Lecture Notes for Forest Mensuration

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Bechu K. V. Yadav

TWO WORDS

I prepared these slides in brief for B. Sc. Forestry students, KAFCOL for the subject " **Forest Mensuration"** that were used during teaching in the class in 2009.

These slides are expected to be useful for the students & persons who are preliminary interested in the forest measurement although these slides are not likely to be sufficient to fulfill their extensive interests.

Lastly, sorry for not managing fonts and colors uniformly and not acknowledging all the materials used although I have acknowledged some major text books used for this purpose. Thanks for using these slides for your own purposes.

Regards,

Bechu K. V. Yadav

Text Books

Avery, T. E. and Burkhart, H. E. 1983**. Forest Measurement.** McGraw-Hill Book Company

Chaturvedy, A. N. and Khanna, L. S. 2000. **Forest Mensuration and Biometrics** (3rd ed.). Khanna Bandhu, 7 Tilak Road, Dehradun, India

Department of Forests. 2004. **Guideline for Community Forests' Resource Inventory .** Department of Forests, Community Forestry Division. Babarmahal, Kathmandu, Nepal

Husch B., Beers,T. W. and Miller, C. I. 2003. **Forest Mensuration** (4th ed.). John Wiley and Sons, *Inc.,* Hoboken, New Jersey, Canada

Kothari, C. R. 2004. **Research Methodology: Methods and Techniques.** New Age International (P) Limited, Publishers- 4835/24, Ansari Road, Daryanganj, New Delhi

Ram Parkash. 2001. **Forest Management**. International Book Distributors, 9/3, Rajpur Road, Dehradun, India

………………..Related handouts and websites………

Unit-1
Introduction

1.1 Definition & Scope of Forest Mensuration

Mensura means “measure” in Latin word.

Forest Mensuration is that branch of forestry which deals with the determination of dimensions (i.e. diameter, height, volume), form, age and increment of single trees, stands or whole woods, either standing or after felling.

- It includes measurements of felled and standing trees, sawn wood and round logs and various other products i.e. bamboos, charcoal, bark, fruits.
- It Concerns with linear, area, volume and weight (biomass) measurements.

Unit-1

Introduction

Objectives:

- ✓ Basis for sale
- ✓ Basis of management
- ✓ Measurement for research
- ✓ Measurement for planning

Scope:

- ✓ Provides foundations of measurement principles applicable to any forest measurement problems
- ✓ Application of statistical theory and use of computer for data processing
- ✓ Forecast of future yields
- ✓ Measurement not only standing trees but also felled timber and their conversion

1.2 Bias, Accuracy and Precision

Bias

It implies systematic distortion arising from such sources as a flaw in measurement or an incorrect method of sampling.

- Difference between true value and the measured
- Inaccurate
- systematic error affecting all the measurements

Eg.1. Instrument not properly adjusted

2. Measure of 100-ft units with a tape only of 99-ft long
3. Under-estimation of tree height by timber cruisers consistently
4. Arbitrary shift of field plot locations to capture typical samples

Accuracy

Accuracy refers to the success of estimating the true value of a quantity. True value can be determined only by very careful measurements with accurate instruments and formula used. As to the Forest Mensuration, although mensuration is a branch of mathematics, F. Mensuration does not attempt to secure absolute mathematical accuracy ***F. Mensuration*** aims at reasonable and relative accuracy, i.e. maximum accuracy which is profitable and possible to obtain in practice.

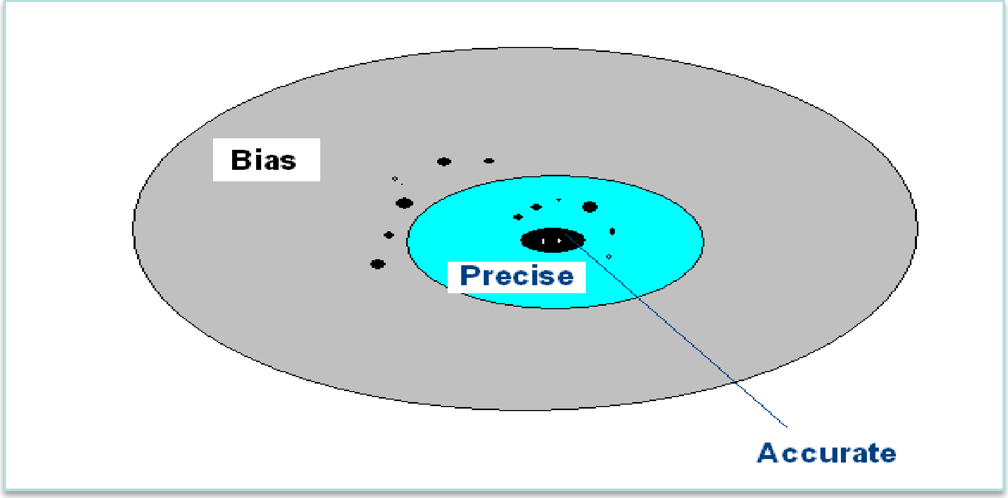
The reasons are:

a) Characteristics of trees
b) Varying methods and conditions of felling and conversion
c) Personal bias of the estimator
d) Biological character of the forest
e) The use to which the measurements are to be put
f) Cost

Precision is the degree to which measurements approach or estimate the average. It gives consistent results from repeated measurements, e.g., 4.44 is more precise than 2.4

In short,

Precision



If target is directly hit the centre, that shows the absolute accurate,
If it hits to the middle circle (>50% to 99.9999%), it is precise
If target hits in outer circle then it is bias (< 50%)

Unit of measurement in forest measurement

12 inch	=	1 foot
3 feet	=	1 yard
66 feet or 22 yards	=	100 links (1 chain)
8 furlongs or 1760 yard	=	1 mile
10 chains or 220 yards	=	1 furlong
I inch	=	25.4 mm
1 foot	=	30.48 cm
1 yard	=	0.9144m
1 acre	=	0.40468 ha
1 mile	=	1.609km
1 cft	=	0.0283 cu m
1 cft/acre	=	0.070 cu m/ha
1 ha	=	2.47105 acres
1 cu m/ha	=	14.291 cft/acre
1 cubic metre	=	35.3147 cubic ft
1 kilogram	=	2.20462 pounds
1 metric	=	0.98420 ton

2. Measurement of Trees

Unit-2

The main object of measurement of individual trees is to estimate the quantity of timber, firewood or any other forest produce which can be obtained from them. It covers:

2.1 Diameter and Girth Measurement

2.2 Height Measurement

2.3 Measurement of Logs and Fuel wood

Diameter Measurement

2.1 Diameter Measurement of Trees

- The linear measurement, the main object of which is to estimate the volume of the trees.
- The volume of a tree is dependent on diameter or girth at breast-height, total height and form factor.
- It is not only necessary for calculation of volume of logs, but also necessary for making inventory of growing stock as well as to correlate height, volume, age, increment of trees.

2.1.1 DBH Measurement & its significance

DBH Measurement

- DBH is simply the average stem diameter outside bark at point, 1.37m above ground
- Universally adopted standard height for measuring girth, diameters and basal area of standing trees

India, Burma, America, Union of South Africa and other British Colonies- 1.37m

In Europe, U.K., DBH is taken as 1.3m. It is recommended by FAO as standard

Significance Of DBH

- Convenient height for taking measurement
- Avoids the fatigue caused unnecessarily
- Saves extra expenditure from not clearing the base
- Abnormalities ,eg. Root swell, disappear below breast-height
- Standardizes diameter measurement giving a uniform point of measurement. Diameter measurement at stump height is preferred, but standardization is lost because height of stump depends upon skill of the labor and the commercial value of the tree.

DBH
Vs
Girth

DBH = Diameter at Breast Height

$= 2r$

Where,

r is radius of stem

Girth = Perimeter of Stem at Breast Height

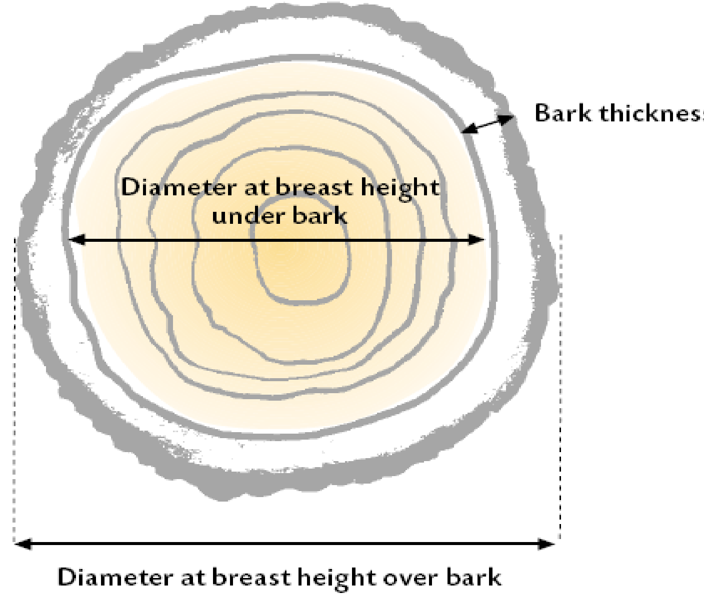
$= 2\pi r$

Thus,

$$Gbh = Dbh * \pi$$

- **DBH**

$$DUB = DOB - 2t$$



- **Girth**

$$g = g' - 2\pi t$$

Under Bark
Vs
Over Bark

Where g = g.u.b.
g' = g.o.b.
t = bark thickness

<u>Ratio of UB and OB</u>

Once the DBHUB has been calculated it can be inserted into a ratio and used to reduce the over bark volume to an approximate under bark volume. The ratio is:

$$\text{Ratio} = \frac{(DBHUB)^2}{(DBHOB)^2}$$

Basic level

The depth of the bark can be estimated by cutting through the bark to the wood or observing the bark of at least five recently felled trees.

Advanced level

Levels of Bark measurement

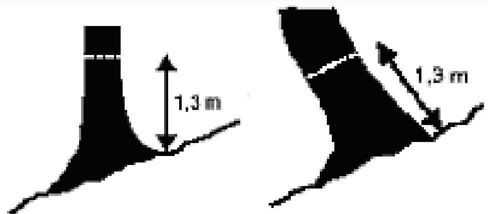
Bark thickness can also be measured with a specifically designed bark gauge to an accuracy of one millimetre. It relies heavily on feel; so to minimise error the following guidelines are suggested:

- If the tree has rough or fissured bark, take measurements on the ridges of the bark.
- Take three to four measurements around the stem and average, as bark thickness may vary from one side of the tree to the other.
- Feel the change in pressure while pushing the chisel into the bark. Avoid pushing too hard or it might go into the wood.

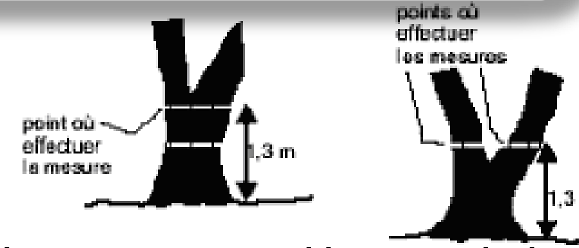
2.1.2 Rules of DBH Measurement and instruments used

Rules of DBH Measurement

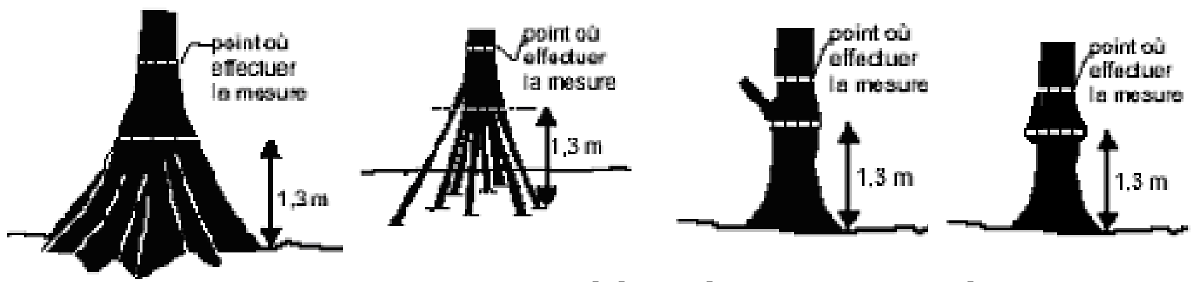
Measuring Point



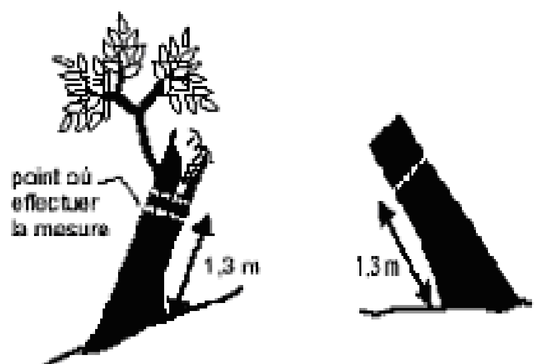
Dbh measurement position on steep terrain



Dbh measurement position on Forked Trees

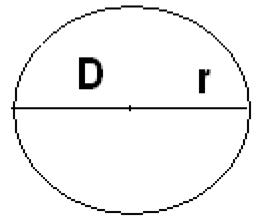


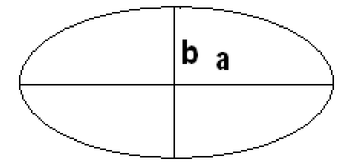
Measurement Position in Buttressed Trees



Dbh in Leaning trees

The diameter or girth of trees are measured assuming the tree section to be circular. Actiually, the tree section is rarely circular It often deviates form circular shape usually tending to elliptical shape Chaturbedi suggested





Errors involved at DBH Measurement

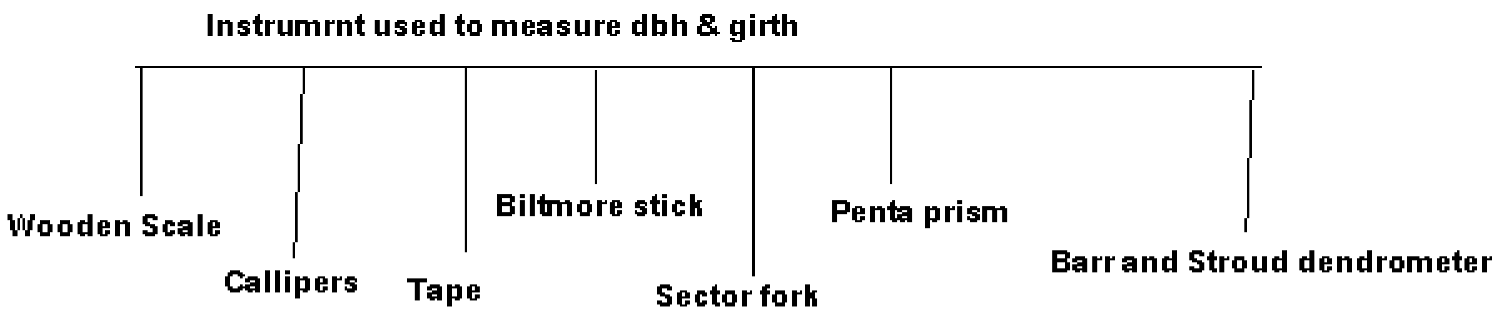
Particulars of the basis calculating area	**Basal Area**	**Errors as compared to the true basal area of ellipse**
i) True area of ellipse	πab	No error or less error
ii) Area of circle based on two diameters a) By formula $\pi \{(a+b)/2\}^2$ b) By Formula $\pi \{(a^2+b^2)/2\}$	$\Pi ab + 2K/32$ $\Pi ab + 4K/32$	$+ 2K/32$ $+4K/32$
iii) Area of circle based on girth measurement by formula $g^2/4\pi$	$\Pi ab + 3K/32$	$3K/32$

Where, π is 3.1416, and $K = e^4 (1+e^2/2) \Pi a^2$

Points to be considered at the time of measuring diameter

- Breast height point should be marked by intersecting vertical and horizontal lines **12 cm long**, painted with **white paint**
- Breast height should be marked by means of a measuring stick on standing trees at 1.37m or **4 ft 6 in** above the ground level, but1.3 (4’3”) in case of FAO
- On the sloppy ground, the diameter at breast height should be measured on the uphill side, **after removing any dead leaves or needles lodged there**
- In the case of leaning tree, **dbh is measured alone the tree stem and not vertically.**
- Breast height mark should be shifted up or down as little as possible to a more normal position of the stem and then diameter measured if stem is abnormal.
- Buttress is formed due to edaphic factor so if buttress is seen, the dbh should be taken a little above the buttress formed.

Instruments for DBH measurement

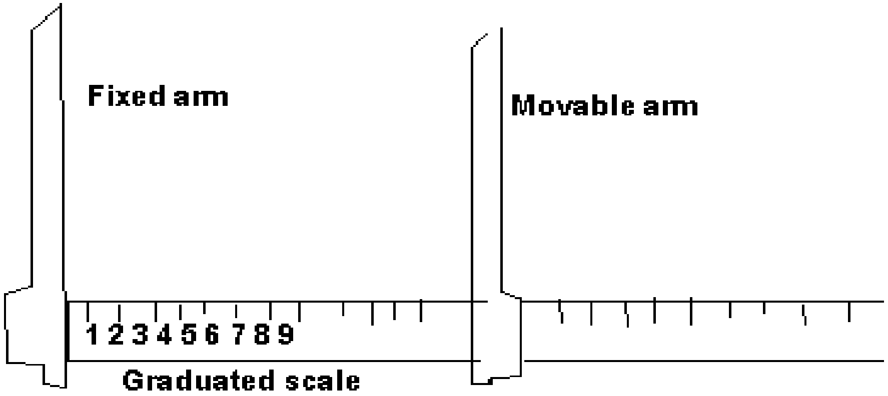


Instruments of DBH Measurement

Mostly used to measure dbh/girth in developing countries are Wooden scale, callipers and Tape. Biltmore stick, Sector fork, penta-prism, Barr and Stroud dendrometer are used to measure the dia. & girth of trees in developed countries Their use depends upon the condition of trees (Felled or standing) & the degree of accuracy Required (research, business, etc)

Caliper

Construction:



Instruments of DBH Measurement

It is generally made of wood, consists of a graduated rule and two arms. One is fixed at rt. angles to one end of the rule and the other movable parallel to the fixed rule. Size more than 120cm in length is rarely used. The use depends on the desired accuracy. Callipers marked are painted to differentiate the reading. In some callipers, the arms are made parallel by screw adjustment. Metal callipers made of alluminium alloy are in use. They are not heavier than wooden callipers and easy to keep clean & adjustment

Instruments of DBH Measurement

Caliper contd…

Types:

1. **Flurry Callipers:**

   Arms from aluminium and graduated from wooden and bound with brass of sizes available in lengths of 80,60,35cms

2. **Fommes Calipers:**

   All aluminum and same size as Flurry.

3. **Indian Aluminum Callipers:**

   They are variable in the length of 50 cm, 75cm & 100 cm & they are graduated to show cm & mm.

Uses:

- To measure diameter of standing trees and logs

Instruments of DBH Measurement

Caliper contd…

Advantages

i. diameters can be reading the directly in cm and mm thus making the instrument applicable for precise scientific work

ii. The points arms touching the tree are always in sight and irregularities if any can be avoided

iii. By firmly pressing the arms against the tree bole, the loose swollen bark is crushed out & irregularity from this source is avoided

iv. It is adaptable for use by unskilled labor

v. The errors are both +ve & -ve and therefore the chances are that they may neutralize to give more accurate results than the tape which gives only +ve errors.

Instruments of DBH Measurement

Caliper contd…

Disadvantages

i. They are not accurate when not in adjustment

ii. Callipers sufficient in size to measure large trees are very awkward to carry & handle.

iii. Two measurements have to be taken on every tree to get the correct diameter. In steep hilly terrain, measurement of second diameter in correct orientation is often very difficult

iv. Movable arm often sticks when the scale is wet or dirty, thus wasting a lot of time.

Caliper contd…

Instruments of DBH Measurement

Precautions:

i) The callipers must be placed on the tree with movable arms well-opened and must not be forced on the tree, there by causing stress or damage to the arms.

ii) The reading must be taken before the callipers is removed from the tree

iii) If the cross-section of stem is more or less elliptical, it is necessary to measure two dia which corresponds to the major and minor axes of ellipse. Since axes of an ellipse are at rt angles to each other, dia is then understood to the average of two measurements

Suppose, d_1 & d_2 are two dia of elliptical cross section of tree, Basal area=$(\pi/4)\ d_1 \times d_2$

Instruments of DBH Measurement

Caliper contd…

Calipers must be placed at right angles to the axis of the tree. If the plane of the calipers is inclined by an angle A from the horizontal plane of tree with diameter D the measured diameter becomes DsecA.

Numerical

If angle formed by the calipers is 60 degree of diameter measuring 30cm. Calculate the error evolved and percentage error.

Solution:

A=60 degree; D=30cm

Error involved = d (secA-1)

= 0.3 (sec60^0-1)

= 0.3 (2-1)

= o.3m

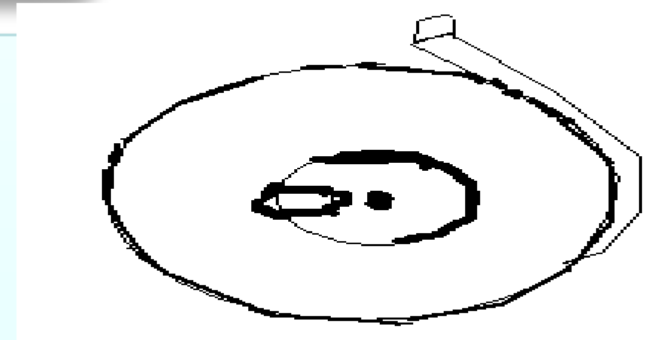
Percentage involved =100(sec60^0 -1)

= 100%

Tape

Instruments of DBH Measurement

Construction:



It is a band of cloth, reinforced cloth, plastic or steel about 1.5 cm wide and of varying length and is used to measure girth of trees and logs. It is usually graduated one side in cm and mm but sometimes it is graduated on both sides to give measurements in metric system on one side and those in British system on the other. The ends of the tape are always plated some metal to prevent their tearing off but in case of longer tapes which are kept encased in some cover by winding it in or in some other cases too, the beginning of tape has a metal ring to hold it.

Tape contd…

Instruments of DBH Measurement

In western countries, tapes are often provided with hook enables one person to measure large trees with tapes lying flat in correct position on the tree.

Types:

1. Cloth Tape

The tapes are made of cloth, though they may be painted with some paint on both sides to give better look and correct them from the influence of water. They are also affected by fluctuations in length due to expansion in use.

2. Metallic Tape

The better quality of tapes are usually reinforced inside by metal wires and are, therefore called metallic tapes. They are painted with some durable paint. So, they are more durable and reliable.

3. Steel Tape

Steel tapes are used for precise work and are mostly used in forest for measurement in sample or research work.

Tape contd…

Instruments of DBH Measurement

In western countries nylon coated steel tapes and fiberglass tapes are available.
The tree measuring tapes are generally 3 m long or at the most 5 m. But land measurement tapes may be 5m, 10m, 30m or even 50 m long. In British measures, these tapes are usually 25ft, 50ft and 100ft long. Such long tapes are generally cased in some leather or plastic case with some winding arrangement so that they are secure inside the case when not in use. The tree measuring tapes, which are usually small, do not generally have cases to cover them, though some steel tapes are 2 or 3 m long are kept in cases with some spring device to wind them back when not in use.
Though trees are meant for girth measurement, some of them are so graduated as to read diameter instead of girth. As girth is equal to πd, the tape is calliberated as per the formula.

Tape contd…

Instruments of DBH Measurement

Advantages

i) tape is convenient to carry

ii) It does not require constant adjustment

iii) Only one measurement is needed even with irregular trees

iv) In case of logs lying on ground, it is not possible to measure two diameters at right angles to each other by callipers and diameter measurement by the tape is easiest

v) The error in case of tape are always positive and systematic and so if any adjustment by tape is needed, it can be done easily

vi) Tape negotiates the whole circumference of the tree while callipers touch only three points on it. So a tape measures the size of the tree better than callipers

Tape contd…

Instruments of DBH Measurement

Disadvantages:

i) if the tree has rough bark, the tape exaggerates the diameter or girth measurement.

ii) it is somewhat slower to use particularly in areas with dense shrub growth

iii) the observer doesn't see the full circumference of the tree and has no knowledge of presence of knots or swellings which may affect the diameter of girth measurement

iv) As the tape has to be swung round the tree it is frequently not applied to in a plane right angles to the axis of the tree

v) Differences in tension of the tape due to elastically affects true diameter or girth measurement

Tape contd…

Instruments of DBH Measurement

Uses of Tape:

- To measure girth and diameter of the trees
- To measure length of seedlings, saplings, shrubs, deadwood, etc
- To measure distance from the base of trees to the point of measurement especially in case of vertex

Causes of Errors by Tape:

- Displacement of the tape from the horizontal
- Elasticity of tape
- Expansion of tape

Tape contd…

Instruments of DBH Measurement

Precautions:

i) The tape should not be old and therefore stretched or possibly with the end broken off.

ii) It must be flat against the tree and not in twisted manner

iii) It must lie in a plane perpendicular to the axis of tree so that the girth and consequently the basal area is over estimated.

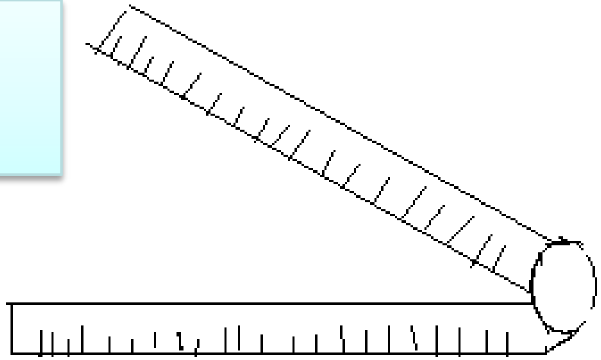
iv) After swinging the loose end of the tape round the tree, care should be taken to see that no climber or branch of nearby shrub has vitiated the girth measurement. If so they should be cut out before swinging the loose end of the tape round the tree

vi) The tape should be taken care of wet and twisted

Instruments of DBH Measurement

Wooden Scale

A flat wooden piece marked in cm. and mm.



Rules of measurement:

i) The diameter should be measured along the passing through pith. In case of eccentric stumps or logs, two diameters, one along major axis and other at right angles to it should be measured

ii) As the end of the scale gets worn off by continuous use, the measurement should be taken from first centimeter & not from zero and deduct one cm from the reading

iii) The scale should be placed on edge so that the ends of the line to be measured coincide with marks of the scale

iv) While reading measurement, the eye should be just above the mark, If this is not done, some error will creep in the measurement & this is called error of parallax.

Instruments of DBH Measurement

Wooden Scale contd…

Uses:

- To measure diameter of stumps or end sections of logs exposed as a result of cross-cutting.
- Stump and stem analysis for measuring radius at successive decade marks.

Two types:

1. 30 cm long and 3 cm width
2. 60 cm long and 1.5 cm width

Folding arrangement at every 15 cm length, first folded at 30 cm

Techniques of measurement:

- Two diameters: one along major axis and other at rt. angle to it.
- Take measurement from first cm., not from the zero
- Eye should be just above the mark

Swedish Bark Gauge

Bark Thickness

- Thickness of bark affects the calculation of volume
- Thickness of bark cab be measured by Swedish Bark Gauge.

Fig.-Swedish Bark Gauge

2.2 Height Measurement

2.2 Height Measurement

Definition

Total height of the tree is the straight line distance from the tip of the leading shoot (*or from the highest point of the crown where there is no leader*) to the ground level, usually measured on slopes from the uphill side of the tree.

Objective

- To find out tree volume
- To read volume tables, form factor table, yield tables, etc
- To find out productive capacity of the site
- To find out the site quality of a locality

Height Measurement

Different Heights of Tree Measurement

1. **Bole Height**

The distance between ground level and Crown Point is called **bole height**, **Crown Point** is the position of the first crown forming **living or dead branch.**

2. Commercial Bole Height

If the height of bole that is usually fit for utilization as timber called **commercial bole height**

3. Height of Standard Timber Bole

Height of the standard timber bole is **from the ground level to diameter over bark 20cm.**

- **Stump height**

The height of the top of the stump above ground which gives the tree stem is lift attached to the ground after felling (20 to 30 cm), called **stump height.** *Value of standing tree before felling is called* ***stumpage value***

Heights of Tree Measurement contd…

Height Measurement

▪Crown Length

The vertical measurement of the crown of the tree from the tip to the point half way between the lower green branches forming green crown all round and the lowest green branch on the bole, called **crown length**

▪ Crown height

The height of the crown as a measured vertically from the ground level to the point half way between the lowest green branches forming green crown all round, called **crown height**

Methods of Tree Height Measurement

1. Ocular estimate

In estimating height of trees by eye, a height scale has to be fixed in mind. This is easily done by measuring the heights of a few trees with some instruments before the start of the work and that of a few trees again in the middle of the work. With this standard in mind, the estimator judges the heights of trees to be measured and records them.

To make it more reliable, a pole of 3 m length may be placed against the tree and then the tree is imagined to be divided in 3 m sections and the height is calculated. If estimator has no practice in dividing the tree in imagination, he can make use of a pencil and divided into sections.

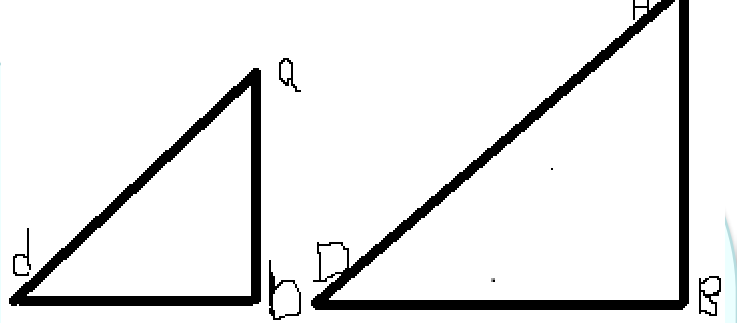
Methods of Tree Height Measurement

2. Non-Instrumental Methods

All non-instrumental and instrumental methods are based on the assumption that the tree is vertical. So, the calculated height does not give the actual height of height because all trees lean on one side or the other some of non-instrumental methods are given below:

a) Shadow Method

In this method, a pole of convenient length is fixed upright in the ground and its height above the ground is measured.



Let,
AB is the tree
ab is the pole
BD is length of shadow of tree
bd is the shadow of ab

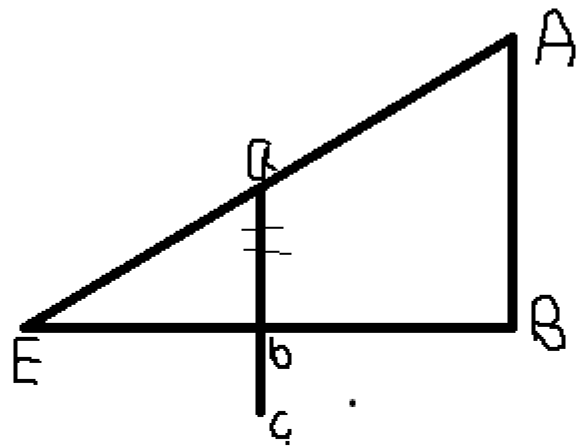
The height of the tree can then be calculated by simple proportion as follows:

$$\frac{AB}{ab} = \frac{BD}{bd}$$

$$AB = \frac{BD \times ab}{bd}$$

It can be applied on clear sunny days. It gives accurate results in the early mornings or late evening (avoiding 11: oo am to 2: oo pm), when tree cast long shadow. It is difficult to apply in well-stocked forests.

b) Single Pole Method



Let AB be the tree and ac be a pole about 1.5 m long, held at b vertically so that distance from So that distance from observer's eye E to b is equal to ab.
Eb = ab, then

$$\frac{AB}{ab} = \frac{EB}{eb}$$

AB = $\frac{EB \times ab}{ed}$ (Since, ab = Eb, AB = EB)

3. Instrumental

Hypsometers, altimeters and clinometers are used to measure height.

