Unit-1: Introduction
1.1 Definition and Scope of Forest Mensuration

Forest

- An area set a side for the production of timber and other forest produce.
- A plant community predominantly of trees and other woody vegetation usually with a closed canopy (Glossary).

Mensuration

- It means measurement of length, mass and time etc.
- Is art and science of locating, measuring and calculating the length of lines, areas of planes, and volumes of solids.
- Forest Mensuration deals with the determination of the volume of logs, trees, and stands, and with the study of increment and yield (Graves, 1906).
- Forest Mensuration is the determination of dimensions, form, weight, growth, and age of trees individually or collectively, and of the dimensions of their products (Helms, 1998).
- It is a tool that provides facts about the forest crops or individual trees to sellers, buyers, planners, managers and researchers.

Objectives

- Provide quantitative information regarding forest resources that will allow making reasonable decisions on its density, use and management.

Forest mensuration serves the following objects

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

Scope

Branch of forestry which provides foundations of measurement principles applicable to any forest management problems.

- Has a wide scope.
- involves all stakeholders i.e. Labors, buyers, sellers, contractors, planners, managers/foresters and researchers.
- applicable to any forest measurement problems of wildlife management, watershed management, insect and disease incidence, recreation, tourism and in fact, many of the mensurational aspects of multiple use forestry.

Importance of Forest Mensuration

It is the keystone foundation of forestry.

- What Silvicultural treatment will result in best regeneration and growth?
- What species is most suitable for reforestation?
- Is there sufficient timber to supply a forest industry and for an economical harvesting operation?
- What is the value of the timber and land?
- What is the recreational potential?
- What is the wildlife potential?
- What is the status of biodiversity on the area?
- What is the status of the forest as a carbon sink?
- What is in the forest now?
- How is the forest changing?
- What can we do to manage the forest properly?
- How can it be assessed?
- And for what purpose?

It helps to answer all these questions and concepts involved in forest management.

- "You can't efficiently make, manage, or study anything you don't locate and measure".
- Forest mensuration is the application of measurement principles to obtain quantifiable information for forest management decision making.

Scale of Measurement

- Nominal Scale: determination of equality (numbering and counting). Eg. numbering of forest types in a stand map.
- Ordinal scale: determination of greater or less (ranking) eg. timber and log grading.
- Interval scale: determination of the equality of intervals or of differences (numerical magnitude of qty, arbitrary origin) eg. Fahrenheit temp., soil moisture etc.
- Ratio scale: determination of equality of ratios (numerical magnitude of qty., absolute origin) eg. length of objects, volumes, etc.

Bias, Accuracy and Precision

Bias

- refers to the systematic errors that may result from faulty measurement procedures, instrumental errors, flaws in the sampling procedure, errors in the computations, mistakes in recording, and so on.

Accuracy

- is the closeness of a measurement to the true value
- Success of estimating the true value of a qty.
- refers to the size of the deviation of a simple estimate from the true population

Precision

- means the degree of agreement in a series of measurements.
- is the closeness of a measurement to the average value.
- Refers to the deviation of sample values about their mean.

Relationship among Accuracy (A), Bias (B) and Precision (P).

- $A^2 = B^2 + P^2$

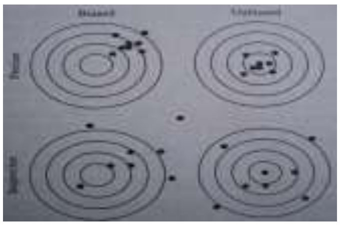


Fig. Precision, Bias and Accuracy. The target's bull's eye is analogous to the unknown true population parameter and the holes represent parameter estimates based on different samples. The goal is accuracy, which is the precise, unbiased target.

2.1.1 Diameter measurement and its significance

- A diameter is a straight line passing through the center of a circle or sphere and meeting at each end of circumference or surface.
- The most common diameter measurements taken in forestry are of the main stem of standing trees, cut portions of trees and branches.
- Diameter measurement is important because it is one of the directly measurable dimensions from which tree cross sectional area, surface area and volume can be computed.
- The point at which diameters are measured will vary with circumstances.
- The most frequent tree measurement made by forester is diameter at breast height (dbh).

- DBH is defined as the average stem diameter outside bark, at a point 1.3 m above ground as measured
- The rational of DBH measurement of individual trees is to estimate the quantity of timber, fuel wood or any other forest products which can be obtained from them.
- DBH is important variable to calculate the product quantity.
- These measurement are also necessary for making inventory of growing stock as well as to correlate height, volume, age, increment with most easily determinable dimension i.e. dbh

DBH has been accepted as the standard height for diameter measurement because …

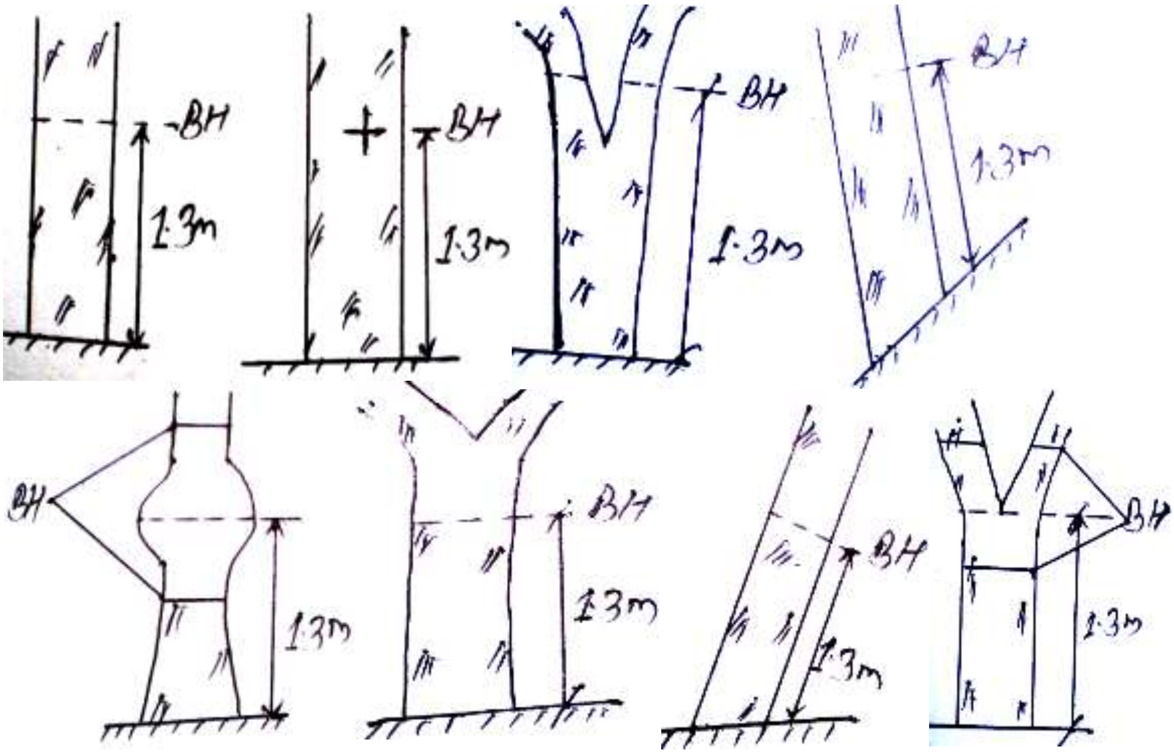
- It is a convenient height for taking measurements and therefore avoids the fatigue unnecessarily caused in taking large number of measurement at any other lower or higher point.
- The base of the tree is generally covered with the grasses and shrubs and even thorns sometimes and so the measurement of diameter or girth at the base is generally very difficult without incurring extra expenditure in clearing the base.
- Majority of the trees develop root swell near the base. This results in abnormal formation from ground level to a certain height along the bole. These abnormalities depend upon the species and the conditions of the ground on which the tree grows. However, in most cases, the abnormalities disappear below breast height.
- It gives a uniform point of measurement and therefore standardizes diameter measurements of trees.
- It is preferred to diameter measurement at stump height because stumps are never cut at uniform height and as such standardization is lost. The height of stump also depends upon the skill of the labor and the commercial value of the trees.
- Even if the stump height is standarized the value of such diameter or girth measurement is completely upset by a change in utilization standards demanding either higher or lower stump.

2.1.2 Rules of DBH measurement and instrument used

Rules of DBH measurement

- Moss, creepers, lichens and loose bark found on the tree must be removed before measuring the dia. over bark.
- Breast height (BH) should be by means of a measuring stick on standing trees at 1.3m above the ground level.
- BH point should be marked by intersecting vertical and horizontal lines 12 cm long, painted with white paint.
- On sloping land, the diameter at BH should be measured on the uphill side.
- In case of the tree is leaning, dbh is measured along the tree stem and not vertically, on the side of the lean for trees growing on flat ground and on the uphill side, for trees growing on sloping ground.
- The dbh should not be measured at 1.3m if the stem is abnormal at the level. BH mark should be shifted up or down as little as possible to a more normal position of the stem and then dia. Measured.
- BH should be taken at the lowest point above which the buttress formation is not likely to extend

When the tree is forked above the BH, it is counted as one tree, but when it is forked below BH, each fork should be treated as though it were a separate tree.



Instrument used in diameter measurement

- The most commonly used instruments for measuring diameters at BH are: Diameter tape, calipers, Biltmore stick, Sector Fork and other optical instruments.

Diameter tape

- The diameter of a tree cross section may be obtained with a flexible tape by measuring the circumference of the tree and dividing by π(D=C/ π). The diameter tapes used by foresters, however are graduated at intervals of π units (in or cms), thus permitting a direct reading of diameter. A diameter tape is a measuring tape that has scales on both sides: one side is specially marked to show the diameter of a tree, and the other is a normal scale.

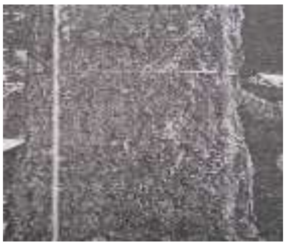
To measure diameter using a diameter tape:

- Wrap the diameter tape around the tree at the required height, ensuring that the tape is not twisted and the correct scale is visible.
- Make sure the tape is held tightly around the tree and at right angles to the main stem, and
- Read the tree diameter from the tape and record to the nearest 0.1cm
- Care must be taken that the tape is correctly positioned at the point of measurement that it is kept in a plane perpendicular to the axis of the stem, and that it is set firmly around the tree trunk.
- These tapes are accurate only for trees that are circular in cross section.
- The diameter tape is convenient to carry and in the case of irregular trees, requires only one measurement.

Calipers

- Calipers are often used to measure tree dbh or when diameters are less than about 60 cm. calipers of sufficient size to measure large trees, or those with high buttresses are awkward to carry and handle, and particularly in dense undergrowth.

- A calipers may be constructed of metal, plastic or wood, consists of a graduated beam/rule with two perpendicular arms. One arm is fixed at the origin of the scale and the other arm slides. When the beam is pressed against the tree and the arms closed, the beam of the caliper can be read on the scale.
- For an accurate reading, the beam of the caliper must be pressed firmly against the tree with the beam perpendicular to the axis of the tree stem and the arms parallel and perpendicular to the beam.



To use calipers to measure diameter:

- Place the calipers over the stem at the required height. Ensure they are held level with the stem and close them gently. Do not apply excess pressure to the calipers as this will compress the bark, resulting in an incorrect measurement.
- Record the diameter then take another measurement at a right angle to the first and record this measurement and
- Calculate the average of the two measurements and record to the nearest to 0.1cm.

These are generally less precise than a diameter tape but may be quicker to use, particularly for small trees, and can take into account some degree of stem eccentricity.

Measurement of upper stem diameters

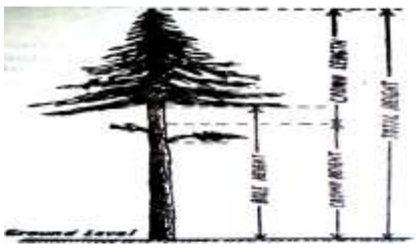
- Tree stem diameters above breast height are often required to estimate form or taper and to compute the volume of sample trees from the measurement of diameters at several points along the stem.
- Diameter measurement can be made at the desired points on the stem after tree felling or by climbing a tree.
- Instruments for measuring stem diameters of standing trees allow diameters to be determined from the ground at some distance from a tree.
- Some instruments are: Barr and stroud dendrometer, the wheeler pentaprism, the speigel relaskop etc.

Unit 2: Measurement of Trees

Height Measurement

- Height is the linear distance of an object normal to the surface of the earth.
- Tree height is the vertical distance measured from the ground surface.
- Height of standing tree is measured to find out its volume. Height of selected trees in a forest are also required to read volume tables, form factor tables, yield tables etc.

- Lastly, heights of trees are required to find out productive capacity of site. Height is generally considered as an index of fertility and with the knowledge of age it gives a reliable measure of the site quality of a locality.
- **Total height** of a standing tree is the distance along the axis of the tree stem between the ground and the tip of the tree.
- **Bole height** is the distance along the axis of tree between ground level and crown point. (crown point is the position of the first crown forming branch).
- **Commercial bole height** is the height of bole that is usually fit for utilization as timber.
- **Height of standard timber bole** is the height of the bole from the ground level up to the point where average diameter over bark is 20cm.
- **Stump height** is the distance between the ground and basal position on the main stem where a tree is cut.
- **Crown length** -The vertical measurement of the crown of the tree from the tip to the point half way between the lowest green branches forming green crown all round and the lowest green branch on the bole.
- **crown height -** The height of the crown as a measured vertically from the ground level to the point half way between the lowest green the lowest green branches forming green crown all round.

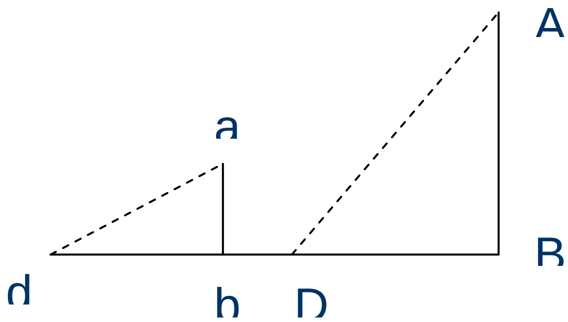


Methods of Height Measurement

Ocular Estimate: by using specific length of pole.

Non Instrumental methods

- **Shadow method**: a pole of convenient length is fixed upright in the ground and its height above the ground is measured. The shadows of the pole and the tree are also measured.



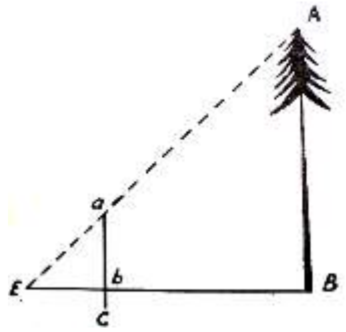
AB/ab = BD/bd, AB = BD x ab/bd

Where, AB is the tree, ab is the portion of the pole above the ground level, BD is the length of shadow of the tree and bd is the shadow of ab.

Single pole method

- Pole of about 1.5 m length vertically at arm's length in one hand in such a way that portion of the pole above the hand is equal in length to the distance o the pole from eye.

AB/ab = EB/Eb i.e. AB = EB x ab/Eb
Where,
AB = tree, ac=pole about 1.5 m long, Eb=ab



Instrumental method

- By using a instruments like hypsometer, clinometer, altimeters, abneys level, improverised calipers etc.
- All these instruments are based either on geometric principle of similar triangles or on trigonometric principles.

