FOREST STAND MEASUREMENT

To obtain information about a stand of forest trees, two approaches can be used; there is the Whole Stand Measurement approach and the Sampling approach.

1. Whole Stand Measurement. In this approach, information about the stand is obtained by making separate measurements on every individual tree in the stand. This will clearly provide accurate information - but will do so only at the price of an enormously laborious and costly operation.

Whole Stand Measurement (also called "Total Enumeration") is used in some European countries where labour is skilled and not costly and above all where individual compartments are very small; it is only used in Australia on a very limited scale for sample plot and research plot work.

2. Sampling. The alternative to Whole Stand Measurement is to use a sampling method of stand measurement. In this approach information about the whole stand is inferred from the accurate measurement of small representative units ("samples") of the stand.

The sampling method of stand measurement will provide information which is sufficiently accurate for most purposes so long as the following requirements of the method are observed:

(i) A sufficient number of samples of the stand must be taken. It is normal to sample approximately 0.5% of the area of the whole stand.

(ii) The samples measured must be representative of the whole stand. Samples must be located randomly within the forest area, not placed only in the best, or only in the worst parts of it.

(iii) The size of the sample and the size of the whole stand must be accurately known.

2. Sampling (continued)

Sampling methods are used exclusively in Australia for the measurement of forest stands.

DETERMINATION OF STAND BASAL AREA

The basal area of a stand is the sum of the sectional areas at breast height of the trees in the stand. Since basal area more or less describes the "density" of the stand, this term is very useful to the forester. It is commonly used in thinning prescriptions such as the prescription for the thinning of Jarrah pole stands.

It is usual to express basal area on a "per acre" basis. Thus when we speak of Stand Basal Area, we mean the average basal area per acre that the stand is carrying and not the total basal area of the stand. Stand Basal Area is therefore found automatically by sampling methods rather than by Whole Stand Measurement.

There are two ways by which Stand Basal Area may be determined: by the use of conventional sample plots or by the use of the Angle Count Technique.

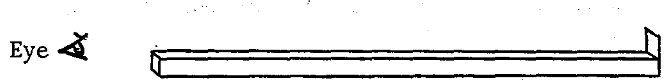
1. Basal Area by Conventional Methods. This involves the establishment of sample plots within the stand. On every plot the sectional area of each tree is determined from measurement of its girth or diameter (see page 15). Plot basal areas are then found by adding together individual tree sectional areas. Then, knowing the size of the sample plot, the plot basal area is converted to a per acre basis.

For example if there is found to be 50 square feet of basal area on a plot of 0.25 acres, the plot is said to carry 200 sq.ft. basal area per acre.

The basal area per acre of the whole stand can be inferred from the basal areas per acre carried on the sample plots within the stand.

2. Basal Area by Angle Counting. This technique allows the estimation of basal area per acre at any point in a stand without requiring any marking out of plots or direct measurement of trees.

The technique involves the use of a simple optical device called an angle gauge, or Relascope. The relascope comprises a short rod with a short metal upright at one end, thus :



Relascope

The observer moves to any point in the stand and then raising the relascope to his eye (as one would sight a rifle) he rotates in a full circle counting all the trees which appear to be, at breast height, larger than the metal upright. Trees which appear to be smaller than the metal upright he ignores and those which appear to have the same dimension as the upright he counts as "half trees".

The number of trees counted is then multiplied by the correction factor for that relascope and the result represents the basal area per acre at that point.

DETERMINATION OF STAND BASAL AREA (continued)

For example if the observer counts 15½ trees as "in" and the relascope correction factor is 10, then the basal area at that point in the stand will be 15½ x 10 = 155 square feet per acre.

Counts of this sort made at numerous points through the stand enable an estimation of stand basal area to be made.

Particular attention must be paid to Borderline trees, but the foregoing method is accurate enough for all but research purposes.

The mathematical principles upon which this technique is based are too complex to deal with in this course. The field technique, however, is a very simple and useful one, and the reader should make every effort to have it demonstrated to him.

DETERMINATION OF STAND VOLUME

The volume of a forest stand is obviously the sum of the volumes of all the individual trees in the stand. Since it is clearly not possible to measure each tree in the stand, a sampling approach must be resorted to.

In Western Australia the term given to the determination of stand volume is Assessment.

