सत्यमेव जयते

FOREST MENSURATION

বন বিভাগ
পশ্চিমবঙ্গ সরকার

DIRECTORATE OF FORESTS
GOVERNMENT OF WEST BENGAL

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PREFACE

Forest Mensuration deals with measurement and quantification of trees and forests. Acquaintance with the techniques and procedures of such measurement and quantification is an essential qualification of a forest manager. As part of the JICA project on 'Capacity Development for Forest Management and Training of Personnel' being implemented by the Forest Department, Govt of West Bengal, these course materials on Forest Mensuration have been prepared for induction training of the Foresters and Forest Guards.

The subjects covered in these materials broadly conform to syllabus laid down in the guidelines issued by the Ministry of Environment of Forests, Govt of India, vide the Ministry's No 3 - 17/1999-RT dated 05.03.13. In dealing with some of the parts of the course though, some topics have been detailed or additional topics have been included to facilitate complete understanding of the subjects. The revised syllabus,with such minor modifications,is appended.

As the materials are meant for the training of frontline staff of the Department, effort has been made to present theories and practices of forest mensuration in a simple and comprehensive manner. Use of mathematical tools, where unavoidable, has been made in simple and elementary form. It is to mention, however, that knowledge of elementary Mathematics, including Geometry, Trigonometry and Mensuration is essential to understand the subject.

Preparation of the course materials needed study of many books and articles including those available in internet. In particular following books have been found very useful to obtain inputs For the course materials,and their contribution is thankfully acknowledged.

1. Elementary Forest Mensuration by M R K Jerram et al.Thomas Murby & Company, London
2. Forest Measurements by T Eugene Avery. Mcgraw-Hill Book Company
3. Forest Mensuration by Chaturvedi and Khanna. International Book Distributors Dehradun

Efforts that have gone into making of these course materials will be rewarded if the frontline staff of the forest department find them useful in their daily activities.

A Basu Ray Chaudhuri, IFS (Retd)
For IBRAD (Consultant)

N K Pandey, IFS
Chairman, SPMU, Forest Department,
Govt of West Bengal

SYLLABUS

Forest Mensuration (9 hours), excursion 1 day		
1.Basic mathematics	Units of measurement of length, area, volume, weight, and density under British and metric systems and their conversion factors	1 hour
2. Measurement of Standing Trees - Girth/diameter and height measurement	-breast height dimensions -use of tape- ordinary/ diameter type and calipers and their advantage and disadvantages -measurement of height using altimeters	1 hour
3.Volume measurement	- Tree shape*, taper* -volume of standing trees - form factor, form height* - measurement of felled trees* -volume of logs using quarter girth formula - pole* -stacked volume of firewood and use of reducing factor	2 hours*
4.Yield assessment	- Volume table – kinds of volume table* – preparation of volume table* – application* – construction of local volume table from general volume table*. - Increment of individual trees and measurement of sample woods* - Yield Tables* - application* –preparation of yield tables* - point sampling, theory of point sampling*, wedge prism	4 hours*
5. Enumeration of growing stock	-total enumeration -partial enumeration, kinds of sampling*, sampling unit*, sampling intensity*, elementary statistical computations*	1 hour

* These are modifications to the MoEF-syllabus, indicating revision/addition of topics.

Lesson 1 — 1 hour

Lesson Plan:

Objective:

To study Basic Mathematics:

- Length, Unit of length
- Area, Unit of area
- Volume , Unit of volume
- Mass and Weight
- Unit of weight (mass)
- Density
- Unit of Density

Backward Linkage: Nil

Forward Linkage:

- Application in subsequent lessons.

Training materials required:

- Copy of lesson 1 to be circulated beforehand.

Allocation of time:

Length, Unit of length	5 mins
Area, Unit of area	7 mins
Volume , Unit of volume	8 mins
Mass and Weight	10 mins
Unit of weight (mass)	5 mins
Density	10 mins
Unit of Density	5 mins
Discussion/Miscellaneous	10 mins

Lesson 2 **1 hour**

Lesson Plan:

Objective:

To study: **Measuring Standing Trees**

- Diameter, Girth at Breast Height
- Diameter Class
- Tree Height
    - Measurement on level ground
    - **Measurement on mountainous**

terrain **Backward Linkage**: Lesson 1

Forward Linkage:

- Application in subsequent lessons.

Training materials required:

- Copy of lesson 2 to be circulated beforehand.
- Tree caliper, Diameter tape

Allocation of time:

Diameter, Girth at Breast Height	15 mins
Diameter Class	5 mins
Tree Height	
• Measurement on level ground	15 mins
• Measurement on mountainous terrain	15 mins
Discussion/Miscellaneous	10 mins

Lesson 3 **1 hour**

Lesson Plan:

Objective:

To study: **Measuring Tree Volume**

- Tree shape
- Volume of stem wood
- Procedures for measurement of stem volume
- Appendix Lesson 3 Forest Mensuration

Backward Linkage: Lesson 2

Forward Linkage:

- Application in subsequent lessons.

Training materials required:

- Copy of lesson 3 to be circulated beforehand.

Allocation of time:

• Tree shape	10 mins
• Volume of stem wood	20 mins
• Procedures for measurement of stem volume	15 mins
• Appendix Lesson 3 Forest Mensuration	10 mins
• Discussion/Miscellaneous	5 mins

Lesson 4 **1 hour**

Lesson Plan:

Objective:

To study: **Volume measurement (continued)**

- Form Factors
- Form Height
- Measurement of felled trees

  Parts of Merchantable produce
- Stem Wood
  - Measurement of length, diameter and volume
  - Quarter Girth Formula

  Small wood

Firewood

Stacked volume, Reducing Factor Pole

Backward Linkage: Lesson 3

Forward Linkage:

- Application in subsequent lessons.

Training materials required:

- Copy of lesson 4 to be circulated beforehand.

Allocation of time:

• Form Factors	10 mins
• Form Height	3 mins
• Measurement of felled trees	
Parts of Merchantable produce	10 mins
• Stem Wood	
• Measurement of length, diameter and volume	8 mins
• Quarter Girth Formula	8 mins
Small wood	3 mins
Firewood	8 mins
Stacked volume, Reducing Factor	
Pole	5 mins
• Discussion/Miscellaneous	5 mins

Lesson 5 **1 hour**

Lesson Plan:

Objective:

To study: **Yield Assessment**

- Volume Table
- Kinds of volume table
- Preparation of volume table based on single variable
- Application of Ms Office Excel
- Volume table from volume girth equation
- Application of volume table
- Preparation of volume table based on two variables
- Constructing Local volume table from General volume table

Backward Linkage: Previous Lessons

Forward Linkage:

- Application of volume table may be seen during tour

Training materials required:

- Copy of lesson 5 to be circulated beforehand.
- Specimen volume Table

Allocation of time:

• Volume Table	5 mins
• Kinds of volume table	3 mins
• Preparation of volume table based on single variable	10 mins
• Application of Ms Office Excel	5 mins
• Volume table from volume girth equation	3 mins
• Application of volume table	6 mins
• Preparation of volume table based on two variables	10 mins
• Constructing Local volume table from General volume table	10 mins
• Discussion/Miscellaneous	8 mins

Lesson 6 — 1 hour

Lesson Plan:

Objective:

To study: **Yield Assessment (Continued)**

- Increment of Individual Trees
    - Current and mean Annual Increment
    - Determination of age
    - Volume Increment
- Measurement of woods
    - Determination of age of woods
    - Determination of mean height
- Volume of sample wood

Backward Linkage: Previous Lessons

Forward Linkage:

- Application in field exercise

Training materials required:

- Copy of lesson 6 to be circulated beforehand.

Allocation of time:

• Increment of Individual Trees	
▪ Current and mean Annual Increment	10 mins
▪ Determination of age	8 mins
▪ Volume Increment	10 mins
• Measurement of woods	
▪ Determination of age of woods	7 mins
▪ Determination of mean height	10 mins
• Volume of sample wood	10 mins
• Discussion/Miscellaneous	5 mins

Lesson 7 — 1 hour

Lesson Plan:

Objective:

To study: **Yield Assessment (Continued)**

- Yield Tables
- Format for yield table
- Preparation of Yield table

Backward Linkage: Previous

Lessons Forward Linkage:

- Application in field exercise

Training materials required:

- Copy of lesson 7 to be circulated beforehand.
- Sample Yield Table

Allocation of time:

Yield Tables	10 mins
Format for yield table	10 mins
Preparation of Yield table	30 mins
Discussion/Miscellaneous	10 mins

Lesson 8 **1 hour**

Lesson Plan:

Objective:

To study:

Yield Assessment (Continued)

Point Sampling

- Theory of point sampling

Wedge Prism

- Sampling with wedge prism
- Calculation of basal area and stem volume

Backward Linkage: Previous Lessons

Forward Linkage:

- Application in field exercise

Training materials required:

- Copy of lesson 8 to be circulated beforehand.
- Wedge Prism

Allocation of time:

Point Sampling

- Theory of point sampling 20 mins

Wedge Prism

- Sampling with wedge prism 20 mins
- Calculation of basal area and stem volume 15 mins

Discussion/Miscellaneous 5 mins

Lesson 9 — 1 hour

Lesson Plan:

Objective:

To study:

Enumeration of Growing stock

Complete Enumeration

Partial Enumeration

Sampling

- Kinds of sampling
  - Simple random sampling
  - Stratified random sampling
  - Systematic sampling
- Sampling units
- Sampling intensity
- Sampling Errors

Backward Linkage: Previous Lessons

Forward Linkage:

- Application in field exercise

Training materials required:

- Copy of lesson 9 to be circulated beforehand.

Allocation of time:

Complete Enumeration	5 mins
Partial Enumeration	10 mins
Sampling	
▪ Kinds of sampling	18 mins
➢ Simple random sampling	
➢ Stratified random sampling	
➢ Systematic sampling	
▪ Sampling units	7 mins
▪ Sampling intensity	7 mins
▪ Sampling Errors	8 mins
Discussion/Miscellaneous	5 mins

Lesson 10 **1 hour**

Lesson Plan:

Objective:

To impart hands-on training on

- Measurement of diameter at breast height (dbh)
- Measurement of heights of trees
- Use of Wedge Prism

To calculate

- Mean Height of each dia class
- Basal Area of each dia-class
- Volume of each dia class and of stand with the help of volume table

Backward Linkage: Previous Lessons

Forward Linkage:

- Application in field exercise

Training materials required:

- Diameter tape
- Altimeter
- Volume table
- Wedge Prism

Allocation of time: (within the time available on Saturday Excursion)

Lesson 6: Yield Assessment (Continued)

Lesson 7: Yield Assessment (Continued)

Lesson 8: Yield Assessment (Continued)

Lesson 9: Enumeration of Growing stock

Lesson I

Basic Mathematics

1. **Length –** Length is the distance from one end to the other end of an object
   For example, the length of the line segment AB is the distance along the line from A to B.

Fig. 1.1

2. **Units of Length**
   Metric System – In metric system the unit of measurement of length is **metre (m)**. Smaller units are **millimetre (mm), centimetre (cm), micrometer (µm**) and **nanometer (nm)**. The larger unit is **kilometre (km).**
   Relations among the various units are given below.
   1 km = 1000 m
   1 m = 100 cm = 1000 mm = 1,000,000 micrometre = 1,000,000,000 nanometre
   1 cm = 10 mm
   1 mm = 1000 micrometre
   1 micrometre = 1000 nanometre
   British System – In British system the units of measurement of length are inch, foot, yard and mile.
   Conversion factors of one unit to another are given below.
   I foot = 12 inches
   1 yard = 3 feet
   1 mile = 1760 yards = 5280 feet
   Conversion factors between Metric and British Units –
   1 inch = 2.54 cm; 1 foot = 30.48 cm; I yard = 91.44 cm = 0.9144 metre;
   1 mile = 1609.34 m = 1.6093 km.
   1 cm = 0.3937 inch; 1 metre = 39.370 inch = 3.281 feet = 1.0936 yard;
   1 km = 1093.61 yard = 0.621 mile.

3. **Area –** Area is the extent of a two dimensional surface or shape. In other words, area of

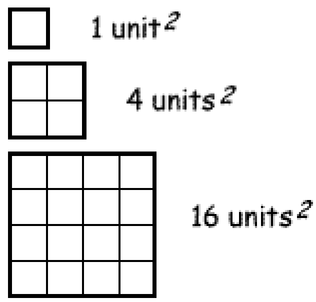


Fig. 1.2

a plane figure means the number of square units the figure covers. In the above diagram, given the extent of one square unit, the second figure (square) contains 4 squares, and the third figure (square) contains 16 squares. Therefore, areas of the second and the third square are 4 sq. unit and 16 sq. unit respectively. The square units could be inch^2, cm^2, ft^2, m^2 etc.

4. Units of Area

Metric System – Commonly used metric system of units for area measurement are square cm (cm^2), square metre (m^2), square km (km^2), hectare (ha) etc. Relations among these units are given below.

1 m^2 = 10,000 cm^2 ; 1 ha = 10,000 m^2 ; 1 km^2 = 100 ha = 1,000,000 m^2

British System - Commonly used British system of unite for area measurement are sq. inch (inch), sq. ft (ft). sq yard (yard), sq mile (mile), acre etc. Relations among these units are given below.

1 ft^2 = 144 inch^2 ; 1 yard^2 = 9 ft^2 = 1296 inch^2 ; 1 acre = 4840 yard^2 ;

1 mile^2 = 640 acre = 3097600 yard^2

Conversion factors (approximate) between Metric and British Units

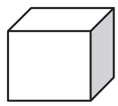
1 inch^2 = 6.45 cm^2 ; 1 ft^2 = 929.03 cm^2 = 0.093 m^2 ; 1 yard^2 = 0.836 m^2

1 mile^2 = 2.590 km^2 ; 1 acre = 4046.24 m^2

1 cm^2 = 0.155 inch^2 ; 1 m^2 = 1.196 yard^2 ; 1 km^2 = 0.386 mile^2

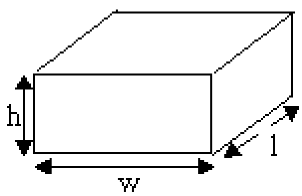
1 ha = 2.47 acre

5. Volume – Volume is the space occupied by a material or object. In other words, volume is the number of unit cubes that fit within the solid figure of the object.



Unit Cube

Unit cube has one unit length, one unit width and one unit height.



Rectangular parallelepiped having length l units, width w units and height h units
Its volume = l x w x h unit^3.
If l = 4 units, w = 3 units and h = 2 units, then volume = 4 x3 x 2 = 24 unit^3. That is, 24 unit cubes can be accommodated within the parallelepiped.

Fig.1.3

6. **Units of Volume**

Metric System – Commonly used units are cubic mm (mm^3), cubic cm or cc (cm^3), cubic metre (m^3), litre etc. Relations among these units are given below.