Principles of the height measurement

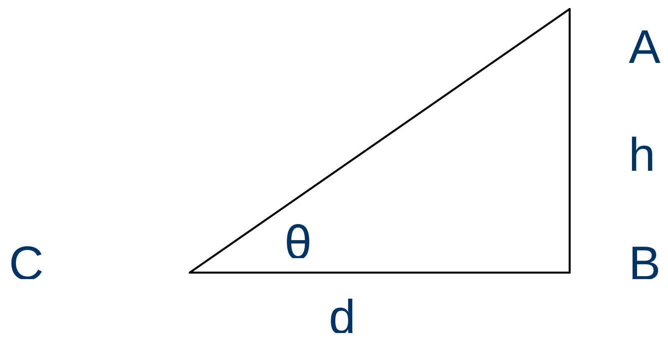
- Many types of height measuring devices and instruments in the course of time, but only a few have gained wide acceptance by practicing foresters.
- The two of the common designs are based on trigonometric principles and geometric principles.

Trigonometric principles

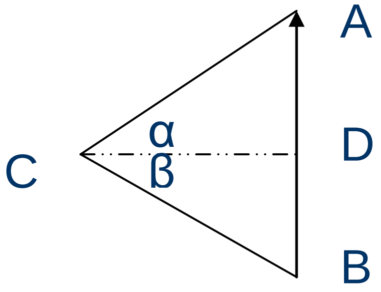
- The principles follow the basic rules of trigonometry for deriving heights of trees from distance and angle measurements. Two laws are applicable for this purpose and they are: tangent law and sine law.

Tangent law

- Applicable to right angle triangle
- Instruments based on this principle are Abney's level, clinometers, altimeter etc.
- with clinometers give the direct height reading is possible at fixed horizontal distances (15 m & 20 m) from the tree.
- For accurate results, trees must not lean more than 5° from the vertical, and the fixed horizontal distance must be determined by taped measurement.

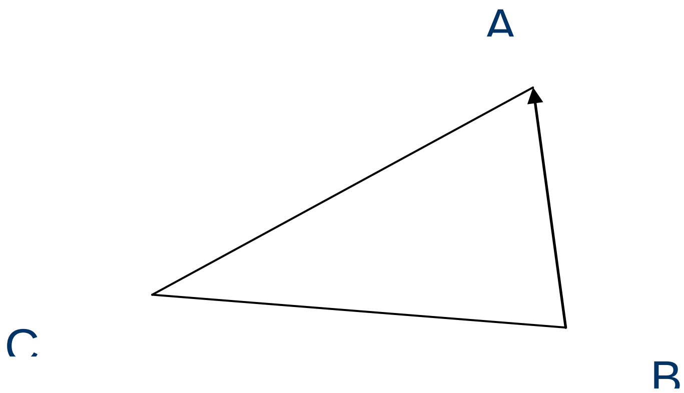


Tanθ = BC/BA, h = d x tan θ



Sine method

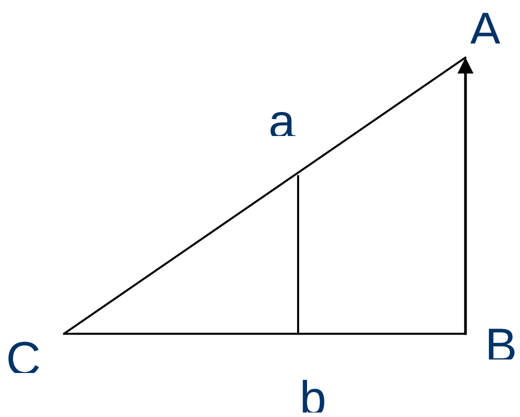
- Applicable to non right angle triangle is useful in deriving tree height in difficult conditions.
- Sines of angles are proportional to the opposite sides.



Sin<ACB/AB = sin < CAB/BC = sin< ABC/AC

Principle of similar triangle

- Corresponding angles are equal and the corresponding sides are proportional.
- By knowing the two sides of a triangle and only one side of the other, the corresponding second side of the latter can be found.
- Useful in rough estimation, not reliable for precise work.
- Eg. Christen's hypsometer, Improvised calipers



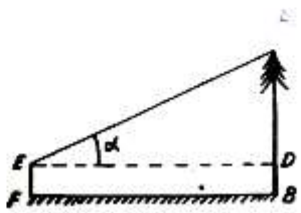
AB/ab = BC/bC,

AB = ab x BC/bC

Measurement of tree height (vertical tree) in plane and slope

On level ground

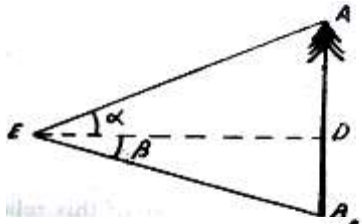
- The height of the tree is calculated with the help of the tangents of the angle to the top and the distance of the observer from the tree.



$AB = AD + BD = ED\tan\alpha + BD = BF\tan\alpha + EF$
Where, AB = tree, EF = eye height of the observer,
BF = horizontal distance

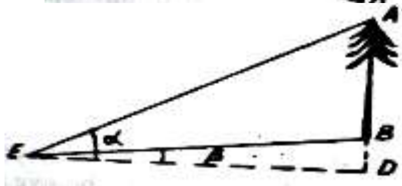
On sloping ground

- Where the observer is standing at such a place that the top of the tree is above the eye level and the base below it.



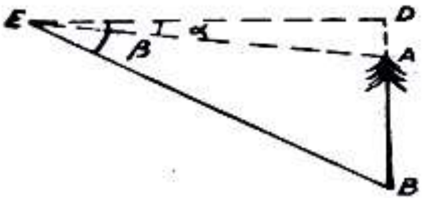
$AB = AD + DB$
$= ED\tan\alpha + ED\tan\beta = ED(\tan\alpha + \tan\beta)$
$= EB\cos\beta(\tan\alpha + \tan\beta)$

- Where top and base of the tree are above the eye level.



$AB = AD - BD$
$= ED\tan\alpha - ED\tan\beta = ED(\tan\alpha - \tan\beta)$
$= EB\cos\beta(\tan\alpha - \tan\beta)$

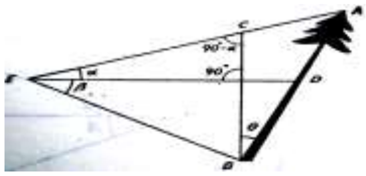
- Where base and top of the tree are below the eye level



$AB = BD - AD$
$= ED\tan\beta - ED\tan\alpha = ED(\tan\alpha + \tan\beta)$
$= EB\cos\beta(\tan\alpha + \tan\beta)$

Measuring of Height of Leaning tree

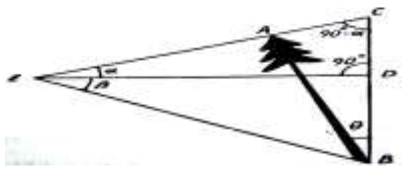
- **Case – I (a):** In case of the observer standing at between the top and bottom of the tree (lean away from observer)
- $AB/\sin\angle AEB = EB/\sin\angle EAB$



$AB = EB\sin\angle AEB/\sin\angle EAB$
$= EB\sin(\alpha+\beta)/\sin[90-(\alpha-\beta)]$
$= EB\sin(\alpha+\beta)/\cos(\alpha-\beta)$

(b) In case of the observer standing at between the top and bottom of the tree (lean towards observer)

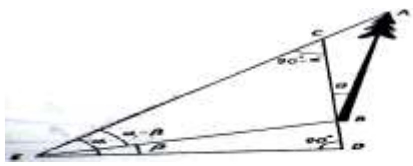
- $AB/\sin\angle AEB = EB/\angle EAB$



$AB = EB\sin\angle EAB/\sin\angle EAB$
$= EB\sin(\alpha+\beta)/\sin[90-(\alpha-\theta)]$
$= EB\sin(\alpha+\beta)/\cos(\alpha-\theta)$

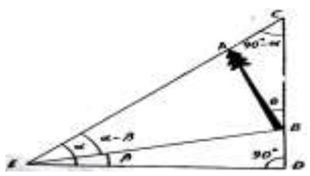
Case (II)

(a) When the observer is below the top and bottom of the tree (lean away from observer)
$AB/\sin\angle AEB = EB/\sin\angle EAB$
$AB = EB\sin\angle EAB/\sin\angle EAB$
$= EB\sin(\alpha-\beta)/\sin[90-(\alpha+\theta)]$
$= EB\sin(\alpha-\beta)/\cos(\alpha+\theta)$



Case-II

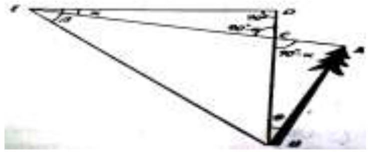
b) This is similar to case II (a) except that the lean is towards the observer.
$AB/\sin\angle AEB = EB/\sin\angle EAB$
$AB = EB\sin\angle EAB/\sin\angle EAB$
$= EB\sin(\alpha-\beta)/\sin[90-(\alpha-\theta)]$



= EB sin (α-β)/cos(α-θ)

Case (III)

(a) When the observer is above the top and bottom of the tree (lean away from the observer).



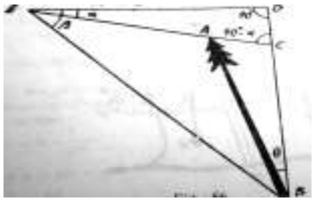
AB/sin<AEB = EB/Sin<EAB

AB = EB sin <EAB/Sin <EAB

= EB sin (β-α)/sin [90+(α-θ)]

= EB sin (β-α)/cos(α-θ)

b) Same as case (III) a, but lean toward from the observer



AB/sin<AEB = EB/Sin<EAB

AB = EB sin <EAB/Sin <EAB

= EB sin (β-α)/sin [90+(α+θ)]

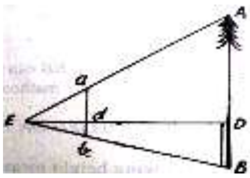
= EB sin (β-α)/cos(α+θ)

Height measuring instruments

- There are various instruments to measure height of a tree.
- Height measuring instruments are called hypsometers.
- Those instruments based on trigonometrical principles are more accurate than the ones employing geometrical principles.
- The Abney's level, Haga Altimeter, Blume-Leiss Altimeter, and Sunto Clinometer are similar in accuracy.

Christen's Hypsometer

- Consists of a strip of metal, thin wood or card board about 2.5 cm wide and 33 cm length. It has two flanges or protruding edges one at the top and other at the bottom**.**
- Relationship: AB = BD x ab/bd where, AB = tree height, BD = staff, ab = distance between flanges, bd = distance above the inner edge of the lower flange.
- Generally used to measure the tree height up to 30 m.



Abney's level

- The instruments consists of a graduated arc mounted on a sighting tube about 6 inch long.
- The arc may have a degree, percentage or topographic scale.
- When the level bubble, which is attached to the instrument, is rotated while a sight is taken, a small mirror inside the tube makes it possible to observe when the bubble is horizontal. Then the angle between the bubble tube and the sighting tube may be read on the arc.

Sunto Clinometer

- It is a handled device housed in a corrosion-resistant aluminum body.
- A jewel bearing assembly supports the scale, and all moving parts are immerged in a damping liquid inside a sealed plastic capsule.
- It is held to one eye and raised or lowered until the hairline is seen at the point of measurement. At the same time, the position of the hairline on the scale gives the reading. Reading can be taken at 15 or 20 m distance from the tree.
- It is also available with a rangefinder and several scale combinations: percent and degrees, percent and topographic, degree and topographic and feet and metric.

Haga altimeter

- It consists of a gravity-controlled, damped, pivoted pointer and a series of scales on a rotatable, hexagonal bar in a metal, pistol shaped case.
- It includes six regular scales for use at 15, 20, 25, 30, percentage and topographic scale.
- Sight are taken through a gun type peep sight; squeezing a trigger locks the indicator needle and the observed reading is taken on the scale.
- A rangefinder is available with this instrument.

Blume-Leiss Altimeter

- It is similar in construction and operation to the Haga altimeter, although its appearance is somewhat different.
- The five regular metric scales are 15, 20, 30 and 40. A degree scale is also provided.
- All scales can be visible at the same time.
- It is available with a rangefinder.

Spiegel Relaskop

- It can be used to measure stand basal area, tree height and diameter at any point up a tree bole.
- There are several makes of the instrument and the number of bands as well as height measuring scales vary from make to make.
- It can be used as a clinometer with readings in degree or percent.
- For height measurement, the horizontal distance is first determined and then height is read directly from the corresponding height band.

Sources of errors in height measurement

- **Instrumental errors** – occur as a result of some deficiency in instrument apart from its incorrectness.
- **Personal errors** – shaking hands, misreading
- **Errors due to measurement** - due to full of shrub and undergrowth
- **Errors due to observation** – due to bushes, the base of the tree is not visible
- **Errors due to lean of trees** – the height of the tree leaning towards the observer is over estimated while that of tree leaning away from the observer is under estimated.

The percentage error due to lean

$$= \frac{\text{Cos (angle of elevation +/- lean angle)}}{\text{Cos (angle of elevation)}} - 1 \times 100$$

Measurement of length, diameter and sectional area of logs

- The ultimate object of all mensurational activity in forest is to calculate or estimate quantity of wood contained in trees and consequently in crops not only for sale but also for research, predicting future yields, estimating increment to assess return on capital etc.

- Measurement of felled trees are to determine the quantity of merchantable volume, to obtain statistical data that could be applied to standing trees for the purpose of estimating the yield, to estimate the growing stock and to estimate the increment of woods and forests.
- Volume estimation may be made most accurately when the logs are separated and accessible to the measurer. A tree, therefore, could be separated into stem wood, which may be further divided into timber and small-wood, crown and branch wood. Stem wood may be measured after division into sections for obtaining real volume.
- The measurement requires length and mid diameter or mid girth except where the tip is measured as frustum of a cone where the diameter or girth at the ends are measured. Logs are neither cylinder nor often of any regular geometrical shape. Therefore in order to calculate the volume, the shape of a quadratic paraboloid is adopted.
- It is usual to cut the tree into logs due to irregularity in tree tapers. The lengths of the logs depend upon the rate of taper and market requirements. As the diameter at the thin end of the log determines the sawn volume that can be taken out of it, the greater the rate of taper, the lesser is the length of the log. Another consideration that affects the length of log is the mode of transport.
- When the logs are made for calculating volume of felled trees for research work, all logs including the first are of uniformly 3m in length except the top end log which may be up to 4.5m. But if the end section is more than 1.5m in length, it is left as separate rate log.
- Simple tape or a graduated rod can be used to measure the length of a given logs. Similarly, diameter tape, caliper and other optical instruments are used to measure the measure diameter and sectional area of logs.
- Logs are the round pieces of a tree with square cut ends. Normally, a log is 8 ft or over in length and suitable for lumber.
- The cross-sectional area or basal is found from the diameter as follows:

Basal area $=\pi$ d2/4

Formulae for log volume calculation

- Volume has been the traditional measure of wood quantity and continues to be the most important measure in spite of increasing use of weight or biomass as a measure of forest productivity.
- Basal portion of the tree corresponds to the frustum of Neiloid, the middle portion to the frustum of Paraboloid and the top portion to a cone.
- The following table gives formula for calculation of volume of the solid of revolution together with the formula for cylinder for comparison

S.N.	Forms of solid	Volume of full solid	Volume of frustum of solid	Remarks
1	Cylinder	Sl	Sl	……
2	Paraboloid	Sl/2	$\frac{S1+S2}{2}$ X l Sm X l	Smalian's formula Huber's formula
3	Cone	Sl/3	$\frac{S1+S2+\sqrt{S1S2}}{3}$ X l	

4	Neiloid	Sl/4	S1 +4Sm+S2 X l 6	Prismoidal or Newton's formula

Where, S is the sectional area at the base
S1 is the sectional area at the thick end
Sm is the sectional area at the middle
S2 is the sectional area at the thin end and
L is the length of the log or height of the solid

- Prismoidal formula or Newton's formula is the best and most accurate method for volume calculation.
- Smalian's formula over-estimates the volume.
- Huber's formula under-estimates the volume.
- Huber's formula is more easy and accurate than Smalian's formula.
- We can use Smalian's formula for calculating the volume of stacks wood.