Assessment Procedure in W.A. The assessment techniques used in local forests have been devised by the Working Plans Branch of the Forests Department who are responsible for this work. A broad description of the procedure they adopt is as follows:

1. The forest is divided into a number of homogenious (like) types such as the "API" types.

2. Randomly placed assessment lines are run in all forest types. The assessment lines (which are in fact sample plots) are 20 chains long and one chain wide (that is, 2 acres in size) and on these the volumes of all trees greater than 12" GBH are measured.

3. The volume per acre on each sample plot is found.

4. This figure is used to find the volume per acre for each type.

5. The volume on each type is then added up to give the total volume of timber in the stand.

Other types of Assessment. Other types of forest stand assessment such as Quarterly Assessment (the assessment of cut-over forest to determine the volume of timber removed and retained by the treemarker) and Land Inspection Assessment (the assessment of the volume of timber on proposed alienations or potential State Forest) are similar in principle to the type outlined above.

The important points to bear in mind when doing any of these assessments are :

Other types of Assessment (continued)

1. The position of assessment lines must always be randomly selected.

2. All trees growing inside the line must be measured and all growing outside the line must be ignored.

3. Measurements of individual trees (particularly of tree height) must be made with the utmost accuracy.

4. For Land Inspection work strip lines run at 10 or 20 chains centres are the best way of making sure that all variations in forest types have been encountered. These lines should run at right angles to the general contours of the land.

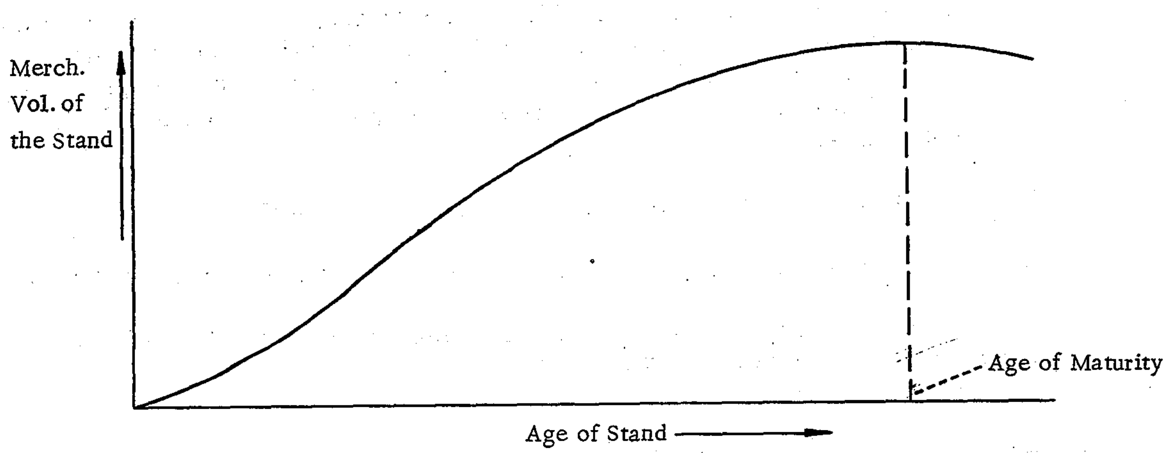
STAND GROWTH

The growth of forest stands is studied in order to determine the rate at which timber is being produced by those stands. This knowledge enables the forester to forecast the future yields from the forest and to recommend the rate at which the forest should be cut.

The Theory of Stand Growth. (The following notes apply to all stands, but it may help the reader to envisage them applying to an even-aged stand such as a pine stand.)

As a forest stand grows, the volume of timber therein increases - but this increase in volume with time does not continue indefinitely, for after a certain time (the age at which the stand becomes mature), increases in stand volume due to growth are counterbalanced by losses in the stand due to mortality and disease.

This is demonstrated in the following graph:



The graph illustrates how the rate of volume production (which is the accumulated growth of the stand) varies with the age of the stand. When the stand is young, the growth rate is rapid; this rate tapers off as the stand reaches maturity and then begins to fall as the stand becomes over-mature.

STAND GROWTH (continued)

To describe the rate of volume production - or the "volume increment", as it is called - of forest stands, three different terms are used. When we wish to describe the volume increment over a period of one year, we use the term Current Annual Increment; when we wish to describe the volume increment over a period of several years we use the term Periodic Mean Annual Increment; and when we wish to describe the volume increment of the stand over its whole life, we use the term Mean Annual Increment.

These terms are important, so it will be worthwhile to examine each a little more closely.