1 cm^3 or 1 cc = 10 mm x 10mm x 10 mm = 1000 mm^3

1 litre = 1000 cc;

1 m^3 = 1m x 1m x 1m = 100 cm x 100 cm x 100 cm = 10,00,000 cc.

British System – Commonly used units are cubic inch (inch^3), cubic feet (ft^3), cubic yard (yard^3) etc. and their relations are as follows.

1 ft^3 = 1 foot x 1 foot x 1 foot = 12 inches x 12 inches x 12 inches = 1728 inch^3

1 yard^3 = I yard x I yard x 1 yard = 3 ft x 3 ft x 3 ft = 27 ft^3

Conversion factors (approximate) between Metric and British system

1 cc = 0.061 inch^3 ; 1 m^3 = 35.318 ft^3 = 1.308 yard^3

1 inch^3 = 16.387 cc ; 1 ft^3 = 0.0283 m^3 ; 1 yard^3 = 0.764 m^3

7. **Mass and Weight**

Mass represents the amount of matter in an object. Weight, in scientific terms, represents the amount of gravitational force acting on an object, that is, the force with which the object is attracted by earth towards its centre. While mass of an object is constant, its weight varies from place to place. However, weight of an object is proportional to its mass, and in everyday usage, mass and weight are used interchangeably. In forest measurement weight normally would mean mass, that is, the amount of matter.

8. **Units of weight (mass)**

Metric System – Commonly used units are gram (gm), kilogram (kg) , quintal and metric tonne. The relations among the units are as follows.

1 kg = 1000 gms, 1 quintal = 100 kg, I metric tonne = 1000 kg.

British System – Commonly used units are pound (lb), imperial ton or long ton etc.

1 Imperial ton = 2240 lbs; there is another unit called short ton, which is equal to 2000 lbs.

Conversion factors (approximate) between Metric and British system

1 lb = 453.59 grams = 0.45359 kg

1 imperial ton = 2240 lbs = 1016.0469 kg = 1.016 metric tonne

1 kg = 2.2046 lb;   1 metric tone = 1000 kg = 2204.6 lbs = 0.984 imperial ton

9. Density

Density of an object or substance is defined as mass per unit volume**.** It is a measure of how much matter in unit volume. Loosely speaking density of a substance gives an indication of how heavy or light is the substance. For example, density of water is 1 gm/cc. It would mean that 1 cc of water weighs 1 gram. In, comparison, iron, known to be heavier than water, has density 7.87 gms/cc. That is, one cc of iron weighs 7.87 grams. We may say iron is 7.87 times heavier than water.

10. Units of density

Metric system – Commonly used units are gram per cubic cm (gm/cc) and kg per cubic metre (kg/m^3).

1 kg/ m^3 = 1000gm/1000000cm^3 = 0.001 gm/cc, or, 1 gm/cc = 1000 kg/ m^3

British system – Commonly used unit is pounds per cubic feet (lbs/ft^3)

Conversion factors (approximate) between Metric and British system

1 lb/ft^3 = 453.59 gm/28316.8 cc =0 .0160 gm/cc

1 gm/cc = 62.4280 lb/ft^3

1 kg/m^3 = 0.001 gm/cc = 0.062428 lb/ft^3.

FOREST MENSURATION

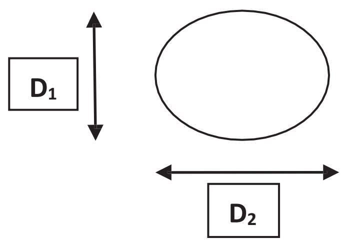
Lesson 2

Measuring Standing Trees

1.Diameter at Breast Height – For convenience of measurement and to facilitate comparison, diameters of standing trees are measured at a fixed height termed **Breast Height**.

Known as **DBH,** the **Diameter at Breast Height** is defined as the average stem diameter, outside bark, at a height 4.5 feet, that is 4 feet 6 inches (approximately 1.3 metre), above ground.

1.1 **Measurement** – DBH is usually measured with **tree caliper or diameter tape**. Tree caliper held at breast height provides easy and quick measurement of DBH. For ordinary work a single reading of caliper will suffice. However, since tree cross sections are not exactly circular, **two caliper readings at right angles** should be made and the average may be recorded as DBH.



D_1 and D_2 are two caliper readings in perpendicular directions.

DBH = $(D_1 + D_2)/2$

Fig. 2.1

A **diameter tape** actually measures circumference or girth of a tree at breast height **(GBH).** However, based on relationship between the diameter and circumference (girth) of a circle, the tape is so graduated that it provides for direct reading of diameter.

Relationship of Diameter (D) and circumference Girth(G) of a circle:
$G = \pi D$, where $\pi = 22/7$ or 3.142
that is $D = G/\pi$

The circumference or girth(G) at breast height **(GBH)** can be measured with an ordinary tape, and then DBH can be calculated from the above formula.

Presumption: Measurement of DBH with tape is based on presumption that tree cross sections are circular, which is rarely the case.
Less Accurate: That is why tape is less accurate than calipers. However, tape is preferred to calipers for bigger stems as the calipers are bulky and difficult to handle.

Trees on slopes: In case of trees growing on slopes DBH should be measured 4.5 feet above ground on the **uphill side** of the tree.

1.2 **DBH and GBH under bark**: In many species bark is quite thick and constitutes a considerable portion of bole volume. In such cases DBH or GBH under bark should be determined to calculate timber volume.

1.3 Bark thickness may be determined with an instrument known as **Bark Gauge**.

If "t" represents bark thickness, then diameter-under-bark (dub) and girth-under-bark (gub) can be obtained from the measured values of diameter-over–bark (dob) and girth-over-bark (gob) with the help of the following formula:

dub = dob – 2t

Subtract double the bark thickness from dob to obtain dub

gub = [illegible] – [illegible] = gob -2[illegible]

Subtract 2π times bark thickness from gob to obtain gub

1.4 **Tree Diameter Classes:** Tree diameters can be measured nearest to 0.1 inch. However, it is more convenient and customary to group measurements into diameter classes. When 2 inch diameter or 4 cm diameter classes are used, group or class limits may be taken as follows.

2-inch Dia Class		4-cm Dia class	
Dia Class or Mean Dia	Dia limits in inch	Dia class or Mean Dia	Dia limits in cm
8 inch	7 to <9	20 cm	18 to <22
10 inch	9 to <11	24 cm	22 to <26
12 inch	11 to <13	28 cm	26 to <30
14 inch	13 to <15	32 cm	30 to <34

1.4.1 Thus trees having diameter from 7 inch to less than 9 inch may be taken as belonging to 8 inch dia class, trees having diameter from 9 inch to less than 11 inch will belong to 10 inch dia class and so on. Similarly, trees having diameter from 18 cm to less than 22 cm may be considered as belonging to 20 cm dia class, trees having diameter from 22 cm to less than 26 cm will belong to 24 cm dia class.

1.4.2 The convenience of grouping actual diameters into dia classes is that all trees of a dia class may be considered as having the same diameter corresponding to the said class for the purpose of enumeration and calculation. For example, all trees of 8 inch class may be considered as having a mean diameter of 8 inch

2. Tree Height

Total Height of a standing tree is the perpendicular distance from the tip of the leading shoot to the ground level. In comparison, **merchantable tree height** means usable portion of the tree stem, that is, the section expected to be utilized in a commercial logging operation.

2.1 Objects of measuring Tree height

a) Heights at known intervals of age give a measure of productivity of the site.
b) Heights of selected trees may be required for application of volume tables and yield tables
c) To determine rate of increment of height.

2.2 Measurement of Height

Methods of measurement employ simple principles of Geometry or Trigonometry and **assume that trees are perpendicular to the ground.**

Instruments used for measuring tree heights are collectively known as **hypsometers**.

The basic trigonometric principle used in hypsometers is illustrated in the accompanying diagram.

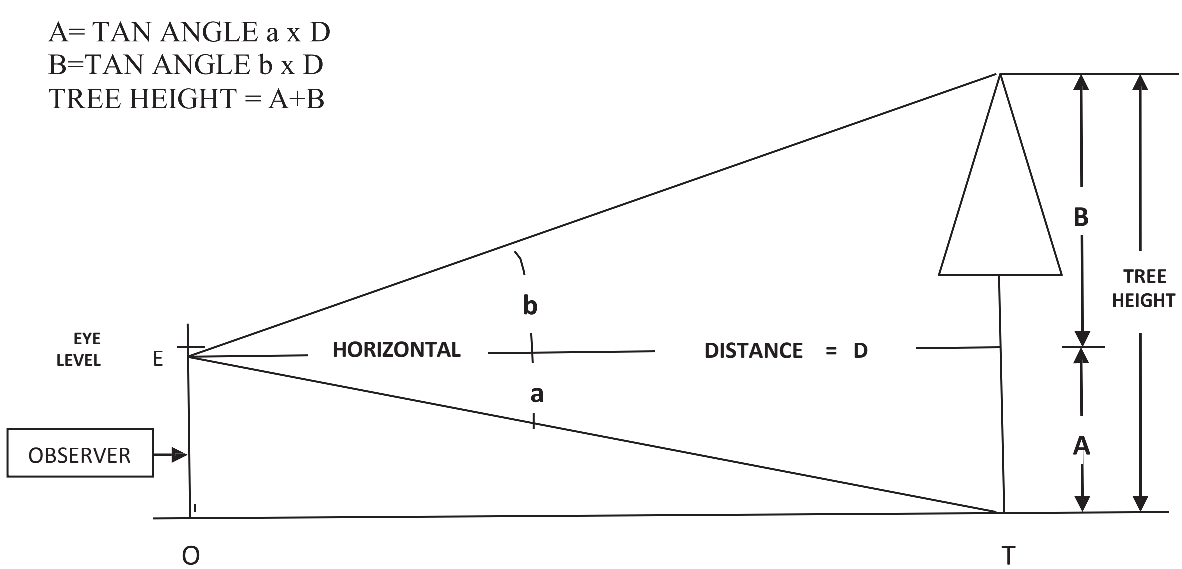


Fig 2.2 illustrating height measurement on a level ground

The observer is stationed at a fixed horizontal distance D from the base of the tree. **On a level ground or on gentle terrain**, his horizontal (level) line of sight will usually divide the tree height into two segments A and B. When the Observer views the base and the top, the line of sight makes angles **a** (**angle of depression**) and **b (angle of elevation)** respectively with the horizontal line.

Then **Tree Height = A + B = D x (tan a + tan b) … (A)**

Abney level and several **altimeters** operate on this principle. Using the above relation these instruments give height readings directly at fixed horizontal distances (D) from the tree.

2.2.1 Accuracy of Measurement: Accuracy of height measurement based on formula (A) above depends on the following factors.

1. Accuracy with which it is possible to determine the horizontal distance D

2. The Observer finds a position from which tree top and foot of the tree are clearly visible.

2.2.2 Measurement on level ground :

On a level ground the measurement and calculation become simpler. In this case

1. Horizontal distance D will be nearly equal to the distance (OT) of the observer from the base of the tree **measured on ground**. and

2. Length of segment A (of tree) will be equal to height of observer's eye level above ground i.e. OE ,which can be approximated as **height (h)** of the observer.

3. Thus Tree Height = **Height of the observer (h)** + **OT X tan b …….(B)**

Advantages in this case are – (1) h is known, (2) OT is accurately measurable by chain and tape; and (3) only one observation for tree top with the hypsometer is involved.

When angle of elevation is 45^0 : The **formula (B**) becomes even simpler when angle of elevation b can be made 45^0 . Since value of tan angle 45^0 is 1 , the above formula in that case becomes

Tree height = h + OT= Observer's height + Observer's distance from the tree ….(C)

Thus in field situations **on level ground**, where horizontal Distance D or OT can be changed with reasonable ease without losing the sight of tree top, the Observer can station himself at a point from which angle of elevation becomes 45^0 and formula (C) is applicable. Based on this principle a **simple handy device can be made to measure Tree Height on level ground**

Simple Right Angle Triangle Device: With the help of a cardboard or similar stiff material make a right angled triangle whose two sides other than the hypotenuse are equal. The acute angles of the right angled triangle will be both 45^0. Please see the diagram below.

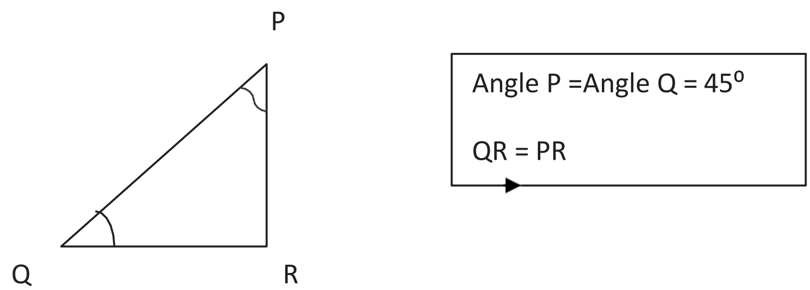


Fig.2.3 - Simple Right Angle Triangle Device

Make an ocular estimation of Tree height. Station yourself at a distance approximately equal to estimated Tree Height. Hold the triangle firmly at the right angle corner and sight tree top along the line of hypotenuse QP. Move and adjust your position to a point where your line of sight along the hypotenuse touches the tip of the tree. The angle of sight in this case will be 45^0. (**Please see Fig.2.4 below**). Now measure the horizontal distance (D = OT) of your position from the tree base. The Tree Height H can be determined with the help of formula (C) above.

The exercise however is applicable only on level ground and where vegetation is not very dense so that you have clear view of tree top from a distance equal to tree height.

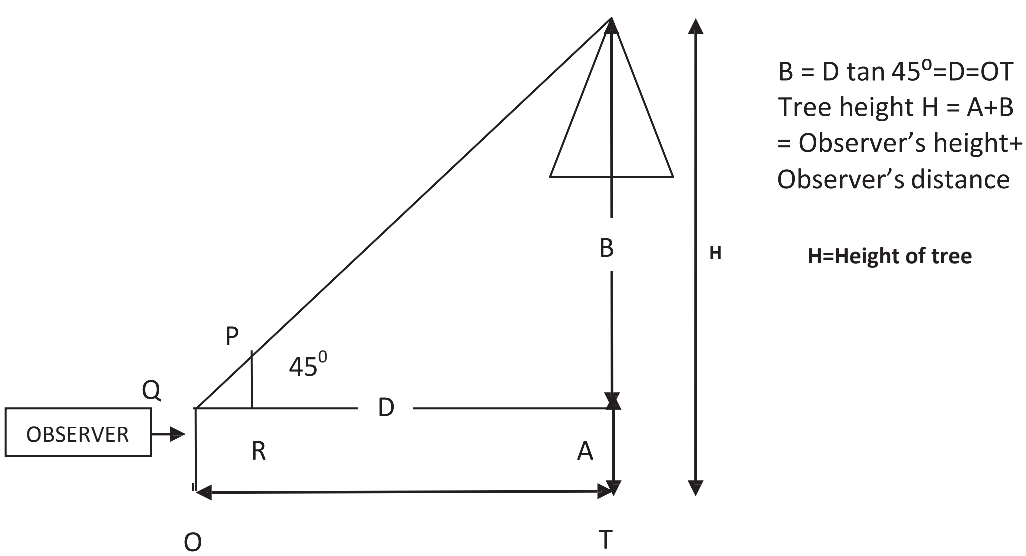


Fig 2.4 – Measurement with Right Angle Triangle

> **Exercise**
>
> In an exercise with an Isosceles right angled cardboard, an observer's line of sight along the hypotenuse touches the tip of a tree. The horizontal distance of the observer from the tree base is 30 m. The height of the observer is 1.5m. What will be the height of the tree?