Hypsometers: Used for determining the height of standing tree from observations taken at some distance from the tree.

Altimeters: Generally altitude measuring instruments, which can be devised to determine heights of tree.

Clinometers: It measures angle of slope. Any instrument which measures angles of slope can be used for height of tree by trigonometrical methods.

Some clinometers designed for this purpose called hypsometers are based on geometrical principles of similar triangles or based on relations between the sides of right angled triangles.

Height Measurement

2.2.1 Principles of Height Measurement

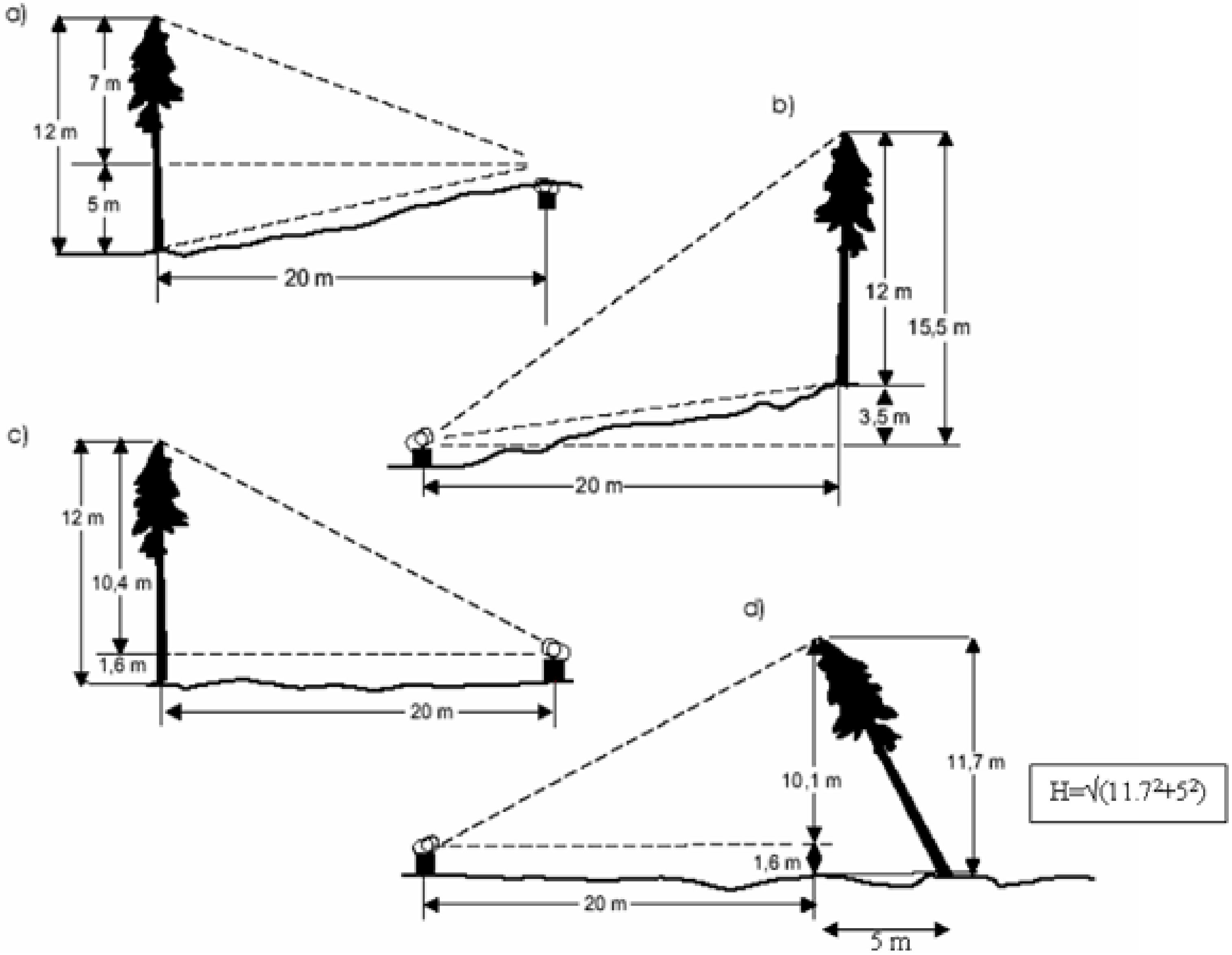
2.2.1.1 Trigonometric Principles

- **2.2.1.1.1 Tangent Law**
- **2.2.1.1.2 Sine Law**

2.2.1.2 Principles of similar triangle

Basics of Tree Height Measurement

Height Measurement



2.2.1.2 Trigonometric Principles

Tangent Law

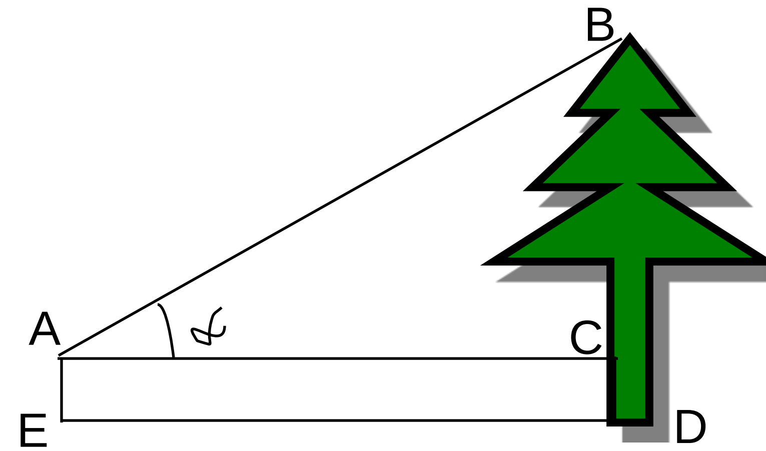
The height of the tree is calculated with the help of the tangents of the angles to the top and base of the tree and the distance of the observer from the tree.

Simple example is of standing tree in plane ground

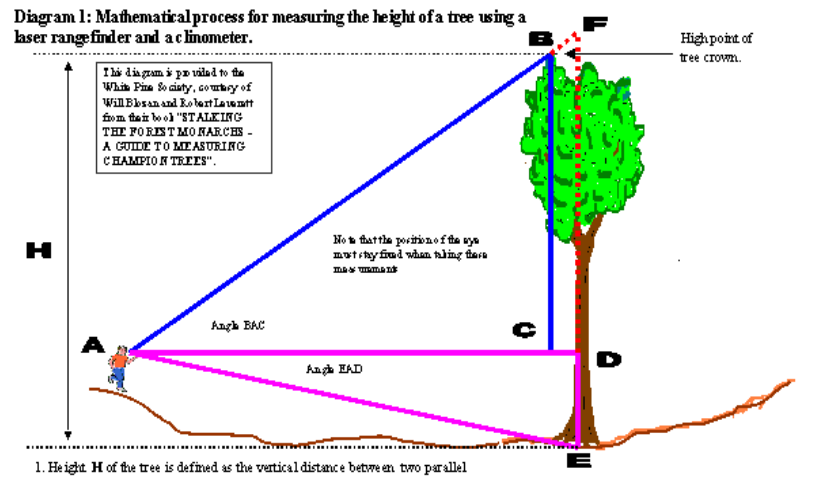
- BD = AE+ ED Tan α

In case of sloping ground

- BE = FD + DE
- = AD (Tan A + Tan B)



Plane



Slope

Trigonometric Principles

Sine Law

In trigonometry, in any triangle, sines of angles are proportional to the opposite sides

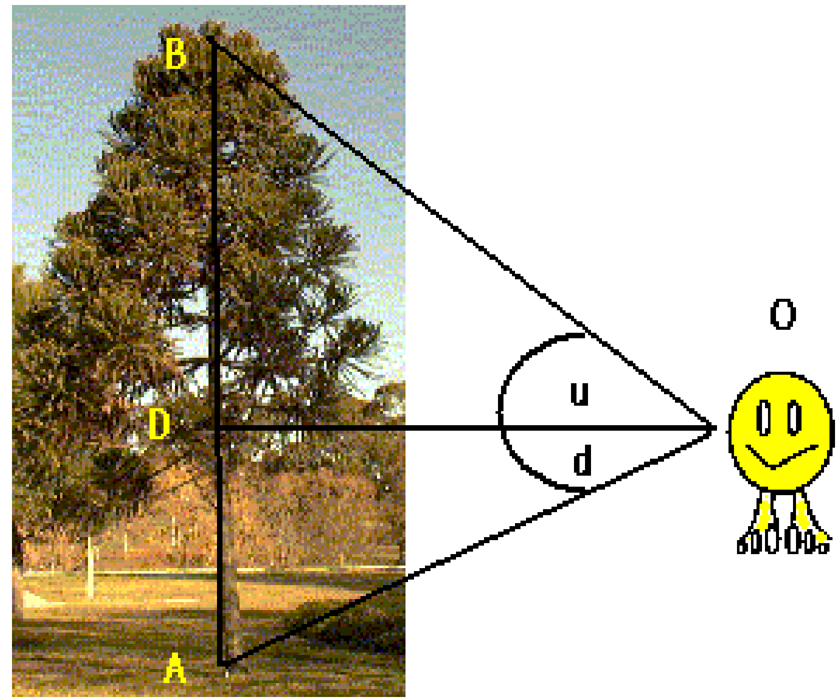
Thus,

$$\frac{Sin\angle AOB}{AB} = \frac{Sin\angle ABO}{AO}$$

$$AB = \frac{AO * Sin\angle AOB}{Sin\angle ABO}$$

$$= \frac{AO * Sin(\alpha + \beta)}{Sin(90 - \alpha)}$$

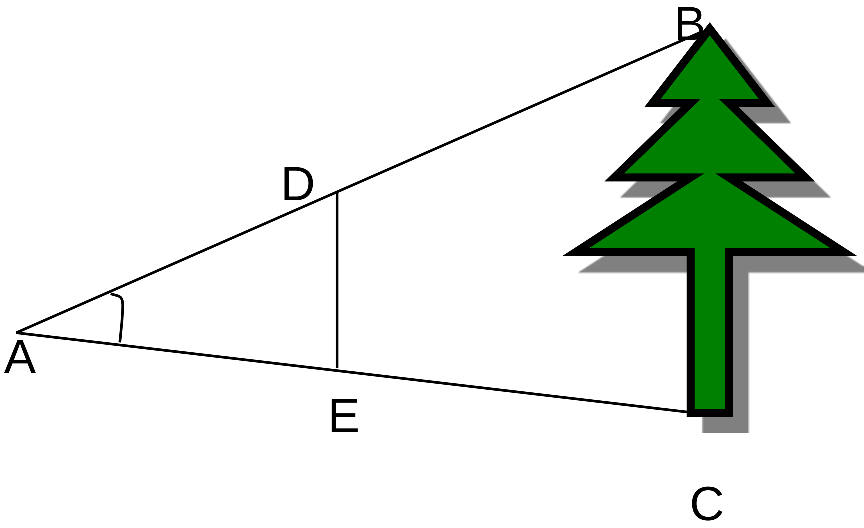
$$= \frac{AO * Sin(\alpha + \beta)}{Cos\alpha}$$



Principles of Similar Triangle

Unit-2.2.1.2

- Two triangles are said to be similar when the corresponding angles are equal and the corresponding sides are proportional.
- ADE and ABC are similar triangles



Thus,

BC:DE = AC:AE

Ht (BC) =DE*AC/AE

Where,

DE and AE are known and AC can be measured in ground

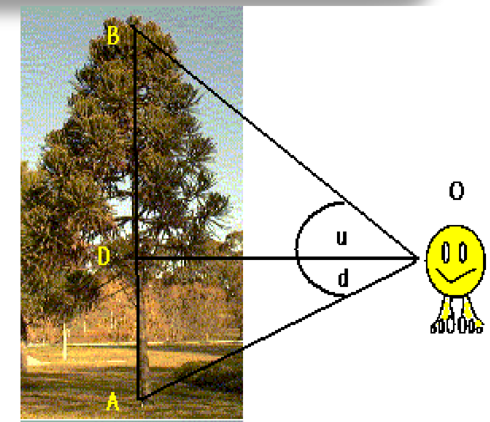
2.2.2 Height of Vertical trees

Height Measurement

On Slope

1. Case I: Observer at the middle of the tree,

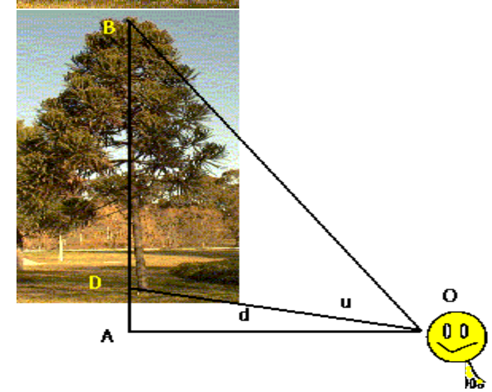
   $AB = DO\ (\tan u + \tan d)$



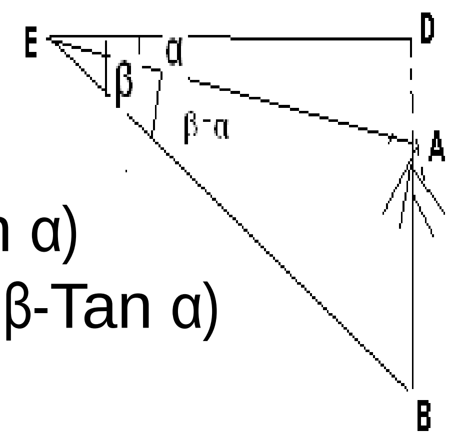
2. Case II: Observer below the bottom of the tree,

   $BD = AB - AD$

   $= AO\ (\tan u - \tan d)$



3. Case III: Observer is above the base and top of the tree.



Height of the tree, $AB = ED.\ (\tan\beta - \tan\alpha)$

$= EB.\ \cos\beta.\ (\tan\beta - \tan\alpha)$

2.2.2 Height of Leaning trees

Height Measurement

Case I: Observer at between top and bottom of the lean tree

(a) Observer away from the lean tree
(b) Observer towards the lean tree

Case II: Observer below the bottom of the lean tree

(a) Observer away from the lean tree
(b) Observer towards the lean tree

Case III: Observer above the top of the lean tree

(a) Observer away from the lean tree
(b) Observer towards the lean tree

Height Measurement

Formula for leaning trees

$$AB = \frac{EB * Sin(\alpha + \beta)}{Cos(\alpha + \theta)} \rightarrow CaseI(a)$$

$$AB = \frac{EB * Sin(\alpha + \beta)}{Cos(\alpha - \theta)} \rightarrow CaseI(b)$$

$$AB = \frac{EB * Sin(\alpha - \beta)}{Cos(\alpha + \theta)} \rightarrow CaseII(a)$$

$$AB = \frac{EB * Sin(\alpha - \beta)}{Cos(\alpha - \theta)} \rightarrow CaseII(b)$$

$$AB = \frac{EB * Sin(\beta - \alpha)}{Cos(\alpha - \theta)} \rightarrow CaseIII(a)$$

$$AB = \frac{EB * Sin(\beta - \alpha)}{Cos(\alpha + \theta)} \rightarrow CaseIII(b)$$

Case I (a) Observer away from the lean tree

Height of Leaning tree

$$In\triangle ACB$$

$$Ext.\angle ECB = Int.\angle CAB + Int.\angle CBA$$

$$\therefore \angle CAB = \angle ECB - \angle CBA$$

$$= (90^0 - \alpha) - \theta$$

$$= 90^0 - (\alpha + \theta)$$

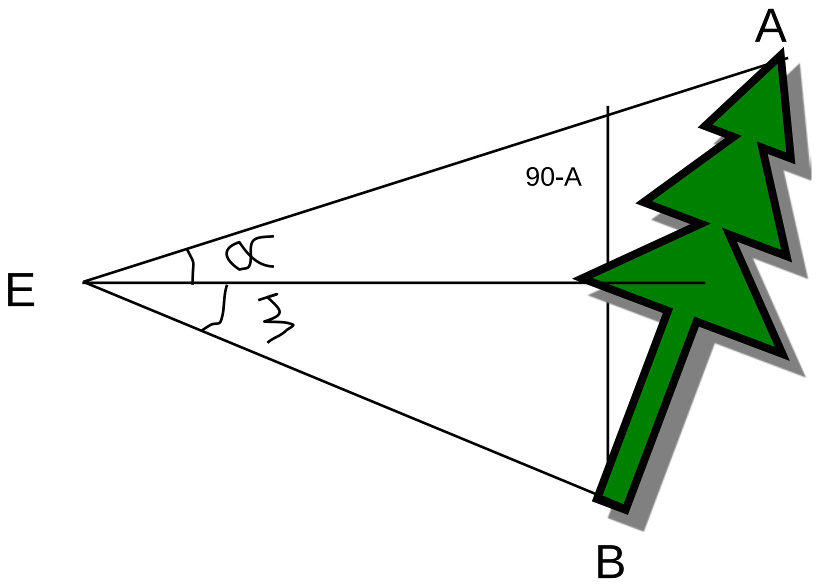
$$In\triangle AEB$$

$$\frac{AB}{Sin\angle AEB} = \frac{EB}{Sin\angle EAB}$$

$$\therefore AB = EB\frac{Sin\angle AEB}{Sin\angle EAB}$$

$$= EB\frac{Sin(\alpha + \beta)}{Sin\left[90^0 - (\alpha + \theta)\right]}$$

$$= EB\frac{Sin(\alpha + \beta)}{Cos(\alpha + \theta)}$$



Case I (b) Observer towards the lean tree

Height of Leaning tree

In triangle ECD, ECD= 90^0-α

And the exterior $\angle$EAB=interior $\angle$ACB+ $\angle$ABC

exterior $\angle$ EAB = $90^0-\alpha+\theta = 90^0-(\alpha-\theta)$

Now,

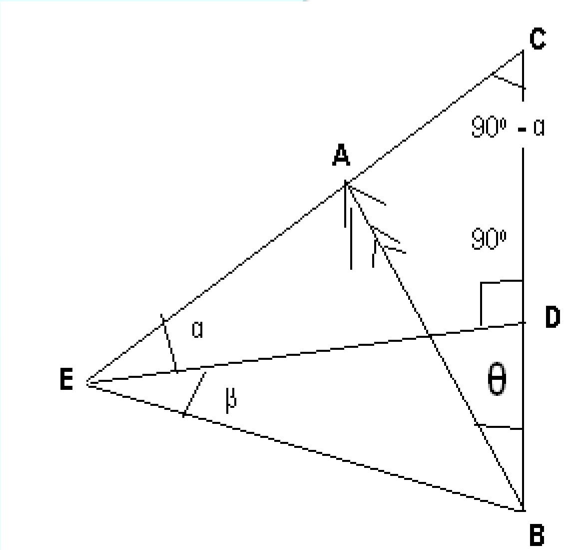
in triangle AEB,

AB/Sin$\angle$AEB=EB/Sin$\angle$ EAB

Or AB= EB Sin$\angle$AEB/Sin$\angle$EAB

AB= EB. Sin $(\alpha+\beta)$/Sin $\{ 90^0-(\alpha-\theta)\}$

AB= EB. Sin $(\alpha+\beta)$/Cos$(\alpha-\theta)$



Case II: Observer below the bottom of the lean tree

(a) Observer away from the lean tree

Height of Leaning tree

Let,

angle AEB=α and ∠BED=β, angle

In the triangle, ECD, ∠ECD=90^0-α

In the triangle ABC,

angle EAB=Exterior angle ECB-interior angle ABC

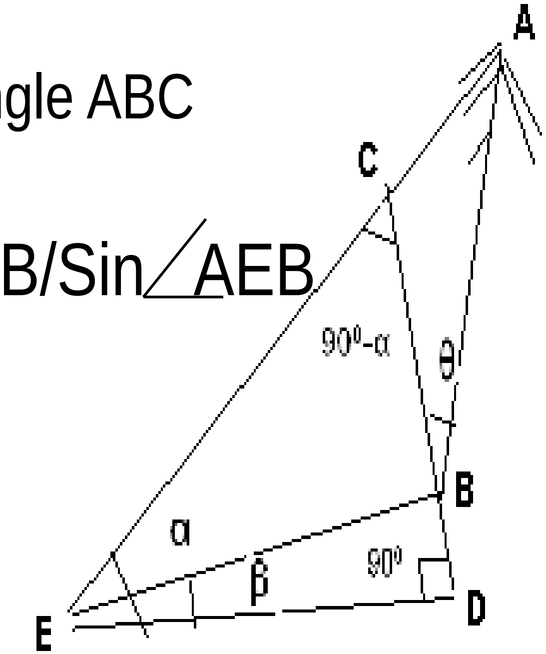
=90^0-α-θ= 90^0-(α+θ)

In the triangle AEB, AB/Sin ∠AEB=EB/Sin ∠AEB

AB= EB. Sin ∠AEB/Sin ∠AEB

AB= EB. Sin (α-β)/ Sin {90^0-(α+θ)}

AB= EB. Sin (α-β)/ Cos(α+θ)}



Case II: Observer below the bottom of the lean tree

(b) Observer towards the lean tree

Height of Leaning tree

Let, angle CEB=α, angle BED=β, angle ABC=Θ

In the triangle, ABC,

Exterior angle ECD=interior angle ACB+ angle ABC

$$=90^0-\alpha+\Theta=90^0-(\alpha-\Theta)$$

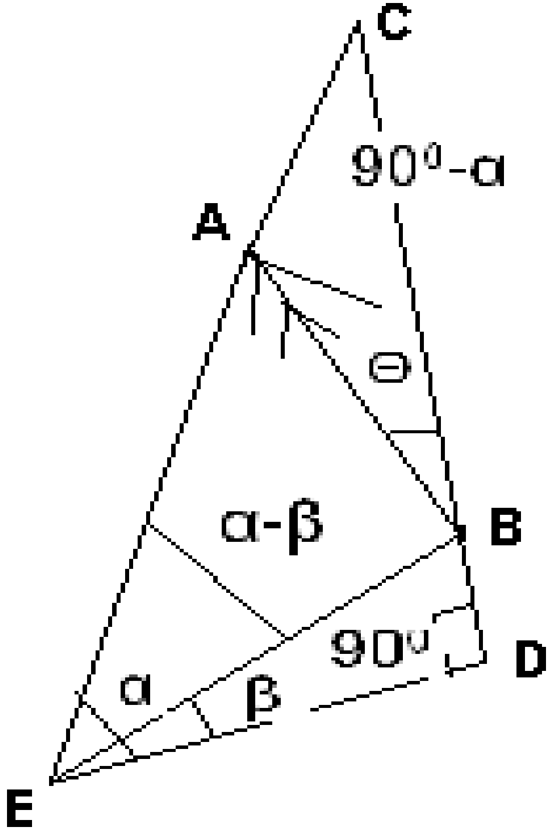
In the triangle AEB,

$$AB/\sin\angle AEB=EB/\sin\angle EAB$$

$$AB= EB.\ \sin\angle AEB/\sin\angle EAB$$

$$AB=EB.\ \sin(\alpha-\beta)/\ \sin 90^0-(\alpha-\Theta)$$

$$AB=EB.\ \sin(\alpha-\beta)/\ \cos(\alpha-\Theta)$$



Case III: Observer above the top of the lean tree

(a) Observer away from the lean tree

Height of Leaning tree

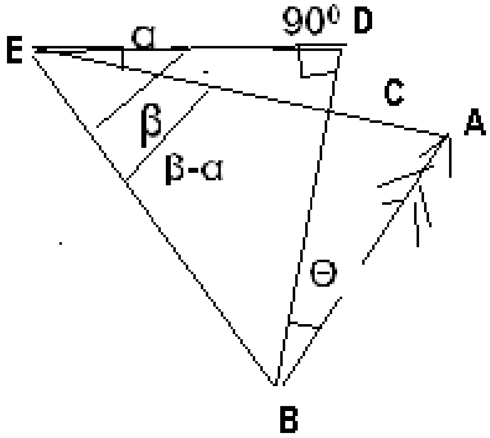
In the triangle ECD,

$\angle ECD = 90^0 - \alpha$

In the triangle ACB,

$\angle EAB = 180^0 - \text{angle } (ACB + ABC)$

$= 180^0 - 90^0 - \alpha + \Theta = 90^0 - (\alpha - \Theta)$



In triangle AEB,

$AB / \sin \angle AEB = EB / \sin \angle EAB$

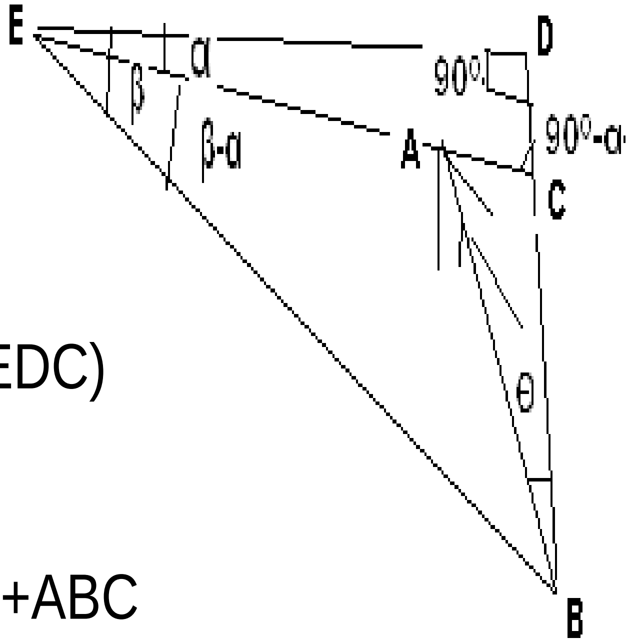
$AB = EB.\ \sin(\beta - \alpha) / \sin 90^0 - (\alpha - \Theta)$

$AB = EB.\ \sin(\beta - \alpha) / \cos(\alpha - \Theta)$

Case III: Observer above the top of the lean tree

(b) Observer towards the lean tree

Height of Leaning tree



Let, AB is the tree,

$\angle DEB = \beta$

$\angle CEB = \beta - \alpha$ where, $\angle DEC = \alpha$,

In triangle ECD,

Exterior $\angle ECB$ = interior angle (CED+EDC)

$= 90^0 + \alpha$

In triangle ABC,

exterior angle EAB = interior angle ACB+ABC

$= 90^0 + \alpha + \Theta = 90^0 + (\alpha + \Theta)$

Now in triangle, AEB, $AB/\sin\angle AEB = EB/\sin\angle EAB$

$AB = EB. \sin\angle AEB/\sin\angle EAB$

$AB = EB.\sin (\beta - \alpha)/\sin 90^0 + (\alpha + \Theta)$

$AB = EB.\sin (\beta - \alpha,)/ \sin (\alpha + \Theta)$

2.2.3 Instruments used Based on

A. Similar Triangles

1. Christen Hypsometer
2. Improved Callipers
3. Smythies' Hypsometer
4. Improved Smythies' Hypsometer

Instrument

A. Trigonometrical Principles

1. Abney's Level
2. Brandis Hypsometer
3. Relaskop
4. Topographical Abney's Level
5. Haga Altimeter
6. Blume-leiss Hypsometer

Instrument

1. Similar triangles

Disadvantages

- It's very slow, fatigue, heavy and rough information

Advantages

- Able to make manually even in the field
- Used by unskilled labor

2. Trigonometrical Principles

Disadvantages

- Manufactured scientifically, repair is difficult on spot, Limited use and expensive
- Only used by skilled labor

Advantages

- It's fast, easy to carry and accuracy maintained available in markets
- Adopted by many countries

Christen's Hypsometer

Instrument

- Made of metal, thin wood or even card board of about 2.5 cm having two flanges to be used with a staff of known length.
- Upper flange to suspend by thread and next one to suspend weight to prevent swinging.
- It is based on similar triangles.
- Usual length of instrument is 33cm (13 feet) used with a staff of 3.6m (12')

Instrument

Christen's Hypsometer

Use: staff is attached with tree base. The observer hang the hypsometer and look to the top and base as well as top of the staff.

Advantage:

- ✓It is light & easily made and transported
- ✓Ht can be read directly
- ✓As the distance measurement is not essential, it can be used anywhere where the top & base are visible
- ✓It is quicker to use
- ✓Useful in conditions where speed is required

Christen's Hypsometer

Instrument

Disadvantages

✓Extra care has to be taken to hold the top and bottom of the tree exactly within the flanges while reading the heights.

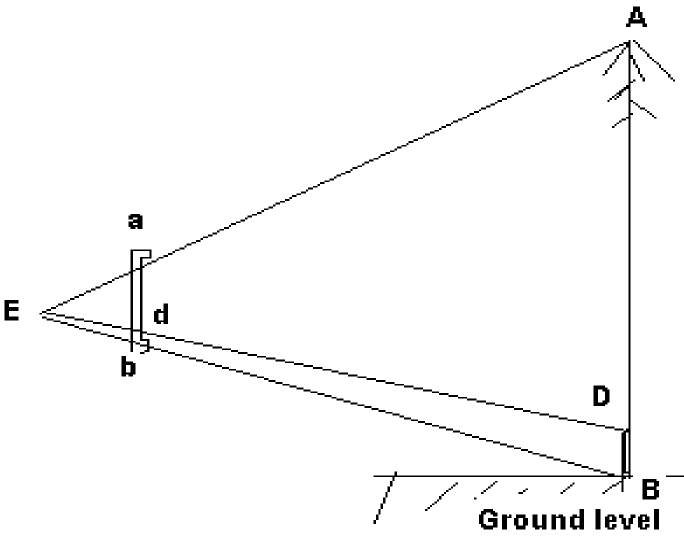
✓ It should be held in a true vertical plane but this is rather difficult due to shaking arm or the wind.

✓ It is not adapted to steady work due to fatigue caused by constantly holding out arm in the required position.

✓A staff is required and Skilled manpower is necessary to use the instrument with consistent accuracy.

Christens' Hypsometer

Principle & method of graduated instruments



AB/ab=BE/bE &=BD/bd

AB= ab*BD/bd

Instrument

A 24 m high tree , BD staff is 4m cm find the length of bd?

bd=4*33/24=5.5cm or

If bd is 5.5 cm, BD staff is 4m, ab is 33 cm.

Find the ht of the tree?

AB/ab=BD/bd

AB=ab*BD/bd=33*4/5.5=24m

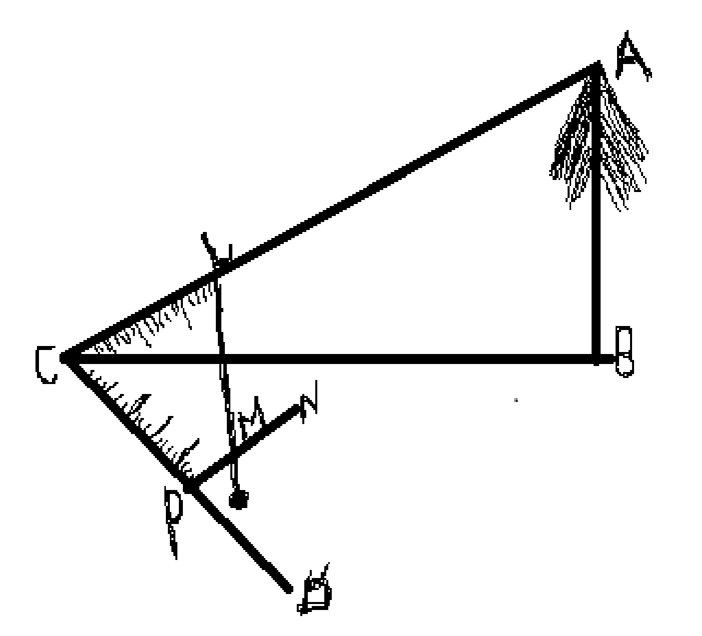
Improved Calliper

Instrument

Sliding arm is graduated and plumb line
is attached to the fixed arm. It is based on similar triangles
Advantage: It can be made in the forest if no other
instrument is available

In fig. AB= Tree, CD= Scale arm,
CL=Fixed arm & PN= Sliding arm
CP in cm = CB in m.
In triangles ABC & MNL
AB:BC=MN:LN:MN=CP

(MN in cm = AB in m.)



$$AB = \frac{BC \times MN}{CP}$$

Smythies' Hypsometer

Instrument

Construction

- Made of a flat card board or thin sheet of wood rectangular or square in shape and provided with a handle
- One side pasted with equal length and breadth.
- Each of 10 divisions indicates 1 m
- Vertical scale is called base or distance scale graduated top to bottom and horizontal scale is called height scale graduated from the handle to outside
- A plumb bob hangs from top corner and semi-protractor showing 0^0-90^0

Instrument

Smythies' Hypsometer contd…

On the other side of the board is pasted a table giving percentage deductions to different angles of depression or elevation to be applied to sloping distance for finding out the horizontal distance. It also measures ht. upto 30m

Method of Use:

From the comfortable place, tip and base of the tree is sighted and sloping distance is measured. To take angle of depression, handle should be towards observer and after sighting the angle, percentage deduction is found out from the table given on the back side and applied to measured sloping distance to get horizontal distance. Considering H.D. and angle of depression, ht. of tree below eye level is obtained from ht. scale.