Quarter Girth Formula

- Volume of log = (g/4)2 x L, where, g is the girth of the log at the middle (in inches) and L is the length of log (in ft).
- Volume of log in cubic feet is calculated using the following formula,
  V = (g/4)2 x L/144.
- This is the system of measurement used in Great Britain and also in Nepal for sale purpose when round timber is sold by volume.
- This formula gives only 78.5 % of the cubic volume of cylinders, thus allowing a loss of 21.46%.
- *Quarter Girth formula is used to estimate the standing volume of a coupe in Nepal*

Solid volume of firewood

- **Xylometric method** W: w = V: v

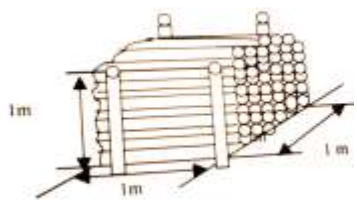
Where, W is the weight of the whole stack of wood, w is the weight of submerged pieces, V is the volume of the whole stack and v is the volume of submerged pieces.

Specific gravity method

- Specific gravity of a piece of wood = weight of wood / wt. of same volume of water
  or = density of wood/density of water

Measurement of Staked volume

- It is the bulk volume occupied by pieces of wood one meter long piled on one meter width, and one meter high.
- This volume contains air space and wood in variable proportions a/c to the form of the logs.
- Piling co-efficient has to be used to get the actual volume.
- Piling co-efficient = π/4=0.7854, if all pieces of wood were cylindrical and of the same diameter.



Dimensions of Chatta

- Standard size of Chatta = 5 ft x 5 ft x 20 ft = 500 cft including air space.
- One Chatta in metric unit = 14.16 m3
- The following formula should be used in order to calculate the amount of fuelwood that is obtained from the total volume up to 10 cm top-diameter of class III and the

remaining portions up to 10 cm top-diameter of class I and II trees which could not be used as timber.

- Amount of fuelwood in terms of number of Chatta

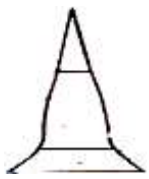
= (0.8778xvol.I+1.4316xvol.II+3xvol.III)/1000

Where, Vol.I = gross volume of up to 20 cm top-diameter of class I trees, Vol.II = gross volume of up to 20 cm diameter of class II trees and Vol.III = gross volume of up to 10 cm top-diameter of class III trees.
(all trees except Khayar having dbh of 27.94 cm (11 in) or more should be classified)
Class I = Green, dead or dying, standing or uprooted tree having good and solid trunk in which sign of any disease or wound is not visible from outside.

Class II = Green, dead or dying, standing or uprooted tree in which complete volume could not be realised due to hollowness or other sigh of defect but at least two straight logs of each 1.83 m (6ft) long or one straight log of 30.5m (10 ft) long which should have at least 20 cm diameter could be recovered.
Class III = Remaining trees which do not belong to class I and class II

Unit-3: Measurement of Form
Tree stem form

- **Form** is the rate of taper of a log or stem
- **Taper** is the decrease in the diameter of a stem of a tree or of a log from base upwards.
- The taper varies not only with species, age, site and crop density but also in the different parts of the same tree.
- Basal portion of the tree corresponds to the frustum of **Neiloid,** the middle portion to the frustum of **Paraboloid** and the top portion to a **cone**.



Metzger's Theory

- Assumption: Tree stem should be considered as a **cantilever beam** of uniform size against the bending force of the wind.
- The wind pressure acts on the crown and is conveyed to the lower parts of the stem in an increasing measure with the increasing length of the bole.
- Thus, the biggest pressure is exerted at the base and there is a danger of tree snapping at that place, to counteract this tendency, the tree reinforces itself towards the base.
- Tapering increases if it is an isolated area, an area where largest density, in those area-tapering decreases.
- Though tapering is the natural processes which can be controlled by human interference. If competition increases, tapering decreases.

Methods of studying form

- By comparison of standard form ratios (Form factor and Form quotient)
- By classification of form on the basis of form ratios (Form class and Form point ratio), and
- By compilation of taper tables

Form Factor

- The ratio of the volume of the tree or its part to the volume of a cylinder having the same length and cross section as the tree.
- Ratio between the volume of a tree to the product of basal area and height.

F = V/Sh

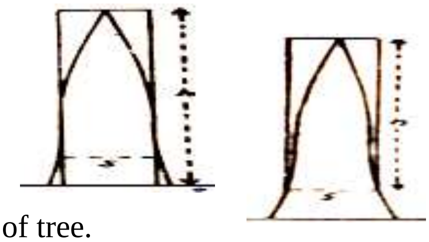
Where, F = form factor, V = tree vol, S = basal area at bh and h = ht of the tree

Types

- Artificial form factor
- Absolute form factor
- Normal form factor
- **Artificial form factor**: known as breast height form factor. Basal area or diameter is measured at dbh and the volume refers to the whole tree both above and below the point of measurement.
- **Absolute form factor**: Basal area is taken at any convenient height and height is taken above this diameter taking. Volume refers only to that part of the above the point of measurement.
- **Normal form Factor**: Basal area or diameter is taken at constant proportion of the total height of the tree like 1/10th, 1/20th etc of the total height and volume refers to the whole tree above ground level.

Use of form factors

- To estimate volume of standing tree
- To study of law of growth



Form height (Fh)

- It is the product of the form factor and total height of tree.

Fh = V/S

Form Quotient (F.Q.)

- The ratio of the mid-diameter and diameter at breast height is called form quotient.

F.Q. = mid-diameter/dbh

Types

- **Normal form quotient** is defined as the ratio of mid-diameter or mid girth of a tree to its diameter or girth at breast height.
- **Absolute form quotient** is the ratio of diameter or girth of stems of one half of its height above the dbh and diameter at breast height.
- Form quotient is the third independent variable of volume table that can be used to predict the volume of a tree stem.
- **Form class:** Form class is defined as one of the intervals in which the range of form quotients of trees is divided for classification and use. Tree may be grouped into form classes expressed by form quotient intervals such as 0.5, 0.55 to 0.6 and so on.
- **Form point ratio: Form point** is defined as the point in the crown as which *wind pressure is estimated to be centered*. **Form point ratio** is defined as the relationship of the form point above ground level to the total height of the tree. If form point ratio is known, the form quotient and form class of a tree can be determined.

Taper tables

- It provides the actual form by diameters at fixed points from the base to the tip of a tree. Volume table can thus be prepared from taper tables in desired unit.

Types of taper table

- **Ordinary taper tables or diameter taper tables-** give the taper directly for diameter at breast height without reference to the tree form.
- **Form class table tables-** give for different form classes the diameters at fixed points on the stem.
- Taper equations represent the expected diameter as a function of height above ground, total tree height and dbh irrespective of tree species and generalized for form class.
- Many different forms of taper equations have been developed as no single one can adequately represent all species in all situations. The use of taper equations allows us

to obtain volumes for any desired portion of a tree stem by predicting upper stem diameters.

Eg. D = dbh √ (bo + b1 (h/H)+ b2 (h2/H2)

Where, d = stem diameter at any given height h above ground, H = total tree height and bo, b1 and b2 = regression coefficient

Equations for Tree Form

Hojer`s formula

d/dbh = C log c+l
c

Where, d is the diameter at any point on the stem. C and c are constants for each form class, l is the distance from the top of the tree to the point at which d is measured, expressed in percentage.

Behre`s formula

d/dbh = l/a+bl

Where, a and b are constants for each class, such that a +b =1 and d an l have the same meaning as given for Hojer`s formula. This formula is more consistent.

Unit-4: Biomass Table and Equation

Biomass measurement (Root, leaf, stem and branch Biomass)

- Biomass is the weight of the above ground vegetative matter produced per unit area. Thus, the wood, their branches, bark and leaves produced by trees, shrubs and other vegetation growing above the ground are included in biomass but it does not include roots, tubers etc (old definition).
- All the plant materials ranging from tree stems, twigs, flowers, leaves, roots, grasses and litter are biomass.
- In ecology, **biomass** refers to the accumulation of living matter. That is, it is the total living biological material in a given area or of a biological community or group. Biomass is measured by weight, or by dry weight, per given area.
- In order to manage the forest scientifically, estimates of present stocking and potential productions are required. The use of biomass as a management tool is a relatively new concept.
- Many of the products available from forests in the middle hills of Nepal, such as fodder, compost material and firewood are quantified in terms of weight rather than volume. The parameter to be measured and the nature of the components for which biomass estimates are to be derived depend on the forest types. In Nepal, the forests can be categorized in to three types for this purpose. They are:
- Natural broadleaf forests with mixed species
- Coniferous forests both natural and plantations
- Broadleaf plantation of single and mixed species
- The general methodology and models for determining biomass estimates are common to all forest types.
- Diameter breast height is the recommended predictor variable. sometimes height is also considered. However, for species which have a very low branching habit or species in a coppiced broad leaf natural forest, diameter measured at 0.3m from the ground level is a better predictor.
- It is necessary to carry out destructive sampling to establish correlations for estimating biomass of standing trees.
- About 30 trees should be selected, felled and separated into main stem, branch wood, twigs and leaves

- The main stem should be considered up to the thin end of 10 cm girth or 3.18 cm dia. The rest should be included in branch wood.
- The felling should be done as close to ground level as possible.
- Separate portions should be weighted immediately after felling. The felled wood loses moisture very fast.
- Disc samples should be collected for oven-dry weight.

Regression equation method

Process of constructing a Biomass table:

- Selection of tree and tree measurement (Measure diameter at breast height and height of sufficiently large numbers of trees) –destructive sampling.
- Weight measurement (green and oven dry weight measurement)
- Model formulation
- Feed the data in to the SPSS (Statistical Package for Social Science) or MS Excel
- Model selection/ Choosing the best model and verifying the accuracy of the model constructed.

Model selection and evaluation

Several statistics were used in comparing and evaluation the candidate regression model

- Adjusted co-efficient of determination (R2adj)
- Significance of the parameter values
- Homogeneity and distribution of the residuals
- Root Mean Squared Error (RMSE)

Biomass equations

- Many forms of regression equations have been used by many workers.
- Equations may be linear, quadratic, cubic, power, logarithmic and exponential etc
- Some models are

B = a + bD, B = a + bD + cH

B= a + d D2H, lnB = a + b ln(D) + c ln(H)

lnB = a + b ln(D)

- Widely used biomass equation is, B or W = a + bD2H

Where, B = Biomass in kg, D = diameter, H = height, a = regression constant, and b &c = regression coefficient

Biomass equations used in Nepal

- Model equation, ln Y = a + b ln X, has been suitable for calculating the biomass, where Y = oven dry weight in kg and X = dbh
- Model equation, ln W = a + b ln dbh, (for plantation species and natural forests) where W = Green weight of tree components (biomass) in kg, dbh = over bark diameter at breast height in cm, a and b = coefficient of the model.

Biomass Tables

- For plantation species- Dalbergia sissoo (oven dry weight in kg)

Dia. (cm)	Weight (kg)			
	Stem	branch	foliage	Total
1	2.49	0.66	-	3.16
5	12.69	2.72	-	15.50
10	41.46	7.57	-	49.28

- For natural forest type (fresh green weight in kg) – Castanopsis indica (Dhale katus)

Dia. (cm)	Weight (kg)			
	Stem	branch	foliage	Total
1	-	0.2	0.3	0.5
5	7.0	2.4	3.7	13.10
10	37.10	12.90	10.5	60.50

Source: Nepal Forestry Handbook, 2002

Volume and Bio-mass of trees and products

Volume Table

- To estimate volume of stand, one can measure directly the volume of each tree in a stand and add all figures together. On large stands this is practically difficult. Therefore, the use of volume table is necessary in that case.
- A volume table is a table showing for a given species the average contents of trees, logs or sawn timber for one or more dimensions.
- Volumes may be listed for some specific portion of the stem only, or for the total stem.
- The volume tables are based on the actual measurements of a large number of trees and provide volume estimate of the same species on the assumption that the trees of the same species with the same dimensions will have the same volume.
- Volume tables do not give exact volume of an individual tree because the volume of the individual tree may be different from the average, which is based on several individuals.
- The volume of a tree mainly depends on three variables i. e. diameter, height and form. Out of these variables, diameter at breast height is the most important because of its ease of measurement.

The volume tables give the information on the volume of the product and beside this, give the following information:

- Name of species
- Locality from which the data were collected
- Method of compilation and collection
- Mathematical equation
- Applicability of the table

Types of Volume Tables

- Trees with identical breast height diameters and total heights, even for the same species, do not necessarily have the same volume.
- Therefore a single universal volume table that would apply to all conditions and species is not possible. There are some basic factors that cause variation in volume.
- Therefore, volume tables can be classified according to the number of variables used, scope of their application and kind of outturn.

Volume tables based on number of variables

Volume table based on one variable: dbh alone

- In this volume table, trees are classified by dbh (ob) only.
- These volume tables show average volumes of trees by diameter classes.
- It is called local volume table. These are easy and quick to use.
- The common model for this type of volume table is

$$V = a + b (g) \text{ or } V = a1 + b1 (d2)$$

Where, v = volume over bark (ob), g = basal area ob at bh, d = diameter ob at bh and a, a1, b & b1 are constants to be estimated.

Volume table based on two variables: dbh and height

- Applicable to larger/wider areas.
- These volume tables give volumes of trees by diameter classes as well as by height classes pertaining to the total height of the trees.
- It is called general volume table
- The common model for this type of volume table is

$V = a + b(d2h)$ or $V = a + bd2 + ch$

Where, v = volume of ob, d = diameter ob at bh, h = height of tree and a, b & c are regression constant to be estimated

Volume table based on three variables: dbh, height and form quotient.

- It is called the form class volume tables.
- These volume tables are more accurate but are expensive and difficult to construct and use.
- The common model for this type of volume table is

$V = a + b1 (d2h) + b2q$

Where, V = volume of tree, h= height, d = diameter at bh, di= diameter at height i above ground level, q = di/d and a, b1, & b2 are regression constant to be estimated.

Volume tables based on scope of application

General volume table

- based on two variables i.e. dbh and height, and on the volume of trees growing over a large geographical area.
- It is applicable to a wider range of distribution of species.
- It shows volumes of trees by diameter classes and in each diameter classes by height classes.
- These tables are used for deriving local volume tables.
- These tables are prepared from either graphical method or regression method.

Regional volume table

- compiled from measurement of trees growing in a region and limited application than general volume tables.

Local volume table

- based on one variable i.e. dbh and compiled from the measurement of trees growing in restricted locality.
- applicable to limited or restricted area only.
- These are either prepared directly from field data or derived from general volume table, either by graphical method or regression method.

Volume tables based on kind of outturn

Standard Volume Tables

- give separately the estimated outturn in the form of standard timber.
- The volume is given in terms of round timber and includes volume of stump.

Commercial Volume Tables

- the 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.

Sawn outturn tables

- contents of sawn timber are given as volume measured down to a thin end diameter to which conversion is done, stump volume being omitted.

Assortment tables

- give volume in round down to various stated thin end diameters. Eg. Standard timber volume and commercial volume table.

Sawn outturn assortment tables

- Similar to assortment table and give sawn outturn in the number of standardized pieces instead of volume in round.

Method of Preparation of volume tables

- Graphical method
- Regression equations method or the method of least squares fit

Regression method is preferable due to its easy application through computers.

Regression equation method

Process of constructing a volume table:

- Measure diameter at breast height and height of sufficiently large numbers of trees.
- Compute the volume of selected sample trees representing the population (using formula, V = $\pi d2h/4$ or others).
- Prepare a table showing diameter, height and volume
- Model formulation
- Feed the data in to the SPSS (Statistical Package for Social Science) or MS Excel
- Model selection/Choosing the best model and verifying the accuracy of the model constructed.