2.2.3 Measurement on mountainous terrain

In mountainous terrain, the observer's position may be either above the top of the tree (Fig. 2.5) or below the base of the tree (Fig. 2.6).

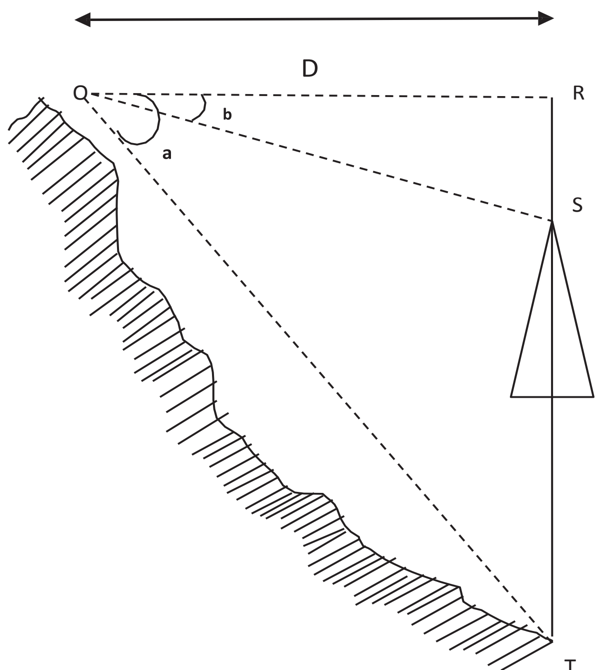


Fig. 2.5

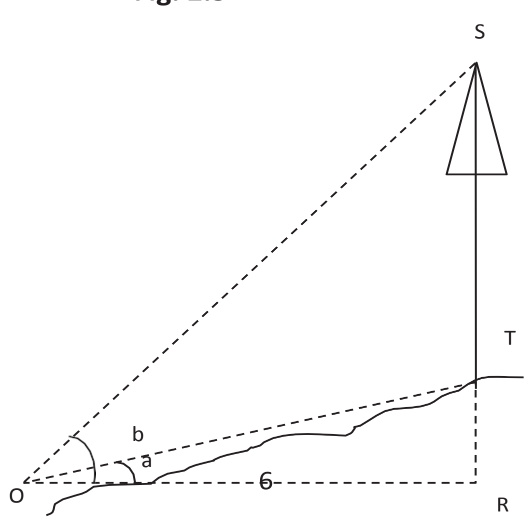


Fig. 2.6

In both the cases illustrated above, **the level line of sight does not intersect the tree and the horizontal distance D=OR is not measurable**.

Modification of Formula (A)

For height measurement in mountainous terrain the Formula (A) requires to be modified.

In the first case (Fig. 2.5), the angles of sight to the top and to base are both angles of depression. It is obvious from the diagram that the tree height will be obtained by taking difference between the two readings. Formula (A) gets modified as follows.

Tree Height = D x (tan a – tan b) ----- (D)

In the second case (Fig.2.6), the angles of sight to the top and base are both angles of elevation and here also the tree height will be obtained by taking difference of two readings as shown below.

Tree Height = D x (tan b – tan a) ……….. (E)

It may be noted that since the horizontal distance D (= OC) is not measurable in either of the two cases, D should be found out from the following relation.

D = OT x cos a ………… (F)

The distance OT which is the distance along the slope to the foot of the tree can be measured, and thus D can be found out. Once D is determined, the tree height can be calculated from formula (D) or (E) as the case may be.

FOREST MENSURATION

Lesson 3

Measuring Tree Volume

1. **Tree shape :** For the purpose of measurement of wood, the portion of tree which is above ground, that is, the **stem** and **crown,** is of consideration. The size and height of the crown and its distinction from the stem depend on many factors like species, age, stem density etc. **Trees take different forms and shapes depending on the conditions under which they are grown. Again trees of the same species of different ages will have different shapes.**

1.1 Taper: Trees are found to taper. In other words, the diameter and girth of a tree gradually reduce from base to top. However, as one goes along the height of a tree, the taper is not uniform. The degree of taper varies from part to part and thus leads to different shapes of the various parts of the stem.

1.2 Complex Form: Since the tree form or shape is complex, measuring tree volume with accuracy becomes a difficult task. **The only accurate means of measuring tree volume is to fell a tree, submerge the various parts in water by turn, and calculate the total volume of displaced water.** It is, however, obvious that for the purpose of management this method of submerging is not feasible and not advisable either.

2. **Tree parts resemble some geometrical solids:** Forest managers therefore try to estimate the tree volume by taking linear measurements and applying the properties of geometrical solid bodies to which the tree parts tend to approximate. **It may be borne in mind therefore that calculation of tree volume based on such linear measurements is only an estimation of tree volume**.

2.1 Parts of a tree stem tend to approximate truncated parts of some known geometrical shapes. The base of the tree tends to be neiloid while the tip tends to be conoid. The main part of the bole tends to be paraboloid **(Fig. 3.1).**

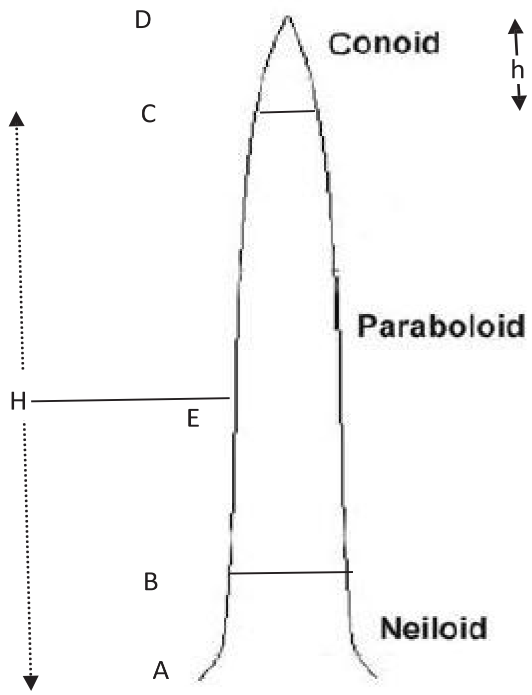


Fig.3.1

3. **Volume of Stem wood:** In order to find the volume of stem wood, volume of individual segments may be calculated and the sum of such volumes will give the total volume.

   Thus from Fig.3.1, the total stem volume or trunk volume of the tree may be computed from the following relation.
   Trunk volume = Volume of segment AB (Neiloid frustum) + Volume of segment BC (Paraboloid frustum) + Volume of segment CD (cone). ………………(3.1)

3.1 Formula of geometrical solids: While calculating the volume of individual sections, formula for volume of the corresponding geometrical solids may be employed. Formulae and diagrams of some geometric solids are given in the **appendix** which may be seen.

3.2 Simplified Volume computation :
In practice, for the purpose of measurement, a stem or log is presumed to have the form of a truncated paraboloid , that is, frustum of a paraboloid. Thus formula of paraboloid frustum can be employed to find the stem volume, taking the stem as one section in the shape of a paraboloid frustum.

Frustum of a paraboloid having A_b = Area of the base, A_u = Area of the top of the frustum, and h = height (length) of frustum	**Volume =** [illegible] ----- known as **Smalian's formula** **or,** **= h.** A , where A_m is basal area at mid-section …… known as **Huber's formula**.

From Fig.3.1, based on above simple presumption, by employing Huber's formula,

Stem Volume V = H. A_E .... (3.2)

where A_E is the cross sectional area at section E; E being the point at mid height (H/2) of the paraboloid segment AC.

3.3 The simplified formula gets modified when total stem volume is to be measured with accuracy. In that case, the top section CD (Fig.3.1) which may be assumed to have the shape of a cone, and was ignored earlier in simplified calculation 3.2, may be taken into consideration. Volumes of the two segments – paraboloid frustum AC , and cone CD - when added together will give total volume of the stem or trunk.

A cone having basal Area A and height h	**Volume = $\frac{h}{3}$. A**

Thus Total Stem Volume = **H. A_E + $\frac{h}{3} \cdot A_C$** ....(3.3)

Where A_C is the cross sectional area at section C, and h is the height of cone (Fig.3.1).

3.4 Cross sections are assumed circular

The sectional areas A_E and A_C employed in equations (3.2) and (3.3) are considered to be circular and are calculated from the measured diameter or girth at the corresponding section or height from the following formulas.

$A = \frac{\pi D^2}{4}$ **, where π = 3.1416, and D is diameter of the section. ....(3.4)**

$A = \frac{G^2}{4\pi}$ **, where G = π D is the girth of the section. ....(3.5)**

The stem of a tree is, however, seldom circular and more often elliptical. It is known that area of a circle having same circumference as perimeter of an ellipse is greater than the area of ellipse. So if the section is elliptical, it is obvious that area calculated from girth (formula 3.5) will be overestimated. Similar case of overestimation occurs when area is calculated from formula (3.4) based on mean diameter. In practice, wherever feasible, two measurements of diameter D_1 and D_2 are taken along major and minor axis respectively of the elliptical section and mean diameter D_m is used to calculate sectional area according to the following formula. **Please refer to paragraph 1.1 of Lesson 1.**

$A = \frac{\pi D_m^2}{4}$, where $D_m = \frac{D_1 + D_2}{2}$ ....(3.6)

4. Procedures for measurement of Stem Volume

The stem volume of a standing tree is obtained by making standard measurement of different segments after the tree is felled. Needless to say, the stem volume so obtained from measurement of felled sections gives more accurate result than any method employed to measure volume of a standing tree. It is, however, neither convenient nor advisable to fell every time a tree to measure its volume. Foresters have to devise therefore methods by which volume of standing tree can be measured.

4.1 Direct Measurement - It is apparent from formula 3.1 or 3.2 or 3.3 that to find tree volume we need to know cross sectional areas (A) of the segments at specified points or sections and lengths of the segments. Cross sectional areas can be calculated if we can measure diameter or girth at the corresponding sections (**Formulas 3.4, 3.5 and 3.6**), and lengths of segments can be found if we can measure the heights (from ground) of end sections of each segment.

4.1.1. If there is no problem with regard to visibility, heights of specified or marked points on tree trunk can be measured with ease from ground by methods described in Lesson 2. However, instruments or devices meant for measurement of upper stem diameter or girth from ground are either not accurate or very expensive.

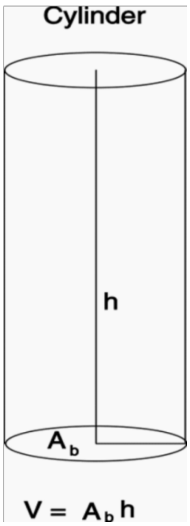
4.1.2 In the direct method a man climbs the tree with the help pf a ladder and makes measurement of diameter (or girth) and height (from ground) at specified and marked points or sections. Cross sectional areas and lengths necessary to find the volume of geometrical solids resembling the segments are found out from the said diameter (girth) and height measurements. Formulas for volume of such geometrical solids are then employed to find segment volumes, which when added together, gives tree volume.

4.1.3 In ordinary measurement, the trunk is considered to be a single paraboloid frustum (see paragraph 3.2 and formula 3.2). Thus measurement of tree height (H) and diameter (girth) at mid height (point E in fig 3,2) will be enough to find trunk volume. However, to bring in more accuracy in calculation, the stem may be subdivided into a number of segments based on change in tree taper. The successive sections are bottom and top section of each segment, and length of each segment being difference in heights (from ground) of the top and bottom section of the corresponding segment. The climber in this case has to measure diameter (girth) and height (from ground) at a number of points or sections as would be necessary to find the volumes of geometrical solids such segments in question resemble.

5. Indirect methods

Volume of standing trees can be found out by Form factors and by using Volume table. These have been described in subsequent Lessons.

APPENDIX LESSION 3 FOREST MENSURATION



Cylinder - The cylinder formula is the simplest of the formulas. Determination of volume requires only the area of one end and the length of the cylinder.

Figure 1. The formula for the volume of a cylinder.

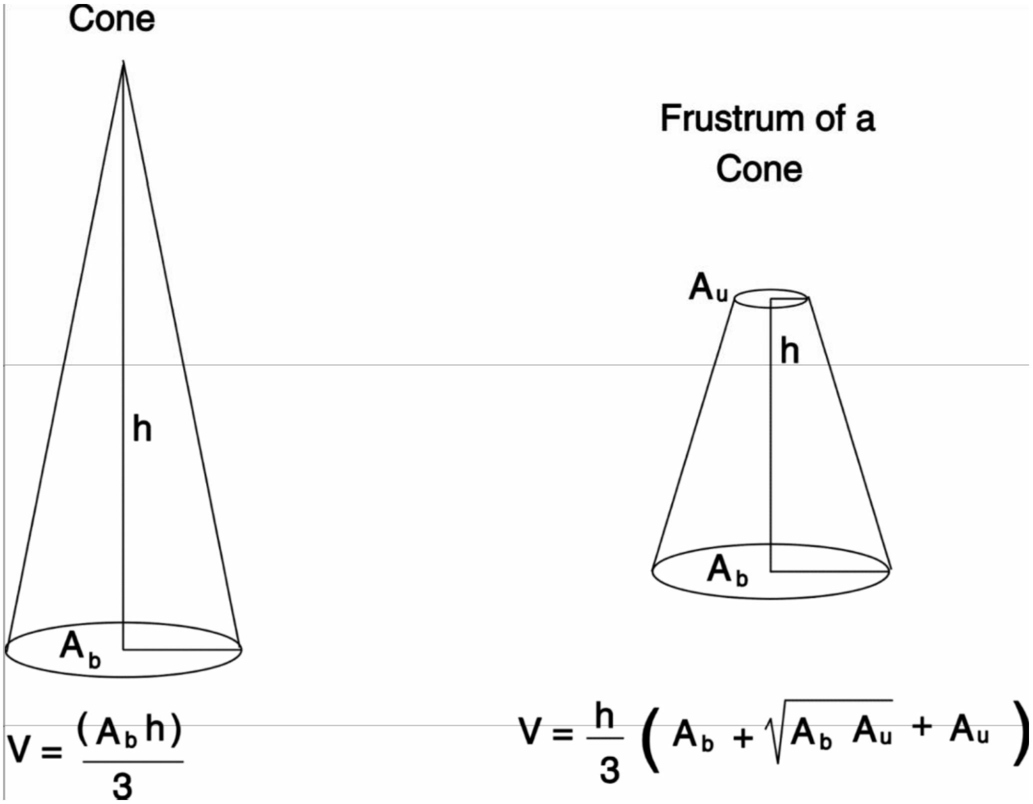


Figure 2. The formula for a cone and the frustum of a cone.