Smythies' Hypsometer contd…

Instrument

To get the ht. above the eye level, top of the tree should be sighted with handle away from the observer. Plumb bob held at that angle and H.D. found and ht. above the eye level is got from the ht. scale.

Similarly, both angles will be angles of elevation in case of the tree lies above the observer's eye and handle away from the observer.

And both angles will be angles of depression in case of tree lies below the observer's eye and handle towards the observer. Ht. is obtained from ht. scale.

Improved Smythies' Hypsometer

Instrument

To obviate the necessity of finding out H.D for the sloping distance measured from the table.

Bhai Singh suggested modifications :

(i) A shape of a quarter of the circle instead of board and graph paper using rectangular and outer rounded layer with small teeth

(ii) Top corner of the graph paper as centre, many quarter circles are drawn from corner to the end at every 2 or 3 m mark interval. In case of bigger graph paper, marks should be at 1 m or even closer

Improved Smythies' Hypsometer contd...

Instrument

(iii) Ht. axis is shifted to the top and graduated from the handle outwards. Zero of both axes at the same point

Methods to use:

A staff of 1.37 m. with a piece of cloth tied to its top is placed vertically at the base of the tree.
See the top of staff, not the base of tree keeping the handle towards the observer.
When the bob becomes constant, hypsometer is turned to a side. The ht. above and below eye level adding ht . Of staff will give ht of the tree

Improved Smythies' Hypsometer contd...

Instrument

If base is greater than 30m or > or < angle, the bob does not contact the ht. scale. Then, both scales should be halved. Each small division represents 2 m instead of 1m. And 60m instead of 30m.

Advantages;

- No distance measurement and easy to construct and carry

Disadvantages

- Wind affects the bob and graph paper may be affected by rain

Abney's Level

Instrument

Construction:

Hollow tube with an eye piece at one end and a short sighting tube fitted at the other.

Eye piece consists of 2 or 3 telescopic hollow tubes and a sighting tube is a small detachable tube fitted with a horizontal wire at the centre. A mirror behind the horizontal wire covering only half of the tube so fitted that it makes 45^0

A spirit level is fitted to the main tube , which can be rotated by one screw. Wheel is for quicker movement and screw is for final adjustments.

Abney's Level Contd……

Instrument

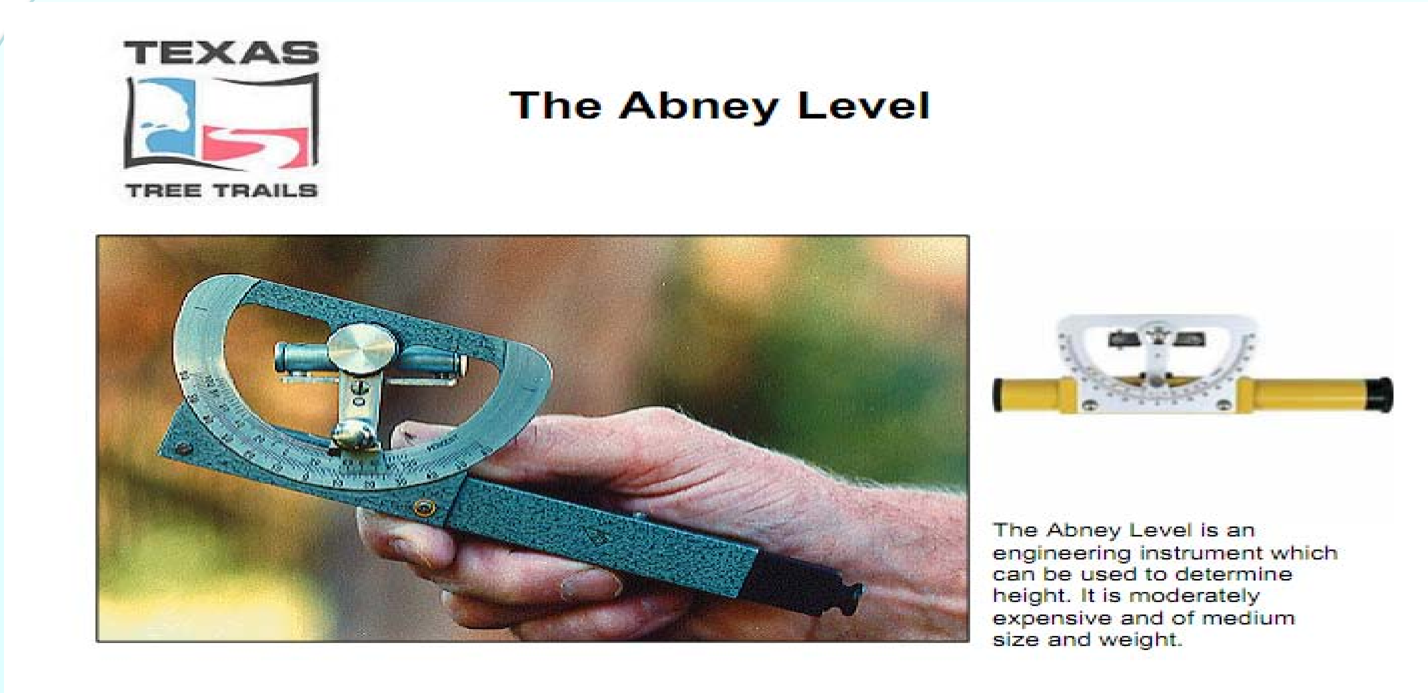
An index arm is also attached to the spirit level. As the spirit level rotated, index arm moves on a graduated semi-circular arc. As the angles of elevation and depression are needed, graduation in degrees up to 90^0 .

On either side of the zero mark at middle. Each division gives the reading of 10'. It is based on trigonometrically principles

It is commonly used instruments. it has Eye piece (hollow telescopic piece), magnifier glass, Protector, wire, screw.

Abney's Level Contd……

Instrument



Methods of Use:

Observer should look through the eyepiece and coincides with top of tree and wire, the spirit should be balanced . It should be balanced by tuning with screw as well as moving to and back ward

Abney's Level Contd……

Instrument

Advantages

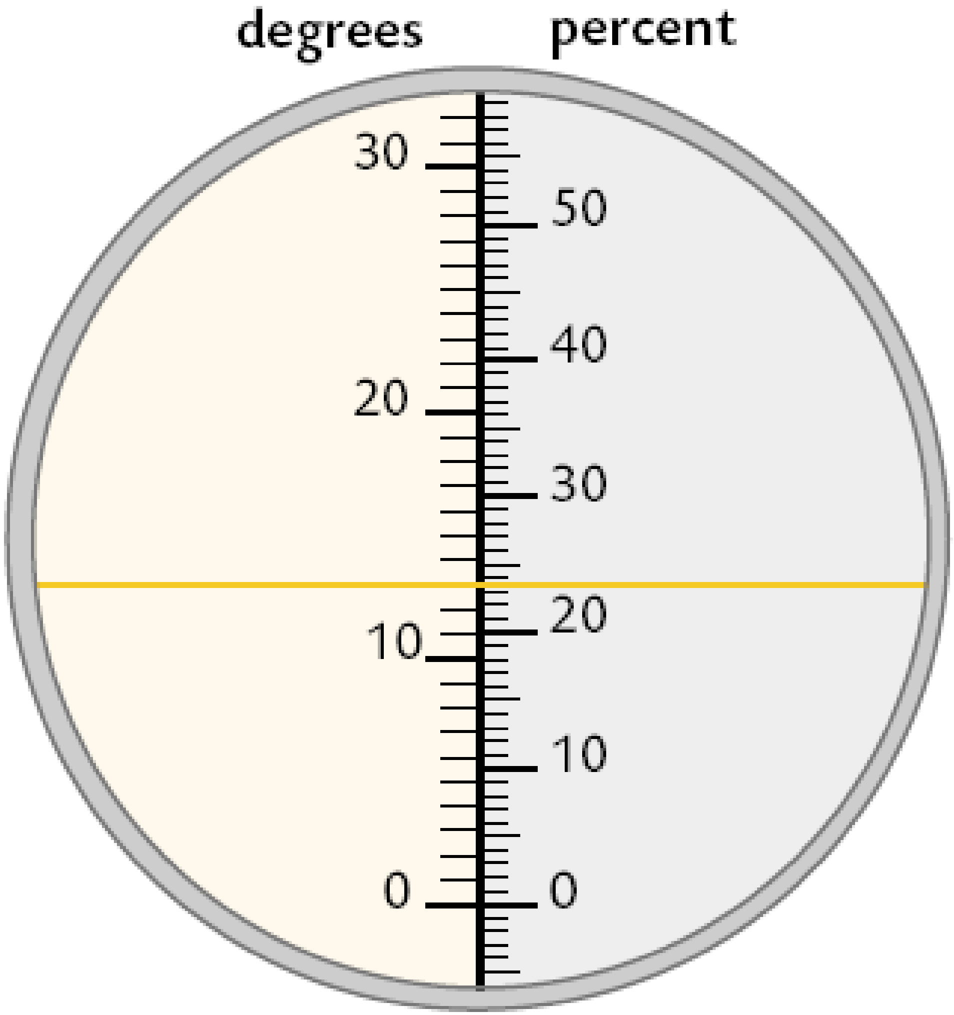
- ✓It gives accurate angle of elevation and depression.
- ✓Readings can be taken after sighting the tree without disturbing the index arm.
- ✓The instrument is small and light and can be used even in hills without difficulty.

Disadvantages

- ✓Shaking of the hand makes the sighting of the top and bottom of the tree a little difficult and time-consuming.
- ✓Sprit level needs adjustment , which is quite tiresome

Instruments used: Sunto Clinometer

Instrument



Instruments used

CLINOMETERS

The Suunto Clinometer (clino) is a tool commonly used by foresters to measure tree heights and also slope angles. At the rear of the clino is a peephole, which shows a percentage scale and a horizontal line (*see Figure 5.3*).

1. First measure the horizontal distance between the base of the tree and the operator.

Instrument

2. Looking through the peephole, line up the horizontal line with the top of the tre and read off the corresponding number from the percentage scale, which is on the right hand side. The scale on the left is in degrees and should not be used!
3. Line up the horizontal line with the base of the tree and again read off the corresponding number from the percentage scale.
4. If the base of the tree is above you (i.e. you're on the downward slope) then subtract the number from Step 3 from the number from Step 2 and multiply by the horizontal distance to get a total tree height.
5. If the base of the tree is level with you or below you (i.e. you're on the upward slope) then add the numbers together and multiply by the horizontal distance to get a total tree height.
6. If the tree is leaning, stand at right angles to the lean so the tree isn't leaning towards or away from you.

Clinometer

The clinometer

Aim the clinometer with both eyes open.

Tree height is measured using the principle of triangulation with a clinometer.
Of all the forestry tools you will use, the clinometer requires the most practice and skill. Assuming that the tree grows at a right angle to the ground (even on a slope),

Haga Altimeter

Instrument

It is based on the trigonometrically rati. It has several scales. Generally, it has two separate consideration

1) Percent of usual scales: 15, 20, 25, 30 &

2) Horizontal Distance from tree: 15, 20, 25, 30

Use: Observer, should be stand at given distance so that ht can be

Parts: Eye piece, Pronges, Scale, Striger, Release striger, Tunning knob

Advantage:

- ✓ It is very easy ti use and read ht directly

Disadvantages:

- ✓ it needs to measure the distance first sometimes in sloppy areas it may be difficult
- ✓ Shaking hands make default reading easily calculated

Vertex IV

Vertex IV and Transponder T3

By Haglof Sweden AB, PO

box 28 88221, 2007

Functions and Construction

Instrument The vertex IV is primarily designed to measure the height of standing objects and most often trees. The instrument can also be used to measure distance, horizontal distance, angle and inclination.

The vertex instrument has with its ultrasonic measuring technique proved to be specially useful in dense terrain with thick undergrowth, where conventional methods such measuring tapes, laser instrument and mechanical height measures are difficult to use.

Vertex IV

Instrument

To define a reference point in a secure and reliable way, the vertex IV works with the transponder T3. The vertex IV communicates with the transponder. This communication eliminates in an efficient way. Any mix up of single from other instruments or places (echos).

A measuring operation will not in any significant way be disturbed by objects in between the vertex IV and the transponder T3. The reference point i.e. the T3 is used as a sight mark for height measuring and can be placed at optional height, where visibility is the best In for example thick vegetation. The reference point height is set in a special menu in the vertex instrument and automatically added to the measured height.

Vertex IV

Instrument

The vertex IV uses ultrasound to measure distance. Unlike for example measuring tapes and laser instrument, ultrasound can be used also when there is no free aim to the reference point. The ultrasound will not pass through an obstacle, but looks for the shortest way.

Heights are calculated trigonometrically using the variables contained when measuring angle and distance. The vertex IV automatically assumes that the measuring object is perpendicularly positioned to the ground.

Vertex IV

Instrument

With the vertex IV, an unlimited number of heights or objects can be measured. The instrument display can show the four lastly measured heights per object at a time.

When using a telescopic method to measure, an in built BAF function can be used for the vertex IV instrument to control the minimum diameter for trees. The function is useful when some trees in an area are covered by other, making the decision whether to include the tree or to exclude it from the area difficult.

Vertex IV

Instrument

By simply measuring the distance between the tree and plot centre, the vertex IV can calculate the minimum diameter the tree should have in order to be included into the counting.

Data can be sent through IR or Bluetooth and results can be stored and processed in for example the digitech professional. Calliper, other PC or handheld computer.

Photo: Calibrating Vertex IV

Vertex IV

Instrument

Function of the arrow keys

Use the arrow keys primarily to scroll through the menu and to change the settings in the SETUP Menu. By pressing down both arrow keys at the same time, the vertex IV is turned off, automatic turn off time is set to approximately 25 sec. When the vertex IV is turned off the DME position can be activated with left arrow key.

The vertex IV turns into a distance measurer. Right arrow (IR) is used to transmit data through IR or Bluetooth (Vertex IV BT Model).

Vertex IV

Instrument

Functions…

Data can only be sent after having made a measuring. Note that the Bluetooth function is available only on vertex IV units ordered and prefabricated with Bluetooth.

The Red Cross Aim

The red dot cross hair sight simplifies spotting the target and holding the instrument straight when measuring heights, for best possible accuracy.

For best possible visibility, the light can be adjusted with the left arrow key when aiming.

Transponder

How to use the T3 Transponder?

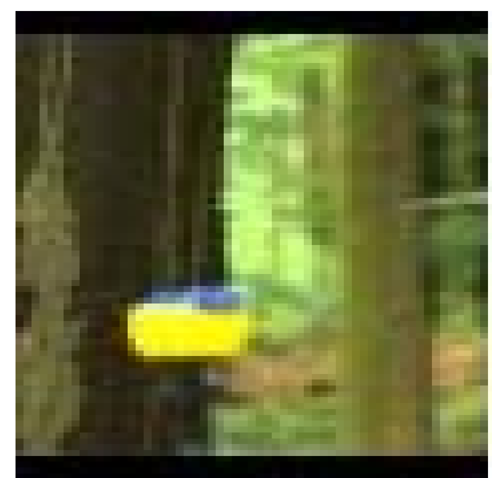
To perform any of the operations described below, keep the measuring unit loudspeaker towards the T3 loudspeaker.

Instrument

Turn on : press measuring unit DME trigger until 2 signal beeps of transponder

Turn off: press measuring unit DME trigger until 4 signal beeps of transponder

Photo: Transponder ready for Vertex



Types of Errors

2.2.4 Sources of Errors

1. Instrumental errors
2. Personal errors
3. Errors due to observation
4. Errors due to measurement
5. Errors due to the lean of trees

Sources of Errors

1. Instrumental Errors

Instrumental errors occur as a result of some deficiency in instrument apart from its incorrectness. Drawbacks of the instruments i.e.

- ✓ Christen Hypsometer keeps on swinging
- ✓ due to wind. Similarly, while turning Smythies' Hypsometer, plumb bob is liable to slip, etc.
- ✓ To eliminate errors, Christen's hypsometer needs suspending a weight below the instrument.
- ✓ Similarly, patience, careful observation and favorable weather conditions need while handling instruments.

Sources of Errors

2. Personal errors

- Shaking hands of the observer
- Could not make steady hands
- Ocular problem with observer in using Sunto-Clinometer

Sources of Errors

3. Errors due to measurement

Correct measurement cannot be obtained due to presence of shrubs and undergrowth.

The tape will not be in level while finding out the horizontal distance by stepping.

Incorrect measurement of angles of elevation and depression may incur errors resulting in incorrect ht.

To reduce such types of errors, the observer should stand at such a distance from the tree that the angle is equal to 45^0 or the horizontal distance from the tree may be roughly equal to the height of the tree.

4. Errors due to observation

Sources of Errors

Invisibility of the base of tree during the angle measurement of the bottom of the tree.

Invisibility of the tip of the tree in case of broadleaved trees

To reduce the error, a staff should be placed against the tree and its top sighted. Later, the height of the staff should be added to the calculated height to get the true height of the tree.

In case of broadleaved tree, the observer should stand far away from the tree as practicable.

Sources of Errors

5. Errors due to lean of trees

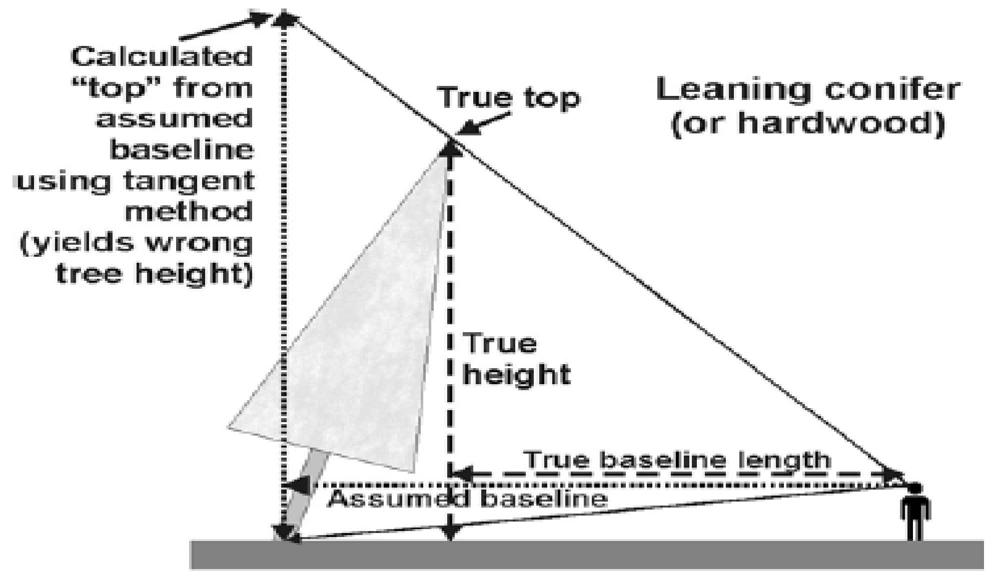
All height measuring instrument assume that the tree is vertical. But the forest trees are seldom vertical. Therefore, by assuming a lean tree to be vertical, serious error is introduced in the calculation of its height.

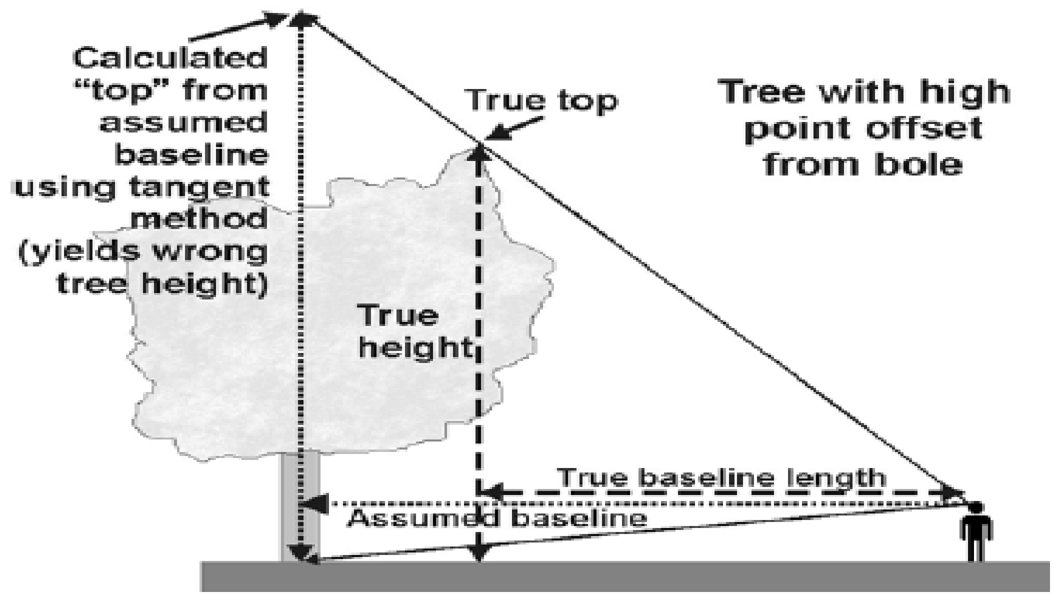
In order to avoid errors due to lean, the following suggestions have been put forward by various workers :

- ✓Take measurement from such a position that lean is to the side rather than towards or away from the observer.
- ✓Measure the horizontal distance from the point of observation to the point vertically below the tip of the tree.
- ✓Keep the angle 45^0 as far as possible
- ✓Measure the height of the tree from two opposite sides, once with the tree leaning towards the observer and other with the tree leaning away. The average of the two will give the height with minimum error.

5. Errors due to the lean of trees

Sources of Errors

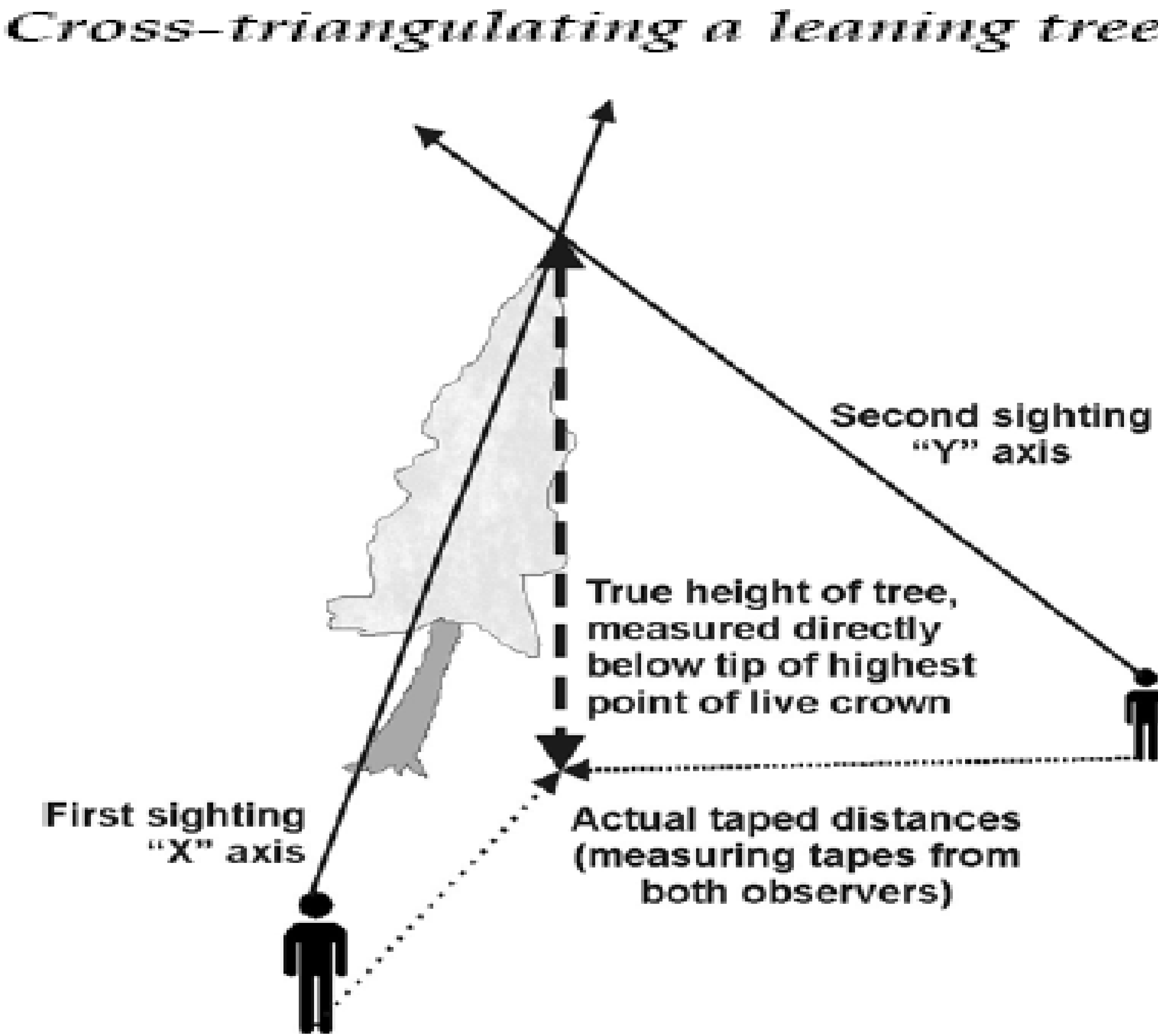




How to measure the height of tree?

Sources of Errors

Height Measurement



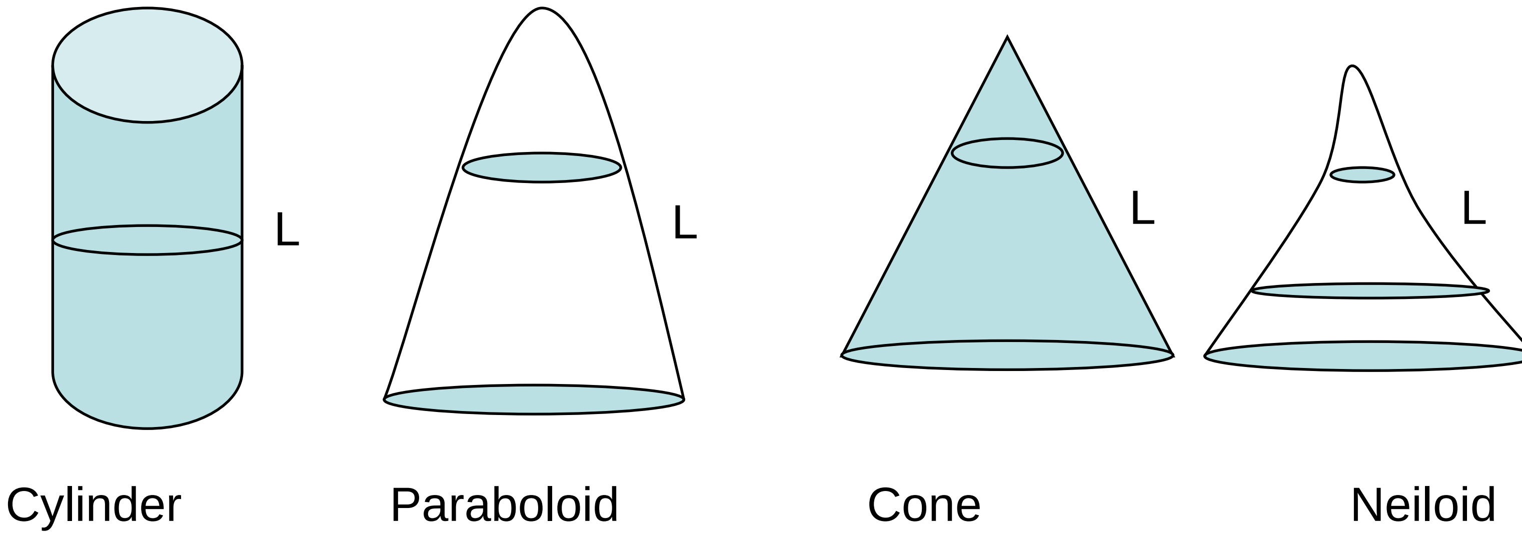
2.3 Measurement of Logs and Fuelwood

Measurement of Logs

Measurement of stacked wood

Measurement of Logs

Different shapes of solid wood



Log size:

- 3m for research purpose
- < 4.5 m for transport

Section area

- The area under each section

$$Area = \pi \frac{d^2}{4}$$

$$Area = \frac{g^2}{4\pi}$$

Calculation of Volume of Logs

There may be different formula for different shape of the log, i.e.

1. Cylinder
2. Paraboloid – Smalian’s formula & Huber’s formula
3. Cone
4. Neiloid – Newton’s formula or Prismoidal formula

Volume of Logs

Form of Solid	Volume of full solid	Volume of frustum of solid	Remarks
Cylinder	sl	sl	
Paraboloid	$\frac{sl}{2}$	$\frac{s_1 + s_2}{2} * l$	Smalian's
		$s_m * l$	Huber's
Cone	$\frac{sl}{3}$	$\frac{(s_1 + s_2 + \sqrt{s_1 * s_2})}{3} * l$	
Neiloid	$\frac{sl}{4}$	$\frac{(s_1 + 4s_m + s_2)}{6} * l$	Prismoidol Newton's

Where,

S is the sectional area at the base in square units

s_1 is the sectional area at the thick end in square units

s_m is the sectional area at the middle in square units

s_2 is the sectional area at the thin end in square units

l is the length of the log or height of the solid in linear units

Measurement of Logs

Description on Formula of Volume of logs

1. Newton's Formula

- Most accurate formula
- Gives volume not only frustum of neiloid correctly, but also cylinder, paraboloid and cone
- All other formulae can be derived from it
- Cumbersome to use as it necessitates the measurement of diameter and calculation of areas of three cross-sections
- Difficult to apply when logs are stacked and mid-diameter can not be measured. Hence, Newton's formula is not used in practice.
- It is only used to calculate the error in volume calculated by other formulae

Description on Formula of Volume of logs

Measurement of Logs

2. Smalian's Formula

- Requires the areas of end cross-sections
- Overcomes the difficulty of measuring mid-diameter of logs when they stacked
- gives volumes of frustums of cylinders and paraboloid with absolute accuracy
- Overestimates the volume and has positive error
- Easier to apply than Huber's and Newton's formula
- Easier to measure by wooden scale than tape or Calliper as log may be lying on the ground

Measurement of Logs

Description on Formula of Volume of logs

3. Huber's Formula

- Requires the areas of mid cross-sections
- Impossible to use it when logs are stacked
- gives volumes of frustums of cylinders and paraboloid with absolute accuracy
- underestimates the volume and negative error
- Nearer true value than the Smalian's formula
- Better than the Smalian's formula because the effect of root swell does not vitiate the result in lower-most log

Comparisons among the formula

Comparison of Formula

- Newton's formula is the most accurate.
- It gives best volume not only of neiloid but gives of cylinder, paraboloid and cone also
- As it requires area measurements of 3 cross section, difficult to apply
- It is only used to calculate the error in volume calculation by other formula

- Smalian's formula overcomes the difficulty of measurement of mid diameter because this requires only measurement of end cross-sections
- This formula overestimates the volume

Comparison of Formula

Difference between Newton's and Smalian's formula

$$\left(\frac{s_1 + s_2}{2} * l\right) - \left(\frac{s_1 + 4s_m + s_2}{6} * l\right)$$

$$= \frac{l}{6}(2s_1 + 2s_2 - 4s_m)$$

$$= \frac{l}{3}(s_1 + s_2 - 2s_m)$$

Difference between Huber's and Newton's formula

$$(s_m * l) - \left(\frac{s_1 + 4s_m + s_2}{6} * l\right)$$

$$= \frac{l}{6}(2s_1 + 2s_2 - 4s_m)$$

$$= \frac{l}{6}[2s_m - (s_1 + s_2)]$$

Volume Calculation by Quarter Girth Formula

Quarter Girth Formula

The volume of the log will be calculated using quarter girth formula

$$V = (\frac{g}{4})^2 * l$$

π of value 3.14 is approximated to 4

Thus this formula underestimates the volume almost 21.5% as compare to full circular volume.