Model Selection

Several statistics were used in comparing and evaluation the candidate regression model.

Adjusted co-efficient of determination (R2adj)

- $R2\ adj. = 1-(1-R2)\frac{(n-1)}{(n-p)}$

Where, R2 = coefficient of determination, n = total number of observations and p = number of parameters used in regression model

Significance of the parameter values

- The significance test of estimated fixed model parameters tested whether the true value of the parameter is zero or not.
- If the absolute test value was greater than tabulated value i.e. the p-value was less than 0.05, the parameter was treated was significant.

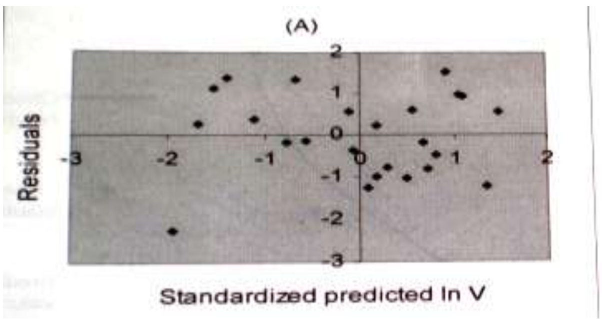
Homogeneity and distribution of the residuals

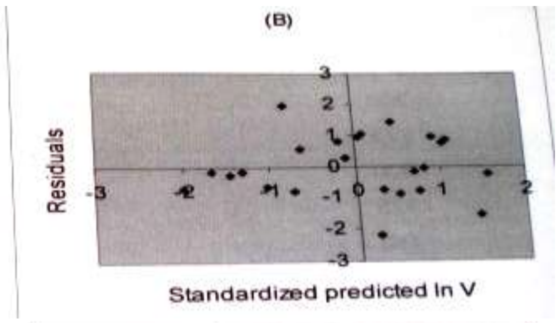
- Plotting of the residuals from the model over predicted values or independent variables should show a random, constant variance pattern around a residual value of zero.

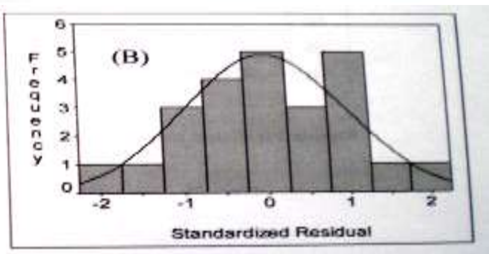
Root Mean Squared Error (RMSE)

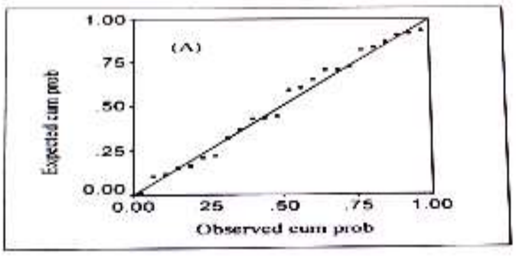
- $RMSE = \sqrt{\frac{\sum (Yi-Yi)2}{n-p}}$

Where, Yi and Yi are the observed and predicted values respectively; n is the total number of observations used to fit the model; and p is the number of parameters.









Preparation of General volume table from regression equation method

- Measure diameter at breast height and height of sufficiently large numbers of trees.
- Compute the volume of selected sample trees representing the population (using formula, V = $\pi d2h/4$ or others).
- Model formulation

Several linear and non-linear model formulation and their performance evaluation

1. V = a + bD + cH
2. V = a + bD2H
3. V = a + bFD2H
4. V = a + bD2 + cD2H +dH2
5. ln(V) = a + bln(D) + cH
6. ln(V) = a + b ln(D2H) etc,

Where, V = volume, D = diameter at bh, H = tree height, F = tree form, a = regression constant; b, c & d = regression coefficient

- Feed the data (models) in to the SPSS (Statistical Package for Social Science) or MS Excel
- Best model selection considering different parameters.

Preparation of local volume table

- Graphical method or
- Regression equation method

In both of these above methods, local volume tables may be prepared either directly from basic data of diameter and volume of trees or derived from the general volume tables of that species.

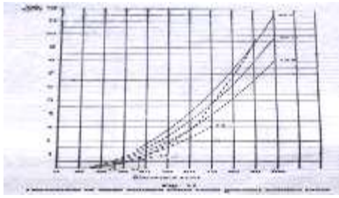
Graphical method based on basic data collected from field

- In this method, the diameters at breast height and volumes of sufficiently large number 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.
- It is seldom followed because it is easier to derive local volume tables from a general volume tables.

Derivation of local volume table from general volume table by graphical method

Local volume table is derived from a general volume table by localizing the heights by dbh classes using the following procedure.

- Measure the heights and dbh values of a sample of trees representative of those to which the local volume table will be applied and record them accurately.
- The figures of a general volume table are plotted on a graph paper showing against the middle of diameter classes for each height class separately.
- Diameter and height figures of field data are then plotted on the same graph by taking the diameters along x-axis and then interpolating the height against these diameters in between the height curves of general volume tables
- Having plotted all points, a smooth curve is drawn through these points.
- The curve so obtained is the desired local volume table curve and represent relationship between diameter and height.
- From this curve, volume may be read at the middle of diameter classes and tabulated to give diameter classes and volume. This table is called local volume table.



Regression Method

Local volume table can be prepared by regression equation method either from basic field data directly or by derivation from the regression equation of the general volume table.

Regression equation from the basic field data directly

- Some regression equations or models are first prepared from the basic field data and out of these models, the best model is selected for preparation of local volume table.

Some models:

- V= a + bD
- V = a + bD + cD2
- ln(V) = a + bD
- ln(V) = a + b ln(D)   etc.

Where, V = volume (m3), D = diameter of trees (ob) at bh, a = regression constant, b & c = regression coefficient, ln = natural logarithms

- The different models used for regression analysis of volume on diameter may be linear, quadratic, cubic, power, logarithmic and exponential etc.

Derivation of regression equation for local volume table from the regression equation of the general volume table

- Instead of developing regression equation for the local volume table directly, it can also be derived from the regression equation of the general volume table for that species.
- For eg. Suppose the general volume equation is V = a + bD2H and the height/diameter relationship equation for any locality is H = c + dD + eD2, the local volume equation will be:

V = a + bD2 (c + dD + eD2)
V = a + bcD2 + bdD3 + beD4
V = a + b1D2 + c1D3 + d1D4
Where, a = regression constant, b1, c1 & d1 are regression coefficients

Difference between local volume table and general volume table

SN	Local Volume Table	General Volume Table
1	Based on the average volume of trees growing in a restricted locality.	Based on the average volume of trees growing over a large geographical area
2.	Based on One variable i.e. dbh	Based on two variables i.e. dbh and height
3.	Applicable to restricted localities	Applicable to a wider range of distribution of species
4.	Show volumes of trees by diameter classes	Show volumes of trees by diameter classes and in each diameter class by height classes
5.	Can be derived from GVT	Can't be derived from LVT

6.	Used for deriving local volume table	Used for estimating volume of individual trees or stands

Volume tables for forest trees of Nepal

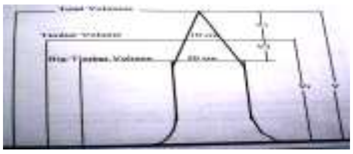
- Volume tables for forest trees of Nepal have been prepared for 21 important tree species and two species groups (miscellaneous species in Terai and miscellaneous species in hills).
- For each species three volume tables are presented: one for the total stem volume, another for the volume to 10 cm top diameter and a third table for the timber volume to 20 cm top diameter.
- The total volume is expressed with bark, which is the usual practice in forest mensuration. The other volume tables (10 cm and 20 cm tops) however, give the timber volume without bark.

Volume equations used in Nepal for preparing volume tables

Total stem volume

ln (V) = a + b ln(d) + c ln(h),

where, v is the total stem volume with bark (m3), d is dbh (cm), h is height (m), ln is natural logarithm and a, b, c are constants.



Stem volume to 10 cm top

ln (v1/v) = a +b (d)

Where, v1= over bark volume of tree top (beyond 10 cm dia.), v = total stem volume over bark, d = dbh, a & b = constants

Stem volume to 20 cm top

ln (v2/vt) = a + b ln (d)

Where, v2 = over bark volume between 10 and 20 cm dia., vt = over bark stem volume to 10 top dia., d = dbh, a & b= constants

- To reduce the bark volume from the stem over bark volume, the following equation form has been used:

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

Where, pb = bark proportion, d = dbh, a & b = constants

SN	Species	a	b	c	R2
1	**Abies pindrow**	**-2.4453**	**1.7220**	**1.0757**	**99.2**
2	**Acacia catechu**	**-2.3256**	**1.6476**	**1.0552**	**96.7**
3	**Adina cordifolia**	**-2.5626**	**1.8598**	**0.8783**	**98.1**
4	**Albizia spp.**	**-2.4284**	**1.7609**	**0.9662**	**98.8**
5	**Alnus nepalensis**	**-2.7761**	**1.9006**	**0.9428**	**97.8**
6	**Anogeissus latifolia**	**-2.2720**	**1.7499**	**0.9174**	**98.6**
7	**Bombax ceiba**	**-2.3865**	**1.7414**	**1.0063**	**98.9**
8	**Cedrela toona**	**-2.1832**	**1.8679**	**0.7569**	**97.9**
9	**Dalbergia sissoo**	**-2.1959**	**1.6567**	**0.9899**	**97.9**
10	**Eugenia jambolana**	**-2.5693**	**1.8816**	**0.8498**	**98.3**

11	**Hymenodictyon excelsum**	**-2.5850**	**1.9437**	**0.7902**	**98.7**
12	**Lagerstoemia parviflora**	**-2.3411**	**1.7246**	**0.9702**	**97.5**
13	**Michelia champaca**	**-2.0152**	**1.8555**	**0.7630**	**98.1**
14	**Pinus roxburghii**	**-2.9770**	**1.9235**	**1.0019**	**99.2**
15	**Pinus wallichiana**	**-2.8195**	**1.7250**	**1.1623**	**98.9**
16	**Quercus spp.**	**-2.3600**	**1.9680**	**0.7469**	**98.6**
17	**Schima wallichii**	**-2.7385**	**1.8155**	**1.0072**	**98.3**
18	**Shorea robusta**	**-2.4554**	**1.9026**	**0.8352**	**98.3**
19	**Terminalia alata**	**-2.4616**	**1.8497**	**0.8800**	**98.9**
20	**Trewia nudiflora**	**-2.4585**	**1.8043**	**0.9220**	**97.7**
21	**Tsuga spp.**	**-2.5293**	**1.7815**	**1.0369**	**99.5**
22	**Miscellence in Terai**	**-2.3993**	**1.7836**	**0.9546**	**98.3**
23	**Miscellence in Hills**	**-2.3204**	**1.8507**	**0.8223**	**97.7**

Model

- Models are simply approximate representations of reality – they are attempts to use statistical or numerical tools to simulate complex physical, chemical and biological processes.
- In the mathematical sense-models = system of assumptions, equations and procedures intended to describe the performance of a prototype system.
- Most models are gross oversimplifications of reality and only provide crude estimate of actual processes.

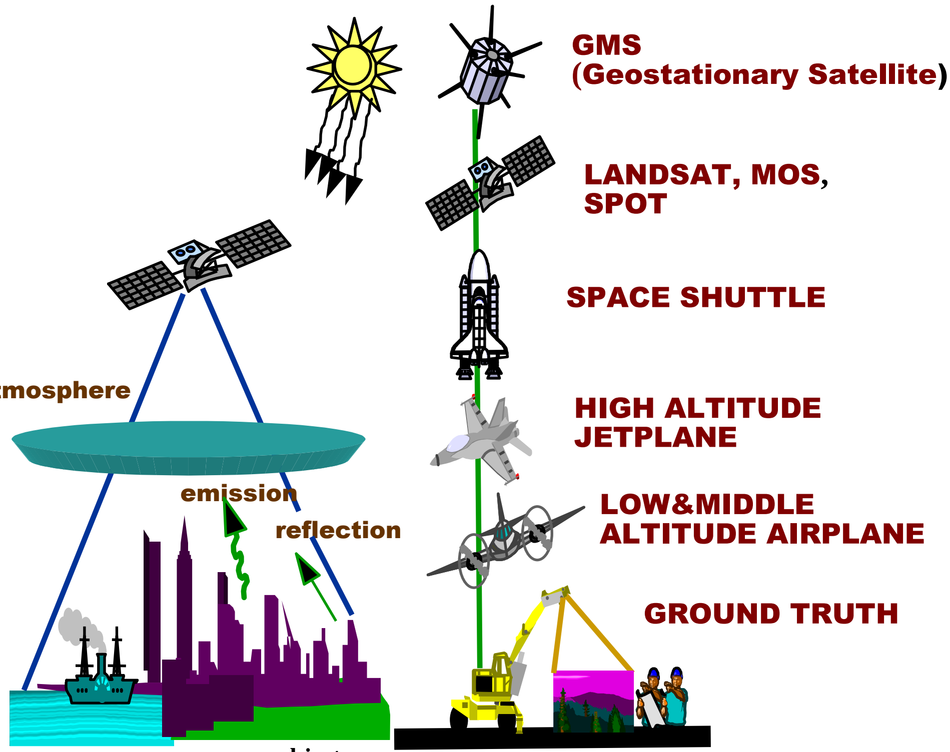
Aerial photographs in Forest Inventory

Remote sensing

- Remote sensing is the science and art of obtaining information about an object, area or phenomenon through analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation.
- Aerial remote sensing- it is that method of remote sensing in which cameras or other devices, fixed in an aircraft flying at fixed altitude are used to take photographs of any resource on earth. It is also called aerial photography.
- Space remote sensing- it is that method of remote sensing in which cameras, sensors or other devices attached to a satellite orbiting round the earth, take photographs of earth and resources inside it.

Remote seasoning

Platforms with Sensor on board



Aerial photography

- Aerial photography is the process of taking photograph of earth's surface and its natural resources from an aircraft flying at fixed altitude from the earth.
- Aerial photographs is the photographs of earth's surface and its natural resources taken from an aircraft flying at fixed altitude from the earth.
- The relative position of the objects on photographs is superficially similar to the actual position on ground.
- Canada was the first country which applied aerial photography in forestry.
- In Asia (tropics), Burma is the first country to start aerial survey of vegetation.
- In Nepal, Aerial photography was used for the estimation of forest and shrub land cover and changes.
- Aerial Photographs are very useful tool for the forest manager.
- A basic knowledge of the location and extent of the forest is critical to the management of forest resources.
- Aerial Photographs are useful in designing and conducting field inventories and used to estimate tree and stand characteristics

Scope

- To determine the volume (value) of standing trees in a given area.
- To get a reliable estimate of the forest area
- The measurement of all or an unbiased sample of trees within the area
- To get the knowledge of location of all tract corners and boundary lines

Types of Aerial photographs

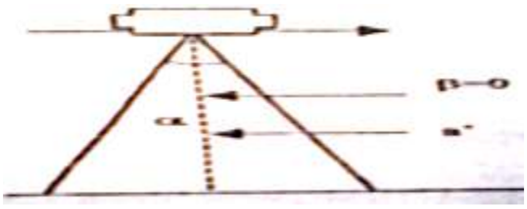
- Aerial photography may be classified into various types depending on the different criteria.

On the basis of position of optical axis of cameras

- Vertical photograph
- Oblique photograph

Vertical photograph

- Optical axis of camera is kept perpendicular or nearly perpendicular to the horizontal plane.
- The degree of tilt is less than 4 degree.
- It is considered to be best because ground features like building, roads, streams, forest boundaries appear same as the map of similar scale covers small area but scale is quite uniform over the whole picture.