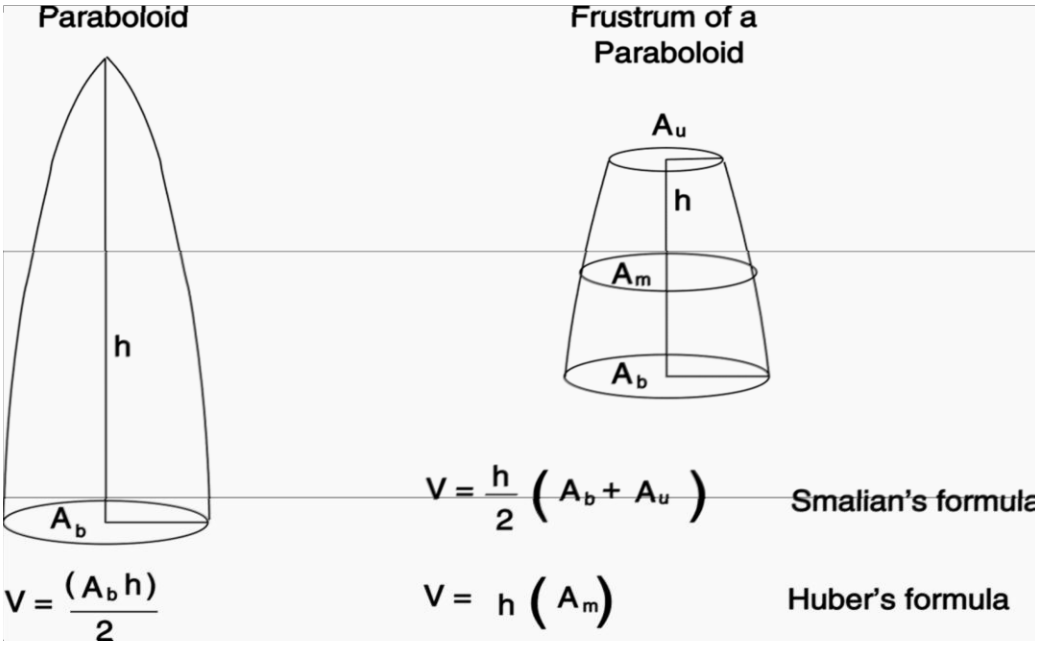


Figure 3. The formula for a paraboloid and the frustum of a paraboloid.

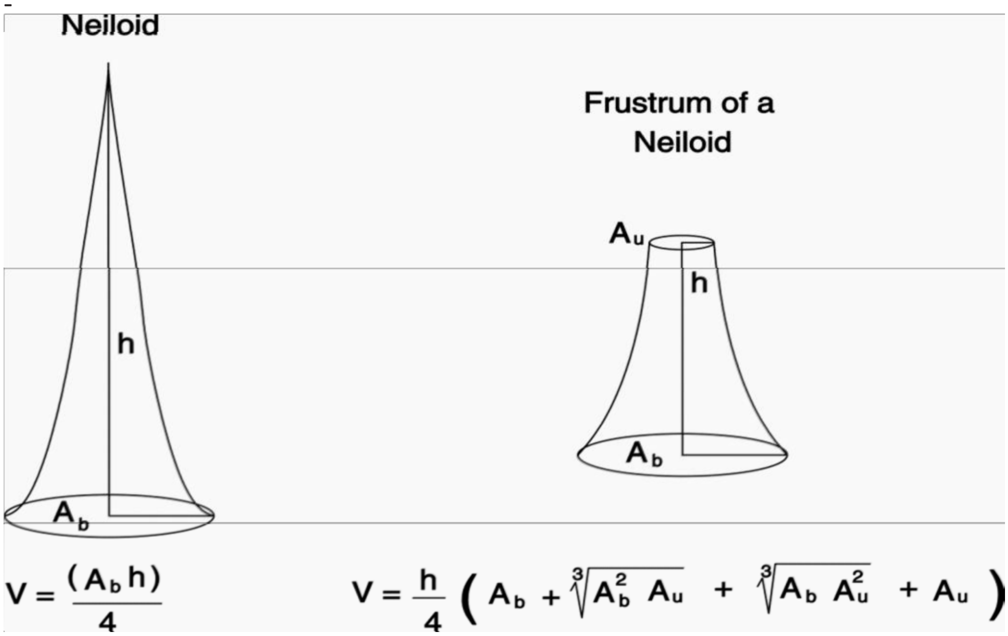


Figure 4. - The formula for a neiloid and the frustum of a neiloid.

(Source: Natural Resource Biometrics September 6, 2000 oak.snr.missouri.edu/nr3110; Tree Volume Estimation By David R. Larsen)

FOREST MENSURATION

LESSON 4

Volume measurement (continued)

1. **Form Factors – Form factor is defined as the ratio of the volume of a tree to the volume of a cylinder having the same length and cross-section as the tree.**

A Cylinder of basal Area A and height (length) H	Volume = A.H

Thus Form Factor $f = \frac{V}{A.H}$ .... **(4.1)**

Where, V = tree volume in m^3,
A = basal area in m^2,
H = tree height in m

1.1 Three kinds of Form Factors – Following three kinds of Form Factors are recognized.

Artificial Form Factor – When A denotes basal area at breast height, V the volume of whole length, and H the total height of the tree, the Form factor is known as Artificial Form Factor.

Absolute Form Factor - When A denotes basal area at a convenient height, and V and H refer to only to the part of the tree above the point of measurement of cross-section, the Form Factor is known as Absolute Form Factor.

True Form Factor - When A is measured at a point which is at a constant proportion, e.g. $1/10^{th}$ of the total height, and V and H refer to the whole length of the tree, the Form Factor is known as True Form Factor.

Unless otherwise stated, Form Factor always means Artificial Form Factor. Usually, Form Factors are determined for stem volume up to a certain minimum diameter. Such Form factors are less than unity.

1.2 Form Height – Form Height is defined as the product of the form factor and total height.

Thus Form height (FH) = $f.H = \frac{V}{A}$ -- **(4.2)**

If Form height remains more or less constant with increasing diameter, it may be presumed that volume is proportional to basal area.

1.3 Procedure to find Form factor

The total length, basal area (cross sectional area at breast height) and stem volume of sample trees may be determined as described earlier. In order to have accurate results, the total length and stem volume may be found out by taking measurement after having the trees felled. The form factor may then be calculated from the formula 4.1

1.4 Measurement of Stem Volume by Form Factors

Form factors may be determined, as explained above, with sufficient accuracy.. If form factors are evaluated for sufficient number of felled trees of different dimensions, then average form factors may be determined for various girth and height classes. Generally it will be seen that for a species in a given location, form factors of trees of different dimensions vary within narrow limits. In other words same form factor will apply to considerable ranges of height and diameter. A table may thus be prepared for average form factors for trees of different girth and height classes. Such table may be utilized for estimation of volume of standing trees from measurements of diameter or girth at breast height and height and by applying the formula

$$\mathbf{V= F \times A \times H} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad \mathbf{(4.3)}$$

Measurement of Felled Trees

2. **Objects of Measurement –** Following are the objects of measurement of felled trees.

   a) To know the quantity of merchantable volume with reasonable accuracy.
   b) To produce data which may be applied to standing trees in order to know the growing stock.

3. **Parts of Merchantable Produce –** Merchantable produce of a tree can be divided into following parts.

   (i) Stem wood – consisting of (a) timber and (b) small wood
   (ii) Crown or branch wood.

   The division between timber and small wood or the minimum diameter of timber (log) is decided by market requirements. Small wood is more often sold as firewood (consisting of billets of about 5 cm diameter) and less frequently as posts of 7.5-10 cm diameter. In general, stem wood up to 3 inch (roughly 7 cm) may be treated as timber and the stem may be logged accordingly. If some parts of the branch wood are straight and large, they can be logged as timber, and the rest adds to small wood.

4. Stem Wood - Timber – It is required to measure length and mid-diameter or mid-girth of stem wood. If the stem is of uniform taper then these measurements can be taken in one length or section. **However, normally since the tree taper is irregular, the stem is divided into several segments or sections. , called logs, and the measurement of length and mid-diameter (or mid-girth) is taken separately for each section. Sum of volumes of the sections gives the volume of stem wood timber. Length of sections is determined by straightness, uniformity in taper and market demand for specific sections**.

4.1 Length – Length of each log or section can be measured by a rod or tape. Length may be measured to the nearest 10 or 5 cm.

4.2 Diameter – Diameter of a log can be measured by a caliper or diameter tape. **Measurement is made at the middle of length of the log.** To know the merchantable volume it is necessary to determine the diameter under bark (**dub**). In case of commercially valuable species like Sal (*Shorea robusta*) and Teak (*Techtona grandis*) the logs are debarked and brought to depot. So, for these trees **diameter should be measured after debarking**. However, there are miscellaneous species, timber of which is prone to rot and damage within a short time, and it is not advisable to debark logs of such species. To find **dub** of these logs, **a circular strip (ring) of bark of small width is removed at the mid-length of the log so as to permit measurement of diameter under bark (dub). To reduce error, two measurements at right angles may be taken and the mean diameter may be used for calculation of volume (please refer to Lesson 2)**. **Diameter may be measured to the nearest centimeter. The mid-sectional area is calculated by the formula (3.4)**

4.3 Girth – Girth is measured by a tape under bark, as explained above, at the mid-length of the log. **The mid-sectional area is calculated by the formula (3.5).** It is not necessary to measure both diameter and girth of the log, as if one is known, the other can be calculated. However, if it is intended to apply Quarter Girth Formula (described later) to find the volume, direct measurement of girth is more handy. Girth under bark (gub) **may be measured to the nearest centimeter.**

4.4 Volume – Volume of a log is determined by using the **Huber's formula, which is**

$V = h \cdot A_m$ (please see paragraph 3.2 of Lesson 3),

where A_m is the basal area at mid section and h is the length of the log.

Values of h and A_m are obtained from the measurement of length and diameter (or girth) as described above.

4.5 Quarter Girth Formula - The British system of measurement had introduced the concept of Quarter Girth Volume, which is calculated by the following formula

Q.G Volume = $\frac{G^2}{4} \cdot h$ **.. (4.4)**

Examination of the above formula reveals that mid-sectional area has been taken as $\frac{G^2}{4}$. If it is compared with the formula of a circular sectional area $A = \pi . \frac{D^2}{4} = \frac{G^2}{4\pi}$, it will be clear that π (= 3.1416) has been approximated to 4 to obtain the sectional area as $\frac{G^2}{4}$, and thereby the formula (4.4) for quarter girth volume has been arrived at.

It is apparent from above that

Quarter Girth Volume = True Volume x $\frac{3.1416}{4.0000}$ = 0.785 x True Volume.

In other words, volume derived by applying quarter girth formula is 78.5 % of cubic contents of a cylindrical log or of that obtained by using Huber's formula.

Thus though calculation of volume by quarter girth formula is simple, it underestimates the actual volume. The idea of using the quarter girth system of measurement, also known as Hoppus's Rule, was that it gives approximately the volume obtainable after rough squaring of the log.

Small wood – Small wood constitutes what is left after logging timber from stem wood and branch wood.

4.6 Small wood is mostly used as firewood, except when wood of dimensions suitable for a specific end use like pole, post, mining timber etc. is available and harvested for the said purpose.

4.6.1 Firewood – Firewood is normally cut into 2.5 feet (approximately 75 cm) long billets and stacked for measurement. Firewood stack has the shape of a rectangular parallelepiped. In general, dimensions of firewood stack are as given below.

Dimensions of Firewood stack	**Length (L)= 5 feet (150 cm)** **Breadth or width (B)= 2.5 feet (75 cm)** **Height (H) = 5 feet (150 cm)** **Stacked Volume = L x B x H** **= 62.5 cubic feet, or** **1.688 cubic metre.**

Keeping in view the transport cost, **a firewood lot is formed by taking together a number of stacks so that lot volume becomes close to carrying capacity of a truck.**

The firewood stack is generally built 8 to 10 cm higher than the intended height (150 cm) so as to allow for shrinkage while drying.

Stacked Volume – Reducing or Conversion Factor.

4.6.2 It is obvious that the stacked volume of firewood does not give the measure of solid content. Solid content or solid volume is the amount of wood (and bark) in a stack. While it may be enough to measure firewood in stacked volume for the purpose of routine work and marketing, sometimes it becomes necessary for research and other purpose to know all outturn in a common unit of measure, that is, in terms of solid volume in cubic metre or cubic feet.

4.6.3 Conversion or Reducing Factor is defined as the ratio of solid volume to stacked volume.

$$\textbf{Conversion or Reducing Factor} = \frac{\text{Solid Volume}}{\text{Stacked Volume}}$$

Thus solid volume of firewood may be obtained by multiplying the stacked volume by this factor.

4.6.4 Procedure to find Conversion or Reducing Factor – It is apparent from the definition of conversion or reducing factor that in order to determine the factor we need to evaluate the solid volume corresponding to a stacked volume of firewood. The stacked volume can be easily calculated by measuring the dimensions of the stack with the help of tape. Stacked volume will be the product of length, breadth and height of the stack. The most accurate method of finding the solid volume is known as Xylometric method. In this method water in sufficient quantity is poured into a large vessel having a graduated scale. Billets contained in the stack are then submerged in the water. The rise in level of water is noted and volume of displaced water is calculated. The volume of displaced water will be equal to the solid volume of the firewood billets. The ratio of solid volume and stacked volume will give the value of factor. The value of the factor will vary widely depending on billet size and shape and the mode of stacking. The value of the factor will be less than unity.

Pole

4.7 In south West Bengal forests are worked on short rotation, and the major produce harvested is pole. Poles of Sal and Eucalyptus have great demand in the market. Poles are sold in the market in terms of size and number. Thus measurement of poles is restricted to recording diameter (or girth) and length of individual pole and keeping an account of number of poles of each size class. In this case also solid volume of wood is not normally found out, though the exercise may be necessary to calculate the total yield from a coupe in terms of solid volume in cubic metre.

4.7.1 Diameter of pole is normally measured at butt end, more precisely at a point about 6 inches (15 cm) above the butt end. Unless otherwise specified, an 8 inch pole would mean that its diameter at a section 6 inches above the butt end is 8 inches.