It is known as Hoppus' Formula in Britain

Even if the log had no tapper, the volume of the square timber would be $2r^2l$.

Measurement of stacked timber

2.3.3 Volume of stacked timber

Stacked Volume

The space occupied by a stack as distinct from the cubic contents of the wood itself, i. e. solid volume.

The volume of the stack is then obtained by multiplying the length, breadth and ht. of stack

V (m^3) = Length (m) * Width (m) * Height (m)

V (cft) = V (m^3) * 35.3

In western countries, the term cord is often used to express the volume of stack wood. ‘Cord’ common term used mostly in pulp industry and fuelwood industry.

Cord Size = $4' \times 8' \times 4'$

Measurement of stacked timber

2.3.3 Volume of stacked timber

The average amount of wood volume in standard cord is around 90 cft. It depends on the amount of space between the logs in the stack.

In standard cord, the length of logs is 4 ft
In case of firewood, the length is less than 4 ft.
In this case, the cord is called short (face) cord.
But sometimes, length is > 4 ft, in this case, the cord is called long cord.

2.3.4 Dimension and Volume of Chatta (Stacked fuel wood)

Measurement of stacked fuelwood

In Nepal, fuel wood is measured in Chatta, its dimension is 20’ $\times$ 5’ $\times$ 5’

A stack of 5’ $\times$ 5’ $\times$ 5’ is called quarter chatta.

Solid volume of firewood in a stack depends on several factors such as, care in stocking, form of billets, length of billets and their diameter.

As the value of fuel depends on the solid content, it is necessary to know the methods of determination of solid contents of stacked wood.

Measurement of stacked fuelwood

2.3.4 Dimension and Volume of Chatta (Stacked fuel wood)

Methods of measurement of solid contents

1. Xylometric Method

Xylometer is used to calculate the volume of billets by the principle of water displacement consisting of graduated vessel and volume of wood. To find the volume of stack, the whole stack is first weighed and only a portion is sub-merged

W/w=V/v

2. Specific Gravity Method

Sp. gr. = Weight of wood/ Weight of same vol. of water

= Density of wood/Density of water c.c.

Volume = Weight (in gm)/sp. Gr.

= Weight (in lbs)/sp. Gr. × 62.5 cft.

3. Measurement of Tree Form

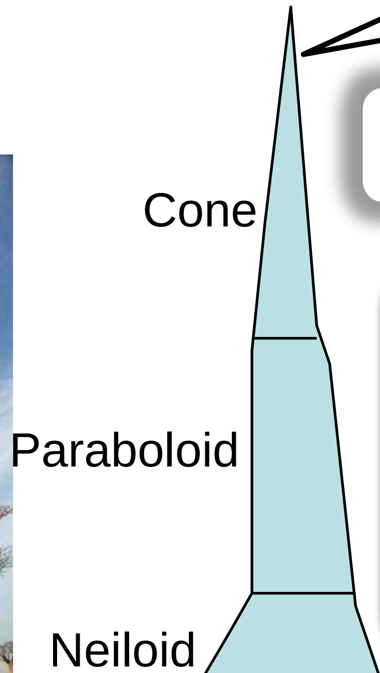
Form is defined as the rate of taper of a log or stem.

Taper is the decrease in diameter of a stem of a tree or of a log from base upwards.

Unit-3

Tree Form

Tree Stem Forms



Methods of Studying Tree Form

A. By comparison of standard form ratios

B. By classification of form on the basis of form ratios

C. By compilation of taper tables

Metzger's or Girder Theory

Tree Form

Several theories have been put forwarded to explain the variation in taper from tree to tree

Metzger, a German Forester proposed the tree stem as cantilever beam of uniform size against the bending force of the wind

The stem of the tree is built in such a way as, with minimum of material , to offer uniformly the greatest resistance to the stress to which it is subjected.

The wind pressure acts on the crown and is conveyed to the lower part of the stem in an increasing measure with the increasing length of the bole.

Thus the greatest pressure is exerted at the base and there is a danger of tree snapping at the place

To counteract this tendency, the tree reinforces along the tree stem so that it affords a uniform resistance all along its length to the pressure

Metzger's or Girder Theory

Tree Form

As the pressure is in the upper part of the tree is les , due to smaller length of lever in that portion it is allocated lesser growth
material than lower part where the pressure gets increased with increased length of bole.

The pressure of wind on crown keeps on changing as the tree is growing in open or crowded portion. Trees growing in complete isolation have larger crowns and so the pressure exerted on them is the greatest.

Mathematically, according to rule of mechanics,

$$S=(P*l/d^3)*32/\pi$$

As the P in case of tree consists of components W=wind pressure per unit area & F=crown area, it will be P=W*F then

$$S=(W*F*l/d^3)*32/\pi= =(W*F*l*32/d^{3*}\pi)$$

For a given tree W, S, F can be considered as constant, therefore $d^3=kl$, where k is constant

Methods of studying form factor

Introduction

The study of form is beset with difficulties because it can not be fixed by one or two measurement. This is due to the fact that the form varies not only from tree to tree but also in the different parts of the same tree. Variation in bark thickness not only from stand to stand and tree to tree but also in the different parts of the same tree adds another dimensions to the problem, However, the form of a tree can be studied in one of the following ways:

1. By comparison of standard form ratios
2. By classification of form on the basis of form ratios and
3. By compilation of taper tables

Methods of studying form factor

By comparison of Standard Form Ratios

A. Form Factor   B. Form Quotient

A. Form Factor

Definition

Form factor is defined as the ratio of the volume of a tree or its part to the volume of a cylinder having the same length and cross section as tree.

$$F = \frac{V}{Sh}$$

Where,
F is the form factor
V is the tree volume in cubic units
S is the basal area
h is the height of the tree

Form Factor

Uses of form factor

- To estimate volume of standing trees

  V = F * S * h

- To study laws of growth

  Form factor along with form point and form quotient give an insight into the laws of growth, particularly the stem form of trees.

Types:

Depending on comparison of standard form ratios, form factors are classified as;

- Artificial form factor
- Absolute form factor
- Normal form factor

Depending on the volume represented, form factors are classified as;

- Tree form factor
- Stem timber form factor
- Stem small wood form factor

Form Factor

Form Height

Form height is defined as the product of form factor and total height of tree. This can be expressed as;

$$F = V/Sh$$

$$Fh = H \times F$$

Form height is used to determine how far is it reasonable to assume that volume is proportional to the basal area.

If form height remains constant with increasing diameter, then the assumption is justified.

Form Factor

1. Artificial Form Factor

This is also known as Breast Height form factor The basal area measured at BH and the volume refers to the whole tree both above and below the point of measurement.

- ✓ Universally used as its computation involves handy measurement and diameter at BH
- ✓ Trees of the same form but different heights will have different form factors

2. Absolute Form Factor

Basal area is measured at any convenient height and the volume refers only to the part of the tree above the point of measurement

3. Normal (True) Form Factor

Form Factor

Basal area is measured at a constant proportion of the total height of the tree, e.g. 1/10th, 1/20th etc. of the total height and volume refers to the whole tree above ground level

Disadvantages

- The height of the tree has to be deter-mined before the point of measurement can be fixed
- The point of measurement may be very inconvenient in case of tall as well as very short trees.

Form Quotient

Form

Quotient

Form Quotient is defined as the ratio between the mid-diameter and the dbh.

This is postulated by Austrian forester A. Schiffel.

It is expressed as;

FQ = mid-diameter/dbh

Types of Form Quotient:

1. Normal Form Quotient (Schiffel's FQ)
2. Absolute Form Quotient (Tor Jonson's FQ)

Form

Quotient

Normal Form Quotient

Schiffel's FQ developed and defined it as ratio between mid-diameter to dbh. But
If tree is just double to the breast (2×1.37m), then FQ will be 1, i.e. defect. To remove the defect, Tor Jonson postulated another formula called absolute FQ.

- Now of historical interest only

Absolute Form Quotient

Tor Jonson postulated it as the ratio of diameter or girth of a stem at one half its height above the breast-height to the diameter or girth at breast-height.

Form Class and Form Point

Form Class:

It is defined as one of the intervals in which the range of form quotients of trees is divided for classification and use.

It also applies to the class of trees which fall into such an interval, which can be grouped such as 0.5-0.55. 0.55-0.6

Form Point:

It is defined as the point in the crown at which wind pressure is estimated to be centered.

In other words, form point ratio is defined as the relationship, usually expressed as a percentage, of the height of the form point above ground level to the total height of the tree.

Taper Table

The most complete information regarding the form of a tree can be given by means of a taper tables or taper curves. It shows the average diameter at any point on the stem for trees of different diameter and height.

Uses

✓ To find volume of the average tree for each diameter and height class readily in office without direct measurement , the only dbh (o.b.) need to measure

✓To prepare volume tables

The construction of taper tables/curves for a certain species or group of species is still different. So, no greatly accept expression for taper curve.

Kinds of Taper Table

1. Ordinary Taper Table
It is also called diameter taper table. This table gives the taper directly for diameter at BH
Volume can be computed without referring to the tree form

2. Form class taper table
This table gives different form classes of the diameters at fixed points on the stem expressed as percentages of dbh (o.b.)

Formulae or Equation for tree form

Hojer's formula:

$$\frac{d}{dbh} = C \log \frac{c+l}{c}$$

Behre's formula:

$$\frac{d}{dbh} = \frac{l}{a+bl}$$

Where,

C and c constants

for each form class

l is the distance from the top of the tree to the point at which *d* is measured

a and b are constants

For each form class

VOLUME & BIOMASS OF TREES & PRODUCTS

Unit- 4

4.1 Volume Tables

4.1.1 Types of Volume Tables

4.1.2 Preparation of Local Volume Table (Graphical and regression techniques)

4.1.3 Preparation of General Volume Table (Regression techniques)

4.1.4 Difference between LVT & GVT

4.2 Biomass Table and Equation

4.2.1 Root, Leaf, Stem and Branch Biomass

4.2.2 Different Biomass Equations

Volume Tables

Unit- 4.1

Volume table is defined as a table showing for a given species the average contents of trees logs or sawn timber for one or more given dimensions. Table showing the volume of a given species for single or multiple dimensions. Given dimensions may be only dbh, dbh and height or dbh, height and some measure of form or taper of the tree.

The main object of volume table is to estimate the volume of an average standing tree of known dimensions.

Based on the assumptions that the trees of the same species with the same dimensions will have the same volume.

Volume Tables contd…

Thus, the volume table does not give exact volume of an individual tree because the volume of the individual tree may be different from the average, based on several individuals.

The choice of variables for volume tables depends on the extent of their intended application, simplicity, speed (money and time).

Single variable will show better estimation of tree volume in restricted zone only. It has limited use. Therefore, for larger area volume table, two variables are preferred. Volume table with three variables are more accurate. Among three variables, diameter is the most important, then height and last of all the form.

Volume Table contd…

Thus, Single Variable: limited use
Double Variable: Regional Use
Multiple variable : National and Research use

Volume table will have different tables:

1. Table of basic average
2. Table of individual and aggregate checks
3. Table for under bark volume
4. Table for bark thickness or bark percentage
5. Other tables: diameter growth table, commercial volume table and conversion factor

Volume Table contd…

Importance

- ✓Easy to assess the volume of standing trees
- ✓Easy to use
- ✓The calculation is time/money/man power consuming and need extra instrument which volume table doesn’t need
- ✓More convenient
- ✓Easy to apply in field
- ✓Measurements and calculation can be done simultaneously
- ✓Standard to use
- ✓Precision (up to .001)

Volume Table contd…

Assumption of Volume table

The trees of the same species with the same dimensions (mainly dia and ht) will have same volumes. So the scope of its applicability is the sources of measurement on which average it is based on

Limitations of its uses

- ✓Same ht and dia of same trees doesn't give same volume
- ✓Volume tables have limited use depends on the locality, aspect, altitude (even for same species)
- ✓Measurements also make differences to develop the volume table (so consideration of accuracy)
- ✓Research works require more sample trees' measurement
- ✓Not use for accurate measurement of single tree
- ✓Table is completely reliant on average ht and dia used to develop volume tables

Types of Volume Tables

- According to the number of variables
  - Single Variable – dbh
  - Two variables – dbh and height
  - Three variables – dbh, height and tree form
- According to the scope of their application
  - General Volume Table
  - Regional Volume Table
  - Local Volume Table
- According to the outturn given by them
  - Standard: round timber, include stump volume
  - Commercial: round timber, exclude stump volume, prepared from thin end of measurement to which conversion is applied
  - Sawn outturn: stump volume omitted, volume of sawn timber
  - Assortment: gives volume in round to various thin end diameters
  - Sawn outturn assortment: give sawn timber volume instead round

Unit- 4.1.1

Volume Table contd…

Classification based on number of variables:

1. Volume tables based on one variable, i.e. diameter alone:

The volume tables show average volumes of trees by diameter classes. Since height varies in the same diameter in different localities, such volume tables can not be used for extensive areas.

2. Volume tables based on two variables, i.e. diameter and height:

As trees of same diameter may have different heights and different volumes in different localities, volume tables based on two variables, are applicable to larger areas. Thus, these volume tables give volume of trees by diameter classes as well as height classes. More accurate than single variable.

3. Volume tables based on three variables-based on dbh, ht. and form quotient:

Such volume tables are called the form class volume tables. Though these are more accurate, these are expensive and difficult to prepare and inconvenient and time consuming in their application.

Types of Volume Tables contd…

Based on scope of application:

(i) **General volume tables:** These are based on the average volume of trees growing over a large geographical area. Applicable to wider range of distribution of species. These tables are usually based on two variables, dbh and total tree height. These tables are used for deriving local volume tables.

(ii) **Regional volume tables:** These are compiled from measurement of trees growing in a region and therefore have a limited application when compared to general volume tables.

Types of Volume Tables contd…

(iii) Local Volume Table: Generally based on one independent variable, i.e. dbh (ob). These tables are compiled from the measurement of tree growing in restricted locality. These are either prepared directly prepared from field data or derived from general volume table, either by graphical equation.

Based on kind of outturn:

i) Standard volume tables: These tables give separately the estimated outturn in the form of standard timber, i.e. From ground level to the limit of the portion of tree stem or branch where diameter is 20 cm. measured overbark, and small wood ,i.e. volume between diameter limits of 20cm and 5cm both measured overbark.

The volume is given in terms of round timber and includes stump. It is calculated on full basal area basis from overbark diameters, but standard stem timber excludes the volume of bark while standard small wood includes it.

Types of Volume Tables contd…

ii) Commercial volume tables: Volume tables in which contents of round timber are given as volume measured down to a thin end diameter to which conversion is done, the stump volume being omitted.

A market requirements decide the minimum limit of exploitation. Scope of applicability is limited.

iii) Sawn outturn tables: Volume tables in which contents of sawn timber are given as volume measured down to a thin end diameter to which conversion is done, the stump volume being omitted.

Types of Volume Tables contd…

iv) Assortment tables: Volume tables which give volume in round down to various stated thin diameters. For example, it will be possible to find out volume of a tree of given linear dimensions when the conversion was done upto 25 cm, 20cm or 15 cm diameter limit.

(v) Sawn outturn assortment tables: Similar to assortment tables except they give sawn outturn in the number of standardized pieces instead of volume in round

Difference between GVT & LVT

Unit- 4.1.4

General Volume Table

- Table showing avg. ht, dia & volume
- Assumption same avg ht & dia of specific species have same volume
- Based on average volume of trees growing over a large geographic area
- Applicable to a wide range of distribution of species
- Based on usually more independent variable i.e. dbh, height, form
- Has limited direct application
- Used for deriving local volume tables
- Prepared from felled trees
- Confidence interval high i.e. less precise

Local Volume Table

- Table showing avg. dia & volume
- Assumption same avg ht have same avg dia of specific species & have same volume
- Based on average volume of trees growing over a small restricted area
- Applicable to a small area of species distribution
- Based on one independent variable i.e. dbh
- Directly applicable to a species designed for the area
- Used for estimating volume of individual tree or stands
- Can also be prepared from standing trees
- Confidence interval low i. e. more precise

Preparation of General Volume Table

Unit- 4.1.3

This volume table is based on the average volume of trees growing over a large geographical area. Applicable to wider range of distribution. Generally based on two variable i.e. dbh and tree height. This table shows volume of trees by diameter classes and in each diameter class by height classes
It has limited direct application. It Can be application to prepare Local volume table.

A. Graphical method
B. Regression equation method or method of least squares

Graphical method:

1. Selection of trees
2. Measurements
3. Plot and find the curve
4. Checks

.

Preparation of GVT…

Graphical method

1. Selection of trees

- Trees with **typical height** and developed need to be selected
- **Evenly** distribution of selected trees over the entire area
- Defected trees should not be selected
- Select smaller number of trees rather much larger number of improper selection – best result
- Care: not to select trees above the average
- Number of trees depends on:
  - The grouping adopted
  - Precision required
  - Deviation of individual trees volume from the mean
- Regression method requires lesser number than Graphical method
- Special fellings are rarely carried out for preparation of volume tables

Preparation of GVT…

Graphical method

2. Measurements

- Measurement techniques vary with the kind of general volume table
- For example, standard volume tables require measuring standard timber and small wood while commercial volume table require only commercial timber volume.
- These standard timber, standard small wood, etc of a felled tree are measured by dividing the total length into sections of 3 m length, odd lengths being included in the last section, which should not exceed 1.5 m measuring the underbark diameter at the middle of each timber section and overbark diameter at the middle of each small wood section , computing their volumes separately and adding them to give the volume of the tree.
- The data of individual trees is then summarized and finally grouped into height and diameter classes in a table called table of basic averages of which a specimen is given below:

A example of General Volume Table

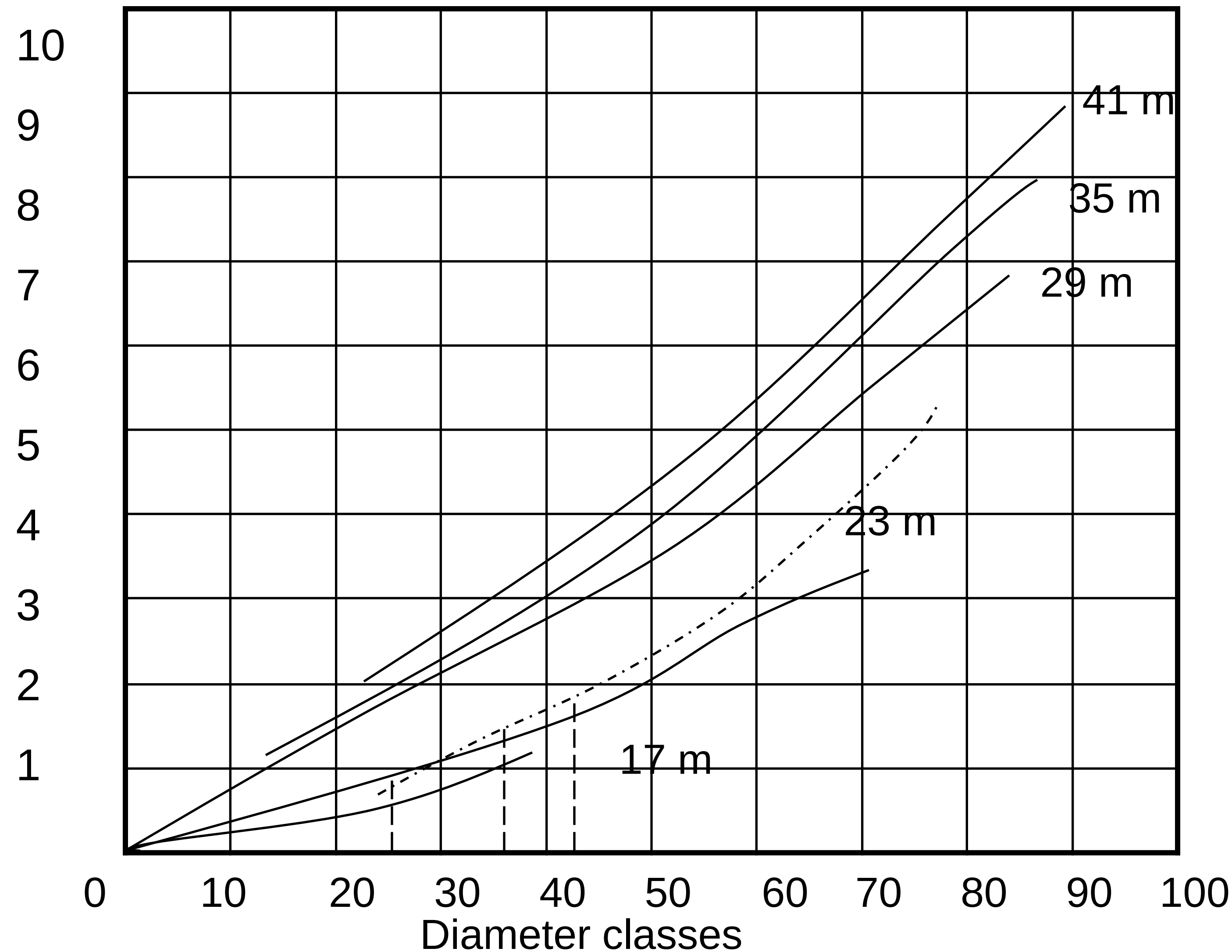
	Volume (m3)				
dbh	Height (in m.)				
(in cm)	17	23	29	35	41
15	0.030	0.068	0.106		
20	0.114	0.182	0.250		
25	0.222	0.329	0.435	0.541	
30	0.355	0.508	0.661	0.814	
35	0.512	0.720	0.929	1.137	1.345
95			7.343	8.879	10.415
100			8.145	9.847	11.549

3. Fitting the curve

- Step-1:
  - Average diameter is plotted against corresponding average volume separately,
  - Smooth curves will be drawn
  - Based on smooth curve, read volume and tabulated
- Step-1a:
  - Average heights is plotted against corresponding average diameter class
  - Smooth curves will be drawn
  - Based on smooth curve, read average heights and tabulated

- Step-2:
  - Corresponding Average volume tabulated from step1 against average heights tabulated from step1a will be plotted
  - Smooth curves again drawn
  - Volumes against average height class will be read and tabulated
- Step-3:
  - Volumes tabulated from step2 again plotted against the middle of diameter classes for each height class.
  - Smooth curve drawn
  - Final volumes are read from these curves against middle of diameter classes and tabulated

Plotting in graph paper



4. Checks

- **Aggregate check:** the actual volume of trees measured should be checked against the total volume read from the curve, should not exceed 1%
- **Height diameter class check:** aggregate check for each diameter and height class, not more than 5%, minimum 20 trees
- **Relative check:** two or more tables which were prepared from the same data, should be checked against each other, should not exceed 3%
- **Average deviation check:** the average deviation of the actual individual tree volumes from those read from the curve is computed and should be as low as possible.

Preparation of GVT Contd…

Regression Equation Method

In this method, while the basic data essentially remains the same as in the graphical method (i.e. ht. and dbh), relationships between volume as dependent variable and dbh, ht and form, etc as independent variables are given mathematical expressions by a regression equation. Various workers have developed various equations or models.

Some of them are given as below:

$V= a+bD^2+CD^2H+dH^2+EDH^2$ (Meyor modified)

$V=a+bD^2+CH+dD^2H$ (Austrian)

$V=a+BD^2H$ (Combined variable)

$V=aD^2H$ (Constant Form Factor)

$\log V=\log a +b \log D + C \log H$ (Schumacher)

$\log V=a + b \log D + (3-b) \log H$ (Dwight)

$\log V=\log a + b \log (D^2H)$ (Logarithmic)

Volume (m^3)/Height (m)

Where, a, b, c, d are regression constant and coefficients

D = Diameter at breast ht

H = Tree height

Local Volume Table

Unit- 4.1.2

This volume table are compiled from measurements of trees growing in restricted locality

Based on one independent variable i.e. dbh

Local volume tables are used

- ✓To estimate the volume of standing trees before felling
- ✓To make confidential estimate of the volume of tree.

This tables are either prepared directly from field data or derived from general volume table

This can be prepared either method by graphical or regression equation

Preparation of Local Volume Table

Local volume tables can be prepared by one of the following Methods:

(i) Graphical method
(ii) Regression Equation method

i) Graphical method:

A model of Local Volume Table:

Dia (cm)	Height in (m)		
	10	20	30
12	.067	.138	-
20	.154	.321	.492
30	.301	.626	.960

Graphical method

A) Derivation of Local Volume Table from General Volume Table:

- General VT gives volume of tree by diameter and height classes
- Figures of general volume table are plotted in a graph showing volumes against the middle of diameter classes for each height class separately
- So, sufficiently large number of trees are measured and recorded by diameter class
- Diameters and height (measured) are then plotted on the same graph
- Volume derived from GVT against average dia and ht
- Table: dia class against volume prepared
- To prepare graph, a smooth curve is drawn through plotted points
- The curve is the desired local volume curve
- It represents the local relationship between diameter and height
- Based on this curve, volume for diameter classes can be calculated and tabulated as Local Volume Table

Regression Equation method to prepare LVT

B) Regression equation from the basic field data

- In this method, dbh and volumes of sufficiently large no. of trees are measured and recorded by diameter classes.
- The average volume for each diameter class is worked out and it is then plotted against the mean diameter of the class and smooth curve is drawn through these points.
- As this method requires calculation of volume of a large number of trees, this method is seldom followed.
- Regression equation or model are first prepared based on the field measured data
- Regression coefficients b and c calculated from the data measured in the field

- Use any of following equations,
  - $V = a + b\,D + c\,D^2$ Parabolic equation
  - $V^{1/2} = a + b\,D$ Linear equation

- r and d.f. should be mentioned

Regression Equation method

C) Regression equation from the General Volume Table

- Instead of developing regression equation for local volume table, it can be derived from the regression equation of the general volume table for the specific species
- If general volume table equation is

$$V = a+bD^2H$$

And height/diameter relationship is

$$H = c+dD+eD^2$$

Then, $V = a+bD^2\ (c+dD+eD^2)$

$$= a+bcD^2+bdD^3+beD4$$

Or, $V = a+b_1D^2+c_1D^3+d_1D^4$

Where, a is regression constant

$b_{1,}\ c_{1,}\ d_1$ are regression coefficients

Preparation of LVT Contd…

Volume equations used in preparing volume tables:

1. Total stem volume:(n(v)= a+b ln (d)+ cl n (h) v=volume o.b.
2. Stem volume to 10cm top ln (V1/v)=a+b (d) V1=volume o.b of tree (beyond 10 cm dia)
   V= Total stem volume overbark
3. Stem volume to 20cm top ln (V2/Vt)=a+b ln (d)
   V2= volume o.b between 10 & 20cm diameter
   Vt= volume o.b to 10 cm diameter

To reduce bark volume from stem overbark volume, following equation form has been used

ln (po)=a+b ln (d)

po= bark porpotion

Total stem volume of Acacia Catechu (m^3) [vo^b]

Sources of error in graphical method:

- ✓ Failure to select proper trees in sufficient number
- ✓ Only two variables can be dealt with at a time
- ✓ Drawing curves always introduces a personal factor and consequent bias.

Regression Analysis

- Dependent Variable: Volume “Y”
- Independent Variable: Diameter, Height, Form “X”

- If field measured data is

X	1	2	3	4	5
Y	3	4	6	9	10

- The equation of straight line : Y = a +b X will be fitted
- By substituting,
  - 3 = a + 1 b
  - 4 = a + 2 b
  - 6 = a + 3 b so on

Normal Equations

- 32 = 5a + 15b…………I First normal equation
- 115 = 15a + 55b……...II Second normal equation by multiplying each equation by coefficient of b and summing up those

Solving by two normal equations

- b = 1.9
- a = 0.7

Substituting both values in equation of line

- Y = 0.7 + 1.9 X

In general;

$$\sum(y) = na + b\sum(x)$$

$$\sum(xy) = a\sum(x) + b\sum(x^2)$$

$$b = \frac{\sum xy - \frac{\sum x \sum y}{n}}{\sum x^2 - \frac{(\sum x)^2}{n}}$$

$$a = \bar{y} - b\bar{x}$$

Chaturvedi suggested following volume equations:

Cedrus deodara, $v = -0.0789 + 0.2836\ D^2\ H$

Dalbergia sissoo, $v = -0.0721 + 0.2393\ D^2\ H$

Shorea robusta, $v = -0.0894 + 0.2605\ D^2\ H$

http://sres-associated.anu.edu.au/mensuration/totalhgt.htm

Some terms related to Biomass

Biomass:

Biomass is defined as the total amount of above ground living organic matter in trees expressed as oven-dry tonnes per unit area. This includes the bole, branch, twigs and foliages biomass as well as root, soil.

Carbon Sequestration:

Carbon Sequestration is the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere. The removal of CO_2 from atmosphere by increasing its uptake in soils and vegetation or in the ocean is a form of carbon sequestration.

Emission:

Emission means the release of greenhouse gases and or their precursors into the atmosphere over a specified area and period of time.

Reservoir:

Reservoir means a component or components of the climate system where a green house gases or precursor of green house gases is stored.

Green House Gases:

The carbon dioxide (dominant 50 %), methane, nitrous oxide, hydroflurocarbons, perflurocarbons and sulphurhexafluoride are collectively form the green house gases which is considered as a main source of climate change. The burning of fossil fuels and forest degradation as well as deforestation considered as source of green house gases.

Factors affecting the biomass

- Density: Density of any substance is its mass per unit volume, often the relative density which is the ratio of density of the substance of density of water is used.
- Moisture content:
- Bark

Density: It is the mass per unit volume. Specific density is ratio of density of any substance with water. The unit is kg/m^3. Volume as well as weight shrink due to dryness. So, there is moisture content in fresh weight , it is expressed in %. Density varies from pith to sapwood. It also varies from stump to top. So, the density of trees varies from part to part.

Moisture content

It is the moisture in wood. But also in all parts of tress. The moisture content varies from species, geographical areas.
It also varies with age and physical condition of tress. So, it is difficult to measure.

It varies in broadleaf and conifer. Moisture content varies up to 151.2 % depending on time of harvest.

Moisture content =((Fresh wt-dry wt)/Fresh wt)*100%

Bark

Bark

According to Kodai Kanal,

$(\text{Bark weight})^{1/2} = a+b*D$

Where,

a constant

b coefficient

D diameter at breast height

Factors affecting the bark % in wood

- Species,
- geographical condition
- Diameter of the tree

How to dry?

- Generally air dry but 12% remaining
- In Lab, there may be less moisture (400^0C till show the constant weight)

Regression Equations

Regression estimation

For single stemmed

- $W = a + b D^2 H$

For multiple stems

- $W = a + b\, NS\, D^2 H$

Where,

w = weight in kg

D is diameter in decimeters

H is height in decimeters

N is number of samples

a is regression constant

b is regression coefficient

r is correlation coefficient

NS is number of shoots

F is variance ratio.