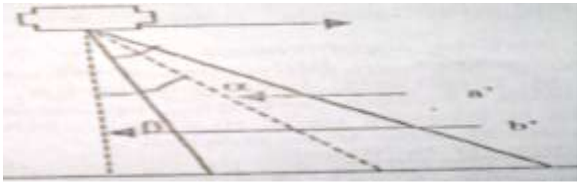



α =angle of view, β = deviation of optical axis from vertical line, a’ = optical axis of camera, b’ = vertical line perpendicular to the horizon

Oblique photographs

Low oblique photographs

- Optical axis of camera is tilted by 30 degree or less from the vertical and horizon does not show in the picture




- **Optical axis of camera is tilted by 60 degree and horizon is apparent.**
- **Unlike vertical photograph the scale of oblique is variable, and that is why there is distortion.**
- **The degree of distortion increases towards the horizon.**

On the basis of films or sensor used

- Panchromatic black and white photograph
- Infra-red black and white photograph
- Color photograph
- infra-red color photograph

Panchromatic black and white photograph

- This film is sensitive to the electromagnetic spectrum in the wavelength range of 0.3 to 0.75 µm.
- When panchromatic film is used, the conventional black and white photograph is produced.
- This film has low sensitivity in the green region of visible spectrum and therefore is not suitable for identification of plant species.

Black and White Infra –red photograph

- By the use of infra-red film and proper filter, the electromagnetic spectrum in the wavelength range 0.3 to 0.9 µm is photographed as black and white photograph.

- The photograph is very useful in identification of broadleaved and coniferous trees.

Normal Color photographs

- A color film with proper filter produced colored photograph in true color. It registers visible colors by human eye.
- It is three-layered film with emulsion sensitive to an additive primary color i.e. blue, green and red.
- The color photography is much more useful in separation and identification of different species and diseases.

Infrared color photograph

- It is also called false color photograph as it shows objects in different color as compared to the true color of the objects.
- The film sensitive to infrared region is used in taking such photographs.
- The normal color of vegetation is green but in infrared color photograph, vegetation appears red.

On the basis of device used

- **Single lens photograph-** single lens camera used
- **Multi-spectral photograph-** more than one camera or a camera with more than one lens used
- **Multi-spectral imagery-** optical mechanical scanner used

On the basis of scale of photograph

- **Small scale photograph-** 1:40,000 to 1:70,000 or more
- **Medium scale photograph-** 1:20,000 to 1: 40,0000
- **Large scale photograph-** 1:5000 to 1:20,000

Season of photography

- depends upon the nature of the features to be identified, the film to be used and number of days suitable for photographic flights
- Less expensive in sunny area
- Best season- during October to February
- Another season- growing season

Eg. Coniferous forests- October to November
Mixed deciduous forests- December to February
Tropical evergreen and moist deciduous forests- January to February

- Spring, winter, summer photographs

Scale of aerial photographs

- Scale = photo distance/ground distance or
- Scale = focal length of camera (f)/flying height above ground (h')

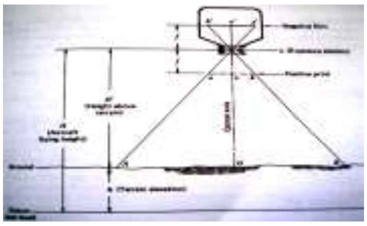


Photo interpretation and technical terms

- Photo interpretation is an act of examining photographic images and judging their significance.
- When we can identify what we see on the photographs and communicate this information to others, we are practicing aerial photographs interpretation.
- Aerial photographs contain raw photographic data. These data, when processed by a human interpreter's brain, become useable information.

- Aerial photographs can be interpreted by using following basic elements/characteristics : Shape, size, pattern, tone, texture, shadows, site, association and resolution.

Tone (or hue)

- refers to the relative brightness or color of objects on an image.
- Relative photo tones could be used to distinguish between deciduous (light tone) and coniferous trees (dark tone) on black and white photographs
- Without tonal difference, the shape, patterns, and textures of object could not be distinguished.

Shape

- It refers to the general form, configuration or outline of individual objects.
- Shape help a great deal in making interpretation in forestry.
- Eg., some species have rounded crowns, some have cone-shaped crowns and some have star shaped crowns.
- Variation of these basic crown shapes also occur.

Pattern

- It relates to the spatial arrangement of objects.
- The repetition of certain general forms or relationship is characteristics of many objects, both natural and constructed and gives objects a pattern that aids the image interpreter in recognizing them.
- For example, the ordered spatial arrangement of trees in an orchard is in distinct contrast to that of forest tree stands.

Size

- Size of objects on images must be considered in the context of the image scale. A small storage shed, for example might be misinterpreted as barn if size were not considered.
- Relative sizes among objects on images of the same scale must also be considered.
- Individual trees have own characteristics of size as well.
- Similarly, size is also helpful in identifying the forest stands.

Texture

- Is the frequency of tonal change on a photo.
- Texture is produced by an aggregation of unit features that may be too small to be discerned individually on the image, such as tree leaves and leaf shadows.
- It is the product of their individual shape, size, pattern, shadow.
- It determines the overall visual “smoothness” or “coarseness” of image features.
- Difference in texture help distinguish tree species.

Shadow

- Shadows are important to interpreters in two opposite respects: 1) the shape or outline of a shadow affords an impression of the profile view of objects (which aids interpretation)

and 2) objects within shadows reflect little light and are difficult to discern on a image (which hinders the interpretation)

- When trees are isolated, shadows provide a profile of image of trees that is useful in species identification.

Site

- It refers to topographic or geographic location and is a particularly important in identification of vegetation types.
- For examples, certain tree species would be expected to occur on well-drained upland sites, whereas other tree species would be expected to occur on poorly drained lowland sites.

- *Alnus nepalensis* is expected to occur in degraded and exposed sites.

Association

- It refers to the occurrence of certain features in relation to others.
- Eg., stack of wood near by the forest would be easier to identify than the stack of wood kept in proximity with small shed in the agricultural land.

Resolution

- It depends on many factors, but it always places a practical limit on interpretation because some objects are too small or have too little contrast with their surroundings to be clearly seen on the image.

There are certain equipments that can be used for the aerial photo interpretation. They help in viewing the photo, making measurements on the photo, performing interpretation tasks and transferring interpreted information to base maps or database.

Forest classification

- Forest classification can be done on aerial photographs using the basic elements of photo interpretation.
- The classification of forest types and plant species largely depends on quality, scale and season of photography, and the ability of interpreter.

- The shape, texture, and tone of tree foliage as seen on vertical photograph along with other basic elements of photo interpretation are key to forest classification.
- The first step in forest classification is to determine which types should and should not be expected in given locality.
- It will also be helpful to get familiar with the most common plant and environmental association.
- This information can be derived by previous maps or direct observation.
- In some regions, photo-interpretation keys are available for recognition of forest cover types and such keys can be used.

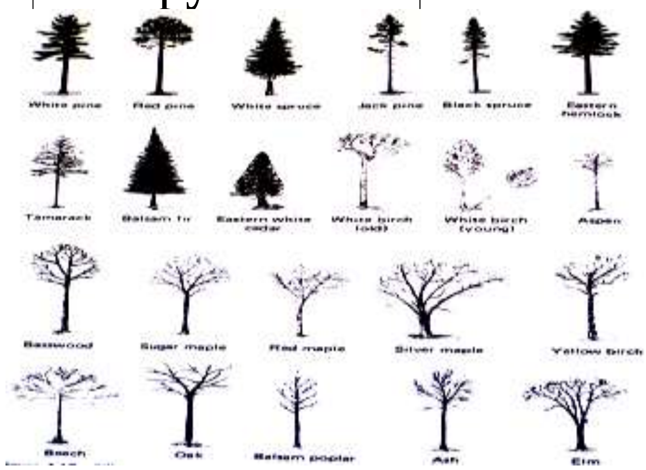
Classification can be conducted in minute details in large scale photographs where species can be identified and in small scale photographs, the knowledge of locality is essential for forest classification.

- In modern days, computer programs (image processing softwares like ERDAS, PCI, ENVI, GRASS etc) are available for making forest classification using the aerial photographs and other imageries.

Relationship between photographic scale and expected levels of plant recognition

Photographic Scale	General Level of Plant Discrimination
1:30,000 – 1:100,000	Recognition of broad vegetative types, largely by inferential processes
1:10,000 – 1:30,000	Direct identification of major cover types and species occurring in pure stands
1:2,500 – 1:10,000	Identification of individual trees and large shrubs
1:500 – 1:2,500	Identification of individual range plants and grassland types

Features	Sugar Maple	Red Maple
Crown Shape	Flatly rounded usually regular	Upright growing branches, irregular
Crown Size	Wide	Moderately wide
Crown Texture	Billowy	Tufted
Crown Density	Compact	Open rather than compact
Crown Outline in vertical view	Definite	Indefinite
Canopy	Closed	Fairly open



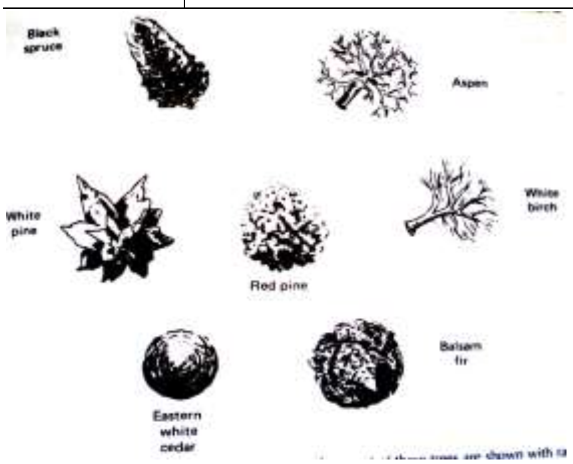


Fig. Shape of individual tree Fig. Shape of individual tree crown

Area Determination

- A truly vertical aerial photo is just like a map and area can be measured with methods similar to that from a map.
- The scale of photographs is known and the area is calculated accordingly.
- But in aerial photo, the center part of the photo is generally true as map but as we move radially outward form the center, the scale changes and there is displacement.
- In determining the area, if all corners are at the same elevation, the area calculations from photographs can be made accurately. If not, substantial error can exist.
- Similarly, if the areas are measured outward the center of the photograph, then some correction will only yield accurate result.
- Thus, we should use the photo where the area to be measured is as close to nadir as possible. Such errors can be reduced by using photos taken from higher flying height.
- Following methods and tools are used to measure area in the aerial photographs - Dot grids, Planimeter and Weight apportionment

Dot Grids

- Determine number of dots per unit area
- Count number of dots in stand or feature on map or photo.
- Calculate the area of stand or feature.
- Convert measurement to ground areas.
- Widely used method of area calculation on aerial photo
- Relatively simple and inexpensive tool for estimating areas on photographs

Planimeter

- Run the pointer of instrument around the boundaries of an area in clockwise direction; usually the perimeter is traced two or three times for an average and read the instrument details.
- Convert measurements to ground areas
- Laborious if many areas need to measured.

Weight apportionment

- Traditional method
- Physically cut a photo into individual areas.
- Weigh each area and determine areas based on their weight.
- Need a very sensitive instrument to weight small pieces of paper.

Volume calculation

- For estimating individual tree volume, multiple entry tree volume tables based on dbh and height can be converted to aerial volume table when correlations can be established between crown diameter and stem diameters.
- Photo determination of crown diameter are substituted for the usual ground measures of dbh, and total heights are measured on stereoscopic pairs of photographs.
- Large scale aerial photographs are essential for obtaining reliable crown diameter and health measurement of individual trees.
- Where only small scale aerial photographs are available, stand variables should be measured than individual tree variable.
- Aerial stand volume tables are multiple entry tables that are used based on assessments of two or three photographic characteristics of the dominant-codominant crown canopy; average stand height, average crown diameter, and percent of crown close.

- These tables are usually derived by multiple regression analysis; photographic measurements of independent variables are made by several skilled interpreters when developing the volume prediction equation.

Other Forestry applications of aerial photography

- Vegetation growth distribution investigation
- Forest resource investigation
- Forest fire monitoring
- Forest disease and pest monitoring
- Shifting cultivation study
- Timber harvest planning
- Monitoring of logging and reforestation
- Forest recreation resource inventory and monitoring
- Wildlife habitat analysis
- Planning forest roads
- Monitoring power line right-of-way vegetation growth etc.

Unit-5: Forest sampling and Inventory

Definition and scope of sampling

- Sampling is the process in which enumeration is to be done only in a representative portion of the whole.
- In Sampling, the information is obtained only from a part of the population assuming that it is the representative of the whole. A part is studied and on that basis, the conclusion is drawn for the entire population.
- For example, a forest area may be of 1000 ha out of which only 100 ha have been selected for enumeration and estimate of the whole population of 1000 ha is made, it is called sampling.
- Population – is an aggregate of objects under study.
- Sample – a finite subset of the population selected from it for the purpose of the study/investigation.
- Sampling unit: The population is divided into suitable units for the purpose of sampling.

Types of sampling units in forest surveys are:

- Compartments,
- topographical sections,
- strips of a fixed width,
- plots of definite shape and size etc.
- Sampling frame: The list of sampling units from which the sample units are to be selected is called sampling frame.
- Sampling Intensity (SI): The ratio of sample to the whole population which is expressed on a percentage

SI = sample area/Total area x 100

Scope of sampling

- Less time
- Reduced cost
- Administrative convenience
- Better supervision
- Check result of census method
- Suitable for infinite/hypothetical population
- Suitable for destructing sampling

Limitations of sampling

Sampling is better over complete census only if

- The sampling units are drawn in a scientific manner.
- Appropriate sampling technique is used, and
- The sample size is adequate.

Sampling theory has its own limitations and problems, which are:

- Proper care should be taken in the planning and execution of the sample survey; otherwise the results obtained might be inaccurate and misleading
- Sampling theory requires the services of trained and qualified personnel and sophisticated equipment for its planning, execution and analysis. In the absence of these, the results of the sample survey are not reliable.
- If the information is required about each and every unit of the universe, there is no way but to resort to complete enumeration.

Types of sampling

Probability/random sampling

- Simple random sampling
- Stratified random sampling
- Multistage sampling
- Multiphase sampling
- Sampling with varying probabilities

Non random sampling

- Selective sampling
- Systematic sampling

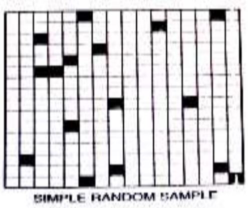
Simple Random Sampling

- It is a selection process in which every possible combination of sample units has an equal and independent chance of being selected in the sample.
- Sampling units are chosen completely at random.
- For theoretical considerations, SRS is the simplest form of sampling and is the basis for many sampling methods.
- It is most applicable for the initial survey in an investigation and for studies that involve sampling from a small area where the sample size is relatively small.

Selection of SRS by lottery and random number table method

When to use

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



16 samples are selected randomly from a population composed of 256 square plots

Advantages

- SRS is a scientific method and there is no possibility of personal bias.
- Estimation method are simple and easy.

Disadvantages

- If the sample chosen is widely spread, takes more time and cost.

- A population frame or list is needed.

Stratified Random Sampling

- It is a method of sampling in which the population is first divided into sub population of called strata of same or different size in such a way that characteristics within the strata are homogenous but between the strata are heterogeneous.
- Samples are taken from each stratum by randomly or other method regarding to optimum or proportional allocation methods.

Criteria of stratification of forest area

- Topographic features
- Forest types
- Density classes
- Volume classes
- Age classes etc.