4.7.2 In normal working, girth (at 6 inch above butt end) and height of poles are measured with tape and they are grouped into 10 cm girth (or 2 inch diameter class) classes and 2 feet (60 cm) height classes.

FOREST MENSURATION

LESSON 5

Yield Assessment

5. Volume Table

5.1 Average Tree Volume – Previous lessons have described how volume of individual trees can be measured or estimated. For the purpose of management, however, foresters are more interested in estimation of total volume of a tree stand or a forest coupe. A forester thus requires average volume of a tree having dimensions within specified range. He takes help of volume table which gives average volume of a standing tree of various sizes and species.

5.2 Volume Table – It is a statement in tabular form showing average volume of trees by diameter (girth), height or form classes.

5.2.1 Kinds of Volume Table – Volume Tables are of following three kinds.

1. Local volume Table – applicable to one forest only

2. Regional Volume Table – applicable to a number of forests in a locality

3. General Volume Table – applicable to forests over a large geographical area.

5.2.2 Choice of variable - The physical factors or variables which determine the volume of a tree are diameter (girth), height and form. A volume table gives average tree volume corresponding to values of one or more of these variables. The choice of independent variable against which values of volume will be shown as dependent variable in the table is guided more by ease and speed of application than by accuracy. This is best served by volume tables based on breast height dimensions. A volume table based on bhd (breast height diameter), however, presumes that trees having same bhd have the same height and form and therefore the same volume. The presumption is not correct, as these variables depend on many factors like age, site qualities and conditions of growth. Thus in order that a volume table based on a single variable should be reasonably accurate, it should be applied to strictly limited conditions, i.e. site A based on whose parameters the volume table was prepared and the site B where the table is applied should have same productive and ecological value and trees grown under same silvicultural system. If it is possible to measure all the variables by simple measurement, a table based on all three variables will be much more accurate and applicable on wider areas than the one based on single variable.

5.2.3 Preparation of Volume Table based on single variable – The tables based on single variable of breast height dimensions are normally local volume tables. The data from a large number of trees is required. Trees felled in successive years may be used for this purpose. Breast height measurement is taken while trees are standing. After the trees are felled and logged into several segments, then lengths of segments and diameters (girth) segments at desired sections are measured to calculate volume of individual trees. The data of breast height diameter (girth) and corresponding volume are then tabulated in a table. A typical data table is shown below.

Table I

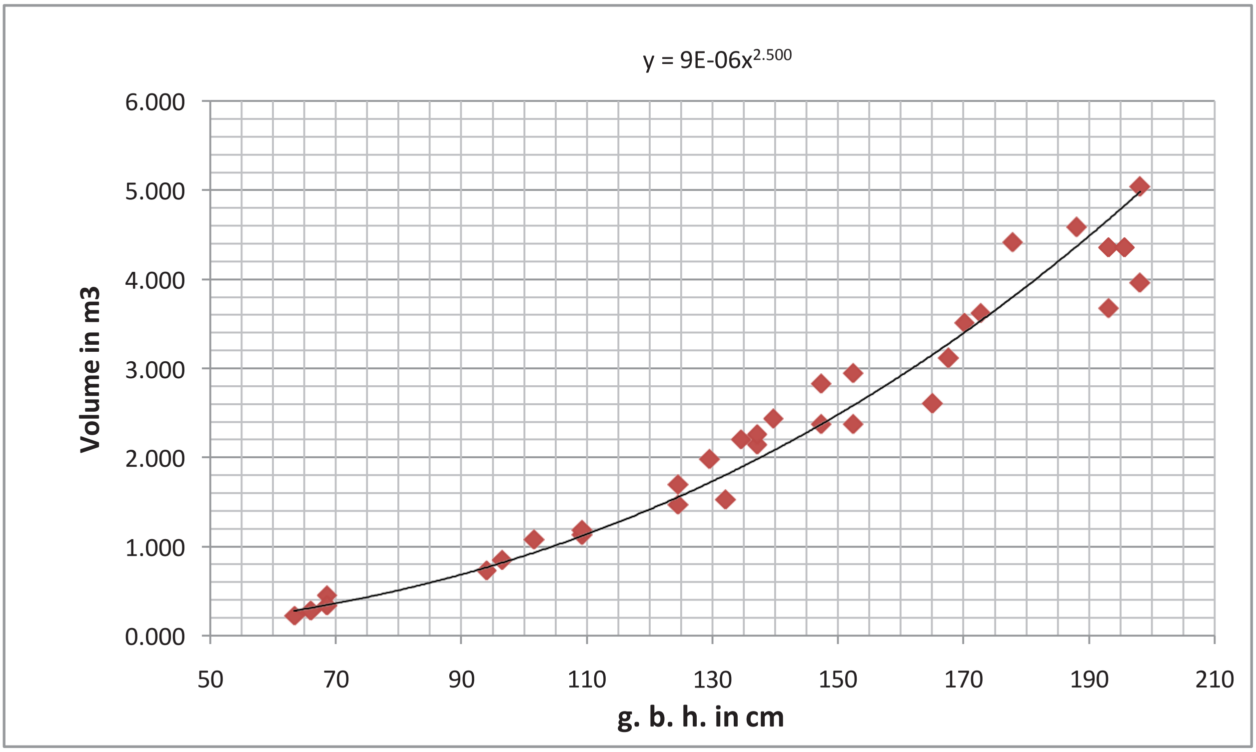
Tree No	g.b.h (o.b) in cm	Volume (u.b) in m^3	Tree No	g.b.h (o.b) in cm	Volume (u.b) in m^3
1	64	0.226	18	137	2.264
2	66	0.283	19	140	2.434
3	66	0.283	20	147	2.830
4	69	0.340	21	147	2.377
5	69	0.453	22	152	2.943
6	69	0.340	23	152	2.377
7	94	0.736	24	165	2.604
8	97	0.849	25	168	3.113
9	102	1.075	26	170	3.509
10	109	1.132	27	173	3.622
11	109	1.189	28	178	4.415
12	124	1.698	29	188	4.585
13	124	1.472	30	193	4.358
14	130	1.981	31	193	3.679
15	132	1.528	32	196	4.358
16	135	2.207	33	198	3.962
17	137	2.151	34	198	5.037

(Table I is based on data taken from 'Elementary Forest Mensuration" by M R K Jerram)

5.2.3.1 It may be noted that in a data table prepared on measurements of a large number of trees though the values of volume show an increasing trend with increasing g.b.h, the increase is not uniform and in individual cases may exhibit considerable variations from the growth trend. It is therefore necessary to transfer the data on a graph by plotting g.b.h values along x axis and the corresponding volumes along y axis. The representative points will appear distributed within narrow limits and a mean curve may be drawn as shown below. The volume table is then prepared from the graph. If it is intended to prepare a table showing volume by 10 cm girth class, then values of y –coordinates (volumes) may be read against x-coordinate values (g.b.h) of 65 cm, 75cm, 85cm, 95cm and so on from the graph. The said sets of values of x and y coordinates, if produced in a tabular form, will give the desired volume table**. It may be noted that volume tables give volume under bark against over bark dimensions (g.bh)**

5.2.3.2 Application of MS Office Excel – The following graph has been drawn with the help of MS Office Excel software programme. The data in Table I under the two columns of g.b.h and volume are selected and with the help of ms office excel a scattered diagram is plotted. The said software also enables to draw a trend line based on the points plotted. The trend line will represent the mean curve referred to above. In this case the power equation representing the curve has also been generated by the excel programme and is shown on the plot area.

The equation is **V = 9 x ��**$^{-6}$ x $g^{2.500}$ **................ (5.1), where g is girth in cm and V is volume in cubic metre. It may please be noted that the above equation relating volume and girth is only illustrative and has been arrived at with the data of the Table I. The equation cannot be applied in general.**



5.2.3.3 Volume table from volume-girth equation - If the volume-girth equation is derived from the available data by applying ms office excel as described above, the values of volumes corresponding to specified girth values of 65cm, 75 cm etc. can be obtained direct from the said equation (without the help of graph) and can be reproduced in a tabular form to give the volume table. Values of volume obtained from the equation will match closely with those obtainable from the graph and volume table prepared from the volume girth equation can be applied with reasonable accuracy. An illustrative volume table prepared from the above equation (5.1) is shown below.

Table II (Local Volume table) - Volume by 10 cm girth class

g.b.h. in cm	Girth Class in cm	Volume (u.b) in m3
$60 \le g < 70$	65	0.307
$70 \le g < 80$	75	0.438
$80 \le g < 90$	85	0.600
$90 \le g <100$	95	0.792
$100 \le g < 110$	105	1.017
$110 \le g < 120$	115	1.276
$120 \le g < 130$	125	1.572
$130 \le g < 140$	135	1.906
$140 \le g < 150$	145	2.279
$150 \le g < 160$	155	2.692
$160 \le g < 170$	165	3.147

In the above volume table, girth class mentioned in column two will include trees having g.b.h in the ranges as mentioned in column one.

5.2.3.4 Application of Volume Table – Of the tree stand whose volume is required to be estimated, g.b.h over bark of each tree is measured. The trees are then grouped in girth classes. Volume corresponding to each girth class is known from the volume table. Then number of trees in each girth class is multiplied by the corresponding volume obtained from the table. The product will give volume in the respective girth classes. Sum of the volumes in the various girth classes will give total volume of the stand or the growing stock.

Exercise

Measurement of a tree stand gave the following results. Use the above volume table to find the stand volume.

Table III

Tree No.	g.b.h (cm)	Tree No.	g.b.h (cm)	Tree No.	g.b.h(cm)
1	62	11	88	21	150
2	95	12	92	22	147
3	91	13	145	23	92
4	110	14	160	24	125
5	106	15	133	25	137
6	75	16	70	26	65
7	124	17	105	27	76
8	135	18	126	28	115
9	147	19	95	29	107
10	121	20	144	30	65

5.2.3.5 Limitations of Local Volume table –

Local volume table based on one variable (breast height dimensions) has the following limitations.

1) Its application is restricted to a small geographical area.
2) Failure in selection of a suitable scale for the graph may bring in errors.
3) It is not suitable to find volume of a very small number of trees in one girth class.

5.2.4 Volume Table based on two variables - General Volume table is based on more than one variable and requires the user to obtain, besides breast height dimensions, estimates of tree height, and also preferably tree form or taper.

5.2.4.1 Preparation of Volume Table based on two variables – The procedure is same as what has been described in paragraph 5.2.3 for preparation of volume table based on single variable, except that total height of felled trees is measured and recorded in height classes usually in ranges of 10 ft or 5 ft (or, say 3 metre or 1.5 metre). Following the same procedures described in paragraphs 5.2.3.1 and 5.2.3.2, graphs of volume versus g.b.h are drawn separately for each height class. Then values of volumes corresponding to designated g.b.h, as read from the graphs or obtained from the volume-girth equation generated by excel programme, are recorded for each height class in a single table to produce the general volume table. A typical volume table is shown below for illustration.

Table IV – General Volume Table based on g.b.h and tree height

GBH class in cm	Height in metre						
	9-12	12-15	15-18	18-21	21-24	24-27	27-30
	Volume (u.b) per tree in m^3						
20	0.002						
30	0.018	0.019	0.021				
40	0.040	0.045	0.051	0.088			
50	0.068	0.079	0.092	0.105	0.119		
60	0.104	0.119	0.139	0.164	0.190	0.21508	
70		0.164	0.192	0.232	0.272	0.30564	0.34526
80		0.218	0.258	0.311	0.368	0.41035	0.4528

(Table IV is based on data taken from 'Elementary Forest Mensuration" by M R K Jerram)

5.2.4.2 Advantages of general Volume table – General volume tables have application over wider geographical areas and may be used in any locality covered by the tables. Introduction of a second variable makes these tables more accurate, particularly when applied on a small population. The tables are useful in estimating volume of growing stock and estimating yield from standing trees.

5.2.4.3 Measurement during Application – While applying the General Volume tables the user has to measure d.b.h or g.b.h, though tree heights are normally estimated. Estimation of tree heights may bring error, which is, however, not serious if the height classes are made not too small.

5.2.5 Constructing a Local Volume Table from a General Volume Table – The estimation of tree heights, while applying general volume table and the possible resulting error may be avoided by constructing a local volume table from the general volume table. The said construction requires a reliable height-diameter (girth) relationship applicable to the locality. Field measurements of sufficient number – 50 to 100 – of total heights covering the desired range of tree d.b.h or g.b.h classes should be obtained from the project area. The available data of d.b.h (or g.b.h.) and corresponding heights can be transferred on a graph paper with d.b.h (g.b.h) as x-coordinates (independent variable) and heights as y-coordinates (dependent variable), and a smooth average curve may be drawn. The said curve can also be generated with the help of ms office excel programme. The curve will represent the relation of average tree height with diameter (girth) in the locality. From the graph, for each dia or girth class the corresponding average tree height can be read and produced on a table as shown below.

Table V – Girth –Height Table

GBH class in cm	Average height in metre
20	10
30	11
40	14
50	17
60	19
70	20
80	23

5.2.5.1 For a given girth class the above table V will give tree height and will guide thus to the corresponding height class of the general volume table IV to read the volume. In other words, based on table V, one can have the following local volume table from the general table IV.

Table VI
Local Volume table constructed from General Volume Table

GBH class in cm	Volume (u.b) in m^3
20	0.002
30	0.018
40	0.045
50	0.092
60	0.164
70	0.232
80	0.368

FOREST MENSURATION

LESSON 6

Yield Assessment (Continued)

Increment of individual trees and measurement of sample woods

6. Increment of Individual Trees

6.1 Increment – Increment is defined as growth in height, diameter and volume in relation to time.

6.1.1 Current Annual Increment – Annual growth is known as current annual increment (CAI). Normally it is used in connection with growth in volume. Thus increase in volume for one year is the current annual increment. Since annual growth in volume is small and difficult to measure, often average annual growth over a small period of time (5 to 10 years) is measured and referred to as current annual increment.

6.1.2. Mean Annual Increment – Mean Annual Increment is defined as the ratio of total tree volume at any point of time to total age.

Thus if V is the volume of a tree at an age of Y years, then

CAI = v = volume put on during the 1-year period between (Y-1) and Y years of age; and

MAI = $\frac{V}{Y}$

6.2. Determination of Age – By definition it is clear that MAI cannot be calculated without determining the age.

6.2.1 From records – The most accurate method to know the age of a standing tree is from records. Thus if we have plantation journal, we can easily know the age of trees of the plantation.

6.2.2 From Annual Rings – Another accurate method of knowing age is to fell the tree and count annual rings on the stump. The annual rings, however, are not clearly visible in all species. The number of rings will give the number of years the tree has taken to grow from the section of cut to its present height. Therefore the number of years the average seedling takes to reach the height of section of cut has to be added to the annual rings counted to know the total age.