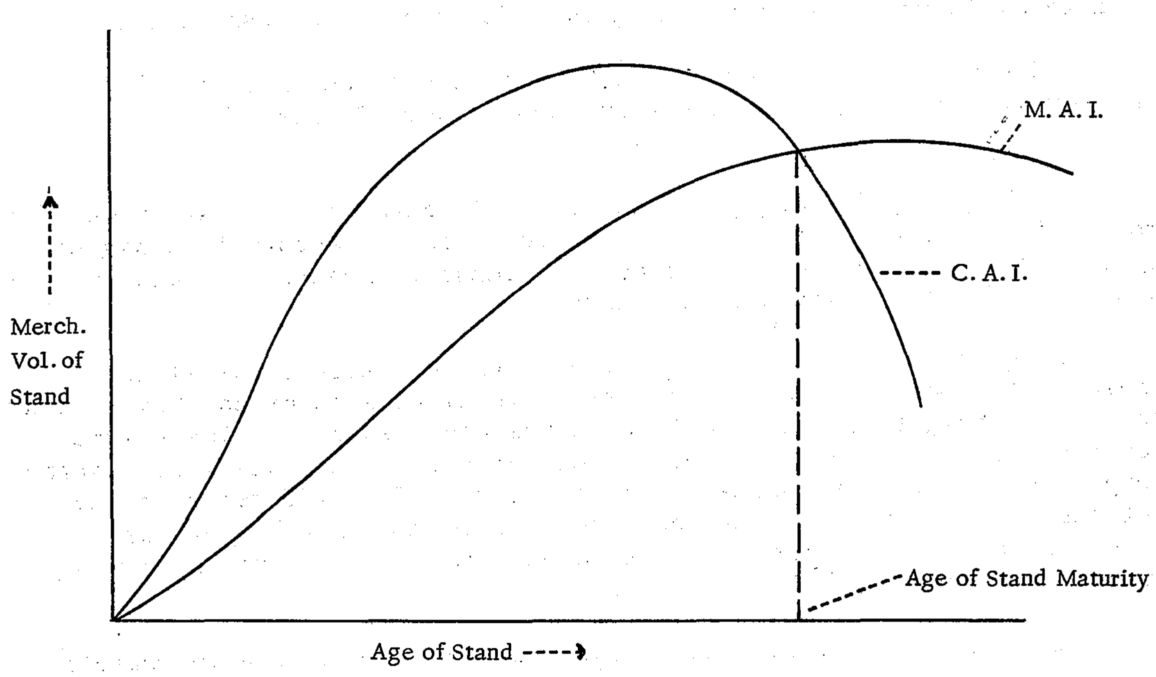
1. Current Annual Increment (CAI). This term describes the "increase in stand volume over a period of one year at any time in the life of the stand." For example if a stand carried 20 loads per acre in 1966 and this had increased to 21.5 loads per acre in 1967, then the CAI for that year was 1.5 loads per acre.

The CAI of a stand is very high when the stand is young, but begins to fall quickly just before maturity is reached.

2. Periodic Mean Annual Increment (PMAI). This term describes the "average annual growth rate of a stand over any period of 5 to 10 years in the life of the stand." For example if a stand carried 20 loads per acre in 1960 and 30 loads per acre in 1965, then the PMAI would be $\frac{30 - 20}{5}$ or 2 loads per acre per year.

3. Mean Annual Increment (MAI). This term describes the "average annual growth rate of a stand over the whole of its life." It is calculated by dividing the present volume of the stand by its present age. For example if a 20 year old forest stand carries a volume of 60 loads to the acre, its MAI will be $\frac{60}{20}$ = 3 loads/acre/annum.

The MAI of a stand is low when the stand is young, and rises steadily as the stand matures. When maturity has been reached the MAI gradually begins to fall off.



MEASUREMENT OF STAND GROWTH

A forest stand "grows" as the individual trees in the stand grow. By "growth of the individual tree" we mean the increase with time of the girth and the height of the bole of the tree" - or in other words, the increase in the volume of the tree.

To measure stand growth we must therefore measure the increase in the girths and heights, and thus volumes, of the trees in the stand. In actual practice, stand growth is estimated from the accurately measured growth of individual sample trees growing in the stand.

There are two techniques which are used to study the growth of individual trees. These are Stem Analysis and Periodic Inventory.