Proportional allocation

- When information regarding the relative variances within strata and cost of operations are not available, the allocation in the different strata may be made in proportion to the number of units in them or the total area of each stratum.
- Proportion to the area
- Formula, $n_i = (N_i/N) \times n$

Where, N = total number of sampling units in the population/forests (total population), Ni = the number of sampling units in the ith stratum (stratum size), ni = the no. of sample units, i = 1, 2, 3, …..k, k = the no. of strata and n = total sample size from all the strata.

- Larger size strata receive large size sample values.

Optimum Allocation

- Sample plots are allocated to various strata according to standard statistical procedure resulting in smallest standard error possible with a fixed number of observations.
- Determining numbers of plots to be assigned to each stratum requires first a product of the area and standard deviation of each type
- Minimize the variance (i.e. maximize the precision) of the estimate
- Other thing being equal, a larger sample may be taken from a stratum with a larger variance so that the variances of the estimates of strata means get reduced.

$n_i = n \times N_iS_i/\sum N_iS_i$

Where, Si = standard deviation of each stratum

- **When to use** – when the sampling units are **heterogeneous** with respect to characteristics under study.

16 samples are selected randomly from a population composed of 256 square plots.

Advantages

- More representatives than SRS & systematic sampling
- Greater accuracy than SRS
- Administrative convenience

Disadvantages

- More time & cost
- Sampling units for each stratum is necessary or separate frame is needed for each stratum

- Need prior & additional information about population & its subpopulation.

Example for determination of plots by proportional and optimum allocation method in stratified random sampling

- A tract of land containing 300 ha has been subdivided into five distinct timer volume classes (strata). Total of 150 sample units will be measured on the ground and other information are given in table.

Volume class	Stratum area (ha)	Std. deviation cords/ha	Area x std. deviation
I	15	20	300
II	45	70	3150
III	110	35	3850
IV	60	45	2700
V	70	25	1750
Total	300	-	11750

According to proportional allocation

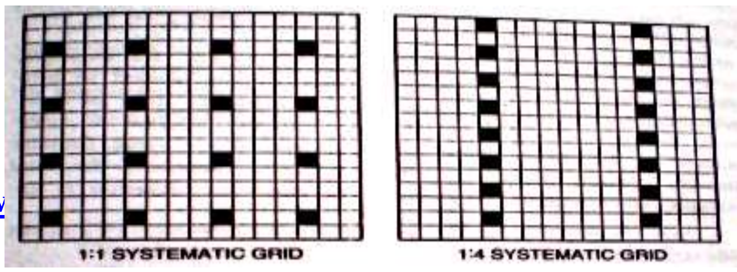
- Class I = (15/300)x 150 = 7 plots
- Class II = (45/300)x150 = 23 plots
- Class III = (110/300)x150 = 55 plots
- Class IV = (60/300)x150 = 30 plots
- Class V = (70/300) x 150 = 35 plots

According to optimum allocation

- Class I = (300/11750) x 150 = 4 plots
- Class II = (3150/11750) x 150 = 40 plots
- Class III = (3850/11750) x 150 = 49 plots
- Class IV = (2700/11750) x 150 = 35 plots
- Class V = (1750/11750) x 150 = 22 plots

Systematic sampling

- In this sampling technique, first unit is chosen randomly and the rest being automatically selected according to some predetermined patterns.
- Systematic sampling is a commonly employed technique if the complete and up to date list of the sampling units is available.
- In this sampling, the sampling units are spaced at fixed intervals throughout the population.
- Measure of every ith tree along a certain compass bearing is an example of systematic sampling.
- A common sampling unit in forest surveys is a narrow strip at right angles to a base line and running completely across the forest, i.e. systematic sampling by strips.
- Another possibility is known is systematic line plot sampling where plots of fixed size and shape are taken at equal intervals along equally spaced parallel lines.
- **When to use**- if the **complete or up to date lists** of the sampling units are available.



16 samples are selected systematically from a population composed of 256 square plots.

Inventory- Introduction and scope

- Forest inventory is the procedure of obtaining information on the quantity and quality of the forest resources and many of the characteristics of the land area on which the forest is located.
- Most forest inventories have been, and will continue to be, focused on timber estimation. Thus, Forest inventory is the tabulated, reliable and satisfactory tree information related to the required unit, respectively units, of assessment in hierarchic order.
- However, the need for information on forest health, water, soils recreation, wildlife and scenic values, and other non timber values has stimulated the development of integrated or multi resource inventories.
- It is also called enumeration or cruise

An inventory of a forest area can provide information for many different purposes; it may be part of-

- A natural resource survey with the aim of allocating land to different uses, i.e. land planning
- A natural project to assess the potential for forest and wood based industry development
- A wood based industry feasibility study
- A resource assessment for forest management planning
- The usual purpose of a timber inventory is to determine, as precisely as available time and money will permit, the volume (or value) of standing trees in a given area. To attain this objective requires a reliable estimate of the forest area and measurement of all or an unbiased sample of trees within this area.
- The information may be obtained from measurement taken on the ground or on remotely sensed imagery (aerial photographs, satellite imagery etc.).

Types of inventory

- **Total enumeration** (census): enumeration is carried out over the entire area of the forest unit under consideration. It is expensive and time consuming.
- **Partial enumeration**: enumeration is to be done only in a representative portion of the whole forest.
- The choice of a particular inventory system is governed by relative cost, size and density of timber, area to be covered, precision desired, number of people available for fieldwork, and length of time allowed for the estimate.
- Regardless of the kind of inventory being under taken, a carefully developed plan is needed to execute the inventory efficiently.
- Many forest inventories are carried out using fixed area sample units. These fixed area sample units are called strips or plots, depending on their dimensions.
- Sample plots can be any shape (circular, square, rectangular or triangular), however, square/rectangular and circular plot shapes are most commonly employed.
- A strip can be thought of as a rectangular plot whose length is many times its width.

Strip system of cruising

- With this system, sample areas take the form of continuous strips of uniform width which are established through the forest at equally spaced intervals, such as 100m, 200m, or 300m etc.
- The sample strip itself is usually 20 m to 40 m wide.
- Strips are commonly run straight through the tract in the north-south or east west direction, preferably oriented to cross topography and drainage at right angles.
- By this technique, all soil types and timber conditions from ridge top to valley floor are theoretically interested to provide a representative sample.
- Strip cruises are usually organized to sample a predetermined percentage of the forest area.
- Cruise intensity (I) = W/D x 100,

Where, W =strip width and D = distance between strips

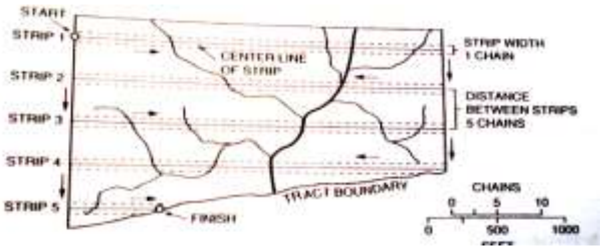


Fig. Strip system of cruising

Advantages

- Sampling is continuous and less time is wasted in traveling between strips than would be the case for a plot cruise of equal intensity.
- Strips have fewer bordering trees than plot cruise of the same intensity.
- With two persons working together, there is less risk to personnel in remote or hazardous regions.

Disadvantages

- Errors are easily incurred through inaccurate estimation of strip width.
- It is difficult to make spot checks of the cruise results, because the strip centerline is rarely marked on the ground.
- Brush and windfalls are more of a hindrance to the strip cruiser than to the plot cruiser.

Line-Plot system of cruising

- Line plot cruising consists of a systematic tally of timber on a series of plots that are arranged in a rectangular or square grid pattern.
- Compass lines are established at uniform spacing, and plots of equal area are located at predetermined intervals along these lines.
- Shape of the plots may be circular, rectangular, square or triangles. But circular plot is widely used.
- Sampling intensity (I)

$$I = \frac{\text{no. of plots x area of plot}}{\text{Total area}} \times 100$$

- An intensity of plot sampling is governed by the variability of the stand, allowable inventory costs, and desired standards of precision.

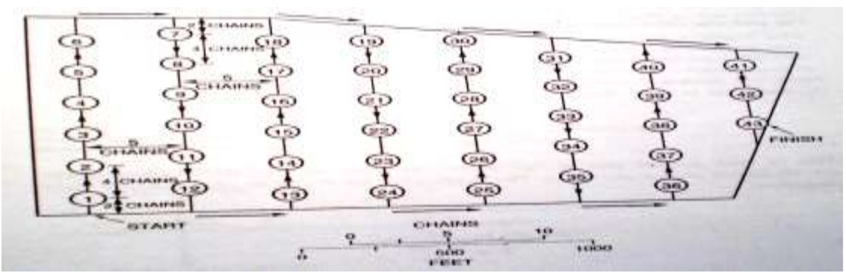


Fig. Line plot system of cruising

Advantages

- The system is suitable for one person cruising.
- The tree tally is separated for each plot, thus permitting quick summaries of data by timber types, stand sizes or area condition classes.
- Cruisers do not have to tally trees while following a compass line.
- Cruiser gets some time, at each plot center to check stem dimensions, borderline trees, and defective trees.

Disadvantages

- It takes more time

According to community forestry inventory guidelines,2061

- **Sampling Method**

Stratified systematic sampling

- **Sampling Intensity**

0.1% (for regeneration and open land) to *0.5 %* (general forest) in community forest

- **Timber Volume Calculation**

Timber volume = π x d2/4 x ht. x ff x TQ

Where, ff = form factor (0.5), TQ, first quality (by 2/3), second quality (1/2)

Tree quality (TQ)

- First quality- straight and clear bole, 3 or more logs with 6 feet length obtained.
- Second quality- straight bole, 2 logs with 6 feet length obtained.
- Third quality – crooked and abnormal bole and only fuel wood obtained.

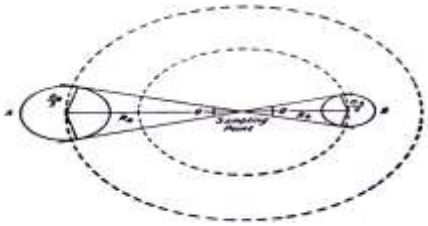
Point Sampling

- Point sampling is a method of selecting trees to be tallied on the basis of their sizes rather than by their frequency of occurrence.
- It has been found that 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.
- Sample points are located within a forested tract, and a simple prism or angle gauge that subtends a fixed angle of view is used to sight in each tree diameter at bh.
- Tree boles close enough to the observation point to completely fill the fixed sighting angle are tallied; stem to small or too far away are ignored. The resulting tree tally may be used to compute basal area, volumes, or numbers of trees per unit area.
- Point sampling can be either horizontal (For basal area estimation) or vertical (For ht. estimation)
- 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.
- 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 per unit area.
- BA conversion factors are dependent or the sighting angle (or critical angle) arbitrarily selected.

Horizontal point sampling

- In horizontal point sampling a series of sampling points are selected randomly or systematically distributed over the entire area to be inventoried.
- Trees around this point are viewed through any angle –gauge at breast height and all trees forming an angle bigger than the critical angle of instruments are counted.

- 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.



From fig, considering the tree section A
Sin θ/2 = (Da/2)/Ra = Da/2 Ra
Similarly, considering the tree section B
Sin θ/2 = (Db/2)/Rb = Db/2Rb
2 Sin θ/2 = Da/Ra = Db/Rb
K = D/R = 2 Sin θ/2
Common basal area factors and angle sizes used in point sampling

Basal area factor	Angle size, min	Angle size, diopters	Ratio (tree dia. to plot radius)	Plot radius factor
1	32.94	0.96	1/104.4	8.696
2	46.59	1.36	1/73.8	6.149
3	57.06	1.66	1/60.2	5.021
4	65.89	1.92	1/52.2	4.348
5	73.66	2.14	1/46.7	3.889
10	104.18	3.03	1/33.0	2.750
15	127.59	3.71	1/26.9	2.245
20	147.34	4.29	1/23.3	1.944
25	164.73	4.79	1/20.9	1.739
30	180.46	5.25	1/19.0	1.588
60	255.23	7.44	1/13.5	1.123

- To illustrate the meaning of BA conversions listed in above table, a sighting angle of 104.18 min. (BAF 10) may be supposed.
- A 1 in. horizontal intercept on a sighting base of 33 in., it follows that all trees located no farther than 33 times their diameter from the sample point will be tallied.
- According, a 1 in. dbh tree must be within 33 in. of the point, a 12 in. dbh tree will be tallied up to 396 in (33ft) and a 24 in. dbh tree will be recorded up to a distance of 66 ft.

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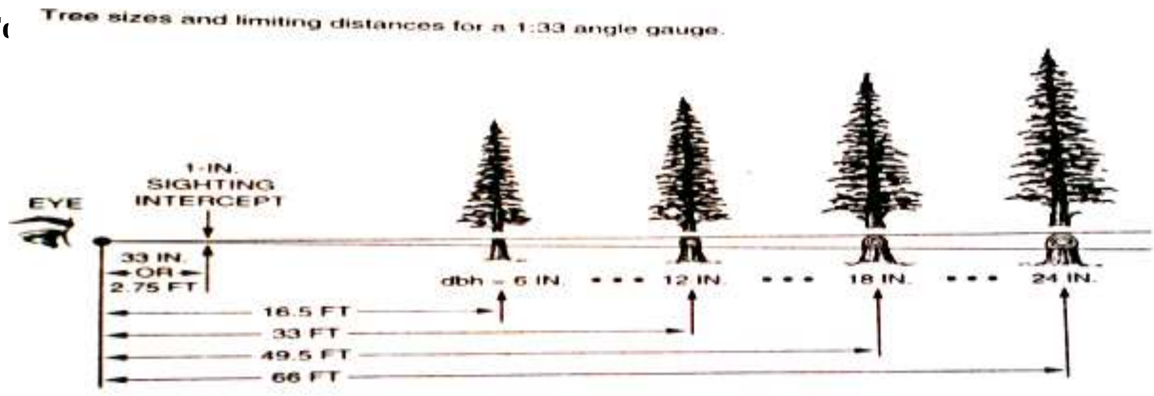


- Basal area per ha = BAF x number of tally trees
  numbers of points
- Number of trees/ha = (no. of trees tallied) x (per-ha conversion factor)/ total numbers of points

(per-ha conversion factor= BAF/BA per tree)

or

= basal area factor of prism/total basal area of the tally trees

- Volume/ha by the stand table method= (no. of trees) (volume per tree) x (per-ha conversion factor)/total no. of sample points
- Volume/ha by the volume/basal area ratios approach
  = (sum of ratios x BA per tree)/no. of trees
  or = (sum of ratios x BAF)/no. of points
  or Volume/ha = basal area x stand form height

Instruments used in horizontal point sampling

- Angle gauge
- Wedge prism
- Spiegel Relaskop
- Tele Relaskop

Choice of instruments

- When steep slopes are regularly encountered, the Spiegel Relaskop is preferred
- For relatively flat topography, either the wedge prism or the stick gauge may be used.
- The prism is primarily desirable for persons who wear eyeglasses.
- The simple stick gauge is preferred in dense stand.

Intensity of point sampling

- There is no fixed plot size when using point sampling; hence it is difficult to compute intensity on a conventional area-sample basis.
- Each tree has its own imaginary plot radius (depending on the BAF used), and the exact plot size can not be easily determined, even after the tally has been made.
- However, approximations can be made on the basis of the average stem diameter encountered at a given point.
- From the a statistical point view, however, the selection of trees according to size rather than frequency may more than offset this reduction of sample size and with an additional saving in time.
- Conversely, it must be remembered that smaller samples of any kind require larger expansion factors.
- Thus, when point sampling is adopted, the so-called borderline trees must always be closely checked, for the erroneous addition or omission of a single stem can greatly reduce accuracy.
- The only accurate method of determining how many sample points should be measured is to determine the standard deviation (or coefficient of variation) of BA or

volume per ha from a preliminary field sample. Then, sampling intensity may be derived by formulae.