Percentage of biomass

Kaul et al suggested following percentage of biomass for different parts of plant for Poplar trees:

▪ Wood	58	Above ground
▪ Bark	13	
▪ Branches	9	
▪ Twigs	4	
▪ Leaves	6	
▪ Roots	20	Under ground= 20% of AGB

Biomass measurement

Biomass is the wt. of above ground vegetative matters produced per unit area. Thus, wood, branches, bark and leaves produced by trees, shrubs and herbs and other vegetation growing above the ground are included in biomass but it does not include roots, tubers etc; growing below ground.

- Girth measurement at 50 cm above ground gives consistently reliable results.

- All measurements should be done during the period when the trees are in stage of dormancy.

Biomass Estimation

Necessary to carry out destructive sampling to establish correlations for estimating biomass of standing trees.

Sample trees:

Trees should be grouped in 5cm girth and 50cm height classes, About 30 trees should be selected in all. Trees should be felled and separated into main stem, branch wood, twigs and leaves.

Main stem should be considered upto the thin end of 1ocm girth. Rest should be included in branch wood. Each portion should be bagged separately in cloth and kept in shade. They should be weighed at intervals till the weight becomes constant. This is dry-weight.

Constraints in biomass measurement

- ✓ Destructive sampling is difficult
- ✓ Root shoot ratio varies by different literature
- ✓ Some time hard to show the relation
- ✓ Different parts have different moisture content so
- ✓ biomass is differed
- ✓ Green/ air dry & oven dry vary wt

In Nepal & India, some regression equations for biomass calculation. Eg., Schima wallichi

$\text{Ln } W = a + b \text{ Ln } DBH$

Where,

W is the weight of green parts (foliage, branch and stem)

W (air dry wt of wood)= $a + b\ DBH^2 * h$

Biomass Table and Equation

Unit-4.2

Many forms of regression equations have been by different workers.

For single stemmed $w=a+bD^2H$

For multiple stemmed $w=a + b\ NSD^2H$

Where, W= wt. in kg

D= Diameter in cm (decimeters) measured at 50cms above ground

H=Height (decimeters)

N=No. of samples

How to measure biomass?

a) By direct measurement

b) Taking the data directly from the field and preparing the equation and biomass table

c) Indirect (By using the biomass table)

d) Biomass table shows the fresh wt not dry wt

Biomass Equations

For spp. (in Nepal), which have a very low branching habit or species in a coppiced broadleaf natural forest, dia is measured at 0.30m from the ground level.

Unit-4.2

Model equations,

ln y = a+b ln x has been found suitable for calculating biomass.

Where y = oven dry wt. in kg (Biomass)

x = dbh

For plantation spp. equation selected is

Weight = a+b ln x

x variable is either dia at breast height at (1.3m) or basal Diameter

Pukkala (1990) has proposed following equation for biomass:

ln (BRA) =-1.567+1.146* ln DBH (Eucalyptus)

Where, BRA- Branch Biomass

Biomass Tables

Unit-4.2

i) For plantation spp.

Eucalyptus cameldulensis (kg)

Dia (cm)	stem	branch	leaf	Total
	weight (in kg)			
5	7.81	1.24	0.99	10.49
10	33.72	5.11	3.46	42.84

Dalbergia sissoo (kg)

Dia (cm)	stem	branch	leaf	Total
5	12.69	2.72	-	15.50
10	41.46	7.57	-	49.28

ii) For natural forest types (Katus-Chilaune) (for fresh green wt.)

Unit-4.2

Castanopsis indica (Dhale Katus)

weight (in kg)

Dia (cm)	stem	branch	foliage	Total
5	7.0	2.4	3.7	13.1
10	37.1	12.9	10.5	60.5

Schima Wallichi (chilaune)

Dia (cm)	stem	branch	foliage	Total
5	6.3	2.3	3.2	11.8
10	36.0	11.4	12.3	59.7

5. Forest Sampling and Inventory

5.1 Forest Sampling

5.1 Definition

Total Enumeration: (*syn.*Total count) It is not possible in case of forest measurement.

Partial enumeration is also called sampling.

Forest Sampling: Sampling is a process in which inventory of the forest is carried out only in a representative portion of the whole.

Sample size (Source: DoF, 2004)

Sample	Plot Size (m^2)	Plants' size
Seedling	10	30 to100 cm ht
Sapling	25	>1m ht & <10cm dia
Poles	100	10 to 29.9 cm dbh
Tree	100 to 500	= or >30 cm dbh
Fuel wood, Fodder	100	- - -
NTFPs	1×1	Depend on size and nature

Forest Sampling Contd…

5.1 Definition

Sampling design:

A sample design is a definite plan for obtaining a sample from a given population. It refers to the technique or procedure the researcher would adopt in selecting items for the sample.

Sample design is determined before data are collected. The researcher should select a sample design which should be reliable and appropriate for his research study.

Sampling unit:

Population is divided into suitable units for the purpose of sampling is called sampling unit. In other words, before selecting the sample, the population must be divided into parts that are called sample units.

Forest Sampling Contd…

How to find the number of sample plots:

Sample intensity= (sample area/Total area)*100

Sample area= (Intensity*total area)/Sample area

Number of sample plot = (total sample plot are/ individual plot area)

Advantage of sampling over total measurement:

1. Reduced cost and saving of time
2. Relative accuracy
3. Knowledge of error
4. Greater Scope

1. Reduced cost and saving of time

✓Data collected certain % of forest areas
✓Save time and cost
✓Less measurement
✓Less number of man power needed

Forest Sampling Contd…

2. Relative accuracy

- ✓Total enumeration is more accurate but sampling may provide better result in case of large areas
- ✓Time elapses raise question
- ✓Appropriate sampling intensity provide better result

3. Knowledge of error

- ✓Total enumeration gives false result
- ✓The error is calculated at last
- ✓But sampling after sampling

4. Greater scope

- ✓Highly trained man power needed
- ✓Volume or biomass
- ✓Partial sampling widen scope

5.2 Types of Forest Sampling

Unit-5.2 Types

1. Simple Random Sampling
2. Stratified Random Sampling
    a. Proportional allocation of field plots
    b. Optimum allocation of field plots
3. Systematic Random Sampling

5.2.1 Simple random sampling

This is defined as process of partial enumeration that the sample units are selected in such a way that each and every unit of the population has an equal and independent chance of being selected in the sample.

Two conditions to select samples:

1. *with replacement:* that sample unit is replaced before making next draw.
2. *Without replacement:* that sample unit is not replaced before making next draw

Unit-5.2.1
Types

Simple Random Sampling Contd…

Selection technique:

(i) Lottery method- Lotto
(ii) By random no. table method- Bingo

Merits

(a) Scientific method and no. bias
(b) Estimation methods are simple and easy

Demerits

(a) If sample chosen is widely spread, takes more time and cost
(b) A population frame or list is needed
(c) For a given precision, it usually requires larger sample size.

Simple Random Sampling Contd…

When to use:

- ✓ If the population is not widely spread geographically
- ✓ If the population is more or less homogenous with respect to the characteristics under study

Most applicable for initial survey in an investigation.

Unit-5.2.2 Types

Stratified Random Sampling

If a population from which a sample is to be drawn does not constitute a homogeneous group, stratified sampling technique is generally applied in order to obtain a representative sample.

In this sampling, the population is divided into several sub-populations, i.e. more homogeneous than total population called **strata.** Then sample items are selected from each stratum. If the items selected from each stratum is based on simple random sampling. The entire procedure first stratification and then simple random sampling, is known as stratified random sampling.

Stratified Random Sampling

Unit-5.2.2 Types

Criteria of stratification of forest area:

- Topographic features
- Forest types
- Density classes
- Volume classes
- Height classes
- Age classes
- Site Classes, etc

Merits

- ✓ More representatives than systematic and simple random
- ✓ Greater accuracy than simple random
- ✓ Administrative convenience

Demerits

- ✓ More time and cost due to wide geographical area
- ✓ Sampling units for each stratum is necessary
- ✓ Require more prior information about population

When to use

- ✓ When populations are heterogeneous
- ✓ If the sampling problems differ in various sections of the population

Stratified Random Sampling

Unit-5.2.2 Types

Assuming that a total of 150 sample units will be measured on the ground, there are two common procedures for distributing the field plots among the five volume classes. These methods are known as *proportional allocation* and *optimum allocation.*

Volume Class	Stratum area, acres	Std.dev., cords/acre	Area×std. dev.
I	16	20	300
II	45	70	3150
III	110	35	3850
IV	60	45	2700
V	70	25	1750
Total	**300**	- -	**11,750**

a. Proportional allocation of field plots

The sizes of the samples from the different strata are kept proportional to the sizes of the strata, which are mostly used. The more the size of strata, the more the sample plots. Suppose, if strata are of 4500 m^2 and 3000 m^2 with a plot size of 30 m^2 of a population of 8000. Then the former has more plots than the later.

Stratified Random Sampling

Unit-5.2.2 Types

Proportional allocation of field plots…

This approach calls for distribution of the 150 field plots in proportion to the area of each type. The general formula is

$$nh = \left(\frac{Nh}{N}\right)\mathbf{n}$$

To compute no. of plots, for example; Class I: 15/300 $\times$ 150 = 7 plots

One disadvantage of proportional allocation is that large areas receive more sample plots than small ones, irrespective of variation in volume per acre. Of course, the same limitation applies to simple random and systematic sampling. Nevertheless, when the various strata can be reliably recognized and their areas determined, proportional allocation will generally be superior to a non-stratified sample of the same intensity.

Stratified Random Sampling

Unit-5.2.2 Types

b. Optimum allocation of field plots

When the cost of selecting an item is equal for each stratum, there is no difference in within-stratum variances, and the purpose of sampling happens to be to estimate the population value of some characteristics.

In case, the purpose happens to be to compare the differences among strata, then equal sample selection from each stratum would be more efficient even if strata differ in sizes.

In cases, where strata differ not only in size but also in variability and it is considered reasonable to take larger samples from the more variable strata and smaller samples from the less variable strata.

With this procedure, the 150 sample plots are allocated to the various strata by a plan that results in the smallest standard error possible with a fixed number of observations. Determining the number of plots to be assigned to each stratum requires first a product of the area and standard deviation for each type, as derived earlier.

Stratified Random Sampling

Unit-5.2.2
Types

Optimum allocation of field plots…

In general terms, for a sample of size *n*, the number of observations n_h to be made in stratum h is

$$n_h = \{N_h S_h / \sum_{k=0}^{n} N_h S_h\} n$$

The number of plots to be allocated to each stratum is computed by expressing each product of "area time's standard deviation" as a proportion of the product sum, eg. 11,750. Thus, the 150 field plots would be distributed in the following manner:

Class I: $300/11,750 \times 150 = 4$ plots

Systematic Sampling

Unit-5.2.3 Types

In some instances, the most practical way of sampling is to select every i_{th} item on a list. Sampling of this type is known as systematic sampling.

An element of randomness is introduced into this kind of sampling by using random numbers to pick up the unit with which to start.

For instance, if a 4% sample is desired, the first item would be selected randomly from the first twenty-five (1-25) and therefore every 25^{th} item would be automatically be included in the sample.

Thus, in systematic sampling, the first unit is selected randomly and the remaining units of the sample are selected at fixed intervals.

For example, let there are 200 trees, where diameters are needed and we have to select 10 trees. Then,

Sampling intervals, K= N/n = 200/10 = 20

Then, say, 1^{st} random start, I = 8^{th} tree

Then, sample selected tree numbers are I, i+K, i+2K, i+3K……= 8, 28, 48, 68…..

Unit-5.2.3 Types

Systematic Sampling

Merits:

✓This method is simple, administrative easier and quicker or it is easy to operate and checking can be done quickly.

✓It is possible to select a sample in the field without a sampling frame.

✓Less costlier in case of large population

Demerits:

✓If there is a hidden periodicity in the population, sampling is inefficient. Eg. If 4% sample, every 25th item may be defective or all good items.

✓Not suitable for more heterogeneous

✓Not suitable for infinite population

When to use

✓When lists of population are available

✓Suitable for chronological (classification a/c to time), alphabetical or numerically ordered data, eg., hospital records, names in telephone directory, etc.

5.3 Forest Inventory

Unit- 5.3.1 Definition

It is originally a commercial term meaning the record showing quantity and value of articles in a store.

Forest inventory, therefore provides the information about size and shape of the area as well as qualitative and/or quantitative information of the growing stock.

Forest inventory defined by Loetsch & Haller 1943 as it is the tabulated, reliable and satisfactory tree information, related to the required units of assessment in hierarchical order.

It is an attempt to describe quantity, quality, diameter distribution of forest trees and many characteristics of land upon which trees are growing.

Synonymous with the term ***"cruise"*** used in North America.

Forest Inventory Contd…

Objective

The main **object** is to determine volume of timber growing in the forest with a view to determine the yield.

Other objects are:

- ✓To assess the value for the purposes of sale or exchange or to estimate the return to be expected from clear-felled areas.
- ✓To determine the current periodic annual increment
- ✓To prepare map of the area showing regions of high or low volume production per unit of area to help decision-making for setting up industries.

In short, the object of forest inventories is to supply information for forest management and planning and for pre-investment decision on forest establishment or expansion.

Scope of Forest Inventory

Unit- 5.3.1 Scope

✓To know the *qualitative & quantitative* record of forest (forest condition, species, species composition, stage of forest)

✓Growing *stock, MAI, annual allowable* harvest

✓*Size and shape* of the forest

✓Users of forest Research and others

✓Provides the information about the *NTFPs*

✓Information about the *tigers & other animals and birds*

✓To show the status of forest species (*extinct, rare)*

✓Forest *Planning*

✓*OP writing* (information for forest management)

✓Help for *forest management options*

✓Support in *decision making* to establish the industry

Inventory Planning

Inventory Planning

Many inventories are planned as multi-storey inventory assessing not only timber production oriented variables, but also non- timber forest products and a large set of variables with ecological background.

Inventories include regional or national assessments, management based inventories, stand or compartment analysis, and cruise

Regional and national assessments are used to determine area, condition, and volume for specific purposes, such as developing resource management policies and programs.

Such surveys usually consist of widely spaced systematically located fixed- sized or variable size plots. The plots may be permanently located to monitor trend and change.

Inventory Planning Contd…

Inventory Planning

Compartment or stand inventories customarily provide information for mgt. planning, land evaluation, and/or assessing silvicultural opportunities, stands are often delineated in aerial photographs, and field visits are made to stands for verification as well as to determine volume, Condition and treatment opportunities.

Cruises are used to determine location of timber and to estimate its quantity by species, product potential, size quality or other characteristics. Cruises Generally consist of measuring temporary sample strips, plots, or points in the stands being assessed.

Inventories for forest management planning are usually one of two types:

- A single inventory to provide information on the current growing stock and rates of growth
- A recurrent inventory to monitor growth rate and other changes in the site.

Inventory Planning

Sources of information:

Two sets of information may be needed: -

- General information on area, spp. and growth rates for the whole forest, and
- More detailed information on those stands that may be partially or wholly harvested in the planning period

Common sources are maps-topographical, geological, soil and vegetation, aerial photographs and Radar or satellite, reports from previous inventories, forest records

Inventory Planning Contd…

Field measurements:

The choice and definition of population and parameters to be included in the inventory has to be made.

- The point of measurement for buttressed trees
- The definition of point of measurement for height, eg., total height, timber height or bole length,
- The treatment of forked or defective stems.

Statistical Consideration, calculation, analysis:

- The design or pattern of sampling
- The statistical analysis and the calculation of estimates used

The **design** also concerns :

- ✓ Choice of sampling unit-plot, point, transect
- ✓ Choice of shape of sampling unit-circular, square, rectangular etc.
- ✓ Choice of size of sampling unit

Inventory Planning

Inventory Planning Contd…

- The methods of calculation, analysis and data capture must be finalized before field instructions are prepared.

Inventory Planning

Execution of field work and control for accuracy

- **Training field terms** : map reading, tree measuring and data recording techniques.
- Checks of field records and procedures are essential to asses and minimize frequency and extent of human errors
- Checks mostly consist of repeating the measurements in a no. of identifiable sampling units checks must cover : plot location and identify plot demarcation, tree measurement , records, etc.

Team management: Effective personnel management must have a high priority.

Inventory Planning

Security of inventory, records and events, result

- Only in exceptional circumstances, should original field data be copied by hand. If owing to rain, the original field that is damaged, a copy must be made immediately.
- The copy must be checked by an independent person against the original and the two copies attached together
- Field forms must be numbered to provide an unambiguous identity and stored in files.
- Immediately after data collection in the field data should be transferred to the computing centre.
- The record of events provides an account of general experience gained, especially on the rate of progress and duration at different stages.
- The inventoried data is presented in the form of results

Inventory Planning Contd…

Recurrent Forest Inventory

- ✓ In both even aged plantations as well as in mixed uneven aged crops, forest inventory may be repeated at regular intervals.
- ✓ Recurrent forest inventory especially useful where growth prediction is based on inadequate data and also where large wood processing industries with high capital investment are dependent on forest.
- ✓ Recurrent forest inventory also produces raw data for more detailed growth modeling in the future and is a part of management system providing updated information on growing stock.
- ✓ Efficient recurrent forest inventory depends on:
- o Efficient field work and plot maintenance
- o Efficient maintenance of records, security and continuity.

Inventory Planning Contd…

Field works for recurrent forest Inventory

The type of permanent sample plot depends on the degree of variation in the crops. In even aged plantations of one species and in mixed crops with a simple structure, small sample plots with summaries expressed as average stand parameters are adequate. The points for consideration are:

- Location
- Demarcation
- Plot size and shape
- Tree identity
- Calculations
- Measurements
- Checking

Forest Inventories in Nepal

- First National Level Forest Inventory carried out as a cooperation project between Nepal and USAID during 1963.
- A systematic rectangular grid of 2.2 miles by 10 miles covering entire country was used.
- Second inventory was carried out by Land Resource Mapping project (LRMP) during 1978-79.
- Third National Level Forest Inventory was started in the early 1990s and the field work was completed in 1998.(Implemented by the Dept. of forest Research and survey with support from Govt. of Finland.)
- Fourth National Level Forest Inventory except sub-national inventories has been started in 2009 and currently the field works is going on supported by Government of Finland and implementing agencies of Nepal Govt. is the same as in 1998.

Following **steps** are being used in Nepal for forest inventories:

1. Aerial Photo interpretation
2. Field Verification
3. Area estimation
4. Determination
5. Random selection of plot location
6. Field work planning

7 Field work : Layout of sample plots in the field

8 Field work : measuring the plot

9 Data analysis

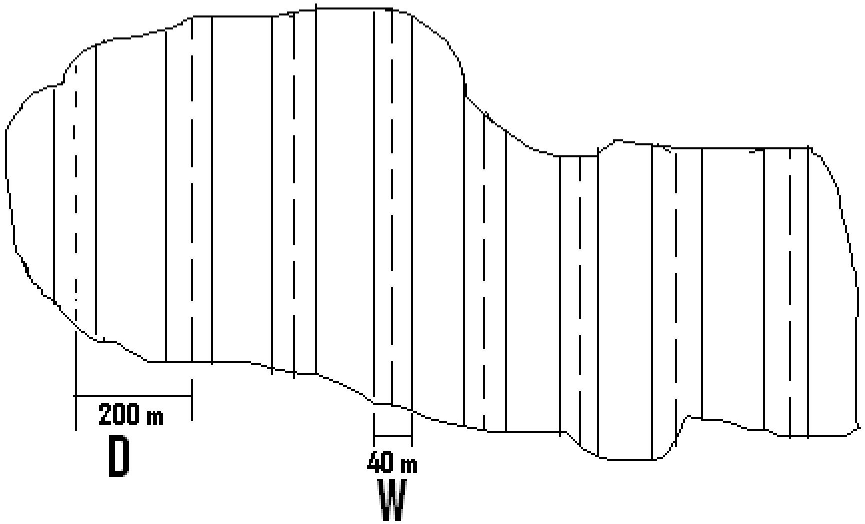
10 Report publication

1. Strip System of cruising

- ✓ In plains area it is easy to make a strip to sample the forest (20 to 40 m wide) despite the laying out the plots
- ✓ The strips are made from one end to other end
- ✓ The width between strips and strip width are fixed using the sampling intensity

Unit-5.3.2

Example of strip of cruising



Therefore, Intensity= (W/D)*100
Where, I is the intensity of sampling in percentage
W is the width of strip in meter
D is the distance between centre lines of the adjacent strips
Generally strip width is taken as 20 m and distance between centre lines are considered as 40 m.

Unit-5.3.3

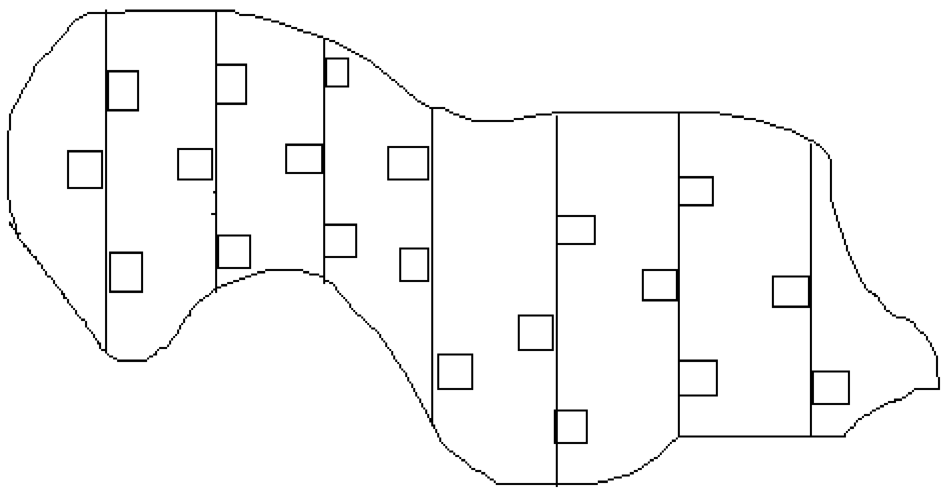
2. Line Plot System of cruising

- ✓sample instruction records
- ✓Firstly the map of the forest is prepared
- ✓Line is drawn based on the fixed distance
- ✓Then sample plots are allocated on the line (in the centre, either left or right side of)
- ✓The bearing of and distance between two lines as well as plots will be noted on sample instruction records

Line System of cruising contd…

- ✓Plot allotment on the ground
- ✓Based on map starting point is found in the field
- ✓first plot according to shape is established
- ✓After that, other nearest sample plot is found with the help of compass and tape
- ✓Similar process is repeated for end of the cruising

An example of Line plot cruising



Intensity= (N*sample plot area/Total area)* 100

5.3.4 Point Sampling

Unit-5.3.4

Point Sampling

Terms used in point sampling

1. Diopter: this is measure value of an angle expressed as its sine. One diopter is approximately equivalent to an angle of 0.57^0 or 34.36 minutes Since $\sin 0.57^0 = 1/100 =$ 1 diopter

2. Basal Area Factor (BAF): It is the multiplying factor associated with any instrument**.** If the instrument gives basal area in square meter

Then, $BAF = 2500K^2$

$= 10000\sin^2 \theta/2$

As $K = 2\sin \theta$

3. Plot Radius Factor (PRF): This factor defines for each tree radius of circle within which the tree.

If the radius of the plot circle are measured in the same unit, then plot radius factor is equal to the reciprocal of the ratio defining critical angle in diopter. The PRF is useful to check the doubtful trees.

Unit-5.3.2

Point Sampling

4. Tree factor

Tree factor is the number of tree per ha represented by each tree tallied

This is obtained by dividing the associated plot area into the square meter area of one ha

$F=10000/(\pi R^2)$

$= 10000/(\pi D^2/k^2)$

$=10000k^2/\pi D^2$

$=4*(2500k^{2)}/\pi D^2$

BAF/BA (where BA is basal area a particular tree)

5. Calibration distance factor

This factor indicates the distance at which a given angle will exactly cover or prism will exactly deviate, a rectangular target which is one meter wide

Calibration distance factor is 100 times the plot radius factor

If the calibration distance factor is C, then BAF=(10000/(1+C)),

Plot radius factor in meter per cm of dia=C/100

Diopter value of an instrument =100/C

Point Sampling Contd…

Point Sampling

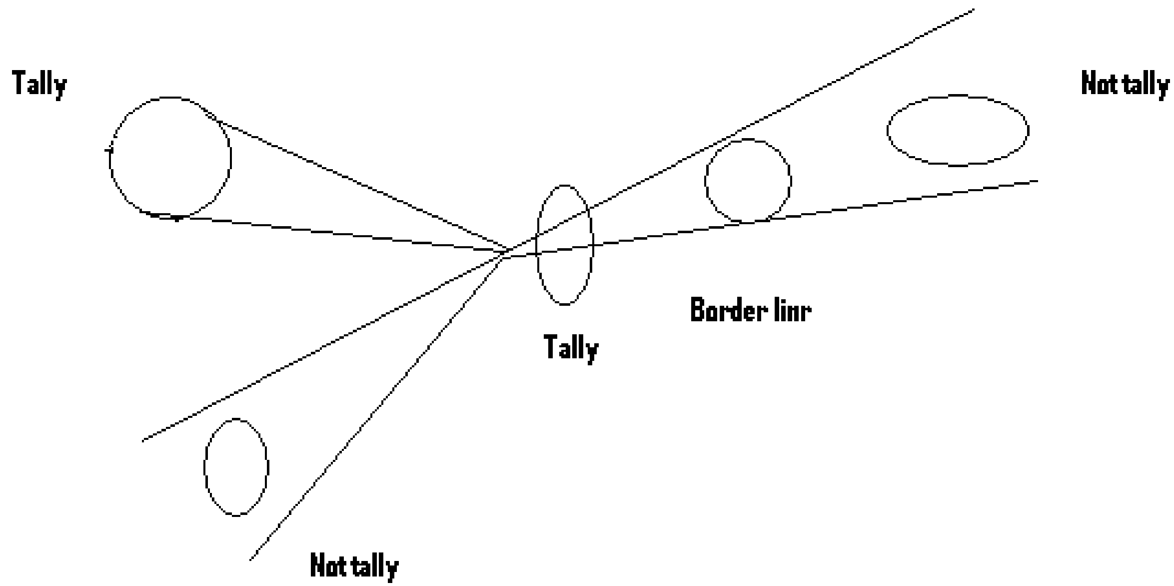
Point sampling (PS) is a method of selecting trees to be tallied on the *basis of their sizes* rather than by their frequency of occurrence. (Developed by Walter Bitterlich in1948)

Counting from a random point the no. of trees whose breast-height cross-section exceeds a certain critical angle when *multiplied by a factor* gives an *unbiased estimate* of basal area/ha. This technique is called : angle count cruising, point sampling, variable plot cruising, PPS (Probability proportional to size) sampling. horizontal sampling has been widely used.

The probability of tallying a given tree depends on its *cross-sectional area* and the *sighting angle* used. The smaller the angle, the more stems will be included in the sample.

Point Sampling

Contd…



Point Sampling Contd…

▪ PS does not require direct measurements of either plot areas or tree diameters. A predetermined basal area factor (BAF) is established in advance of sampling and resulting tree tallies can be easily converted to basal area /unit area.

▪ BA conversion factors are dependent or the sighting angle or critical angle arbitrarily selected. Even though all trees are of same basal area, some are counted while others are not because of being *far away* from sampling points and they do not form an angle bigger than *critical angle.* Inclusion of trees in tally for a given angle depends upon

(i) sizes of trees

(ii) their distance from the sampling point.

Point Sampling Contd…

There are two types of sampling units. They are fixed and points. Point sampling is based on latter one. Two methods of point sampling,

1. vertical point sampling
2. horizontal point sampling

Generally horizontal point sampling is generally used in field.

1. Horizontal point sampling

In horizontal point sampling, a series of sampling points are selected either randomly or systematically distributed over the entire area to be inventoried.

Trees around the point are viewed through any angle gauge at breast ht. All trees forming an angle bigger than the critical angle of instrument are counted.

Uses of Horizontal Point Sampling

Basal area per ha (BA): if n trees tally then n trees tally trees

F=1/n

1/n=BAF/BA

BA per ha =BAF*n

Number of trees per ha = BA Per ha /BAF

Volume per ha (V) = Basal Area* Stand Form Height

The BA is directly calculated by a point sampling instrument

The standard form ht is obtained from sub sample of trees.

Pressler's formula , Volume of single tree=(2/3) *GH

Where G is basal area of tree & h is the ht at which diameter is half the diameter at breast height.

To find this walk towards or away from a tree until its breast ht point exactly covered by band 4.

Then tilt the instrument upward until the point is found is exactly covered by band 1 (half the width of band 4)

Instruments for Horizontal Point Sampling

1. Simple angle gauge: It is a simple instrument consisting of stick 1 m. long with a peep-sight at one end metal blade 2 cm wide fixed at the other end at right angles to the axis of the stick. The width of blade and length of the stick determine the angle

2. Wedge Prism: This is wedge –shaped piece of glass. Rays of light passing through the prism. This property is utilized to see if the tree tallies or not. When tree is viewed through the prism at breast ht at right angles to the line of sight and simultaneously seeing the trunk of the tree directly from over the prism, it will be seen that the portion of tree viewed through the prism is displaced sideways depending on the critical angle of prism

The tree is **counte**d if image overlaps the directly viewed tree, the tree is ignored if there is gap

The BAF of wedge prism= $10000/(1+4(L/D)^2$ in m^2/ha

Where L (m) is distance from the prism to two rods just overlap and D distance apart (rod to rod)

Instruments for Horizontal Point Sampling

3. Spiegel Relaskop:

A diameter class per hectare from horizontal point sampling:
To know diameter class distribution, it is necessary to find out the diameter of the tally trees.
The number of trees belonging to the diameter class are obtained by multiplying the actual number of tally trees of that diameter class by a factor which is equal to

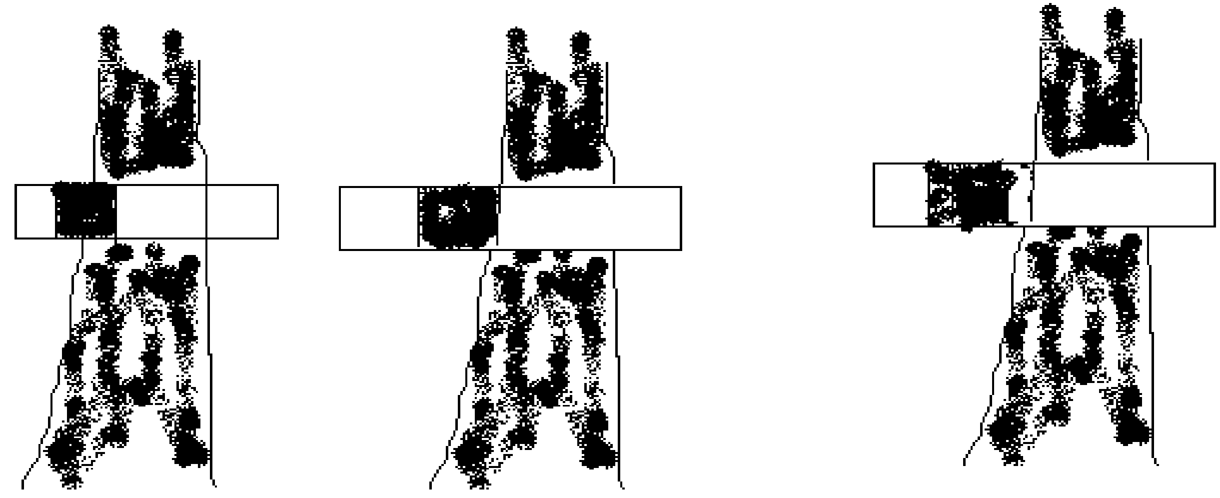
N = BAF***/*** Basal area of the mid-point of the diameter class
Example, If diameter classes = 10 cm starting from 10cm
Basal area of the average tree = 30-40 cm class

$$\pi (0.35)^2/4 = 0.0962 \text{ m}^2$$

Number of trees per m2 of basal area of this class = 1/0.0962 = 10.4 trees/m^2

Trees actually tallied in this class will be multiplied by 10.4 to get the number of trees per hectares belonging to this class.