1. STEM ANALYSIS. We know from our study of forest botany that the tree increases the size of its bole by adding a new layer of woody tissue onto the outside of the bole each growing season. The result of this activity is the production of annual rings in the wood of the stem.

The technique of Stem Analysis utilises this knowledge for the study of tree growth.

The Technique. Sample trees are randomly selected from the stand. They are each cross-cut into a number of short sections. The growth rings on each section are then examined and for any particular period of time (for instance, the last 15 years) the following is derived :

(i) Diameter growth (and thus sectional area growth) - this is found by direct measurement of the distances between growth rings on the section surfaces.

(ii) Height growth - this is found by counting the number of rings present at different heights up the bole of the tree.

From these figures, volume growth can be calculated.

When this has been done for all sample trees, the information is pooled and an estimate of stand volume growth for the period can be made.

(A detailed description of the stem analysis technique can be found in "Forest Mensuration" by Bruce and Schumacher, Chapter V.)

2. PERIODIC INVENTORY. Stem analysis enables us to study the past growth of the stand; the technique of Permanent Inventory is designed to study the present growth of the stand. Permanent Inventory is widely used in W.A. to determine stand growth data.

The Technique. Permanent sample plots (one acre in size) are established in the forest. On these the sectional area at breast height and the merchantable height of each tree are accurately measured. The volume of timber on the plot is then calculated. Periodically after this (for instance once every five years) these plots are remeasured. The difference in the volume of the plots between measurements represents the growth that has taken place between measurements - and thus represents the volume increment of the plot for that period.

Stand volume increment can be inferred from the volume increments of the various plots within the stand.

2. PERIODIC INVENTORY (continued)

It must be emphasised that both the Stem Analysis and the Periodic Inventory Methods of computing stand increment are sampling methods, so that the accuracy of the final estimate can only be as good as the accuracy of the samples. When doing this work it is therefore most important to remember to :

1. Place sample plots randomly within the stand.
2. Use a sufficient number of samples to adequately cover all the variation in the stand.
3. Take the utmost care to make accurate measurements of sample trees and of sample areas.
4. Check and double-check all arithmetic calculations.

Only if close attention is given to these points will foresters have reliable growth data upon which to base their estimates of future stand growth.

ESTIMATION OF FUTURE STAND VOLUME OR YIELD

The purpose of finding stand growth rate is to enable the estimation of future stand volume, or yield. This can be illustrated with a simple example.

Example : A forest stand carries 5000 loads of timber. If the PMAI of the stand is 100 loads per year, what will be the volume of timber in the stand in 5 years time?

Present volume = 5000 loads

PMAI = 100 loads per year

Volume increment in 5 yrs. = 100 x 5 = 500 loads.

Therefore Volume in 5 yrs. = 5000 + 500

= 5500 loads.

Once the standing volume of the forest and its rate of growth are known, future yields can be readily calculated in this manner. In actual fact, calculations of future yield are usually slightly more complex than the example given, for such factors as the growth of different size classes, mortality, the effect of present cutting and many other variables have to be taken into account.

The estimation of future yields from plantations is greatly simplified if Yield Tables exist. These are tables compiled from past inventory and measurement data showing for a given species the expected yields from stands of a given age and site quality.

A Yield Table for P.radiata can be seen on page 16 of the Forests Department publication "Pine Volume Yield and Log Tables".

ESTIMATION OF FUTURE STAND VOLUME OR YIELD (continued)

Important points to remember about Yield Tables are :

1. They are compiled for only the given species and cannot be applied to other species.

2. Yield Tables are local in character and should not be applied in widely differing localities.

3. Yield Tables assume normal treatment of the stand, so that if thinnings are delayed etc., the yield table estimates will be upset.

4. Yield Tables assume the stand has a normal density. If the stand is understocked (due to failures at planting, for instance) yield table estimates will not apply.

Yield Tables are valuable tools in plantation management and the reader should familiarise himself with their use.

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APPENDIX I - LIST OF REFERENCES

The following texts will provide useful further reading in forest mensuration for those readers who found these notes too brief or too elementary.

1. "Elementary Forest Mensuration" by M.R.K.Jerram (1939).

2. "Forest Mensuration" by Bruce and Schumacher (1950) - Part I only.

3. "Forest Measurement" by H.C.Belyea (1931).

4. "Forest Mensuration" by H.A.Meyer (1953).