If the statistical approach is not feasible, the following rules of thumb will often provide acceptable results:

- If the BAF is selected according to tree size so that an average of 5 or 12 trees are counted as each point, use the same number of points.
- With a BAF 10 angle gauge and timber that averages 12 or 15 in. in diameter, use the same number of points.
- For reliable estimates, never use fewer than 30 points in natural timber stands or less than 20 points in even-aged plantations.

Advantages

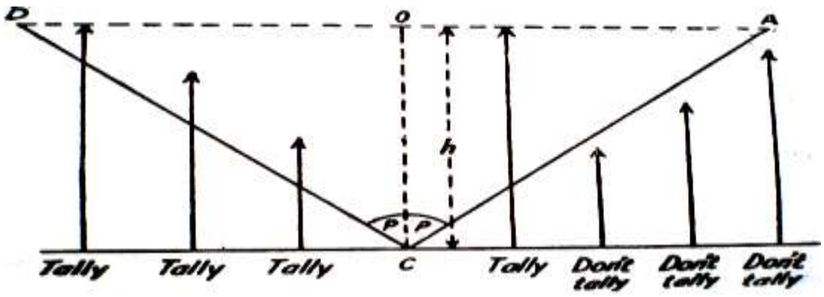
- It is not necessary to establish a fixed plot boundary; thus greater cruising speed is possible.
- Large high value trees are sampled in greater proportions than smaller stems.
- BA and volume per ha may be derived without direct measurement of stems.
- When volume per ha conversions are developed in advance of fieldwork, efficient volume determinations can be made in a minimum of time. Thus the method is particularly suited to quick, reconnaissance type cruises.

Disadvantages

- Heavy underbrush reduces sighting visibility and cruising efficiency.
- Because of the relatively small sized of sampling units, carelessness and errors in the tally (when expanded to tract totals) are likely to more serious than in plot cruising.
- Slope compensation causes difficulties that may result in large errors unless special care is exercised.
- Unless taken into account, problems can arise in edge-effect bias when sampling very small tracts or long, narrow tracts.

Vertical Point sampling

- A method for deriving the mean stand height
- Within a full 360 degree sweep around the sample point all trees appearing taller than a critical angle are counted.
- Instrument used – Conimeter
- This instrument subtends a critical angle of 45 degree.



- By using Conimeter, if the number of trees per ha is N, then number of tree counted (n) in the area can be counted from the Conimeter.
- The average height of the trees (h) in meter (when the critical angle is 45 degree) is
- $h = 100 \times \sqrt{(n/N)}$

$\sqrt{(\tan p)}$

i.e. $h = 56.4 \times \sqrt{(n/N)}$

For crop height, the height at which the instrument is kept will require to be added.

Unit : 6

Growth Prediction

- Tree growth is the increase in its size with time.
- Tree growth shows elongation and thickening of roots, stems and branches.
- Growth takes place simultaneously and independently in different parts of a tree and can be measured by many parameters, for eg. Growth in diameter, in height, in crown size, in bole volume etc.
- Growth causes trees to change in weight and volume (size) and in form (shape).
- Increment is the increase in diameter basal area, height, volume, quality, price or value of trees or crops during a given period.
- Tree growth is influenced by the genetic capabilities of a species interacting with the environment.

Pattern of growth

- Patterns of growth of a tree in terms of change in diameter, based 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.

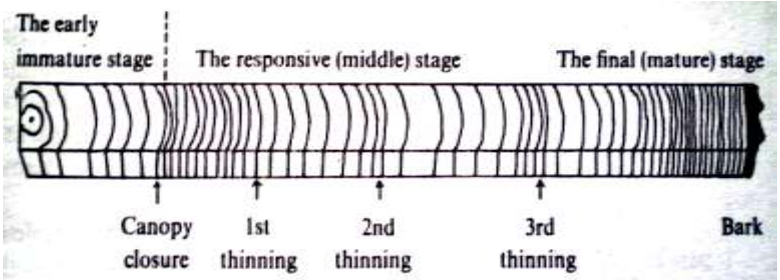
Growth determination

- For trees having growth rings: Stump analysis, Stem analysis and Increment boring
- For trees without annual rings: From periodic measurements/ continuous forest inventory

Diameter growth

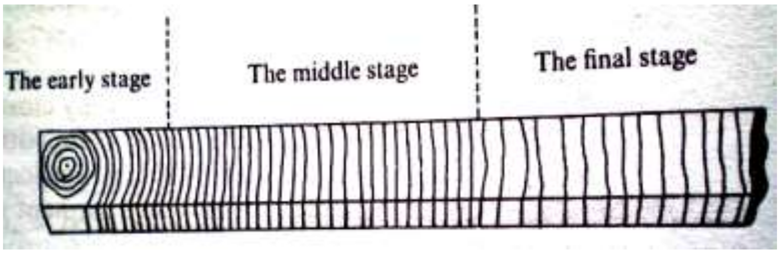
The **pattern of diameter growth in even aged plantation** of one spp. is commonly marked by

- Early immature stage before canopy closure when rate of dia 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 in natural forest

- An early stage of extremely slow diameter (and height) growth while the sapling is dominated by over wood.
- A middle stage when the tree is growing more rapidly but is still severely affected by its larger neighbours.
- The final stage when the tree is a dominant with a large, free, well developed crown and neighbouring trees of same size are few and distant



- Whatever the structure of forest, rate of diameter growth depends on degree of competition.
- Diameter growth may not be regular along the whole of the bole length and there is no constant relationship between the diameter increment at one point along the bole and at another.
- The shape of the tree that diameter growth tends to be greatest towards ground level.

- Diameter growth from felled trees covered under stump and stem analysis.
- In standing trees, it is determined either by repeated measurement of diameter at periodic intervals or by the use of increment borer in case of trees having growth rings.

Some formula for diameter growth determination

Pressler's formula

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

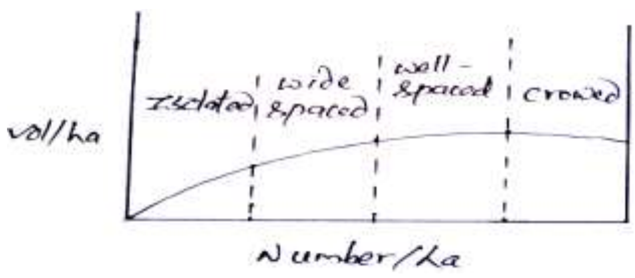
Compound interest formula

- P = 100 ((D/d)1/n_1)

Where, d is the initial diameter, D is the after n years and p is the rate of diameter increment percent

Basal area and volume growth

- **Basal area growth** depends on site quality, species and age.
- Basal area growth is a function of diameter growth.
- As the number of trees/ha increases, basal area will increase with each tree.
- After tree competition begins and tree numbers increase, sum of tree basal areas will increase but basal area per tree will decrease.
- Basal area growth may be estimated from periodic measurement of dbh.
- **Volume growth** is a function of basal area and height.
- Height growth of trees is adversely affected in both excessively open and very dense stands.
- Since height development in closed stands remains reasonably constant, volume has a straight line relation to basal area.
- Total volume increases with number of trees up to a certain density after which, increasing number of trees will cause a reduction in volume.
- Volume growth, the most important growth determination, may be estimated by taking periodic measurement of dbh; dbh and height; or dbh, height and form; and determining volumes at the beginning and at the end of a period from a local, standard, form class volume table or direct measurement as appropriate and then taking the difference.



Some formula used for volume growth percent

Compound interest formula

- P = 100 ((V/v)1/n – 1)

Pressler's formula

- P = 200 (V-v)/n(V+v)

Where, v is the initial volume, V is the volume after n years and p is the rate of volume increment percent.

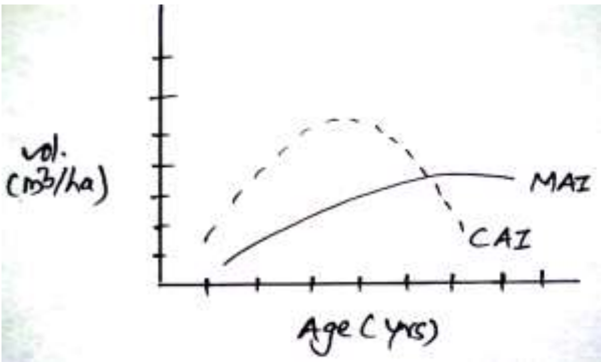
Stand Growth

- The structure of stand changes from year to year because of the birth/regeneration of new trees and the increase in size, death and cutting of the individual trees that make up the stand.
- These changes can be expressed in terms of various stand parameters: volume, weight, basal area, average stand diameter, height and so on.
- The net effect of these changes (stand growth) may be positive, indicating increases, or negative, indicating decreases.
- Yield is thus dependent on a wide variety of factors contributing to a rise or fall in stand growth.
- Knowledge of stand growth or increment is one of the most important requirements for intelligent forest management.
- 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.
- 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 asymptote.
- Many problems of stand growth are best understood by considering a stand to be a population of trees and by studying the changes in the structure of the population.
- The basic elements of stand growth are accretion/cut, mortality and ingrowths.
- **Accretion** is the growth of all trees that were measured at the beginning of the growth period. It includes the growth on trees that were cut during the period plus tree that died and were utilized.
- **Cut** is the number or volume of trees periodically felled or salvaged, whether removed from the forest or not.
- **Mortality** is the volume of trees initially measured that died during a growth period and were not utilized.
- The volume of those trees that grew into the lowest inventoried diameter class during the growth period is termed **ingrowth**.
- **Gross growth** is a measure of the change in total volume from a given stand. In any given diameter class, it is the change in volume, plus mortality during the growth period.
- **Net growth** represents the stand volume increment based on the initial trees after mortality has been deducted.
- Method of estimating stand growth may be based on analysis of a given stand from measured variables or on the use of yield growth information that may be presented in tabular or equation form.
- The important methods of estimating growth fall under four headings: stand table projection, total stand projection, yield tables, and derived growth and yield functions.
- The determination of growth by repeated inventories of permanent sample plots or of entire woodlands, is one the most logical methods of determining past growth.
- The data obtained from a series of periodic measurements give a complete historical record of stand growth.

- The future growth of stands can be predicted with the help of yield tables prepared from the studies of growth in sample plots, systematically distributed over the entire forest.
- Growth of a stand is a function of stand density and site quality and their effect on growth prediction.

Current Annual Increment and Mean Annual Increment

- **CAI**- increment which a tree or crop puts on in a single year. The CAI varies from year to year being affected by seasonal conditions and treatment.
- As current growth is difficult to measure for a single year, the average annual growth over a period of 5 to 10 years commonly substituted instead.
- It is important to maintain the distinction between CAI and PAI (periodic annual increment). The PAI is a more realistic indicator of the capacity of a tree (or stand) of a certain age or size to grow.
- **MAI**- is the mean volume of a tree or crop put on from origin up to the desired age i.e. the total increment up to a given age divided by that age



- When curves of current and mean annual increments are plotted over tree age, the two do not coincide with each other through the life of the tree or stand except at two periods-one at the end of first year growth and the second in the year of the culmination of the MAI.
- The CAI rises to a maximum and then gradually fall off.
- The MAI also increases to a maximum at a later age but with much lower rate.
- The MAI continues to rise towards a maximum even after the CAI has started falling.
- When CAI falls to such an extent it is equal to MAI, the MAI reaches its highest points. This is the year of culmination of the MAI. This culmination point for MAI is regarded as the ideal harvesting or rotation age in terms of most efficient volume production.
- During the following and subsequent years, the CAI is less than the MAI and the MAI also begins to drop. But this drop is not as rapid as that of CAI.
- The CAI will be zero when there may be no growth at all. Unless the tree or stand is cut, loss of volume may start taking place due to rot or other damages, resulting in negative CAI. But the MAI value is never zero and in no circumstance negative likes CAI.

Stump analysis and stem analysis

Stump analysis

- 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

Objectives

- To find out age/diameter relationship to determine the rotation age

It also shows the influence of external factors affecting single trees or the stand, on the rate of diameter increment of trees or stand by correlating rate of diameter increment with effects of the factors involved.

Factors affecting the ease of counting annual rings

- Species - counting is difficult if the colour differentiation between late and early wood is slight;
- Age of tree - ring width is very small in old trees;
- Environmental conditions:

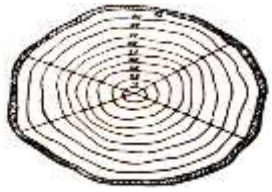
– early or late frosts and drought sometimes promote formation of false rings;

– under exceptionally good growing conditions, there may be little differentiation into early and late wood;

- Extent of ring distortion - due to branch whorls, defects, compression wood, tension wood.

Methods

- Select stump of tree (use old stumps if available, or fell trees which are representative for investigations, dbh is measured and recorded before felling)
- Measure stump height and under bark diameter of each stump.
- Mark four radii on stump and insert pin in each decade.
- Measure the radius of each decade on each marked radii from pith outwards
- Sum the radii at successive decades for each stump/tree and get the average diameter at successive decades.

Advantages

- Data can be collected from stumps of felled trees as long as the wood remains sound. Thus, it can be carried out with or without special fellings.
- Data can be collected any time with minimum of manual labor.
- The data can be multiplied to any desired extent with no objection other than the time taken in measuring.
- Field work is simple and easily learnt.
- Each stump provides data for the whole life of the tree.

Stem analysis

- Analysis of a complete stem by measuring annual rings on a number of cross-sections at different heights in order to determine its past rates of growth.

Objectives

- To determine age-diameter, age-height and age-volume relations throughout the life of the tree analyzed
- To assess the average rate of diameter, height and volume increment.

The data of the stem analysis can also be used for preparing local volume tables by correlating diameter volume relations.

Types of stem analysis

- Partial stem analysis and
- Complete stem analysis

Partial stem analysis

- Partial stem analysis is confined to one position on the stem.
- It provides data on diameter growth only, e.g. take a sample core at breast height to determine the growth of DBHOB over time.

Complete stem analysis

- Complete stem analysis involves a number of positions along the stem and permits diameter, height and volume growth.
- The procedure used in sampling a stem for the analysis differs somewhat depending on whether the tree is standing or felled.
- In case of standing trees, stem cores are the basis of analysis. Cores are obtained using an increment borer (bark to pith core) or increment hammer (core of recent growth only).
- Felled trees, the analysis is based on complete stem sections (discs) 2 to 5 cm thick, taken at the nearest representative point

Method

- Fell the tree and cut stem into sections of desired lengths (eg. every 3m length)
- Determine and record species, dbh, total height, years to attain stump height, and total age.
- Measure and record the height of the stump, length of each section and length of tip.
- Measure and record the average diameter at the top of each section.
- If only one radius is measured, the average radius should be used. The average radius should be located on each cross section and marked with a line along it with a soft pencil. In many cases, it is desirable to measure more than one radius because of stem eccentricity.
- From the center of each cross section, measure outward toward the cambium along each radius, recording the distance from the center to each interval. The fractional part of a decade or other desired period, will be measured and recorded.

Advantages

- The data are collected from standing trees carefully selected and so it is more reliable. This more so because the entire tree is analyzed and data are not collected only from the lower part of the stem as in stump analysis.
- It gives complete information about the growth of trees in respect of diameter, height and volume and so it is self contained.

Stand Structure, Site Quality and Yield

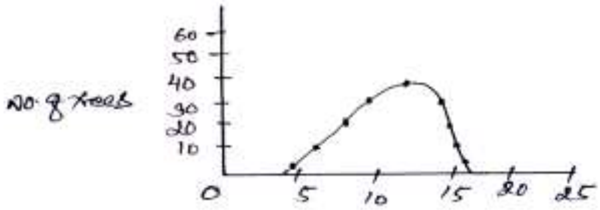
Stand Structure

- Stand structure is the distribution and/ or representation of age and/or size classes of trees in a stand.
- It keeps on changing with passage of time and age.
- The structure is the result of several factors: growth habit of the tree species, especially the degree of shade tolerance, ecological conditions and history of disturbance and management practices under which the stand originated and developed.
- There are two typical stand structures – even aged and uneven aged.