Condition of tallying trees



✓It may be overlap, that counts whole (n)

✓It may just touch the margin of trees ½ count (.5*n)

✓More gap seen and completely out

✓Basal area factor is important in horizontal point sampling so,
BA/ha= ∑d/10,
where d is dbh in cm of tree enumerated

✓But the critical angle is important vertical point sampling and tan-1i.e. 630 26’

✓Then V/ha= F/10 *∑d2
Where, F is form factor and d is dbh in cm

Volume Calculation

An example: If sample plot is 0.5 ha, the BAF of wedge prism is 2, trees overlap are 10 and boundary is 13 then BA of sample plot.

No. of tally=10+6.5=16.5

BA per ha=N* BAF= 16.5*2=33m^2/ha

Therefore, BA of sample plot =33*.25=8.25m^2

If we have from factor, then V=BA per ha * FF* avg. ht

Sampling Error in Point sampling

•It doesn't give the real representative picture of the forest

•The trees are not selected with the same probability

•Diameter and species variation may affect the sampling

Non-sampling error

•Instrumental & personal error

•Deviation from the prescribed point

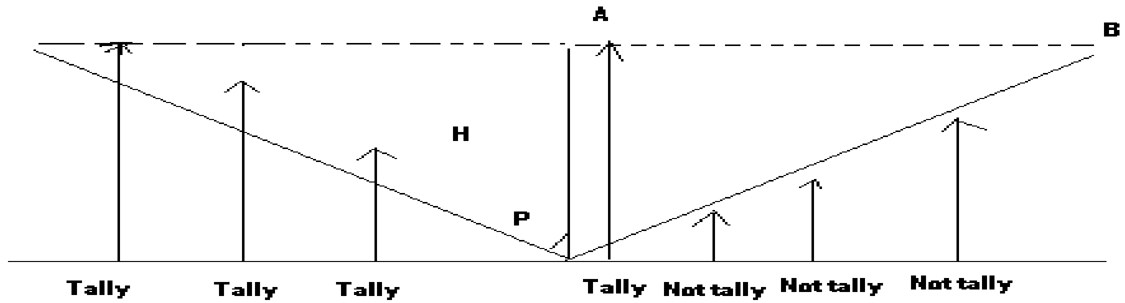
Bias due to concealed trees

Error due to incorrect inclusion or exclusion of borderline trees

Bias due to imaginary circle extending outside the sound

Vertical Point Sampling

Hirata developed a method for deriving the mean stand ht through vertical point sampling. Within a full 360^0 sweep around the sample point all trees appearing taller than a critical angle C are counted.



<u>As shown in figure,</u>

AB= h*Tanp

Area of the base of the cone which tree ht is h= $\pi\ (AB)^2$

$= \pi\ (h*tanp)^2\ m^2$

$= \pi *h^2*tanp^2/10000$ ha

If the number of trees per ha is N, then number of trees in this area

$n=N*\pi*h^2*tan^2P/10000$

$h=\sqrt{}\ (100000n/N*\pi*tan^2P)$

$h=(100/tanP)*\ \sqrt{}\ (n/N*\pi*)$

If the critical angle is 45^0

Then , $h=(100/\ \sqrt{}\ \pi)*\ \sqrt{}\ (n/N)= 56.4 *\sqrt{}\ (n/N)$

NTFP Inventory

General consideration for NTFP Inventory

- ✓Common understandings about participatory inventory
- ✓Local people have knowledge about the collection, harvesting, flowering, fruiting, seeding and regeneration
- ✓Follow inventory guidelines according to size and parts of use
- ✓Time, knowledge and resources available

Unit-5.3.5

Unique features of NTFP inventory

- ✓Characteristics of NTFPS and their part use affect the NTFPs inventory
- ✓Sampling method depends upon the quantification (estimation, measurement of ht, dia, wt, counting)
- ✓Availability of NTFPs in certain season
- ✓Spatial distribution of NTFPs
- ✓Integration with management

NTFP Inventory

Key elements of NTFP inventory

- Do not undermine the validity of traditional knowledge of the people (lifelong experience)
- Utility of accuracy
- Technicians rely on the measurement
- Combination of traditional knowledge & technical skill

Unit-5.3.5

Justification of the inventory

- Legal requirements about the NTFPs inventory in OP
- Sustainability: consideration ecosystem, how much collect, when collect, where collect, what parts collect
- Feasibility study: social, economical and environmental consideration
- Monitoring biodiversity: NTFPs are also part of bio-diversity

Ranking of NTFPs based on importance

i. Pair-wise ranking

ii. Criteria based ranking (predetermined criteria- social, economical & ecological)

NTFP Inventory

Unit-5.3.5

NTFP Inventory of terai, hills and mountains

Although it was necessary to put forward the inventory techniques of important NTFPs found in Terai, Mid-hills and High Mountain in each locality, The inventory of only one species has been here given as a an example, i.e. Inventory of **Chiraito (*Swertia chirata*):**

Chiraito (*in Nepali*) is a useful medicinal plant found mostly in high hills (altitude- 1500 to 3000m). It is one of 32 species of *Swertia chirata.*

Importance

80-90% of Nepal's chiraito is exported to India and remaining 10-20% to the other countries like Europe, America, China, Malasia, Singapore, etc.

It has varieties of medicinal properties being used mostly for fever, cough, diabetes, gastric, etc. All parts, i.e. root, branch, stem, are useful to make medicines.

NTFP Inventory

Unit-5.3.5

Yield and Income

According to Agriculture Research Centre, Pakhribas, Chiraito produces on an average 150 kg (upto3 tones) per hectare (ha). Similarly, the leaflet of Jadibuti Production and Processing Company Limited shows 1000 kg per ha gives NRs. 10000/-. If we calculate the yield of Pakhribas at the then rate, i.e. @400/-, it gives NRs. 1200000/-

To get better yield and income, Chiraito plants are to be collected only after having ripened completely. Mansir and Paush are suitable months. If Chiraito plants need to be collected before their ripening, some plants are to be left for future seeding.

NTFP Inventory

Unit-5.3.5

Field Data Collection Form

Sample Plot No.	Sample Plot Area (m^2)	Counted No. of Plants	25% plants' wt of the counted plants	No. of planted weighed	Remarks

Data Analysis

$$\text{Average wt per plant} = \frac{\text{Total wt. of the collected plants}}{\textit{Total No. of plants weighed}}$$

$$\text{No. of plants per ha} = \sum_{n=1}^{\infty} \left(\frac{\textit{No.of plants counted in all sample plots}}{\textit{Areas of all sample plots}} \times 10000 \right)$$

Total No. of plants in block = Block's area × No. of plants per ha

Total wt. to be collected in a block = Total No. of plants in that block × Wt. per plant

Use of Arial Photographs in Forest Inventory

Unit-5.3.6
Introduction

Aerial Photographs (APs)

- Aerial Photographs (APs) is a perspective projection of earth's surface while map is its orthographical projection.
- AP provides images on a photographic film or paper
- It shows actual images of objects found on earth and ground features
- Scale of APs vary from place to place even in the same photograph
- It records all ground objects whether wanted or not for a specific purpose. So, unwanted details may obstruct to perceive wanted details
- It can be subjected to rough or quick study which is received on ground
- It provides 3-Dimensional view of the earth's surface and objects on it.
- It facilitates selection of best locations for many purposes such as road alignment, bridge and dome sites, forest destruction, etc
- It has to be studied and interpreted under a stereoscopic and/or with certain aids and instruments

Use of Arial Photographs in Forest Inventory

Unit-5.3.6
Introduction

Classification

APs can be classified on the basis of :

a) Film used
b) Device use
c) Scale of photograph
d) Position of optical axis of camera

Time of Photography:

Ideal time of photography: 9-11 am & 1-2 pm. Other times are not suitable to maintain accuracy because ***morning*** Sun is not risen well and shadow of hills and trees are longer and ***Noon***: Very high sun increase chance of hot spot so image be blunt. Condition of the weather cloudy as well,

Season of Photographs

Season of photograph: October to February

Broad vegetation types	Optimum season of Arial photography
Coniferous forest	October-November
Mixed forest	December - February
Sal tropical forest	Mid march –mid April
Tropical evergreen forest	January-February

Use of Arial Photographs in Forest Inventory

Unit-5.3.6

1. Location of forests, their distribution and area:

A map of forests in general and by functional classification in particular is required. In the productive forests, maps of forest areas by forest types, by productivity of sites and by maturity classes, etc are necessary to assess the yield of forests.

2. Growing stock in the production forests

Inventory of trees by species and by diameter classes is required. This aids in estimating volume by location so that management plans could be drawn or industrial plan may be prepared.

3. Information about various factors affecting production:

The information on site, diameter and height, increment, age, timber quality and also about areas where new forests could be raised is necessary.

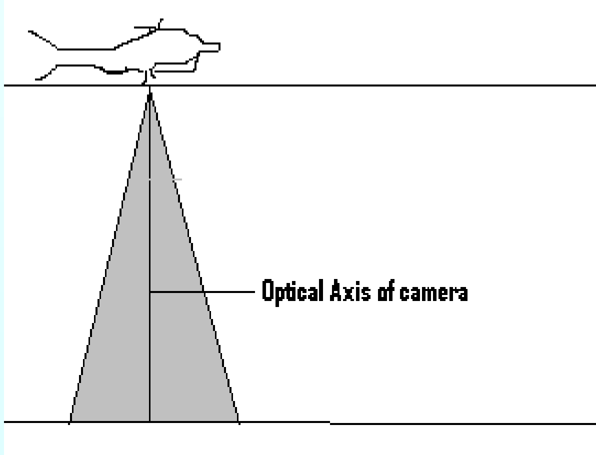
Types of Aerial Photographs

a. Types

Two types:

1. Vertical
2. Oblique

1. Vertical Aerial Photograph



A vertical photograph is one which has been taken with optical axis of Camera approximately perpendicular to the horizontal plane

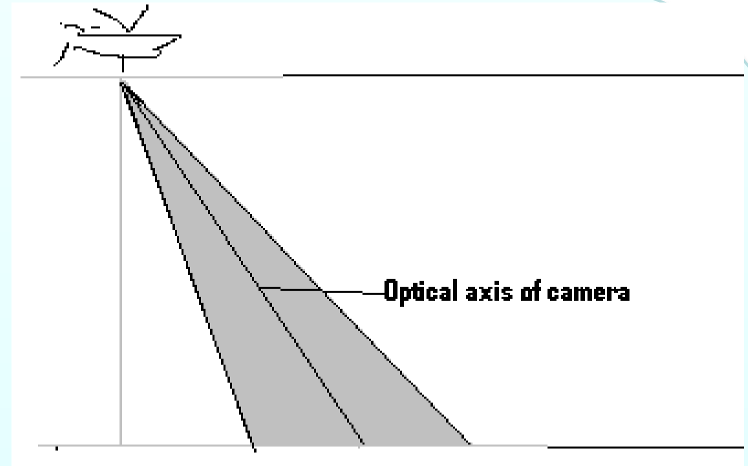
A deviation up to 4^0 is acceptable

This gives the map of the earth detail somehow in same scale

Types of Aerial Photographs

a. **Types**

2. Oblique Aerial Photographs:



An oblique photograph is one which has been taken with the optical axis of the camera intentionally tilted from perpendicular position obliquely. The degree of tilt from the perpendicular further classifies oblique photographs into high oblique photograph and low oblique photograph.

A high oblique photograph is one which is taken with the optical axis of the camera making an *angle* $>30^0$ with the vertical axis and which shows the apparent horizon on the photograph.

Photo Interpretation and Technical Terms

Photo Interpretation

Photo interpretation

It is defined as an act of examining photographic images and judging their significance. This includes interpreter and photograph

1. Interpreter:

✓Good vision

✓Well-trained for photo interpreter

✓Sufficient experience of doing the work successfully

✓Good knowledge of locality and type of forest present there

✓Good power of concentration and great deal of patience

2. Photographs

Photographs should be of high quality and free from defects

Scale of Photographs

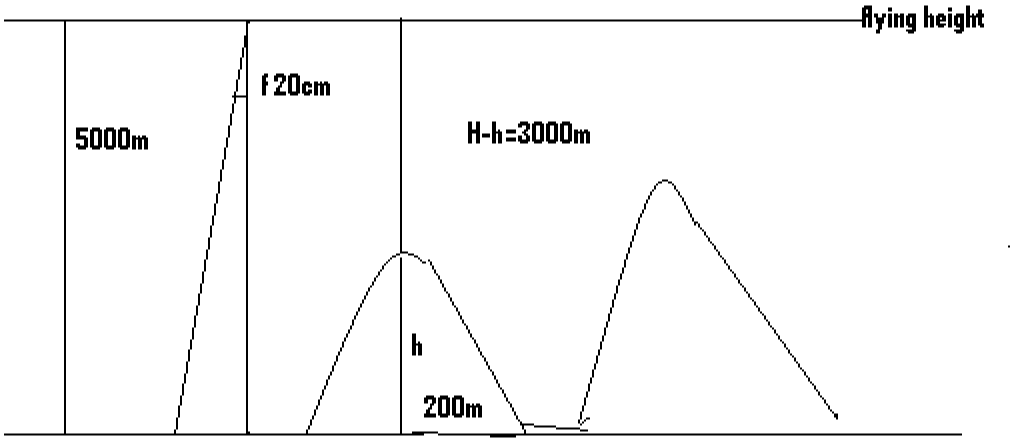
Scale of photography

The scale of photography is the ratio of distance on a photograph to its corresponding distance on the ground.

It is either expressed as ratio or representative fraction

Types of Scale

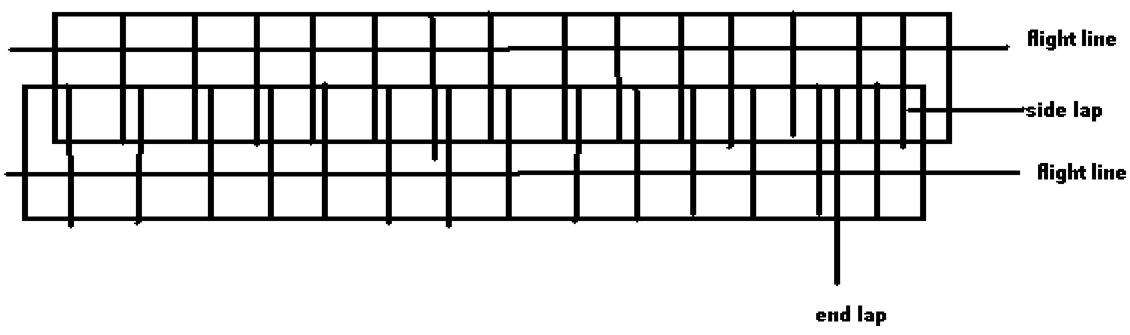
1. Small scale (1:40000 to 1:70000) used for broad land classification
2. Medium scale (1:20000 to 1:400000),use for preparation of forest inventory
3. Large scale (1: 5000 to 1:20000); use for preparing working plan, road alignment



Flight line and overlap

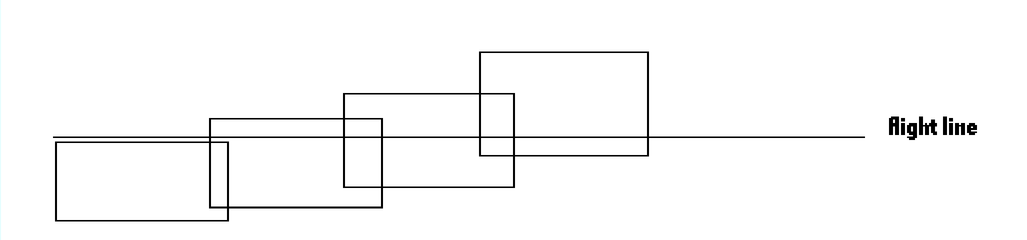
- In order to prepare the Arial photograph, a flight line is marked on a map called flight map
- These are straight and continuous lines from one end to another and are laid parallel to each other in such way that while the entire is area is covered
- There is 30% overlap in between photographs taken from two consecutive flight lines
- The direction of lines is decided on the basis of requirement of navigation, photo interpretation, shape and size area photographed
- The lateral of side laps depends up on the distance between two consecutive flight lines and as already stated they are arranged to have a side 30% but it should not be less than 15%.

⓾



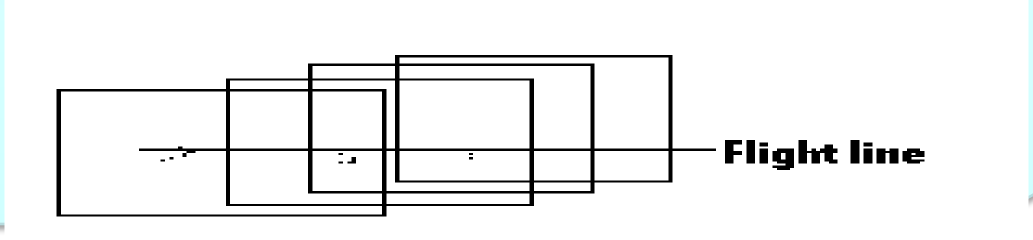
Deviations in Flight line

1.Drift: if is the horizontal displacement of aircraft due to wind from its original determined course or planned flight while photographer continues to make exposures oriented to the predetermined flight line.



2. Crab: it is the continuous caused by the failure to orient the camera so that axis perpendicular to the long dimension of the film is parallel to the track of the airplane. This is indicated in vertical photography by sides of photographs not being parallel to the principal point baseline

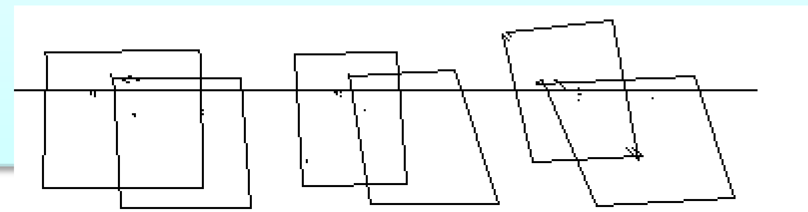
3. Drift and tilt: should not be exceed 10% of the width, otherwise it may affect in the result in stereoscopic interpretation.



Deviations in Flight line

4. Tilt: is angle between the optical axis of the camera and plumb line for given photograph. Tilt is caused by deviation of the optical axis from the perpendicular.

It should not be exceed 2^0 in normal condition but in extreme it may acceptable up to $5^{0.}$



Technical Terms

Technical Terms

It is done on the basis of following pictorial elements:

1. **<u>Tone:</u>**

Tone refers to the relative brightness of objects on photographs. On B/W photographs, tone varies from white (1) to black (10) with various shade of grey in between. The tone of an object provides more information than any other single element of object recognition. Young stands are lighter compared to mature stands. The phenological changes such leaf fall, new flush of leaves, flowering and fruiting also affect tone of trees' spps on Aps.

Technical Terms

Identification

It is done on the basis of following pictorial elements:

2. Size:

The size of an object image depends upon the object's size, scale of photograph and resolve power of camera. The minimum size of object to be visible on Aps should be about 1/20th minimum. A super highway should not be confused with rural road, a small residence with an apparent building, etc.

The size of the crowns and their heights often give a good indication for identification of certain species when other pictorial elements, i.e. tone may not differentiate them from other species.

3. Shape:

Shape refers to the general form or outline of individual objects eg. Roads, building, rivers, trees, etc.

The shape of a tree crown is important in identification of the species. Most conifers and young broadleaved species have an ovate shaped while those of mature broadleaved species are dome shaped crowns(circular).

Technical Terms

Identification

4. Texture:

Texture is the degree of coarseness or smoothness of an image and is dependent on shape, size, tone, scale, sun elevation as well as reflection properties of the objects.

In forestry, smooth texture is often associated with young trees and coarser texture with older trees.

It is more useful in interpretation of larger groups of objects like tree stands. Branching habit and age of trees decide the texture of trees.

5. Location or site:

As different species are found in different places under the influence of locality factors, location or site is helpful in identifying species, eg ridges and slopes are covered by coniferous in hills whereas, nallah and valleys covered by broadleaved species. In plain, only certain species are found while in hills, other certain species are found, eg. Fir, spruce, chirpine and deodar occur in certain elevation and on certain aspects.

Technical Terms

Identification

6. Association:

Association refers to occurrence of certain features in relation to others. Some tree species are so closely associated that each helps to confirm the presence of others. Certain tree species can be identified by recognition of other species, which grow together, eg. Khair and Sisoo are associated with fresh alluvial deposits in riverain areas.

7. Shadow:

Shadow of objects falling on ground gives an indication of objects. It depends on the time of photography and direction of flight. Shadow of the trees falling on ground help in identification of species as they give an indication of the shape of the crown.

Wind, however, affects the shadows and makes identification difficult

8. Pattern:

Pattern refers to the spatial arrangement of objects like orchard, plantation, etc is a characteristics of man made objects. Those can be easily separated from natural objects such as natural forest, ridges, drainage, which have random pattern.

It describes the regularity and characteristics arrangement of different shades of tone or texture in a photograph.

c. Forest Classification

Different information are used to classify APs:

i) Forest cover type (stand ht class)
ii) Crown density
iii) site class
iv) volume class

A. Small scale photography

i) Forest cover type: tree forest –F

Young plantation-p, Re-growth-R, Shifting cultivation-S, permanent cultivation-C, Blanks-B, Non-forest-W

ii) Crown density: 5-19, 20-60 & >60%

Iii) Site class: Poor, medium, good and very good

Iv) volume class: low (15-49), medium (50-99) & high (>100 m^3/ha)

B. Large scale photography

Cover type (plantation, pure, mixed, natural, degraded, re-growth forest)

<u>Stand ht class</u>: below 7.5, 7.5-12.5, 12,5-17.4, 17.5-22.4, 22.5-27.5 & > 27.5m

Crown density: 5-20, 20-40, 40-60, 60-80 & >80%

d. Area determination

Measurement can be determined directly from photographs

Planimeter: As boundaries of forests are delineated on the photographs, its area can be measured by polar planimeter

By weight apportioning method: Forest divided into subclass, cut with electric scissors, weigh in lab with sensitive balance, same can be done for other as well but this method is when weigh and area relation is established.

Estimation of area by sampling sub class can be estimated the areas and then applied for whole

Partial delineation: strata delineated representing the whole

Transect method: series of parallel and spaced lines are drawn, length is measured based on that area calculated

By dot grid: scale and number of square, let 25 dots, scale 1:50000, if 1:25000 what is area?

d. Area determination…

<u>Plot sampling method</u>: Number of small circular plots are distributed over the photographs,

Area of that plot is calculated

Number of sample plot (p) is counted (N)

Whole area =N*Sa

<u>Error estimation:</u>

1) errors due to mis-interpretation
2) errors due to variation in scale of Arial photographs

e. Volume estimation

Individual tree volume: multiple volume table based on ht & dia can be converted into Aerial volume

- If the relation is established between crown dia and dbh of the tree

Aerial stand volume table: if we know the stratum like dominant, co-dominant, dominated strata in small area

Assess ht and general dia of each stratum which can be related with *crown dia* (by regression equation).

Then volume can be estimated.

Out line tract boundaries on the photographs, using the effective area of every other point in each flight line.

Assure stereoscopic coverage and avoid duplication

Delineate important forest types based on the stand density, further based on ht as well, measure ht, crown closure (dia)-make strata.

Measuring the ht by parallax method

To determine the ht of objects using stereoscopic parallax pairs photographs, it necessary to measure or estimate

1. Absolute stereoscopic parallax:
2. Differential parallax

h= H*dp/(p+dp)

Where,

h is ht of measured object, H is ht of aircraft above ground datum, p is absolute stereoscopic parallax at base of object being measured & dp is Differential Parallax.

Example: two stereo readings for reading are 10.75 & 9.63mm, so Differential parallax is 1.12mm, average photo base p is 91.44mm & aircraft ht 3600ft find ht of building

h= (3600)1.12 /(91.44+1.12)= 43,56ft

6. Growth Prediction

Unit-6

Tree growth is intermittent process characterized by changes in stem form & dimension over period of time

In forest, a growing trees add a layer of wood from ground to tip annually just under the bark, from ground level to tip and all around the stem. In cross section, these layers appear as annual rings, and the volume of each ring is a measure of the wood added to the central stem that particular year.

Tree growth shows elongation and thickening of roots, stems and branches. It is influenced by the genetic capabilities of a species interacting with the environment

Patterns of growth of a tree in terms of change in diameter, basal area, height, form and volume are affected to varying degrees by the crop structure, competition and stocking.

Even aged crops of one spp. have very different growth patterns from uneven aged crops of several species.

6.1 Diameter growth

Unit-6.1

Diameter growth of an individual tree can be obtained by measuring the diameter at the beginning and end of a specified period and by taking the difference. Since annual increment is small, when instruments such as callipers and diameter tapes are used, measurements are commonly taken at intervals of several years. Repeated measurements of permanent plots may give precise result. Precise measurement of minute increments in diameter may be required in research.

(i) In even aged plantation of one spp.

- *Early immature stage* before canopy closure when rate of diameter growth is little affected by competition.
- *Responsive middle stage:* On canopy closure ring width decreases but responds quickly to treatment such as thinning and fertilizing.
- *The final (mature stage)* when ring width is narrow and is not so markedly responsive to treatment.

Diameter growth Contd…

Unit-6.1

(ii) Diameter growth in natural forest

An *early stage* of extremely slow diameter (and height) growth while the sapling is dominated by overwood.

A *middle stage* when the tree is growing more rapidly but is still severely affected by its larger neighbors

The final stage when the tree is a dominant with a large, free, well developed crown and neighboring trees of same size are few and distant.

Whatever the structure of forest, rate of diameter growth depends on degree of competition. Though the width of ring of trees normally decreases as tree becomes older.

The thinner wood layer added over a larger diameter or bole surface. So, the volume is greater than previous years.

Age, rate of diameter growth depends upon soil moisture and amount of leaf functioning for photosynthesis process.

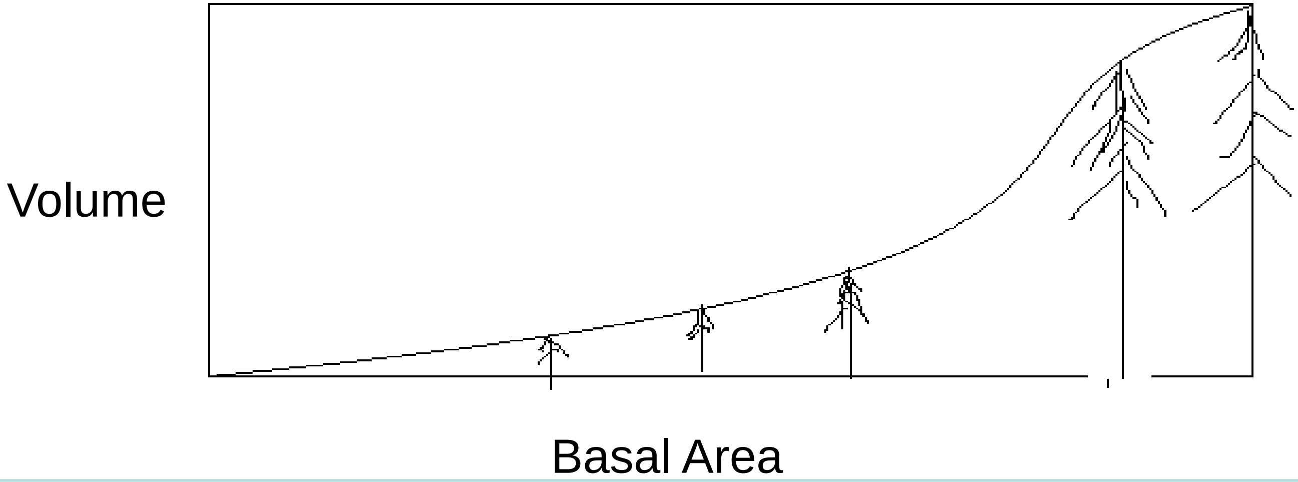
Wider spacing among tree results in more root growing space and larger crowns which lead to faster dia growth.

Height growth

Unit-6.1

- Changes in tree height are of prime concern for predicting future stand composition & selecting ideal crops in the pure stands
- Height growth proceeds slowly in seedling is well established.
- This is followed by the rapid growth for 20-30 yrs depending upon the species & sites.
- Cumulative growth followed by the growth in ht, dia, volume and basal area as well.
- Wood production in central stem can be predicted by past rate of increment in dia & ht.
- In even aged plantations, height growth on age shows a typically sigmoid pattern with slow early and late stages and fast growth between.
- In irregular forest and especially with shade tolerant species, the early rate of height growth may be extremely slow and only accelerated when the tree is released from overhead shade.

6.2 Basal Area & Volume growth



Unit-6.2

The cumulative curve follows the same general configuration for most functions of tree growth Whether it is tree ht, dia, basal area or cubic volume

Although the exact of the cumulative growth curve will differ with variable used and climatic functions , the elongated S-shaped pattern is characteristic that can be invariably expected.

From the forgoing , it is seen that wood production in the central stem of tree can be predicted by measuring past rates of dia & ht growth

The primary objective of the most tree growth studies is the reliable predictions of future wood yield.

Basal Area & Volume growth contd..

Unit-6.2

Although the cumulative growth curves for both area and volume growth are typically S-shaped, the exact form of the curves is variable. Basal area growth may be estimated from periodic measurement of dbh. Bole surface are growth may be estimated by calculating surface area from periodic measurements of stem diameters at predetermined intervals along the stem.

Volume growth, the most important growth determination, may be estimated by taking periodic measurements of dbh, dbh and ht, or dbh, ht and form and determining volumes at the beginning and at the end of a period from local, standard, or form-class volume table as appropriate, and then taking the difference.

6.3 Stand Growth

Unit-6.3

Stand structure changes from year to year. These changes take place as a result of growth, death and cutting of trees. The growth of stand makes them the biggest renewable natural energy resource and, therefore numerous studies have been made to predict it, treating the stand as a unit as well as population of trees.

Treating the stand as a unit, growth function models have been suggested by many workers. Some of these models are given below:

(i) Exponential, W= Be^{kt}

(ii) Time power, W= Bt^{k}

(iii) Monomolecular, W= $A\,(1 - Be^{-kt})$

(iv) Auto catalytic or, Simple logistic, W= $1/Be^{-kt}$

(v) Gompertz, W= AB^{kt}

Where,

W = Plant characteristics, whose changing magnitude is measured.

t = time

A, B & K = constant

e = Base of natural logarithm

Stand Growth Contd…

Essentially, the growth of any stand parameter viz., height, diameter, volume or biomass, follows a pattern of slow growth in the beginning which becomes rapid at an early age and slows down in later years and culminates as an asymptote.

Methods of determining past growth of stands:

Unit-6.3

The usual method of determining past growth of stands is by repeated measurement of sample plots as measurement of the whole stands is not a practical preposition.

Even this could be done either by laying out temporary sample plots each time, an estimate of growth is to be made. The methods of laying out a temporary sample plot each time, growth is to be determined results in measuring different sample units each time and therefore the precision will be poorer and the accuracy generally lesser.

Stand Growth Contd…

Unit-6.3

It can be done by laying permanent sample plots. The method of repeated measurements in permanent sample plots is better. The following two methods are commonly used for the purpose:

1. The method of control
2. Continuous forest inventory method

Method of predicting future growth of stands:

Future growth of stands can be predicted with the help of yield tables prepared from the entire forest. Growth of a stand is a function of stand density and site quality. Therefore, before describing yield table, method of its preparation and its uses, it is necessary to have knowledge of stand density and site qualities and their effect on growth prediction.

Stand Growth Contd…

Unit-6.3

Estimates of stand growth are needed to decide the health of the forest, the volume of material that can be harvested (yield) without violating the sustainability of the forest, the allowable cut, where the cut will be made and the trees which will comprise it.