6.3 Volume Increment - Volume increment over a short period of say 10 years may be calculated from measurements on a felled tree. The method is explained below.

1) The total height H of the tree is measured after felling the tree.

2) The mid diameter, that is, the diameter at height H/2 is measured and mid-sectional area **S** is calculated.

3) The tree is cut from the top until 10 rings are found. The length (height) **h** up to the cut is measured. It would mean that the tree has taken 10 years to reach from height **h** to **H**.

4) The diameter at height **h/2** (what was mid-diameter 10 years back) is measured first by sawing through the tree at this point and measuring from 10th ring in from the cambium. From measurement of this diameter, mid-sectional area **s** (what was mid-sectional area 10 years back)) at height **h/2** is calculated.

5) Then Volume increment (**I**) in the last 10 years is calculated from the following equation

$$\mathbf{I = S \times H - s \times h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (6.1)$$

It is apparent from above that in the above method it is necessary to find both present mid-sectional area **S** and what was mid-sectional area 10 years back **s** by taking measurements at sections H/2 and h/2.

Presssler's method has simplified the procedure. In this method the length the tree has grown in last 10 years is first cutoff. Thus the tree of original height H is reduced to height h. Thus **h** is substituted in place of **H**, and **S** and s are both measured at h/2. The increment in 10 years is then found out from the equation –

$$\mathbf{I = (S - s)\, h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (6.2)$$

Measurement of woods

6.4 Classification

Even-aged woods – Even aged woods are those in which all the trees are of same age. Examples are plantations or coppice crops established after clearfelling.

Regular woods – Regular woods are those where despite age difference the individual trees show uniform height before attaining maturity. They usually originate from natural regeneration with short regeneration period. They are also often called even-aged.

Irregular woods - Irregular woods are those which exhibit large number of age gradations intermixed and varying heights and crowns throughout the rotation. Usually they originate from natural regeneration allowing long regeneration period.

6.5 Determination of age of woods – If records are available, then the most reliable means to know the age is to consult these records. Otherwise, age of the woods has to be determined from age of individual trees. In case of even-aged wood, age of a single tree would give age of the wood. In case of irregular woods, age of several sample trees may be found out and mean age of the wood may be calculated from those of the sample trees.

6.6 Determination of Mean Height – For the purpose of volume determination, Mean Height may be defined as the height (h) which when multiplied by the mean form factor (f) and the mean basal area(A) of a wood would give the arithmetic mean volume. It can be expressed in the following equation–

$$\mathbf{h \times f \times A} = \frac{V\text{[illegible]}}{N\text{[illegible]}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (6.3)$$

There is no method to find mean height that would comply with the above definition. However, in practice mean height may be determined by the following methods.

1) If the population is divided into several diameter classes, then mean height of each diameter class may be obtained by measuring heights of a number of trees in the class and calculating the arithmetical mean height. Mean height H of the crop is then determined from the following formula.

$$H = \frac{n_1h_1 + n_2h_2 + n_3h_3 + \cdots \ldots}{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(6.4)}$$

where n_1, n_2, n_3 etc. and h_1, h_2, h_3 etc are the number and mean heights respectively of the trees measured in each diameter class, and N is the total number of trees measured.

2) If the object of finding mean height is to find volume of the wood, a better method would be to find total basal areas s_1, s_2, s_3 etc. of a number of trees in each class and arithmetical mean heights h_1, h_2, h_3 etc in the corresponding class, and then apply the following formula

$$H = \frac{s_1h_1 + s_2h_2 + s_3h_3 + \cdots}{S} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(6.5)}$$

where s_1, s_2, s_3, etc. are sum of the basal areas of the trees measured in class 1, 2 , 3 etc and h_1, h_2, h_3 etc are the mean heights in the corresponding class, and S is the total basal area of the trees measured.

3) In this method heights of a number of representative trees in each diameter class are measured. A graph is prepared with heights as ordinate and diameters as abscissae. From the graph mean height values for each diameter class are read. Mean height of the wood is then calculated from the formula given below.

$$H = \frac{mh_1 + mh_2 + mh_3 + \cdots \ldots}{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6.6)}$$

where mh_1, mh_2 , mh_3 etc. are the mean heights of the corresponding class and N is the number of classes.

6.7 Volume of sample or unit woods – The forests being dealt here are small, one acre or 0.5 ha in extent. Measurement of volume of such sample woods is required for management purpose and for preparation of yield tables. These plots should preferably be regular in shape so that their areas can be calculated accurately.

6.7.1 Methods to find volume - Since it is not possible to clear fell all the trees of the plot and measure their volume, the underlying principle is to select sample trees, measure volumes of sample trees and then find the volume of the plot by the rule of proportion or by graphical method. The other method is by application of volume table if such volume table is available. In the latter case d.b.h or g.b.h of all trees is measured and their heights are estimated. The volumes are obtained from the volume table according to their size classes. The sum of individual tree volumes gives the volume of the plot.

6.7.2 Estimation of volume from sample trees - The sample trees are selected regardless of the diameter class or any other groups they belong to, but so as to ensure that they adequately represent all diameter classes. If possible the sample trees are felled for measurement and volumes calculated. Sample trees are normally obtained during thinning of the plot or from the surrounding buffer zone bearing similar crop. Volumes of the sample trees are plotted on a graph paper as ordinate against their diameters (or girths) as abscissa. A smooth curve is drawn. Diameters of mean trees in each diameter class are calculated by measurement of d.b.h of all trees in the respective class. Corresponding to these diameters of mean trees, volumes of mean trees are read from the graph. Volume of mean tree, when multiplied by the number of trees in a class, gives the volume of that class. Sum total of volumes of each class gives the volume of the plot.

Mean tree, in theory, should be the tree whose volume multiplied by the number of trees gives the volume of the crop, group or class. Since volume is often the parameter to be determined and not known, the practice is to take the mean tree as one whose basal area multiplied by the number of trees would give the total basal area of the crop, group or class.

FOREST MENSURATION

Lesson 7

Yield Assessment (Continued)

Yield Tables

7.1 An Yield table is a tabular statement which displays the course of development of an even-aged wood from an early stage to the age of rotation at periodic intervals of five or ten years.

Yield Tables provide per unit of area (acre or hectare) the following information–
1) The number of trees
2) Mean d.b.h or g.b.h
3) Total basal area
4) Mean height
5) Volume of main crop
6) Volume of thinning
7) Form factors.

7.2 Application – Some major applications of yield tables are:
1) Determination of volume and increment of woods
2) Determination of site quality
3) Forecasting yield

7.3 Model Yield Tables – A model format for yield table is shown below.

Table 7.1
Format for Yield table

Quality Class I

Age	Main crop						Thinnings		Total Volume (a+b)	C.A.I (d-a) /10	M.A.I (a+c)/ age
	Mean Height	Mean Diameter at breast height	No of stems per acre	Basal Area Sq.ft per acre	Form Factor	Volume cubic feet per acre	Volume cubic feet per acre	Sum of thinnings			
						A	b	c	d	e	f
30	31	3.0	1550	74	.30	690	-		690		23
										138	
40	45	4.5	940	105	.45	1940	130	130	2070		51.75
										179*	
50	56	6.3	600	131	.46	3330	400	530	3730		77.20

(source: Elementary Forest Mensuration by M R K Jerram)
* C.A.I = (3730 – 1940)/10 = 179 between 40 and 50 years.

7.4 Local and General Yield table – A Yield Table may be called Local if data for its preparation are collected from forests of one district or division. It will be a General Yield Table if the data are obtained from similar forests in different districts or divisions. There is no set rule for territorial limits of applicability of a yield table.

7.5 Site Quality - Separate yield tables are prepared for different site qualities. There have been varying opinions on the basis of classification of sites. The exercise for preparation of yield tables was originally taken up to forecast volume and increment at various ages of even aged woods. The quality of woods or site quality was thus based on volume production under proper treatment. Adoption of volume as the indicator of site quality has been questioned and objected to by many due to various reasons. It has been recommended to use height as indicator of site quality. Classification of woods on the basis of height is preferred by many as measurement of height is easy, and of the factors that make up volume, height is least affected by minor variations in treatment. Other schools of thought believe that site quality should be assessed on ecological basis, that is, on the character of vegetation. However, it has been the practice to classify sites on the basis of volume or one component of volume such as mean height.

7.6 Preparation of Yield Tables

7.6.1 Sample plots – Data for yield tables are obtained from sample plots. Normally they are between 0.2 and 1.0 acre in area. The sample plots to be chosen should be
1) not less than 30 in number for each quality class;
2) fully stocked**,** well distributed over whole area;
3) of stock of normal development;
4) surrounded by crop of similar growth.

The sample plots are of three kinds, namely (1) permanent, (2) semi-permanent, and (3) temporary.

7.6.1.1 Permanent Sample Plots – They are established in even aged wood at young age of the crop and subjected to periodic measurement till the rotation age.

7.6.1.2 Semi-permanent or Period Sample Plots – If left only with permanent plots, it will take a whole rotation to prepare complete yield tables. To reduce the time schedule, a number of semi-permanent plots with age difference of a number of years (say 20) can be established and subjected to periodic measurement till the complete series is obtained.

7.6.1.3 Temporary Sample Plots – For immediate preparation of yield tables, temporary sample plots may be established covering the whole range of age gradation and measurements be taken from these plots simultaneously. The accuracy of tables so prepared depends on the premise that woods in these plots have received and shall receive the same treatment.

7.7 Strip Volume Method – Methods of determining mean height and volume of sample woods or unit woods have been described in previous lesson. Upon measurement of sufficient number of sample plots belonging to various quality classes and covering whole age gradation, a data table of the type shown below (Table 7.2) is prepared. The Table 7.2 is given for the purpose of illustration only. In practice, the number of sample plots should be much higher than shown here. The figures under the volume column are plotted on a graph against the figures under the age column. Two curves are drawn passing approximately through the trajectories of the highest and the lowest points (See Fig.7.1). The space between these two curves are divided into a number (equal to the number of quality classes involved) of strips of equal width by drawing curves with curvature conforming to the maximum and minimum curves. The volume curves of Fig. 7.1 determine the quality classes of the plots. In the illustration given in Fig.7.1, the uppermost strip covers Quality I, that is, those plots whose representative age-volume points are contained in this strip are assigned Quality I. Similarly, those plots whose points are contained in the middle strip are Quality II sites and those falling in the lowest strip are Quality III. The plots illustrated here thus get classified as follows.

Quality I : Plots 1, 5, 9, 10, 15, 17, 19 and 23;
Quality II : Plots 2, 4, 7, 8, 11, 13, 16, 21 and 22;
Quality III : Plots 3, 6, 12, 14, 18 and 20

7.7.1 Then through each strip a mean curve is drawn (shown in dotted line) which is accepted as representing volume against age for the corresponding quality class. Values of ordinates (volumes) against specific values of abscissa (age) are recorded and used to fill in the volume column of yield table. Similarly for each quality class, data of the corresponding plots are employed to construct separate graphs of (1) age-mean height, (2) age-g.b.h/d.b.h, (3) age-basal area per ha, and (4) age- no of stems per ha. From these graphs so constructed, values of the ordinate parameters are read against specific abscissa (age) values and used to fill in the corresponding columns of the yield table.

Table 7.2 (Figures are per acre)

Plot No	Age in years	No of trees	Basal area at b.h (sq.ft)	Mean Height (ft)	Volume (cu. ft)	Plot No	Age in years	No of trees	Basal area at b.h (sq.ft)	Mean Height (ft)	Volume (cu.ft)
1	15		62	16	1800	13	49	680	154	52	4700
2	17		60	14	1400	14	50	750	132	44	3500
3	18		61	13	1100	15	54	450	182	69	6400
4	21		84	20	1700	16	62	450	169	65	4700
5	27	1400	130	33	3300	17	62	369	184	73	6200
6	29	2400	99	25	2050	18	68	420	148	56	4450
7	34	1480	133	35	3250	19	74	270	192	83	7800
8	35	1670	113	32	2800	20	74	350	146	61	4000
9	35	910	156	46	4450	21	76	295	173	70	5500
10	46	620	165	55	4800	22	79	265	177	72	6300
11	47	740	150	47	4230	23	81	245	192	86	7200
12	48	860	132	40	2900						

(The Table is obtained from M.R.K Jerram's "Elementary Forest Mensuration" and is for illustration only)

7.8 Strip Height Method – In modification of strip volume method described above, in this method mean heights instead of volumes are employed for the purpose of quality classification. Thus from Table 7.2, the values under Mean height column are plotted against age and in the same manner as shown in Fig. 7.1, the strips of quality classes are constructed and the plots are assigned their quality class. The rest of the procedure is same, except that volume figures for filling in yield table are obtained here from age-volume curves drawn separately for each quality class from the data of corresponding plots.

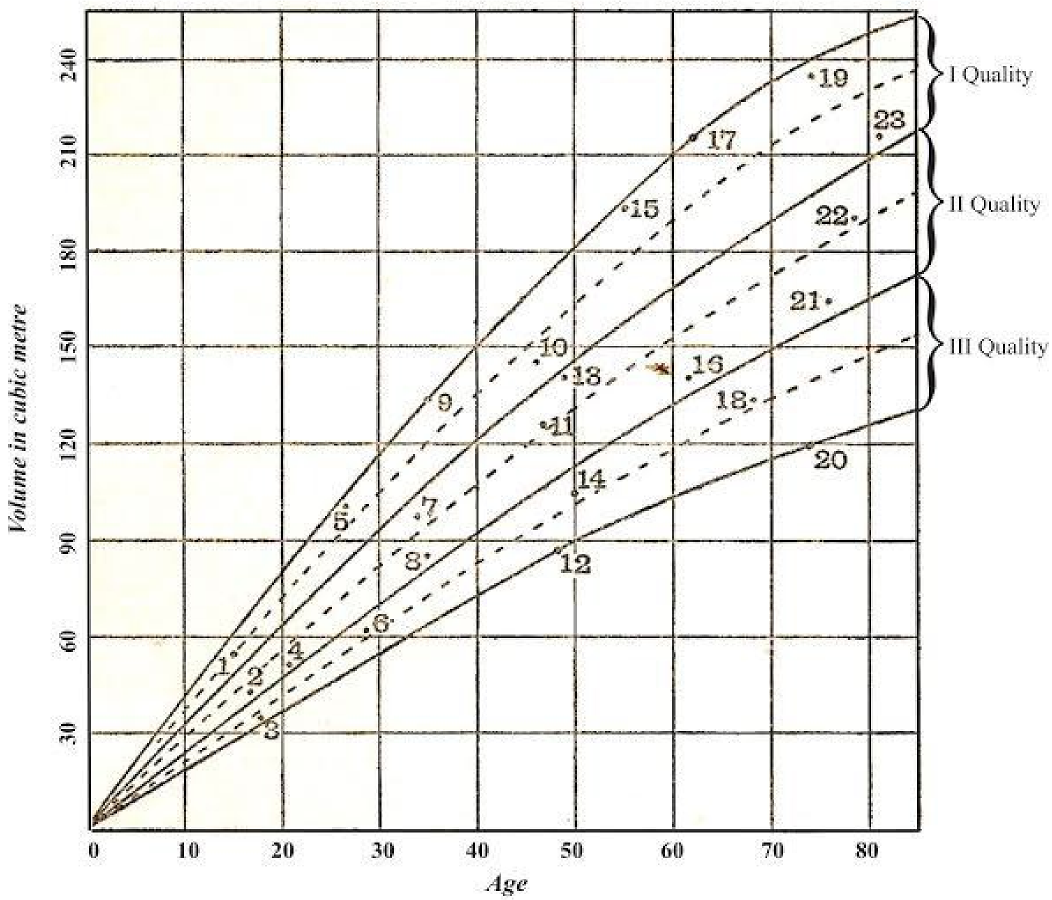


FIG. 7.1 Strip volume method of assessing the quality of woods

(The Fig. 7.1 is obtained from M.R.K Jerram's "Elementary Forest Mensuration)

FOREST MENSURATION

LESSON 8

Yield Assessment (Continued)

Point Sampling – Wedge Prism

8.1 Point Sampling – It is a method of selecting trees to be counted or tallied on the basis of their sizes rather than by their frequency of occurrence. Point sampling provides an efficient way of making an unbiased estimate of the basal area and volume of forest stands. It is widely used because it is simple and takes much less time than other methods available for estimation of basal area and volume.