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APPENDIX II - CONVERSIONS OF SOME COMMON UNITS

LINEAR MEASURE

12 inches	=	1 foot
3 feet	=	1 yard
22 yards) 100 links) 66 feet)	=	1 chain
80 chains) 1760 yards) 5280 feet)	=	1 mile

SQUARE MEASURE

144 square inches	=	1 square foot
9 square feet	=	1 square yard
484 square yards	=	1 square chain
4840 square yards) 10 square chains)	=	1 acre
640 acres	=	1 square mile

CUBIC MEASURE

1728 cubic inches	=	1 cubic foot
27 cubic feet	=	1 cubic yard

Liquids :

2 pints	=	1 quart
4 quarts	=	1 gallon
6¼ gallons	=	1 cubic foot

Timber :

1 cubic foot	=	12 superficial feet
50 cubic feet) 600 super feet)	=	1 load

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APPENDIX III - SOME MENSURATION PROBLEMS

1. Calculate separately (i) the number of cubic feet and (ii) the number of super feet, in each of the following pieces of timber :

   (a) 8" x 2", 16'.

   (b) 4" x 2½", 10'.

   (c) 10" x 8", 12'.

   How many Running Feet are there in the parcel.

2. Convert the following units :

   (a) 25 loads to super feet.

   (b) 360 super feet to cubic feet.

   (c) 150 cubic feet to loads.

   (d) 3½ miles to chains and links.

   (e) 162 cubic feet to cubic yards.

   (f) 2240 acres to square miles.

   (g) 150 square chains to acres.

3. Calculate the volumes in cubic feet of the following logs :

   (a) Length 22 feet, centre girth 6 feet.

   (b) Length 10 feet, crown girth 9 feet and butt girth 12 feet.

   (c) Length 12 feet, butt girth 5 feet (form factor 0.6).

4. A log 12 feet long has a butt girth of 12 feet and a crown girth of 8'0". The mid-girth is 9'6".

   (a) Find its volume by Hubers Method; and

   (b) Find its volume by Smalians Method.

5. The following data applies to a pine stand :

YEAR	STANDING VOLUME (loads/acre)
1950	19
51	25
52	31
53	36
54	40
55	44
56	48
57	51

Continued on next page.....

APPENDIX III - SOME MENSURATION PROBLEMS (continued)

From this data calculate the following :

(a) The C.A.I. for periods 1951 - 52
1955 - 56
1956 - 57

(b) The P.M.A.I. for periods 1950 - 57
1952 - 56
1953 - 57

5. A S.Q. III Pinus radiata stand carried the following volumes/acre :

14,604 cubic feet of timber at Age 30

16,024 cubic feet of timber at Age 32

16,380 cubic feet of timber at Age 36

Calculate the MAI of this stand at Ages 30, 32 and 36.

6. (a) Calculate the life of a mill which has a permit area of 50,000 acres and an annual cutting coupe of 2000 acres.

(b) Calculate the life of a mill which has a permit area carrying 100,000 loads and an annual intake of 2500 loads.

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APPENDIX IV - ANSWERS TO PROBLEMS GIVEN IN APPENDIX III

1. (a) 1.8 cubic feet and 21.3 super feet.

   (b) 0.69 cubic feet and 8.3 super feet.

   (c) 6.6 cubic feet and 80 super feet.

   Number of running feet in the parcel = (16 + 10 + 12) = 38 R.ft.

2. (a) 15,000 super feet.

   (b) 30 cubic feet.

   (c) 3 loads.

   (d) 280 chains or 2,800 links.

   (e) 6 cubic yards.

   (f) 3½ square yards.

   (g) 15 acres.

3. (a) 63 cubic feet.

   (b) 89.5 cubic feet.

   (c) 19.4 cubic feet.

4. Volume by Hubers method = 86.2 cubic feet.

   Volume by Smalians method = 99 cubic feet.

5. Current Annual Increments are : 1951 - 52 = 6 loads/acre/annum.
   55 - 56 = 4 " " "
   56 - 57 = 3 " " "

   Periodic Mean Annual Increments are :
   1950 - 57 = 4.57 loads/acre/annum
   52 - 56 = 6.75 " " "
   53 - 57 = 3.75 " " "

6. Mean Annual Increments are : Age 30 = 486.8 cubic feet/acre/annum
   32 = 500.8 " " " "
   36 = 510.6 " " " "

7. Mill lives are (a) 25 years

   (b) 40 years

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