In assessing stand growth, we need to consider each of the following components:

1. Regeneration and other non-measurable trees;
2. Accretion - the sum of the individual increases in size of the trees of measurable size present at the commencement of the growth period;
3. Ingrowth - the quantity of trees entering the measurable stand since the previous assessment;
4. Mortality - the quantity of trees lost through death;
5. Drain - the quantity of trees harvested during the growth period.

6.4 CAI and MAI

Unit-6.4

Increment: Increase in diameter basal area, height, volume, quality, price or value of trees or crops during a given period

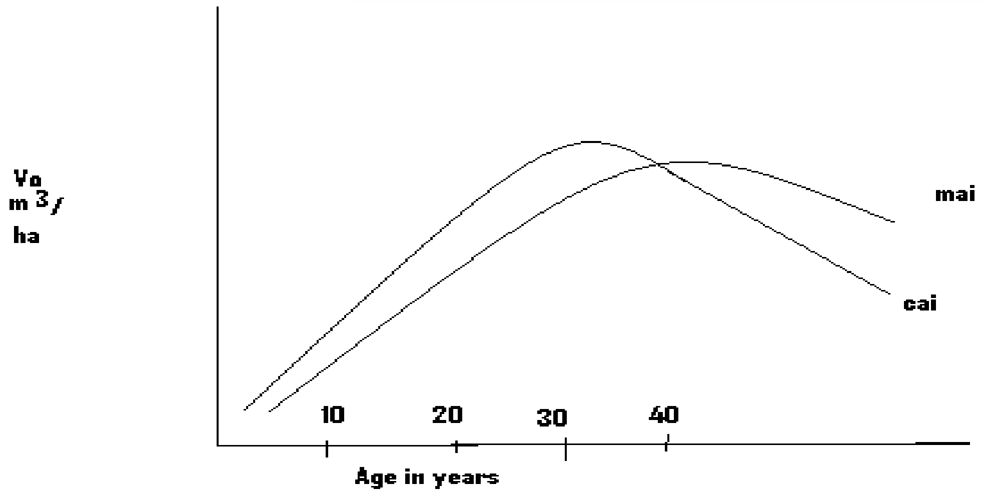
CAI: current annual increment is defined as the increase in tree size in one year.

PAI: it is difficult to measure the increment annually, the average annual growth over a period of 5 to 10 years is commonly substituted instead. The difference in tree size between the start and end of a growth period divided by a number of years involved is properly termed as periodic annual increment.

MAI: is derived by dividing total tree size at any point to time by total age.

Total increment: it is the increment of a tree from origin to age when trees cut

CAI & MAI relation



Unit-6.4

CAI is small in early stages (seedlings and saplings), increases slowly at first, then more rapidly to the maximum, after which it begins to decline, and finally ceases with its mortality. The sum of CAIs laid on for the entire period gives the total volume, which when divided by the age gives the MAI.

It is an arithmetically derived value and coincides only twice in the life of a crop; once at the end of the first year and once later, when culminates and equals the CAI.

CAI & MAI relation

Unit-6.4

A time may come when there may be no growth at all and so the CAI will be zero. Unless the tree or stand is cut, loss in volume may start taking place due to rot or other damages and then CAI will become negative. But the value of MAI is never zero. In other words, until the tree or stand is cut or destroyed, the MAI is always positive.

The curves of CAI and MAI cross each other at the maxima of MAI curve. The age at which they cut, is the age of maximum production. In short,

- To begin with the MAI, keeps below the CAI
- While the CAI is more than MAI, the MAI is rising
- The CAI attains the maximum before MAI
- The CAI is falling when the MAI is still rising
- When the CAI is equal to the MAI (the two curves intersect), the MAI is stationary, and has attained its culmination point.

The MAI curve is flat at this point and the MAI is about the same for some years and some years after it.

If the crop is felled at this age, at which the MAI is maximum.

Increment Percent

It is defined as the average annual growth in diameter, basal area or volume over a specified period expressed as percentage of diameter, basal area or volume

A. <u>Diameter increment %</u>

Unit-6.4

A) Compound interest formula: the increment of a diameter , ht & volume in tree is like the increase in capital at compound interest

So, $D= d(1+p/100)^n$ how to derive p

Where, D is diameter after n years, d is dia at initial year, p rate of increment in % and n is number of years

$D= d(1+p/100)n$ how to derive p

by compound interest formula

$(1+p/100)= \sqrt[n]{D/d}$

$P= (\sqrt[n]{D/d}-1)*100$

Increment Percent

Determination of current annual growth

Unit-6.4

1. Pressler's formula

based on simple interest rate,

Mean of two diameter = (d+D)/2

Annual increment in diameter = (D-d)/n

As

I=PTR/100, R=I*100/PT

so,

P (increment) =200(D-d)/ (d+D)*n

2. Compound interest formula,

$$P = \left(\sqrt[n]{D/d} - 1\right) * 100$$

Increment Percent

B. Volume increment percent

a) Compound interest formula

$D = d(1+p/100)^n$

how to derive $P = (\sqrt[n]{V/v}) - 1 * 100$

b) P (increment) $= 200(V-v)/(v+V)*n$

Therefore,

$p = 200(V^2-v^2)/(v^2+V^2)*n$

c)Schneider's formula *simpler formula*

$P = 400/nD$,

Where,

D is the present diameter at the point of boring

n is number of rings in the outer most

centimeter in the radius

6.5 Stand Structure, Site Quality & Yield

Unit-6.5

Stand Structure

Stand structure refers to distribution and representation of age and/or size classes of trees in a stand. It keeps on changing with passage of time and age. It is the result of growth habits of species, locality factors and above all the management practices under which it was originated and developed

The stand structures of the properly managed forests can be broadly classified into two groups:

1. Even-aged stand
2. Uneven-aged stand

Stand Structure contd…

Unit-6.5

1. Even-aged stand

It is a stand consisting of trees of approx. the same age. The period required to regenerate a stand under different methods of regeneration varies 1 or 2 years to about 20 or 30 years, depending on the system of management and the species concerned; differences in age upto 25% of the rotation age are allowed in cases where the stand is not harvested for 100 years or more.

Though the trees are nearly of the same age-class, competition for light and moisture results in crown differentiation with the vigorous trees occupying dominant positions, the less vigorous the dominated position and those left behind in the struggle occupying suppressed position. This results in wide range of diameters found in a stand at a particular age.

Stand Structure contd…

Unit-6.5

Even-aged stand…

The pattern of diameter variation naturally varies with age. Studies made by various workers indicate that the diameter distribution in an even-aged stand follows definite laws and the relationship between number of trees and diameter can be described by computed data.

Even aged stands have definite beginnings and endings. The future growth of stand can be predicted with the help of yield tables. Stand is the function of stand density and site quality.

Stand Structure contd…

Unit-6.5

2. Uneven-aged stand

A stand in which individual stems vary widely in age, the range of difference is usually more than 20 years. In case of long rotation crops, more than 25% of the rotation is found.

When nearly all age gradations or age classes are present in a particular area, it is called a selection forest.

The proportion of trees of different diameter classes varies unsystematically from place to place. Generally, there is a preponderance of trees of higher diameter classes at the cost of trees of lower diameter classes. The shortage in the lower diameter class as a result of lack of regeneration and establishment makes the structure more and more unbalanced gradually.

Stand Structure contd…

Unit-6.5

Uneven-aged stand…

A French Forester De Liocourt during a study of diameter distribution in selection forests found that stem numbers in successive diameter classes had a fixed ratio with a stand.

$N_1:N_2 = N_2: N_3 = N_3:N_4 = q$

Where,

N_1, N_2, N_3, N_4 are numbers in successive diameter class-1 to 4. The ratio is called De Liocourt Quotient. In other words, the numbers of trees in successive diameter classes are in a geometric series. If the number of trees is plotted against diameter classes, the resultant curve is of a laterally inverted J-shaped.

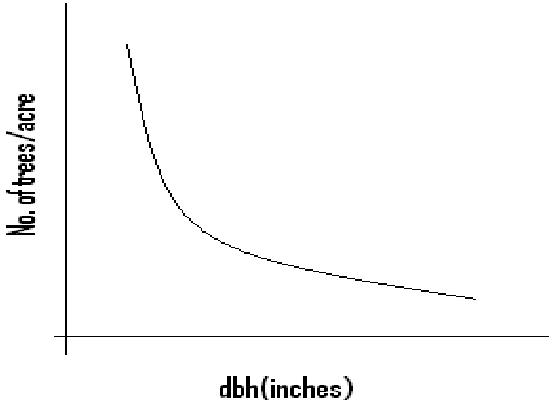


Figure: Typical dbh distribution for regular, uneven-aged stands

Stand Structure contd…

Unit-6.5

Uneven-aged stand…

Mayer (1953) termed stands where the numbers of stands by diameter classes decrease in constant geometric progression as a ‘balanced forest’. Balance can apply to an uneven-aged forest where age classes are spartially separated, i.e. they occupy separate areas.

Balance exists if the decrease in the number of stems follows a geometric progression.

$$Y = Ke^{-ax}$$

(Modified in the form exponential function)

Where,

Y = No. of stems in the dia. Interval

x = dia. at breast height

a = percentage reduction in number of stems for each dia.

K = relative stand density

e = 2.71828

Terms related to density

Stand density

It is defined as a measure of the relative completeness of tree stocking expressed as decimal coefficient, taking normal number of trees, basal area or volume as unity.

Unit-6.5

Canopy density

It is a measure of relative completeness of canopy and expressed as a decimal coefficient taking closed canopy as unity.

Classification of Canopy density:

- *Closed:* If density is 1
- *Dense*: density is between 0.75-1
- *Thin:* 0.5-0.75
- *Open:* under 0.5
- *Pure:* even aged forest rarely closed canopy

Spherical Densiometer

(An instrument for measuring forest overstorey density)

Robert E. Lemmon,

forest densitometers

5733 SE comell Dr.

Bartlesville, OK

Instructions:

Unit-6.5

- Hold instrument level, 12”-18” in front of body and at elbow height, so that operator’s head is just outside of grid area.
- Assume four equi-spaced dots in each square of the grid and systematically count dots equivalent to quarter- square canopy openings.
- Multiply the total count by 1.04 to obtain percent of overhead area not occupied by canopy. The difference between this and 100 is an estimation of over storey density in percent. (Assuming each dot to represent one percent is often accurate enough)
- Make four readings per location- facing North, East, South and West- record and average.

Site Quality

Unit-6.5

The productivity of a site for tree growth is usually evaluated on a stand basis. Considered in this way, site quality expresses the average productivity of a designated land area for growing forest trees. A common way of expressing relative site quality is to set up from three to five classes, or ordinal ranks, such as site I, II and III. The characteristics of each class must be defined to enable any area to be classified.

Site is complex of physical and biological factors of an area that determine what forest or other vegetation it may carry

- ✓Site quality is measure of relative productive capacity of a site for a particular species
- ✓Different site gives different growth response to different spps.
- ✓This help to evaluate the vegetation characteristics and site factors

Site Quality contd…

Site Quality can be evaluated by following factors:

1. Site factors :

_it is effective climatic, edaphic and biotic factors which influence the growth and development of forest or other vegetation in locality.

So, CVP= (Tr/Ta)*(P8G/12)*(F/100)

Where, CVP index= climate, vegetation and productivity index

Tr & and Ta are maximum and minimum temperature, P is precipitation in mm , G is growing period in months and E is a measure of evapo-transpiration

Unit-6.5

2. Vegetative characteristics:

Site qualities can be described and differentiated either by the types of plants occurring naturally in the area or basal areas, volume, diameter or heights of trees which form the dominant part of the vegetation in the area.

Site Quality contd…

Unit-6.5

3. Plant indicators:

One possible way to evaluate site quality is to use the composition of the vegetation and search for some characteristics of plants which may be correlated with site qualities. This approach is based on the theory that certain species of lower vegetation, i.e. herbs and shrubs are clear indicators of the suitability of the site for a particular tree species or forest type. As such they can be used to describe and differentiate site qualities.

4. Tree characteristics:

The most important characteristics of tree which reflect the productivity of site are its volume, basal area, dia and ht. As the primary object of site quality differentiation is to assess its productivity, the quantity of wood produced per unit area should therefore be the ideal measure of site quality, but as this method requires prior calculation of volume, it is difficult to apply in practice.

The site classes are delimited by one of the following methods:

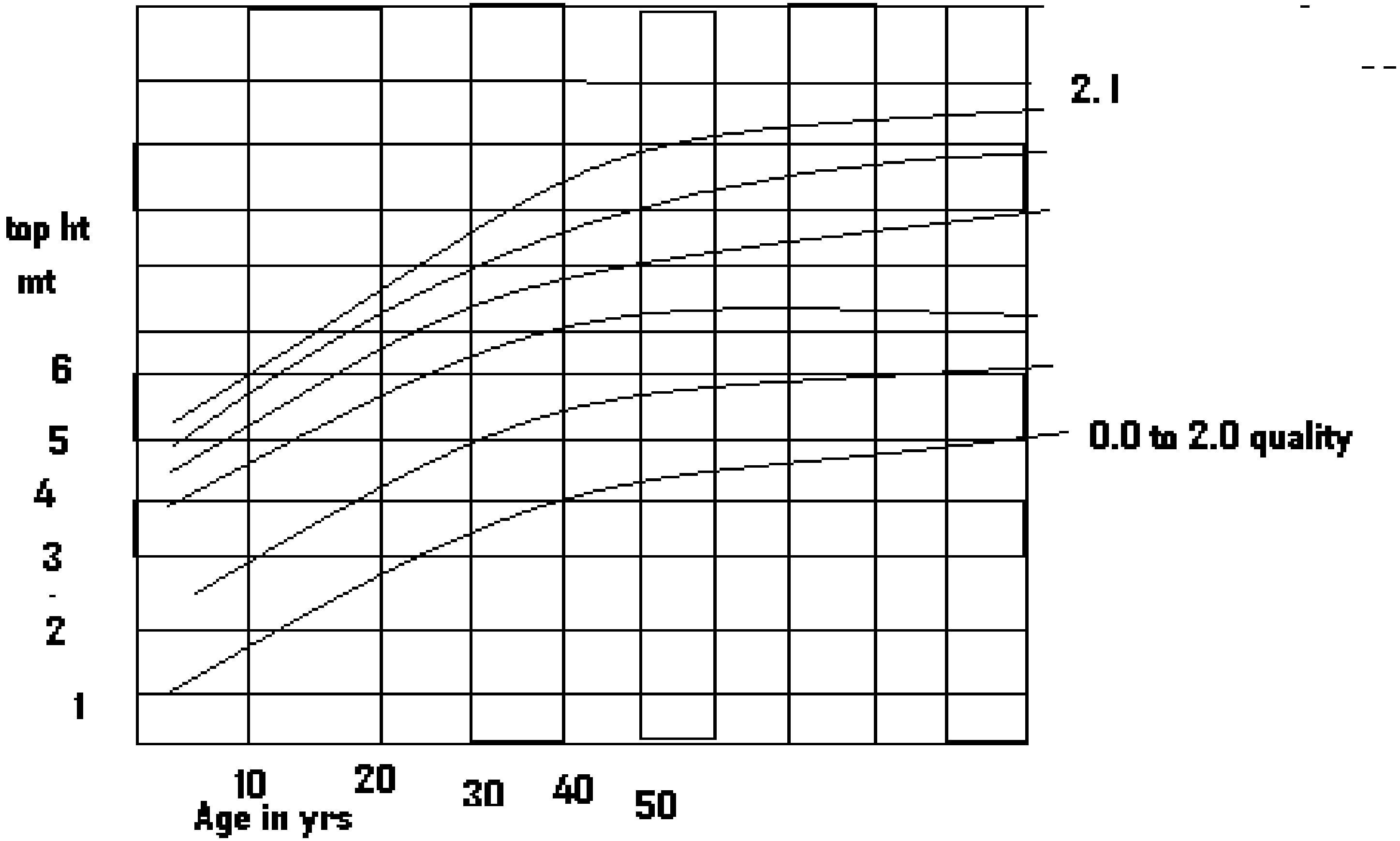
a) Strip-height method based on Baur's method

b) British Forestry Commission (BFC) method

c) FRI Method

Site Quality Graph

Unit-6.5



Yield

it is the total amount available for harvest in a given time.

It is the summation of annual increments.

Factors affecting the yield:

a) Point in time in stand development

b) Site quality

c) The degree to which the site is occupied

Unit-6.5

The measure of stand density most commonly used in growth and yield model.

The term yield is used in forestry with a number of qualifiers e.g. annual, intermediate, final, sustained, financial. Each has a special connotation for management. In this course, we shall use yield in a very general sense implying the accumulation of increment available at a particular time for a particular purpose, e.g. the total amount of wood capable of being harvested at a certain time.

Yield

Unit-6.5 Types

Types of yield:

1. Final yield

All the material that counts against the prescribed yield and which is derived from the main fellings in a regular forest.

2. Intermediate Yield

All material from thinnings or operations preceding the main felling in a regular forest, or its cash equivalent. (*syn. Subsidiary Crop*)

3. Normal Yield

The yield from a normal forest

4. Total Yield

The standing volume of a crop plus the total volume removed in thinnings since its establishment as a more or less even aged stand; or the sum of the *final* and *intermediate yields.*

5. Sustained Yield

The material that a forest can yield annually or periodically in perpetuity.

Method of Determining Growth

1) Stump analysis 2) Stem Analysis 3) Increment Boring

1. Stump Analysis

Unit-6.6

Definition

It is the analysis of a stump cross-section by measuring annual rings in order to estimate the age of the tree and its past rate of diameter and basal area growth.

Object

- To find out age/diameter relationship to determine the rotation age in absence of yield tables
- To determine the progress of diameter increment on stump throughout the life of the tree analyzed over any desired period.
- To the influence of external factors affecting single tree or the stand.

Stump Analysis Contd…

Stump Analysis

i.If old stumps are available, sound stumps of trees of rotation size and over are selected taking care to see they were not uppressed in the past life-time. Stump selected should be of average trees So that they can serve as the representative of crop.

ii.If old stumps are not available, trees are specially selected and felled for this purpose. Such trees should be of the rotation size and over and should be representative of the site quality to which the results of investigating are to be supplied. They should be of the typical shape and development and the tendency to select trees above the average quality must be avoided. Suppressed, dominated, abnormal or malformation trees should not be selected.

iii.After selection, the breast height diameter is measured and recorded and then the tree is felled. As felling cut is seldom smooth and horizontal, the stump is cross-cut by a saw to remove a disc to leave smooth and horizontal cross-section. Cross-cutting has also to be done in case of old stumps selected for analysis.

Stump Analysis

Stump Analysis Contd…

iv. Stump height & underbark girth of each stump are measured and recorded. From the girth, average radius underbark is calculated and recorded for each stump.

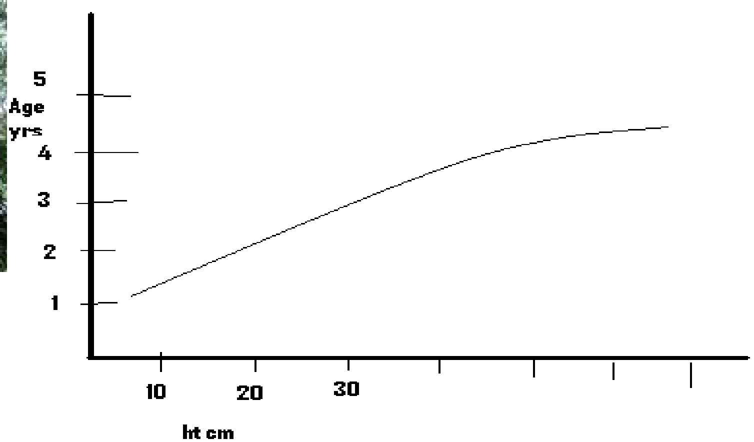
v. Four radii are marked on the stump with pencil. If rings are not clearly visible, the surface is moistened with water or chiseled along the marked radius. On each radius, decades (10 rings) are counted from pith outwards and a pin inserted at each decade. Incomplete or false rings are not counted.

vi. The radius of each decade on each marked radii is then measured from pith outwards in centimeters and millimeters in one setting of the scale on each radius to avoid error and recorded.

vii. The radii at successive decades are then totaled for each stump and halved to get average diameter at successive decades.

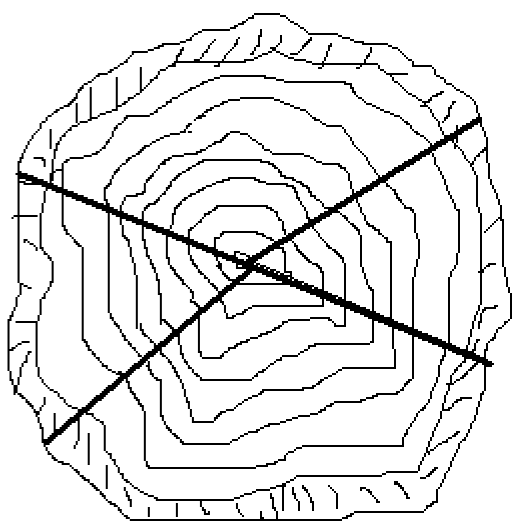
Besides this, data are collected to determine age to grow to stump height and for drawing taper curves.

Stump Analysis Contd…



viii. For taper curves, sufficient no. of trees of different diameter classes is selected and their underbark dia. at 15 cm, 45 cm and 75 cm from ground level and dbh (o.b.) are measured.

Unit-6.6



Remember:

- ✓Each radii 10 rings counted from pith outward
- ✓Incomplete or false rings not measured
- ✓Pins inserted at each decade on all radii
- ✓Check all four pins lie on same ring
- ✓Measure the each decade on each radii
- ✓Radii at successive decades totaled for each stump and halved to get average diameter at successive decades.

Stump Analysis contd…

1.Radius of successive decade

A model of data Collection Form

Trees No	Stump ht	G UB at stump	Calculated average radii	Radius at successive decade			Total radii length	Total no of rings
				10	20	30		
			1					
			2					
			3					
			4					
			Total					

Unit-6.6

Stump Analysis contd…

2. Age & height from ground level

A model of data Collection Form

Unit-6.6

Sapl ing no	**Ground level**		**10cm**		**20cm**		**30cm**		**40cm**	
	No of rings	Age yr	No of rings	Age yr	No of rings	Age yr	No of rings	Age yr	No of rings	Age yr
Total										
Aver age										

Stump Analysis Contd…

Unit-6.6

Advantages

i. Data can be collected from stumps of felled trees as long as the wood remains sound. Thus it can be carried out without felling

ii. Data can be collected at any time with minimum of annual labor

iii. The data can be multiplied to any desired extent with no objection other than the taken measuring

iv. Filed work can be learned

v. Each stump provides data for the whole life of trees

Stem Analysis

Unit-6.6

Definition

Stem analysis is defined as the analysis of a complete stem by measuring annual rings on a number of cross-sections at different ht in order to determine its past rate of growth

Objects

- The most important object of this investigation is to determine age-diameter, age-ht, age-volume relations throughout the life of the tree analyzed and thus assess the average rate of diameter, height and volume increment.
- The effect of external factors, eg. Lopping, defoliation, etc, on the rates of growth of trees can also be determined
- The data of the stem analysis can also be used for preparing local volume tables by correlating diameter-volume relations.

Stem Analysis

Unit-6.6

Field work

1. Selection of tress of typical shape no malfunctioning
2. Measure and record dia at dbh and then make horizontal mark all around the bole at this level.
3. The height of the tree and its crown width is also calculated and recorded and then fell to take measurements:

a) Height of the first green branch and lowest point of the full crown to calculate clear bole and crown length

b) Total height of the tree

c) Height of the points with diam.(o.b) and diameter (u.b)

4. The felled tree is then divided into sections from base including stump, the lowest section being 2.74 m long so that breast height corresponds to its mid-point and all 3 m long except the upper most. The odd length at the top is treated as a separate section if it exceeds 1.5 m in length, but included in the previous section if 1.5 m or less.

Stem Analysis Contd…

Unit-6.6

Field work…

5. The mid-points of these sections are marked on the tree at 1.37 m, then 4.24 (2.74+1.5), 7.24 m (5.74+1.5) and so on. The mean diameter overbark is callipered at each mark and recorded. A ring of bark is then peeled off at these points and the underbark diameters callipered and recorded.
6. If the mid-points of sections fall on points unsuitable for ring counting on account of knots, rots or breakage, they are shifted up or down for a distance not exceeding 30 cm, which were assumed to be mid-point.
7. The tree is then cut at these mid-points by a cross-cut saw for ring counting. If the measurements cannot be done in the field, transverse sectional discs 5-8 cm thick are sawn, but in such cases, sectional height is noted.
8. For each section, average radius is calculated on the basis of two diameters (u.b) callipered at right-angles, totaled, averaged and halved and then recorded.

Stem Analysis Contd…

Unit-6.6

Field work…

9. If annual rings are not clear, on these radii, they are brightened by moistening or chiseling.

10. Rings are first counted on the section at 1.37 m counting is done by decades from the pith outwards along the marked lines. A pin is inserted on completing each decade leaving incomplete decade at the circumference. It should be checked that the decade pins are on the same annual ring

11. Incomplete rings are also marked off and counted from the cambium

12. The radii are measured from the pith outwards to each pin. The measurements are taken to the nearest millimeter. This work is first done on the 1.37 m section on which the radial measurement for the outmost full decade along the selected radii are first entered under appropriate decade and then the successive radial measurement to other decades are entered. Then the two are totaled in red ink.

Stem Analysis Contd…

13. The difference between the rings on breast-height and any other section gives the age to that section. Besides this counting work, seedling height data are also collected in the field.

Unit-6.6

Advantages

- The data are collected from standing trees carefully selected and so, it is more reliable.
- It gives complete information about the growth of trees in respect of diameter, height and volume and so, it is self-contained.

Recent Advances in Stem Analysis:

Conventional method of stem analysis is both time-consuming and laborious. Pluth has developed a computer program for complete stem analysis, but has not yet been used everywhere.

Increment Boring

It is defined as the boring of a tree stem with pressler's increment or any other borer to determine increment of trees with annual rings

Filed work:

1. Selection of trees: Typical trees are selected

2. Measurement:

✓Two dbh (ob) are measured & recorded

✓Bark removed

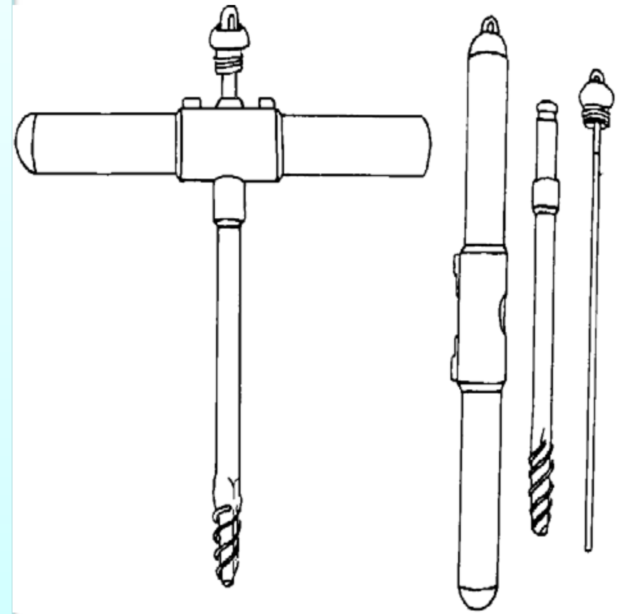
✓Bored to 4-5 cm so that at least 15-20 rings

✓Length of outermost 5 rings measured, one end of each of the two diameter on a particular tree recorded and totaled

Increment Boring Contd…

3. Computation

- ✓Width of 5 rings & average diameter class curve
- ✓Age –dbh curve
- ✓Increment for lowest dia and added the increment to lowest to get final diameter
- ✓Then, again resulted dia is taken as original and increment for that is determined and added to get other Diameter.



First period increment			Second period increment		
Initial dia	increment	Final dia	Initial dia (final of first period)	increment	Final dia

Unit-7

7. Growth and Yield

7.1 Growth and Yield in even aged forest

7. 2 Growth and Yield of uneven aged forest

7.3 Growth and Yield Modeling Approaches

7.3.1 Stand table projection

7.3.2 Whole stand modeling

7.3.3 Individual tree Modeling

7.3.3.1 Distance Dependent Models

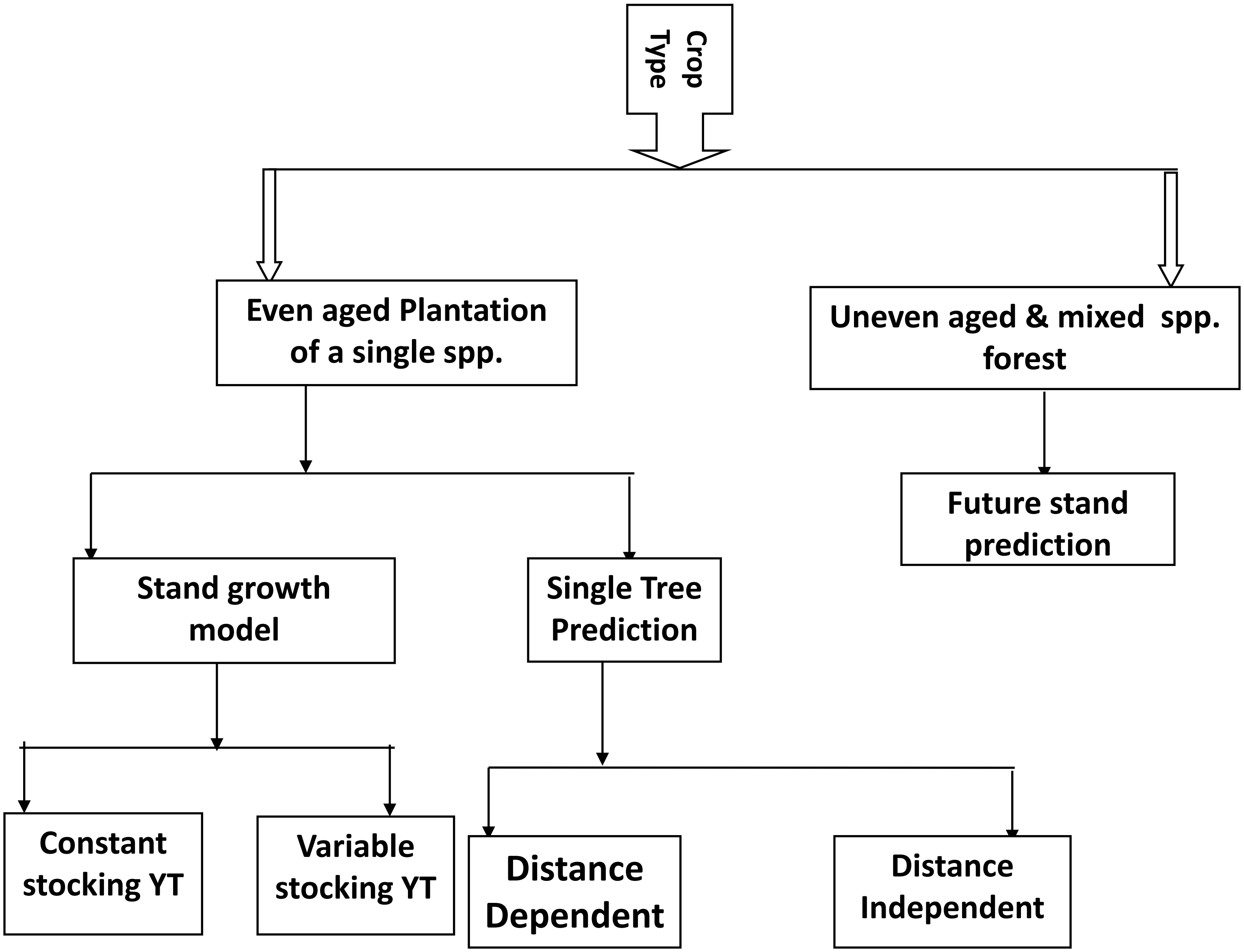
7.3.3.2 Distant Independent Models

7.4 Application of Growth and Yield models

7.5 Yield Table

Growth and Yield

Unit-7



Some Definitions

Unit-7

Growth:

Growth shows elongation and thickening of roots, stems and branches. There are many external (Temp. light, water, oxygen supply, nutrient supply, etc) and internal factors (Genetic control, etc) affecting plant growth. Growth: is the increase over a given period of time

Yield:

The volume or number of stems that can be removed annually or periodically, or the area over which fellings may pass annually or periodically, consistent with the attainment of objects of management.