8.2 Theory of Point Sampling - In point sampling, the area is sampled by viewing trees around a sample point through an angle gauge or prism. The basic principle has been illustrated in Figure 8.1.

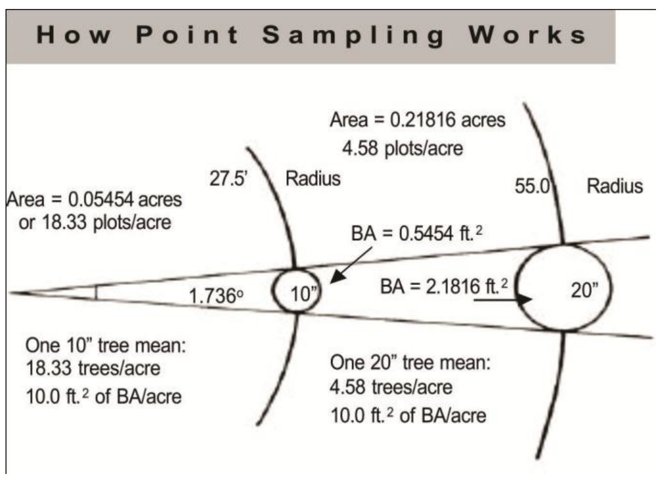


Fig 8.1

(Fig taken from Michigan State University Extension Bulletin E-1757, authored by Robert Marty, Department of Forestry)

8.2.1 For the purpose of Illustration, sighting angle of 1.736 degrees is chosen. When the sighting angle used is 1.736 degrees, any 10-inch diameter tree whose distance from the sampling point is within 27.5 feet will appear larger than the projected angle, and so will be selected for sampling. Thus, 10-inch trees are sampled over a circular plot of 0.05454 acre, being the area of the circle of radius 27.5 feet. Similarly, a 20-inch diameter tree, if located within 55 feet from the sampling point, will exceed an angle of 1.736 degrees, indicating a sampling area of 0.21816 acre (being the area of a circle of radius 55 feet), and will be selected. The ratio of diameter of tree to plot radius is a constant for the specified angle 1.736 degree. In the case cited, the ratio is $\frac{10}{27.5\ x\ 12} = \frac{20}{55\ x\ 12} = \frac{1}{33}$. **It thus follows that all trees located no farther than 33 times their diameter from the sample point will be tallied.** It is also seen that area sampled in the 20 inch tree (twice the diameter of the first case) is four times the area sampled for 10-inch trees. The unique feature of point sampling, then, is that the probability of tallying any given tree is proportional to its stem basal area.

8.2.2 If we consider the first case, we find that the ratio of sampled area (0.05454 acre) to 1 acre is 1: 18.335. It means that 18.335 areas can be fitted into a single acre. That is, when a single tree of 10 inch d.b.h is tallied, it is tacitly assumed there are 18.335 such stems per acre. Since basal area of 10 inch d.b.h tree is $\frac{3.1416\ 5x5}{144}$ sq.ft = 0.5454 sq.ft, when multiplied by 18.335, it yields a basal area of 10 sq.ft per acre. Taking the case of 20 inch d.b.h, the sampled area is 0.21816 acre and thus 4.584 such areas can be fitted into single acre. Since basal area of 20 inch d.b.h tree is $\frac{3.1416\ x10x10}{144}$ sq.ft = 2.1816 sq.ft, when multiplied by 4.584, it also yields a basal area of 10 sq.ft per acre. Thus it is seen that each tree larger than the projected angle represents a fixed basal area per acre, regardless of its size. The constant figure of 10 sq. ft per acre is the Basal Area Factor or BAF for the sighting angle of 1.736 degree.

8.3 Wedge Prism – It is the most widely used instrument for point sampling. The wedge prism is a wedge shaped piece of glass, properly ground and calibrated, that bends or deviates light rays at a specific offset angle. The angle of deviation of light rays passing through the prism depends on the angle of the prism, which is very small. This property is utilized for tallying a tree during point sampling.

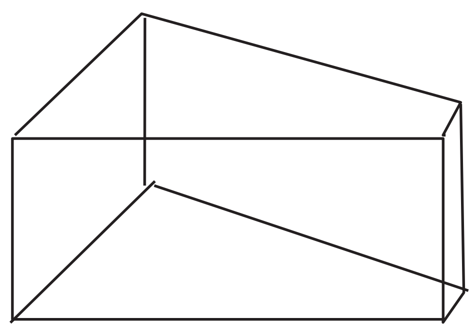


Fig. 8.2 Wedge Prism

Wedge prisms that are available in the market are normally calibrated and have specified BAF. The calibration can be verified by measuring the BAF independently through a simple procedure. The prism should preferably have mounting and the mounting should be attached to a staff which can position the top of the prism at 4.5 feet above the ground, that is, breast height.

8.4 Procedure for sampling with prism

8.4.1 Sample size – The number of point samples will depend on the area of the stand. While sampling for the purpose of reconnaissance, 3 to 7 well spaced point samples should do. However, for the purpose of compartment examination and assessment, one point sample per acre may be taken for stand up to 40 acres. (Michigan State University Extension Bulletin E-1757, authored by Robert Marty, Department of Forestry)

8.4.2 Location of Sample Points - Sample points may be selected within the stand at random or systematically. Systematic sampling is easier and takes less time and is thus more common in practice. The sample points may be spaced evenly along parallel cruise lines which are oriented at right angles to contour lines. This ensures that varying stem conditions are captured in proportion to their occurrence. All sample points should be located at least one chain inward from the boundary to avoid edge bias.

8.4.3 Selecting Sample Trees – When viewed through a wedge prism, the tree stem appears to be displaced. The amount of offset or displacement is determined by the prism strength, which is measured in diopters (Deviation in Prism diopter = 100 x tanδ, where δ is angle of deviation). The prism should be held 4.5 feet above the sampling point and rotated by 360 degree at that position to have a complete sweep of the stand. Fig. 8.3 shows how the images of stems appear to be displaced when seen through the prism. Sample trees are those which are displaced by less than their full width at breast height.

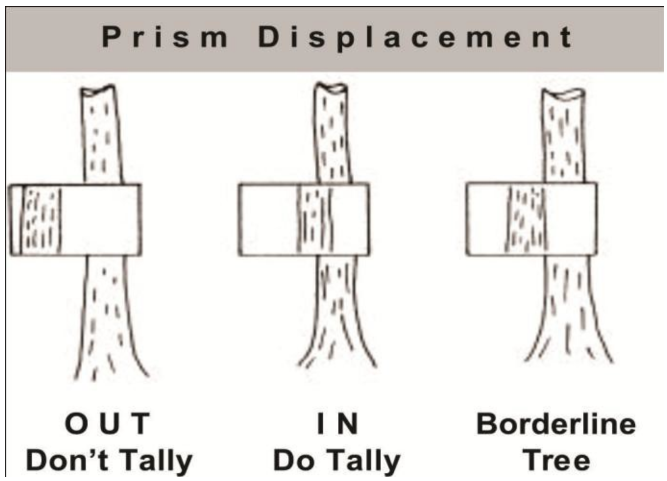


Fig. 8.3

(Fig taken from Michigan State University Extension Bulletin E-1757, authored by Robert Marty, Department of Forestry)

Use of a staff with the prism holder helps to rotate the prism correctly. With borderline trees (see Fig. 8.3) where the prism displaces equal to width at breast height, it becomes difficult to decide whether to count such trees or not. The thumb rule is to count every second borderline trees, or count half for each tree. When the exercise demands accuracy, the d.b.h of the tree in question and its distance from the sampling point may be measured physically and the measurements may be subjected to calculation to know whether to include the tree or not. The measurements may also be referred to standard table which for a specified BAF, shows qualifying distance for a given d.b.h.

8.4.4 Wedge Prism Device and Point Sampling Theory - That the basis of selection of sample trees in a wedge prism exercise conforms to theory of Point Sampling can be explained as follows. Since deviation of 1 Prism Diopter means a right angle displacement of 1 unit per 100 units of distance, a 3.03 diopter (approximately equal to 1.736 degree or 104.16 minute) prism will produce a displacement of 1 unit per 33 (=100/3.03) units of distance. It would mean that it will produce 10 inch displacement per 330 inch or 27.5 feet distance. If we compare this position with Fig. 8.1, it is clear that the 3.03 diopter prism will produce a critical angle of 1.736 degree.

8.4.4.1 Now if we focus our attention on Fig. 8.3, the tallied trees are those which are partially offset, that is, displacement for each of them is less than its d.b.h. It follows from the previous paragraph that to produce a given shift with a 3.03 diopter prism, the distance has to be 33 times the amount of shift.

Thus a tree will have displacement equal to its d.b.h, if its distance from the sampling point is 33 times d.b.h. Therefore, all trees located at distances less than 33 times their d.b.h from the sampling point will undergo displacement less than their d.b.h. Now according to the theory of point sampling (see paragraph 8.2.1), all trees located no farther than 33 times their diameter from the sample point will be tallied**.** Since these are the trees that suffer displacement less than their d.b.h and are partially offset, they are counted in the wedge prism exercise.

8.4.4.2 The point could be easily understood by referring to Fig. 8.1. The 10-inch diameter tree shown to be located at a distance of 27.5 ft (=330 inch) will suffer a shift of 10 inch, being equal to its d.b.h, when viewed through a 3.03 diopter prism, as it has been explained that a 3.03 diopter prism produces 10 inch shift per 330 inch distance. Viewed through the prism the tree will appear just completely offset. However, if the 10-inch diameter tree is located within 27.5 ft (=330 inch), the amount of shift will be less than 10 inch, that is less than d.b.h. The tree in this case will be partially offset and will be counted in. According to the concept of point sampling also, as described in Fig. 8.1, a 10-inch diameter tree within 27.5 feet from sampling point will appear bigger than the angle 1.736 degree and will be included as a sampling tree (see Fig. 8.1).

8.4.4 Calculations for Basal Area (BA) and Stem Volume (V) – The method of point sampling has some distinct advantages. Firstly, measurement of stand area or d.b.h of trees is not necessary. Secondly by simply tallying trees through wedge prism, the basal area per acre can be calculated by simple formula.

[illegible] = $\frac{[illegible]}{N\ [illegible]}$ .... **(8.1)**

Stem Volume per acre can be calculated from the following formula

V in cu ft per acre = Mean Form Factor x BA in sq.ft per acre x Mean Height in ft. ....(8,2)

To employ formula (8.2), it is, however, necessary that mean form factor and mean height of the stand should be known, or otherwise they need to be determined by separate exercises.

Exercise: In an exercise of Point Sampling in a tree stand with a prism of BAF 10 sq.ft per acre, the total number of trees tallied in 48 sample points is 359. Find the basal area of the stand per acre. Given mean form factor is 0.42 and mean height is 62 feet, calculate stem volume per acre.

FOREST MENSURATION

LESSON 9

Enumeration of Growing Stock

9.1 Forest Inventory - The purpose of forest inventory is to provide information about shape and size of forest area and qualitative and quantitative information of the forest resources. Inventory or enumeration is normally defined as counting, singly or together, of individuals of one or more species in a forest crop and their classification by species, size, condition etc. (*Forest Mensuration by Chaturvedi and Khanna*). The concept of forest inventory has widened with time and theoretically now includes the entire range of forest resources including wildlife and non-wood forest produce.

9.2 Object of Inventory - When we talk about enumeration of growing stock, we refer to timber inventory/enumeration whose object is to determine the volume of timber growing in the forest and forecast yield. At times, though less frequently, timber enumeration is undertaken for the purpose of (a) estimating return from felling coupes, (b) determining periodic annual increment and (c) identifying regions of high or low volume production.

9.3 Kinds of Enumeration – There are two kinds of forest enumeration, namely, (1) Total or Complete; and (2) Partial or Sample.

9.4 Total or Complete Enumeration – Total enumeration requires that enumeration or tallying of the desired species above a specified diameter limit is carried out over the entire area of the forest unit under consideration. It simply means 100 % tally of all trees in a forest unit.

9.4.1 When Employed – Total enumeration is done in small areas of valuable forests which demands accurate evaluation.

9.4.2 Disadvantages - Total enumeration expends lot of money and time. It is not economically feasible for forests over large areas. It is also not advisable for large forest units, because by the time total enumeration is over, the information obtained may be obsolete or of little use. Large extent of the job may also bring in inadvertent errors. Therefore, some form of partial enumeration becomes necessary. Careful measurement of 5 to 10 percent of the units in a population will frequently give more reliable information than rough estimates obtained from the entire population (*Forest Measurements by T. Eugene Avery*).

9.5 Partial (Sample) Enumeration – Partial enumeration, as the name suggests, means that enumeration is done only in a representative portion of the whole forest. Let us take the example of a forest block of 1000 ha. If it is decided to undertake enumeration over 100 ha and thereby make estimation for the entire block, it is called partial or sample enumeration. In this case the sample area selected is 100 ha. The ratio of the sample to the whole population is called **sampling fraction or sampling intensity** and is expressed as a percentage. In the present example the sampling intensity is 10/100, that is, 10 %.