Yield is the total available amount available for harvest at given time

Yield can be regarded as the summation of the annual increments

Forest Growth Model:

It describes the development of tree crops as they increase in age or as time changes

Stand:

A stand is a spatially continuous group of trees and associated vegetation having similar structure and growing under similar soil and climatic condition.

Unit-7

Some Definitions

Stand Growth Model:

It describes the stand and predicts growth through general parameters- total BA, mean values, forms and variance, CAI.

Variable Stocking Growth Model:

Assumption is that variation in growth can be predicted by using different models for each site or site quality class

Site Quality:

It is a measure of the relative productive capacity of a site. It depends on site factors, vegetative characteristics, plant indicators and tree characteristics.

Competition:

The struggle for the available food, light and moisture, which takes place among species and individual in an assemblage of plants.

Competition is of two types:

•*intraspecific* *2. Interspecific*

Whatever the structure of forests, rate of growth depends on degree of competition.

Some Definitions

Unit-7

Stand structure:

It is the physical and temporal distribution of trees in a stand. Distribution and representation of age and/or size classes of trees in a stand

-Keeps on changing with passage of time and age

-Result of growth habits of species, locality factors and management practices under which it was originated and developed

The distribution can be described : - by species;

- by vertical or horizontal spatial patterns;

- by size of the parts of trees, including the crown volume, leaf area, stem cross-section

- by tree age;

- by combination of the all above

Concept of Growth & Yield

Unit-7

Growth and yield models are designed to make predictions of potential yield from managed forests, based on data static inventory and permanent sample plots.

A model is an abstraction or simplified representation of a component of the real world. In forestry, the term *model* generally refers to a table, formula, or computer software package that describes how the forest structure is going to change.

Mathematical models permit estimates of growth to be predicted and management strategies to be optimized by computer. However, the final decision still rests with the manager (who must interpret the output and determine which strategies are feasible and ecologically and socially acceptable).

Growth & Yield Contd…

Unit-7

Optimization models can be developed for both even and uneven aged forests once the basic growth and yield simulation models have been formulated. These models can be very helpful for regional and national planning. Furthermore, if the forests are managed under multiple goals and for multiple products, optimization models can be developed using goal programming.

There are a number of ways to classify growth and yield models based on modeling assumptions, mathematical complexity, and prediction resolution. However, the simple classification proposed by Munro (1974) is still largely applicable today;

1. Stand level models
2. Distance-independent tree-level models
3. Distance-dependent tree-level models

Growth & Yield Contd…

Unit-7

Stand-level growth and yield models use stand parameters (e.g., age, density, site quality, basal area, volume, etc.) as inputs and predict how these parameters change over time. Examples of stand-level models include yield tables and yield functions.

Tree –level models use either stand table data or individual tree data as inputs. Changes in the attributes of classes or individual trees (e.g., dbh, total height, crown ratio) are predicted and stand-level attributes are obtained by summing the individuals. When stand table data are used as inputs, the models are often referred to as size-class models, and when individual trees are used as inputs, the models are referred to as single-tree models.

Growth & Yield Relationship

Unit-7

Growth: is the increase over a given period of time

Yield is the total available amount available for harvest at given time. Yield can be regarded as the summation of the annual increments.

Factors related Growth & Yield:

a) The point in time in stand development

b) The site quality

c) Degrees to which the site occupied

For even-aged stand, these factors can be expressed quantitatively through the variables of stand age, site index & stand density

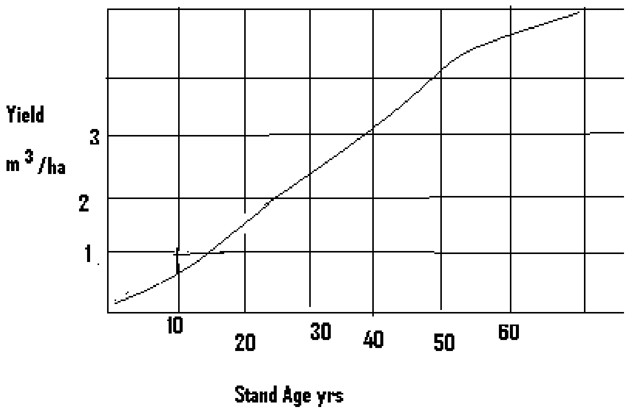
The measure of stand density most commonly used in G & Y models for natural stands have employed no. of trees per unit area

The Growth curve increases up to the inflection point of the yield curve and decreases thereafter

Rotation age is set sometimes as maximum MAI & CAI

Rotation age is not only depends up on the max production but also on stumpage value, tree size, mgt etc

Mathematical Relationship of Growth & Yield



Unit-7

$Y= e^{10-32*} A^{-1}$

Where, Y is the yield cubic m/ha and A is the age in yrs.

Equation of this type often fitted by linear regression techniques performing logarithmic transformation

$\ln Y = a+b*A^{-1}$ where Y is natural log of Yield (summation of increment),

Taking the first derivation dY/dA gives CAI

$CAI= (e^{10-32*} A^{-1})(32A^{-2})$

Growth and Yield of Even-aged Forest

Unit- 7.1

Even-aged stands

Stands where all trees are born or initiated at about the same point in time. While the tree sizes will increasingly vary as the stand ages , the calendar age of all trees is about the same when the stand is regenerated.

- Even aged stands have definite beginnings and endings.

Characteristics of even-aged forest

- bell-shaped curve.
- As the stand age, the bell shape is retained, but the total no. of tree decreases and the bell flattens and shifts to right. Form 100 year rotation or more, age variation up to 25% may be allowed

Growth and Yield of Even-aged Forest

Growth

- *Early immature stage* before canopy closure when rate of diameter growth is little affected by competition
- *Middle stage (responsive):* on canopy closure, ring width decreases but responds quickly to treatment such as thinning and fertilizing
- *Final stage(mature stage):* When ring width is narrow and is not so markedly responsive to treatment.

Growth and Yield of Uneven-aged Forest

Unit- 7.2

Uneven-aged stands

Stands are distinguished by lacking a definite beginning or end in time.

-Trees on any given area vary by age as well as size and frequently can be of several different species.

- The range of difference is usually more than 25% of rotation

- The system favors the tolerant climax species as the new seedlings grow up under the shade of old trees.

Uneven aged stands could be conceptualized as a summation of several different even-aged stands growing on the same parcel of land at the same time

Uneven aged stands have considerable differences in the age of the trees present and three or more age classes are represented

Growth and Yield of Uneven-aged Forest

The characteristics of uneven-aged forest

- Reverse J- shaped for uneven- aged stands

Unit- 7.2

Growth

Early stage: Extremely slow while sapling is dominated by overwood.

Middle stage: Tree is growing more rapidly but is still severely affected by its larger neighbors.

Final stage: Tree is dominant with a large, free, well-developed crown and neighboring trees of same size are few and distant.

Growth and Yield of Uneven-aged Forest

Yield of Uneven aged forest

Growth & Yield Equations: Moser & Hall (1969) developed equation of Volume-age for uneven aged stands

$$Y=[(y_0)\,(8.3348BA_0^{-1.3175})] * [0.9348-1.0203BA_0^{-0.0125})e^{-0.0062t}]^{-105.4}$$

Unit- 7.2

y_0 is the initial volume in cft/acre, BA_0 is initial Basal area/acre

t=time elapsed interval, year from initial conditions

Y= is predicted voume in cft, t yrs after observation of initial conditions y_0 and BA_0 at time

Difficulties:

- o In modeling uneven aged stands: stands composed of trees that differ markedly in age.
- o Age is not usable variable for Growth & Yield prediction purpose
- o Site quality assessment by site-index method is questionable

Growth and Yield Modeling (introduction only)

Unit- 7.3

- Growth and yield modeling has a long history in forestry.
- Methods of measuring the growth of uneven-aged forest stands have evolved from those developed in France and Switzerland during the last century.
- Uneven-aged growth and yield modeling has progressed rapidly since the first models were pioneered by Moser and Hall (1969)
- Projects tree growth usually as a function of present size and stand level variables (age, site index, BA/ha)
- Models assume that spatially all spp. and sizes of trees are uniformly distributed throughout the stand
- Not necessary to know individual tree locations

Growth and Yield Modeling Contd…

Common growth models

Simple Linear yt= a+b (t)

Linear transformation yt= at^{b} or log yt=(log a)+b(log t)

Exponential models yt=ae^{bt} or log yt=(log a)+t (b log e)

Polynominal models yt= a+bH+CH^{2}+……

Unit- 7.3

Hypothesis

1. ∆V = f (A, dh, N, v, BA, S)

Where,

∆V = Volume increment

A = age — Dh= dominant ht.

N= No. of stems/ha — V = volume/ha

BA= Basal area/ha — S= Site index

2. ΔD= f (RB,HD,Td) — ΔD=dia. Increment
   RB=Relative BA
   Hd=Dom.ht
   Td=Tree dominance

Growth and Yield Modeling Contd…

Unit- 7.3

- Growth and Yield models which use individual trees as the basic unit have been developed for mixed species, uneven aged as well as pure even aged stands

  An example is FOREST, a computer model published by Ek and Monserud (1974) for simulating the growth and reproduction of even or uneven aged mixed species stands

  Usual input for FOREST, a distance dependent model, is set of tree coordinates and associated tree characteristics (e.g. ht, dia, age, clear bole length and species)

- In any year of simulation optional redirection routines may be called to allow for regeneration by seed and sprout production of the overstory
- Silvicultural treatments, including site alteration, cutting or pruning operations may be specified for implementation as stand develops
- Output of the model is the form of periodic stand tables with yield and mortality for various products

1. Stand table projection

Stand Table is a table showing the distribution of stems by diameter classes for each of the series of crop diameters.

A stand table gives number of trees in each diameter class. Future stand tables can be predicted from current stand tables using a stand table projection method.

Unit- 7.3.1

✓Recognizes the structure of a stand and growth projections are made according to dbh classes.

✓best suited to uneven-aged, low-density and immature timber stands

✓There are cases where the reverse information is needed, i.e. predicting the past instead of the future. Examples of these scenarios include estimating timber damages and retroactively establishing the tax basis of timber that was earlier inherited or purchased (Quang, McCarty, Shanna 2006).

3. Stand table projection contd…

Unit- 7.3.1

The procedure growth prediction

- ✓A conventional inventory showing the number of trees in each dbh class.
- ✓Past periodic growth, by dbh classes, is determined from increment borings or from re-measurements of permanent sample plots, when increment borings are used, growth values must be converted from an inside-bark basis to outside bark readings
- ✓Past diameter growth rates are applied to the present stand table to derive a future stand table showing the predicted number of trees in each dbh class at the end of the growth period.
- ✓Numbers of trees in each class must then be corrected for expected mortality and predicted ingrowth.

3. Stand table projection contd…

Unit- 7.3.1

- ✓ Both present and future stand tables are converted to stock tables by use of an appropriate local volume table. Thus, for short growth periods, the expected changes in tree height during the growth period are inherently accommodated by diameter increases.
- ✓ Periodic stand growth is obtained as the difference between the total volume of the present stand and that of the future stand.

A Example of Stand Projection

The upward movement of trees into larger dbh classes is proportional to the ratio of growth to the chosen diameter class interval

$$\text{Growth-index ratio} = g/i$$

Where,

g = diameter growth (in inches)

i = diameter-class interval (in inches)

3. Stand table projection contd…

An example,

using the 6-inch dbh class,

Diameter growth = 2.2” and Interval = 2”

Here,

Unit- 7.3.1

Growth-index ratio = 2.2”/2” = 1.10

The interpretation of a growth-index ratio of 1.10 is that 1oo% of trees move up one dbh class, and 0.10 or 10% of these advance two classes. It means 90% moves up to the 8” and 10% move all the way to 10” class.

None will remain in the 6” class in this instance. If the growth-index ratio had been less than unity, for example, 0.80 or 80% of the trees would move up one class interval, and 20% would remain in the present dbh class.

3. Stand table projection contd…

To apply the method of stand table projection, the following data are required:

a) Diameter growth information

b) Present stand table

c) Local volume table

d) Information to calculate ingrowth

e) Estimates of mortality

Unit- 7.3.1

Assumptions:

- *All trees in each diameter class are located at the class mid-point and that all trees will grow at the average rate.*
- *Trees in each diameter class are evenly distributed through the class and that each tree will grow at the average rate,*
- *Recognize the actual position of trees in each diameter class and apply the diameter growth for individual trees in the class*

2. Whole stand modeling

Unit- 7.3.2

- Estimation of stand growth is crucial for forest planning and decision making.
- Whole stand Model is used to estimate and predict stand growth and yield. it is summarized to produce the stand-level variables actually needed for planning and decision-making.
- This model can predict current conditions based on measurements of stand basal area and the average dominant height of all trees, regardless of species.
- For future basal area estimates, a projection model based on existing basal area and commonly measured stand variables is needed.

2. Whole stand modeling contd….

- Stand variables overlap with respect to age, trees per acre, basal area per acre, and stand dominant height.

Unit- 7.3.2

- Current basal area per acre can be obtained through typical inventory procedures, while projected dominant height can be estimated using currently published site index/dominant height equations.

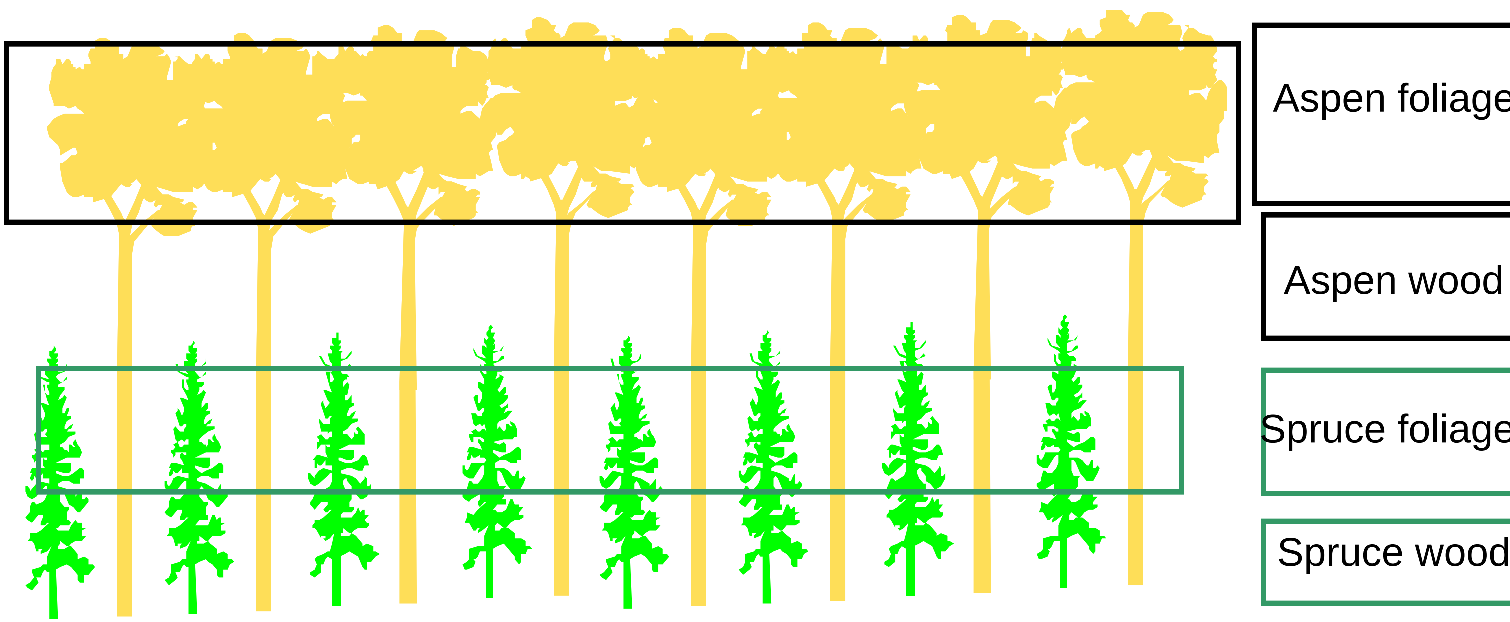
- In this modeling, growth and yield mostly are used as dependent variables and site quality, crown classes or stand density, number of trees, quadratic mean diameter, stand mean age, basal area, volume and crown class proportion of the stand trees are used as independent variables.

2. Whole stand modeling contd….

Limitations of whole-stand (stand-level) models:

1. Not feasible (yet) for many complex uneven-aged stands.
2. Not where detailed tree-level information is crucial,
3. cannot be reliably generated from stand-level variables.
4. Observational data for fitting whole-stand models are not available for the full array of silvicultural treatments and natural disturbances.

Unit- 7.3.2



3. Individual tree Modeling

Unit- 7.3.3

- Approaches to predicting stand growth and yield which use individual trees as the basic unit are referred to as individual tree models
- Individual tree models work by simulating the growth of each individual tree in diameter, ht, and crown and deciding whether it lies or dies, calculating its growth and volume, and growth rates.
- Models based on individual tree growth provide detailed information about stand dynamics and structure including the distribution of stand volume by size classes
- The components of tree growth in tree models are commonly linked together through computer program which simulates the growth of each tree and then aggregates these to provide estimates of stand growth and yield

1. Individual tree Modeling Contd…

- In any year of simulation optional routines may be allowed for regeneration by seed and sprout production of the overstorey
- Silvicultural treatments, including site alteration, cutting or pruning operations may be specified for implementation as stand develops
- Output of the model is the form of periodic stand tables with yield and mortality for various products

Unit- 7.3.3

Based on whether or not individual trees are required tree attributes, Individual tree models can be divided into two classes:

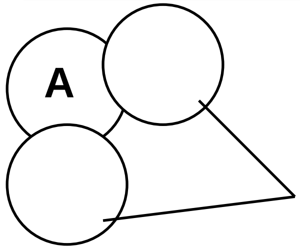
1. Distance Dependent Modeling
2. Distance Independent Modeling

1. Distant Dependent Models

Unit- 7.3.3.1

- ✓Growth of each tree is stimulated as function of its attributes, site quality, and a measure of competition from neighbors.
- ✓Each individual tree is mapped to determine the distance to, bearing, and size of all adjacent trees that are competing with the subject tree for light, moisture, nutrients.
- ✓The radius of the zone of influence of each tree is assumed to be circular and related to tree's dbh
- ✓Tree growth is commonly adjusted by random component representing genetic & micro site variability

1. Distant Dependent Models contd…



Neighboring
Adjacent Trees

Where,
A = Subject Tree

Unit- 7.3.3.1

Tree	Tree	Tree
Tree	Subject Tree	Tree
Tree	Tree	Tree

- These models use measures of point density to estimate the level of competition for each tree and model growth as a function of tree size and competition (Husch *et al*, 2003).
- Yield estimates are obtained by summing the individual tree volume & multiplying by appropriate expansion factors

1. Distant Dependent Models contd…

Here, by simulator PTAEDA developed by Daniels & Burkhart in 1975 for loblolly pine,

Unit- 7.3.3.1

$$C_i=\sum_{j=1}^{n}(dbh_j/dbh_i)/DIST_{ij}$$

Where

Dbh_j = dbh of j^{th} competitor

Dbh_i = dbh of i^{th} subject tree

$DIST_{ij}$=distance between subject tree I & j^{th} competitor

CI_i= competition index of i^{th} subject tree

n= number of competitors

1.2 Distant Independent Models

Unit- 7.3.3.2

- ✓ Distance independent models project tree growth either individually or by size classes, usually as a function of present size & stand level variables (eg. Site index, BA per unit area)
- ✓ It is not necessary to know location when applying these models
- ✓ Typically distance independent models consist of a diameter growth component,

i) a ht growth component (ht-dia relation to predict ht

ii) a mortality component

- ✓ Mortality may be generated i.e. determined through random process or it may be predicted as a function of growth rate

1.2 Distant Independent Models

- ✓ Each tree is modeled separately and its competitive position is determined by its individual diameter, ht. and condition to its stand characteristics, such as basal area and average diameter

Unit- 7.3.3.2

- ✓ Distance-independent models only require information about tree characteristics as inputs. These models predict tree growth based on initial tree characteristics and general expressions of competition (eg. Stand density index, total basal area, basal area of larger trees, relative height).
- ✓ Distance-independent models are more common than distance-dependent models primarily because detailed information about tree locations is relatively unavailable.

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Application of Growth & Yield Models

Unit- 7.4

- To model the flows of timber and other resources for forest management planning .
- To assess tree and stand responses to silviculture treatments and aid in the design and selection of appropriate treatments given management objectives.
- By linking growth and yield models to wildlife habitat suitability models changes in habitat quality can be assessed.
- To predict changes in tree and stand values for periods between successive inventories.
- To evaluate the impact of management policies on the sustainable use of forests
- To understand the general tree growth responses in relation to habitat characteristics
- To examine relationships between stand growth and structural diversity
- To forecast the development of both pure even-aged and mixed-species uneven-aged stands
- To make decisions for feasible investment options
- To make comparisons to choose best original spacing, rotation timing
- To predict work programs when budgeting costs and revenue

Yield Table

Yield Table is a tabular a statement which summarizes per unit area basis all essential data relating to the development of a fully-stocked and regularly thinned even-aged crop at periodic intervals covering the greater part of its useful life.

Unit- 7.5

Yield tables are valuable in such forest management activities as regulating cut, determining rotation length, making growth estimates, and forest valuation.

Yield tables are not applicable to uneven aged stands, since there is no one representative average age. A similar type of table has been produced for uneven-aged stands showing the volumes produced in growth for given periods with a certain level of growing stock on land of different site qualities.

Yield records for uneven aged stands over long periods are required to prepare this kind of table.

Yield Table contd…

- ✓ Yield Tables are a necessary forest management tool. They are used for predicting yields, as a standard for stocking, and as a measure of site quality. Yield predictions are used in analyses such as the financial analysis of proposed programs.
- ✓ It differs from the volume table in the sense that while an average tree by dia and/or ht classes, yield table gives different parameters of crops,i.e. BA, Volume of standing crop, volume removed by thinning, MAI, CAI, etc

Unit- 7.5

In short it gives all the quantitative information regarding development of a crop

There are several types of yield tables for even aged stands, depending on the independent variables used to predict growth.

1. Normal yield tables
2. Empirical yield tables
3. Variable density yield tables

Yield Table contd…

Unit- 7.5

Application of Yield Table

- Prediction of Yield
- Determination of site quality
- Estimation of G. S. at present or future
- Determination of increment of CAI and MAI
- Determination of rotation of maximum volume production: where CAI meets MAI
- Preparation of stock map by site quality
- Guide to silvicultural thinning

Limitations

✓Mainly used for pure stand

✓Age of stands needs to be known and so, not applicable to uneven-aged forest

✓A lot of data necessary to develop yield tables

✓Inflexible for change

✓Give result only for certain specific condition

Yield Table Contd…

Unit- 7.5

A model of yield table for Sal, S.Q.I, even aged fully stocked stands

Age	**Hdom (m)**	**Stems/ha**	**B.A/ha (m2/ha)**	**Stem vol.(m^3/ha)**
				standing
5	4.9	8581	19.4	49
10	11.2	3553	23.4	119
15	16.8	2127	27.4	191
20	21.2	1481	31.0	259
25	24.6	1120	34.1	320
30	27.2	892	36.9	374

Kinds of Yield Table contd…

1. Normal yield table

Many yield tables represent a normal forest. Early yield tables assumed ‘normal’ or near max’ stocking and hence were called “normal yield tables’. These tables are of limited usefulness because most stands do not have normal stocking but rather something less.

Unit- 7.5

- ✓ Temporary plots are deliberately located in fully stocked or normal density portions of a series of stands of varying ages representing various site qualities
- ✓ Volume-Age curve for each site quality classes & ages to compile normal yield tables

Application:

- Limited application, no reliable methods are available for predicting yields of non-normal or under-stocked stands
- The usual procedure has been continued to compute the ratio of BA of stands to Ba shown in Normal yield table and to apply this ratio for Volume as well

Kinds of Yield Table contd…

2. Empirical Yield Table

This includes stocking as a variable and many have been made for plantations. But in many cases, only normal yield tables are available and something there are no yield tables that fit the forest being managed.

Unit- 7.5

- ✓ An empirical yield table is similar to a normal yield table except that it supposedly applies to average rather than full stock or normal
- ✓ Problem of normality eliminated

Application:

- Adjustment made for deviation from the average density
- The resultant tables should more closely approximate realizable yields under operational forest mgt (use of average density)

Kinds of Yield Table contd…

3. Variable-Density Growth & Yield Equation

A multiple regression approach to yield estimation (MacKinny & Chaiken 1939) for natural stands of lobololly pine,

$$\text{Log } Y = b_0 + b_1A^{-1} + b_2S + b_3\log SDI + b_4C$$

Where, logY is logrithm of yield (cft/acre)

A^{-1} is reciprocal of stand age

us site index

logSDI= logrithm of stand density index

C is composition index (BA per acre/total stand BA)

Kinds of Yield Table contd…

4. Size Class Distribution Models

The distribution of volume by size class as well as overall volume is needed as input to many forest mgt

Widely applied G & Y model for even aged forest (no. of trees per unit area in each diameter class)

Mean total ht is predicted by age, stand density, site index

Volume per diameter class is calculated substituting the value of ht & diameter class into taper equation

Yield estimated by summing the voumel in diameter classes of increment

So $V= a+b\ dbh^2*H$

Others are based on logarithmic model as well

Many examples from page 293, Forest measurement by Avery and Burkhart, 1983

Kinds of Yield Table contd…

Size class Distribution models …

Diameter distributions in regular, uneven aged stands are J-shaped

So J-shaped model is used in uneven aged distribution

Alternative is parameters as a functions of some initial value & elapsed time from initial value

Other model is stand-table projection model by Ek (1974)

n=stand ingrowth-mortality-upgrowth+ingrowth

n_{is}-15.123$N^{0.38753}e^{-0.32908BA1.58011}N^{-1}$)

n_m= 0.03443n[(BA/N)/(ba/n)]$^{0.54748}$

nu= 0.0101070$n^{0.81433}$S[(ba/n)/(BA/N)]$^{0.14611}e^{-0.00160BA}$

Where, n_{is} is merchantable trees , is n_m mortality, nu is ingrowth present diameter to next diameter

n is no. of trees in specified diameter, N no. of trees per acre

BA is stand basal area /acre, ba is basal area of specified diameter class

S site index (ht for 50 yrs)

Kinds of Yield Table contd…

Unit- 7.5

Yield Tables are further classified as:

Based on grades of thinning

1. *Single Yield Table*

   Parameters have been given only for one grade of thinning which is usually C-grade

2. *Multiple Yield Table*

   Table in which data are given for different grades of thinning

Based on volume/value given

1. *Volume Yield Table*

   Yield Table which expresses outturn in terms of volumes

2. *Money Yield Table*

   Yield Table in which outturn is expressed in terms of money instead of volume

Sustained Yield

The material a forest can yield annually (or periodically) in perpetuity

- The regular continuous supply of desired produce to the full capacity of the forest
- The concept of s, yield was brought to U.S, from Europe at the beginning of 19th century

The concept of S. Yield,

1) Ensures stability and continuous supply of raw materials to the industries and to meet social and domestic needs of the people.
2) The basic consideration is that the later generations may derive from the forest at least as much of the benefits as the present generation.
3) Forest should be exploited such that annual or periodic felling do not exceed annual or periodic growth.

Sustained Yield contd…

Sustained Yield Management

Continuity of harvest, indefinitely, without impairment of productivity of soil.

Pre-requisites for Sustained Yield Management

To maintain a complete succession of equal areas of crops of all ages from one year to age of maturity.

For higher rotations, age classes may be formed [1-10, 10-20, 20-30, 30-40 Age class]

Limitations

1) Not possible to apply S. Yield principle in the first rotation

(- Density and quality of crop **vary** due to past management and also the composition of main spp. In mixture)

2) Virgin forests with a large proportion of deteriorating trees cannot be suitably worked under S. yield principle.

3) Forests under afforestation programmed provide various yields until after the end of first rotation.

4) Lack of technical manpower.

5) Inflexible to market conditions

Sustained Yield contd…

Management steps for Sustained Yield

To bring forest to clear- felling system in which all age-gradations from one year to rotation are present.

For natural regeneration, ten or even more age-gradations may be grouped (0-10, 10-20, 20-30,……..,to form age-class and the oldest age-class felled and regenerated to ten years

In selection forest, trees felled for exploitable size diameter

Source: Sustained yield concept in forest management-B.K. Paudyal. 1986. Forestry (9): 3-8

Yield Regulation

Regulation of production and supply of wood, determination of yield and prescribed means of achieving it.

(How much, where and when to cut?)

Objectives:

1. To cut each crop/ tree at maturity
2. To obtain max. yield of desired produce
3. To cut, approximately, same quantity of materials annually/periodically
4. To limit the area to be felled to that which can be regenerated

Yield regulations involved two functions

i. Calculation/ determination of amount of yield and prescribing the means of achieving it.

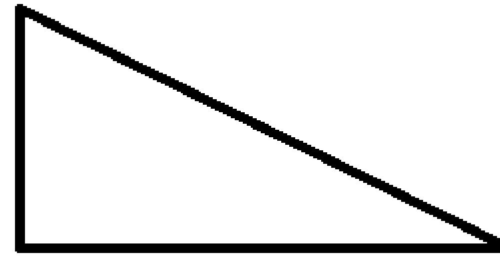
ii. Construction of a cutting (felling) plan

Correct regulation of yield is one of the main functions of sound forest management.

Estimating growing stock

Growing stock can be expressed as right angled triangle.

Area under the curve is growing stock volume and can be calculated by area of triangle.



Area of triangle = 1/2 base*ht

Therefore, $Gr = 1/2*R*Yr = R*Yr/2$

By substituting value of Gr in Hundeshagen formula

$(Ya/Ga = Yr/Gr)$

$Ya = Ga*Yr / Gr = Ga*Yr/ \; R*Yr/2 = Ga*2/R$

$Ya = 2*Ga/R = 2Ga/R$

Growing stock volume can be estimated by using a yield table:

Summation formula:

$Gr = n\,(Vn + V2n + \ldots . Vr\text{-}n + Vr/2)$

Where r= rotation age

n=no. of years between yield tables

Gr=Total vol. of g. stock on r years

Vn=Yield table volume/ha at age n, 2n,…..

Estimating Yield for Abnormal Stocking

Hundeshagen formula

$Ya/Ga=Yr/Gr$

Where Ya= actual yield

Ga=actual growing stock

Yr and Gr at rotation age

Yr=yield in a fully stocked forest

Gr= Growing stock in a fully stocked forest

Assumptions:

1. Yield to have straight line relationship with growing stock
2. Forest has normally distributed age structure
3. 10% volume produces 10% yield, this assumptions may not be bad for slightly over/ under-stocked stands.

Von Mantel's formula

Also called 'triangle formula'. An extension of Hundeshagen formula.

Basic assumption is that, in a regulated forest, growing stock increases in straight line with age.

Application of von Mantel's formula requires measurement of entire G.S. However, there is a limit below which it is practically impossible to measure.

In Howard's modification, enumeration were down to half exploitable girth, assumptions being made that girth was directly proportional to age.

Howard's formula for yield $Y=V/(3/8r)$ or $8v/3r$

Where V=vol. of G.S. enumerated down to half rotation age

Assumptions

1. Straight line relationship between yield and age
2. All assumptions required for using Hundeshagen formula

-Simple, no need of a yield table

-Neglects age class distribution and rate of growth

-Best applicable to regular, even –aged or nearly even aged normal forest.

The estimate using von Mantel's formula is lower than the yield table estimate. One reason for the difference is that measurement is assumed to start at age zero


Thank you