9.5.1 Sampling Units, Population, Parameters and Variables – A **sampling unit** is one of the units into which an aggregate is divided for the purpose of sampling. **Sampling units,** which are indivisible and normally mutually exclusive, are sampled for study and enumeration. Records of measurements over such sampling units are kept separately. **Population** is the aggregate of all arbitrarily defined sampling units. In the above example, if a 0.5 ha plot is designated as a sampling unit, the 1000 ha block of forest comprises a population of 2000 sampling units. The sample area of 100 ha thus comprises 200 **sampling units**, which need not form compact areas. In statistical notation, the Population size N is 2000 and the sample size n is 200, thereby giving a sampling intensity of $\frac{n}{N} = \frac{200}{2000} = \frac{1}{10}$ or 10 %.

9.5.1.1 Constant characteristics that describe the population as a whole are called **parameters**. In the above case of population of 2000 sampling units (plots), mean number of trees per plot is one parameter. Similar examples of parameters would be mean Basal Area per acre, Volume per acre etc. However, any characteristic that may vary from one sampling unit to another is known as a variable. Examples are d.b.h, height, form and tree volume.

9.5.2 Advantages of Partial (Sample) Enumeration – Following are the advantages of sample enumeration over total enumeration.

(1) **Less cost and time** - Sample enumeration requires collection of data from a part of total forest block under consideration. Thus **it costs less and saves lot of time**.

(2) **Accuracy** – When done on sound statistical principle, sample enumeration provides reasonably accurate estimate of growing stock. The extent of errors or the probability of having characteristic values within specified limits remains known.

(3) **Wider scope** – As it involves less time, the scope of enumeration is widened.

9.6 Kinds of sampling – Broadly there are two kinds of sampling that are used in forest inventories – Random Sampling and Non-random Sampling.

9.7 Random Sampling – It is the method of sampling in which sampling units comprising a sample are selected in a such a manner that all possible units of the same size have equal chance of being chosen (*Forest Mensuration by Chaturvedi and Khanna)*. Following two variations of random sampling are often used in forest inventories.

9.7.1 Simple Random Sampling – It is the method of sampling in which every possible combination of sampling units has an equal and independent chance of being selected (*Forest Measurements by T. Eugene Avery*). Allowing every possible combination of n sampling units an equal chance of being selected is accomplished by ensuring that selection of any given unit is completely independent of the selection of all other units. One way of doing this is to assign every unit in the population a number and draw n numbers from a table of random numbers. In the example cited earlier, the Population consists of 2000 sampling units and the sample area comprises 200 units at 10 % sampling intensity. Now each of the sampling units in the population is given a number from 0000 to 1999. Then 200 different four digit numbers (less than population size 2000) are selected by using the table of random numbers. The sampling units corresponding to these 200 numbers will comprise the select set of units.

9.7.2 Stratified Random Sampling – In this method, the population is first divided into subpopulations of known size, and then random sample of units in proportion to their size is selected in each subpopulation. Simple random sampling is appropriate for uniform forest crop. But more often the forest crop is heterogeneous in character and therefore stratified random sampling becomes a necessary option. While applying this method to a forest block, the area is divided into homogeneous groups or strata and then from each stratum, sampling units in number proportion to the area of the respective strata, is selected by random sampling. The criteria for stratification may be species, site qualities , crop density etc. For example, the forest block of 1000 ha is subdivided into three strata, based on site quality, of areas 400 ha, 500 ha and 100 ha. **For 10 % sampling**, the number of units of 0.5 ha to be chosen by random sampling in the respective strata will be as follows.

Stratum	Area	No of sampling units
I	400	80
II	500	100
III	100	20

9.8 Non-random Sampling – In this method of sampling samples are selected according to the subjective judgement of the observer on the basis of certain rules or guidelines (*Forest Mensuration by Chaturvedi and Khanna)*. Subjective judgement, however, leads to bias in selection.

9.8.1 Systematic Sampling – This method of sampling is quite frequently used in forest inventories. It is a non-random sampling method in which sampling units are selected according to a predetermined pattern. The most commonly employed pattern is regular spacing of units.

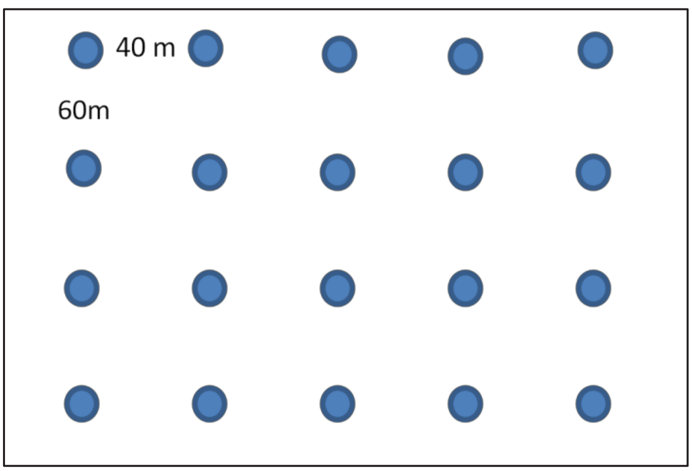


Fig. 9.1 Systematic Sampling

The Fig.9.1 shows a typical design of systematic sampling where the units are regularly spaced; in this case they are spaced at 40 m x 60 m. The first unit to start from may be selected at random or according to a predetermined arbitrary rule. When the first unit is selected at random and the others in accordance with a specific pattern, the sampling referred to as systematic sampling with random start. Rectangular or square layout of sampling units may often provide more efficient estimates than simple random samples of same intensity. However, the gain cannot be evaluated and cannot be defended by standard statistical formulas and techniques.

9.9 Size of Sampling Units - On statistical considerations, small sampling units are more efficient than the larger ones, as larger number of units yields better precision. However, considering all pros and cons, the choice of size of sampling units is finally guided by a judicious compromise between maximum efficiency, cost and convenience. A working rule adopted in some countries in Europe is that the size of the sampling unit should be large enough to accommodate at least 20 trees (*Forest Mensuration by Chaturvedi and Khanna)*.

9.10 Shape of Sampling Units – In India shapes that are normally used are plots, strips, topographic units and clusters. Plots may be of different shapes like square, rectangular, circle, polygonal etc. In certain cases, instead of plots, units are laid in the form of **strips** of 20 to 40m wide at a particular bearing at regular intervals. In the **strip sampling**, the survey party starts from a base line at one end of the forest and while moving along the central line of a strip does enumeration on both sides till the other end of forest is reached. The party then moves to the central line of the next strip and enumerates back to the base line. The intensity of sampling is calculated from the following formula.

$$I = \frac{}{D} x\ 100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(9.1)}$$

Where I is the intensity of sampling,
W is the width of the strip in metres,
D is the distance in metres between central lines of two adjoining strips.

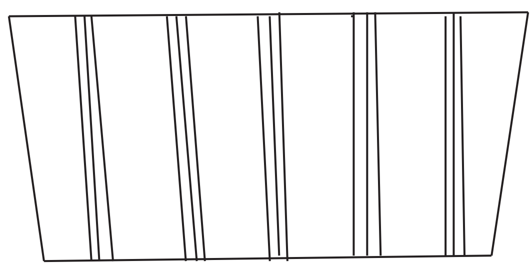


Fig. 9.2 Strip Sampling

9.10.1 Topographical sampling unit is a sampling unit whose boundaries are predominantly topographical or natural features like nalas, streams, ridges etc. Artificial features like roads, inspection paths, compartment boundaries etc can also be used as boundaries of topographic units. **Cluster sampling units** are those which are group of smaller units. The smaller units are record units and the Cluster is the statistical unit.

9.11 Sampling Intensity - Sampling intensity means percentage of the area of population to be included in the sample. It depends on many factors such as object of inventory, forest type, precision required, kind of sampling, fund available etc. Sampling Intensity recommended for various terrains are as follows.

Terrain	Method	Sampling Intensity (%)
Plains	Strip sampling Line Plot Survey (0.05 ha circular equidistant plots on parallel lines)	5 to 10 2 to 5
Hills	Topographical Units	20 to 25 when area of theforest is more than 2000 ha

(Source: F*orest Mensuration by Chaturvedi and Khanna)*

The above recommendation should however be seen more as illustration than any guideline.

9.12 Sampling Errors - Since enumeration is done over sample area and the result is applied to whole population, it gives rise to what is known as sampling error. If there was no error from any other source, the difference between population parameter (true value) and the estimate is the error of the estimate. It can be expressed by the following formula.

$$E = M - Y \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (9.2)$$

where E is error in the estimate'
M is the population mean (arithmetic), and
Y is the sample mean.

APPENDIX FOREST MENSURATION LESSON 9

Elementary Statistical Computations

1 The Mode is defined as the most frequently appearing value or a class of values in a set of observations. **The Median** is the middle value of the series of observations when they have been arranged in order of magnitude. The Arithmetic **Mean** is the arithmetic average of the set of observations. In a true normal distribution of population, values for the mode, median and mean are identical. For example, following are the observations of diameters (dbh) in inches taken on a sample of 26 trees.

Haphazard listing dbh (inches)			Frequency Table	
			dbh (inches)	No of trees
8	9	10	5	3
8	9	9	6	0
5	7	7	7	6
10	5	8	8	9
9	8	9	9	5
10	7	8	10	3
8	7	7		Total = 26
5	8	8		
7	8			
n=26				

(Source: *Forest Measurements by T. Eugene Avery*).

It may be seen that d.bh of 8 inches has been observed maximum number of times (9 times). Therefore, for the above set of observations, **8 inch is the mode value**. When n is even, to find median position, we need to add 1 to the number in the sample and then divide by 2. In the above case the median position is (26+1)/2 or 13.5. If we arrange the observation values in order of magnitude, we get the following series.

5	5	5	7	7	7	7	7	7	8	8	8	8	8	8	8	8	8	9	9	9	9	9	10	10	10

Since both the 13th and 14th values are 8 inch, the median value will be recorded as 8 inch. The **sample mean** or the arithmetic average, denoted as $\bar{x}$ is calculated from

$$\bar{x} = \frac{\sum x}{n}$$

where $\sum$ = sum of over entire sample

x = value of individual observation

n = number of observations in the sample.

In the above case the sample mean $\bar{x} = \frac{204}{26} = 7.85$ inch.

2 Standard Deviation is a measure of dispersion of individual observations about their arithmetic mean. In a normally distributed population, approximately two-thirds (68%) of the observations will be within ± 1 standard deviation of the mean. The Standard Deviation of a population is a parameter, and is commonly denoted by the Greek letter σ. However, the sample standard deviation is a statistic which is an estimate of the population parameter σ, and is denoted by s. The estimated standard deviation is calculated from the following formula –

$$s = \sqrt{\frac{\sum (x-\bar{x})^2}{n-1}} \quad \text{or} \quad = \sqrt{\frac{\sum x^2 - \frac{(\sum x)^2}{n}}{n-1}}$$

where $\bar{x}$ is the arithmetic mean and $(x - \bar{x})^2$ is the squared deviation of an individual observation.

For the example given above, the standard deviation will be

s = [illegible] = [illegible] = 1.41 inch.

3. Standard Error of the mean – The standard deviation is a measure of variation of individuals about their mean. If we pick up different samples of the individuals, since the individuals would vary, there will be variation of means computed from different samples. A measure of variation among the sample means is the standard error of the mean. It may be defined as a standard deviation among the means of samples of a fixed size n (*Forest Measurements by T. Eugene Avery)*.

Calculation of standard error of the mean depend on the manner in which the sample is selected. For simple random sampling from a finite population, the standard error of the mean $s_{\bar{x}}$ is computed from the following formula –

$s_{\bar{x}} = \frac{s}{\sqrt{n}}$ where it is presumed that sample size n is very small compared to Population N,

In the example cited earlier if the 26 tree samples were drawn from a population much larger than 26, the standard error of the mean will be

$$s_{\bar{x}} = \frac{1.41}{\sqrt{26}} = \frac{1.41}{5.099} = 0.28\ inch$$

The above value of standard error of the mean indicates that if several samples of 26 units each were drawn from the same population, the standard deviation among the sample means might be expected to be approximately 0.28 inch.

4. Confidence Limits – Standard error of the mean indicates that sample means vary about true mean of the population. Confidence Limits provide a method of estimating the probability of a given sample mean being more than some specified distance from the true mean. The standard error of the mean s_x and a table of t values are used to set up confidence limits. **For simple random samples from normally distributed population,** the confidence limits are

Mean ± t. $s_{\bar{x}}$, or $\bar{x}$ **- t** $s_{\bar{x}}$ **to** $\bar{x}$ **+t** $s_{\bar{x}}$

The table giving distribution of t values has a column labeled df which refers to degree of freedom. In the case of simple random sample, df will be one less than sample size, that is, n-1. For the given example of sample of 26 trees, the estimated mean or sample mean was 7.85 inch and standard error of the mean was 0.28 inch, and df as stated above is 26-1, that is, 25. Now corresponding to df = 25, the 95 percent t value (can be read from t table) is 2.060. Confidence limit for this probability P =0.95 thus comes to (7.85 – 2.06 x 0.28) to (7.85 + 2.06 x 0.28), or 7.27 to 8.42 inch. It means that if 26 samples were randomly selected, there is 95% probability that the true population mean lies between 7.27 and 8.42 inch.

The Distribution of *t*

df	Probability								
	0.5	0.4	0.3	0.2	0.1	0.05	0.02	0.01	0.001
1	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657	636.619
2	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	31.598
3	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841	12.941
4	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604	8.610
5	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032	6.859
6	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707	5.959
7	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	5.405
8	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355	5.041
9	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250	4.781
10	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169	4.587
11	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	4.437
12	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055	4.318
13	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012	4.221
14	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977	4.140
15	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.947	4.073
16	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921	4.015
17	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898	3.965
18	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878	3.922
19	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861	3.883
20	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845	3.850
21	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831	3.819
22	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819	3.792
23	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807	3.767
24	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797	3.745
25	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787	3.725
26	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779	3.707
27	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.690
28	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.674
29	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.659
30	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750	3.646
40	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704	3.551
60	0.679	0.848	1.046	1.296	1.671	2.000	2.390	2.660	3.460
120	0.677	0.845	1.041	1.289	1.658	1.980	2.358	2.617	3.373
∞	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576	3.291

Source : Forest Measurements - T. Eugene Avery, The American Forestry Series

Lesson 10

Saturday Excursion

Exercise

1. **Visit to a forest area bearing mature crop of some dominant species.**
2. **The trainees may be divided into groups of 3 or four persons.**
3. **Each group may be assigned a small stand.**
4. **The trainees may be asked to do the following:**
   - **(a) Measurement of diameter at breast height (dbh) of all trees in the stand.**
   - **(b) Distribution of trees in convenient dbh class (of 2 inch or 4cm)**
   - **(c) Measurement of heights of all trees**
   - **(d) Calculation of Mean Height of each dia class and stand**
   - **(e) Calculation of Basal Area of each dia class and stand**
   - **(f) Calculation of volume of each dia class and stand with the help of volume table.**

5.Demonstration of Wedge Prism.