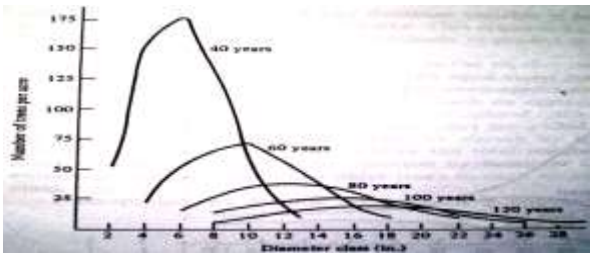
Even aged stand

- An even aged stand is a group of trees that has originated within a short period of time. The trees in an even aged stand thus belong to a single age class.

- The limits of the age class may vary, depending on the length of time during which the stand formed. A natural stand may seed in over a period of several years.
- More commonly, the age class for an even aged stand will extend to 10 or 20 years.
- Even aged stands may be composed of shade tolerant or shade intolerant species, although even aged stands of intolerant species are more common.
- An even aged forest may consist of several even aged stands belonging to different age classes.
- Even aged stands have definite beginnings and endings
- The characteristics of even aged forest is bell-shaped curve

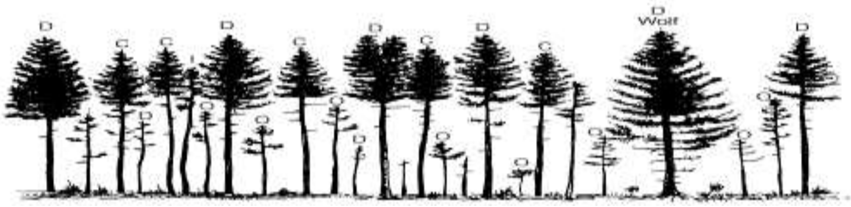


- As the stand ages, the bell shape is retained but the total number of tree decreases and the bell flattens and shift to right.
- The trees in an even-aged stand are fairly consistent in height with variation depending of their crown position as dominant, codominant, intermediate or suppressed.



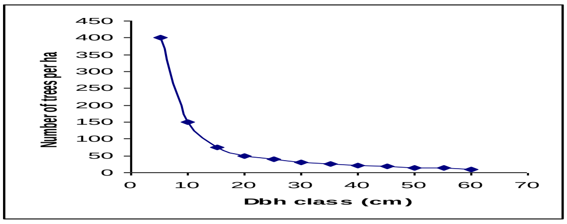
Uneven aged stand

- A stand consisting of trees of many ages and corresponding sizes is said to be uneven aged.
- The trees in uneven aged forest originate more or less continuously, in contrast to the single reproductive period characterizing an even aged forest.
- In an uneven aged forest, the trees in the crown canopy are of many heights, resulting in an irregular stand profile as viewed from a cross section.
- Trees on any given ha vary by age as well as size and frequently can be of several different species.
- The more shade tolerant species tend to form uneven aged stands.



- The typical diameter distribution for uneven aged stand is a large number of small trees with decreasing frequency as the diameter increases (reverse j shaped curve).
- 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 represented.



- Traditionally, stand structures have been broadly classified on the basis of tree ages. However nowadays, it can also be described using species composition, diameter distribution, height distribution, and crown classes

Species Composition

- The species present in a stand has always been an important parameter in describing forest stands. Species composition is an important indicator of wildlife management, site quality and past disturbance history.

Height

- Height is another widely used stand structure parameter. Height is an important factor in determining individual and total stand volumes.
- Height is widely used as a measure of site quality and stand productivity. Height of the stand characterizes vertical structure of the stand.

Density and stocking

- Measure of stand density and forest stocking are both used to depict the degree to which a given site is being utilized by the growing trees or simply to indicate the quantity of wood on an area.
- Stand density is a quantitative measurement of a stand in terms of basal area, number of trees or volume per ha.
- It reflects the degree of crowding of stems with in the area.
- Stocking on the other hand, is a relative term used to describe the adequacy of a given stand density in meeting the management objective.

Site Quality

- **Site** is the totality of environmental conditions that exist at a specified location. Site is an abstract concept which combines a magnitude of environmental factors affecting tree growth into a unified classification.
- The environmental factors that influence growth include:

- soil factors, e.g. physical and chemical properties, soil moisture, soil.
- microorganisms;
- topographic factors, e.g. slope, elevation, aspect;
- Competitive factors, e.g. other trees and lesser vegetation, animals, man.
- climatic factors, e.g. air temperature, humidity, radiant energy, precipitation, wind;

Reason for site assessment

- As a criteria in land use allocation and development
- As the basis for choice of species for planting
- As the basis for forecasting growth of managed forest-especially plantation.
- **Site quality** is a relative productive capacity of a site for a particular species. It is an index related to timber/forest productivity.
- A common way of expressing relative site quality is to set up from three to five classes or ordinal ranks, such as site quality I, site quality II and site quality III, designating comparative productive capacities in descending rank.

Determination of Site Quality

- **Physical factors/site factors:** site factors are the effective edaphic, climatic and biotic factors which influence the growth and development of forest or other vegetation in a locality. It is very difficult to quantify the effect of all these factors together.

Paterson formula,

CVP index (I) = (Tv/Ta) x (PxG/12)x (E/100)

Where, CVP index = climate, vegetation and productivity index, Tv and Ta = maximum and minimum temperatures

P = precipitation in mm, G = the growing period in months and E = measure of evapotransipiration

Vegetation Characteristics

- The characteristics of the vegetation which could serve this purpose could either be the types of plants occurring naturally in the area or the volume, basal area, diameter or heights of trees which form the dominant part of the vegetation in the area.
- **Plant indicators**: herbs and shrubs are clear indicators of the suitability or otherwise of the site for a particular tree species or forest type.
- **Tree characteristics:** the most important characteristics of the tree which reflect the productivity of the site are its volume, basal area, diameter and height.

Site index

- Of all commonly applied indirect measures of site, dominant height in relation to age of trees has been found most practical, consistent, and useful indicator (site index method).
- Height of dominant portion of a forest stand at a specified standard age is commonly termed as site index and is a measure of site quality.
- Site index 50 at index age 50 years means height of dominant trees is 50 m or ft, 100 or 250 trees/ha are taken for site assessment.

Reason for selecting height for site quality assessment

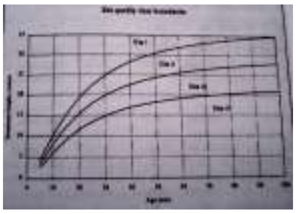
- Height growth is more sensitive to difference in site
- Height growth is little affected by varying density levels
- Height growth is little affected by species composition.

Limitation of site index

- Exact stand age is difficult to determine
- Not suitable for uneven aged stands, areas of mixed species composition, or open lands.
- An index based on total height on age alone may not be providing valid estimate of growing capacity for a particular site
- Site index is not a constant, it may change due to environmental and climatic variations
- Site index value of one species cannot be translated into a usable index for a different species on same site.

Site quality class for Sal (index age 20)

Site quality	Stem volume (ob) m3/ha	Dominant height (m)
I	259	21.2
II	189	17.3
III	123	13.5
IV	68	9.7



Yield table

- **Yield** is the total amount available for harvest at a given time from a forest. Thus, yield is summations of annual increments.
- The growth and yield of forest are related with time in stand development, site quality and degree to which the site is occupied.
- Yield from a forest can be estimated or even predicted for a future time period by the use of a yield table.
- A yield table is essentially a tool of long term planning. It is a type of growth or experience table which lists expected productivity or volumetric yield for a given age, site or crop quality and sometimes other indices such as density. Thus yield tables usually refer only to even aged stands.
- Yield of a forest stand can also be determined using different models. These models use different stand parameters like, age, density, site quality, basal area, volume etc as inputs and predict how these parameter changes over time.
- These models can be of stand level models (e.g. yield table and yield function) or tree level models.
- **Yield table** is a tabular statement which summarizes on per unit area basis all the 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.
- It differs from the volume table in the sense that while the volume table gives the volume of an average tree by diameter and / or height classes, yield table gives different parameters of crop, volume removed in thinning MAI, CAI etc. in short it gives all the quantitative information regarding development of crop.
- Data to prepare such tables may be obtained from: permanent sample plots; temporary sample plots; Stem analysis.
- Permanent sample plot information is by far the most satisfactory on which to base yield tables.
- The main purpose of yield tables is to provide estimates of present yield and future increment and yield. The tables may be presented in tabular or graphical form or in the form of a regression equation relating yield to age, site and stand density.
- There are three main types of yield table, viz. normal, empirical and variable density

Normal Yield Table

- A normal yield table is based on two independent variables, age and site (species constant), and applies to fully stocked (or normal) stands.

- It depicts relationships between volume/unit area together with other stand parameters and the independent variables.
- Since only two independent variables are involved, normal yield tables are conveniently constructed by graphical means.
- The data presented in normal yield tables are averages derived from many stands considered to be fully stocked at the time they were sampled.

Empirical Yield Table

- In contrast to normal yield tables, empirical yield tables are based on average rather than fully stocked stands. This simplifies the selection of stands for sampling.
- The resulting yield tables describe stand characteristics for the average stand density encountered during the collection of field data.

Normal and empirical yield tables essentially have the same limitations, namely:

- The difficulty of locating fully stocked stands or representative average stocked stands from which to collect the basic data;
- Stocking may not have always been 'fully stocked' or 'average';
- The problem of selecting correction factors to apply to stands of density other than normal or average.

Variable Density Yield Table

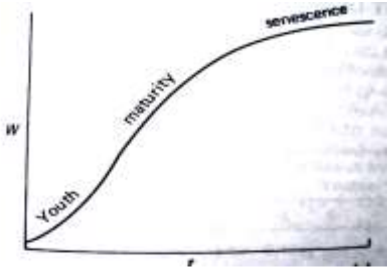
- The limitations listed above for normal and empirical yield tables led to the development of techniques for compiling tables with three independent variables, stand density being included as the third variable: hence the term variable density yield tables.
- Basal area/area, mean diameter or other stand density indices are used to define the density classes.
- Such yield tables are particularly useful for abnormal stands e.g. abnormal due to early establishment problems, insect and fungal attack, drought, fire, fluctuating demands for produce, etc.
- Estimation of yield is one of the main purposes of a yield table. If the rotation is not yet complete, the history of growth to the present can be compiled and presented in yield table form.
- Likely future yield is then predicted by extrapolating the relationships of the stand variables on age and site. Such forecasts, however, should be limited to short periods (approx. 5 years).
- For a species in its second rotation, the yield table of the first rotation can be used for long term forecasting provided there has been no change in site productivity.
- If a change in productivity is detected, it is essential before applying the yield table to ensure that the growth trends of the various site classes are not affected.

Unit:7

Growth and Yield

- Forest management decisions decision are predicted on information about both current and future resource conditions.

- Stand dynamics (i.e. the growth, mortality, reproduction and associated changes in the stand) can be predicted through direct or indirect methods.
- Techniques for forecasting stand dynamics are collectively referred to as growth and yield models.
- Growth and yield forecasts may be required for a short term or long term basis, for the overall stand volume or volume by product and size classes.
- **Growth** is the increase (increment) in its size over a given period of time.
- **Yield** is the total amount available for harvest at a given time.
- Thus, yield can be regarded as the summation of the annual increments.
- The factors most closely related to growth and yield of forest stands are the point in time in stand development, the site quality and the degree to which the site is occupied.
- Growth curve of the tree is S or sigmoid shaped



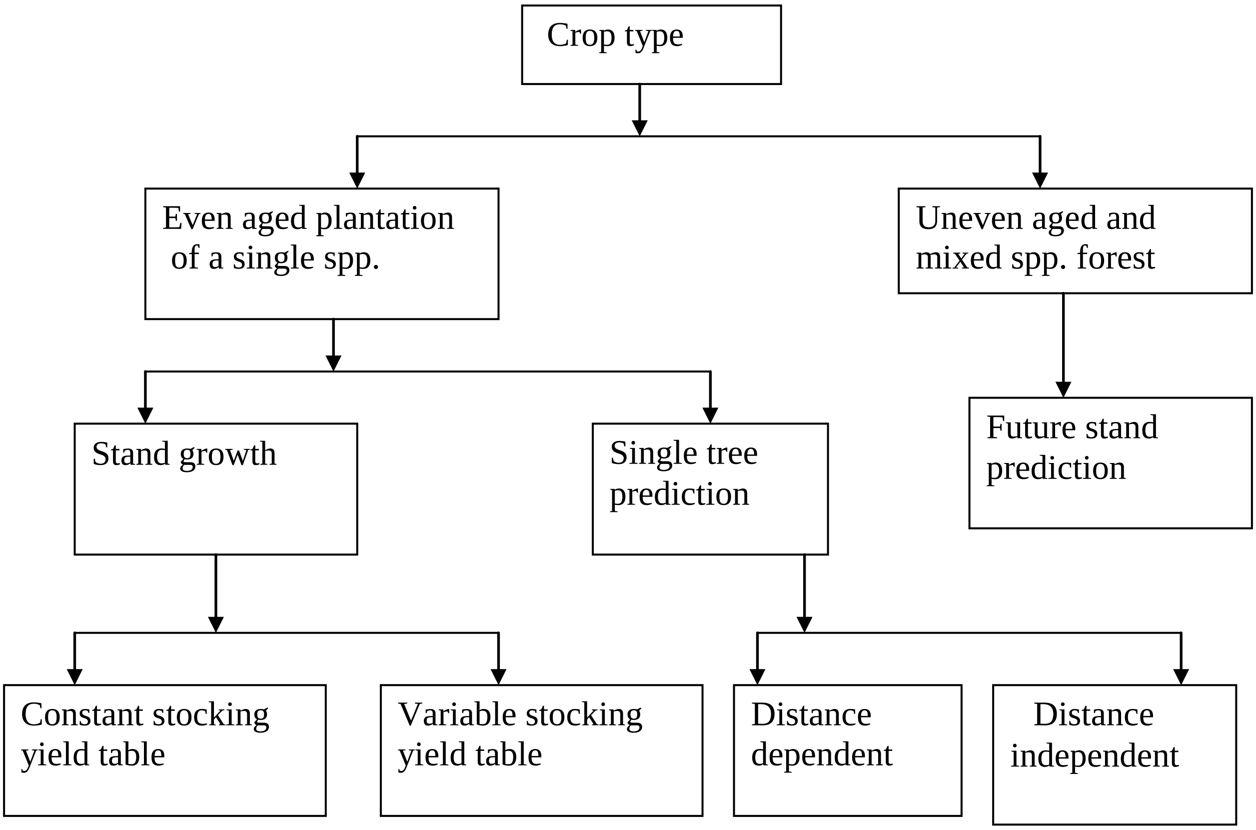
Forest growth models

- A forest growth model describes the development of tree crops as they increase in age, or as time changes.

Uses:

- to make decisions (for feasible investment options),
- to make comparisons (to choose best original spacing, rotation timing),
- to predict work, programmes when budgeting costs and revenue.
- Simplest model – for crops with least variation (even aged stands of a single species)
- Complex model – for crops with much variation (uneven aged and mix spp.- tropical evergreen forest)

Growth model classification

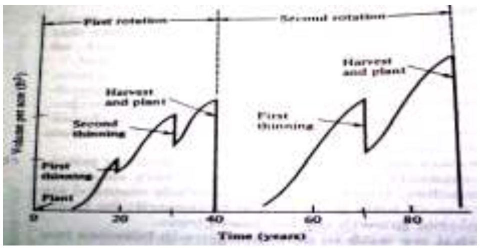


Growth and yield of even aged stands

- The stands consist of trees of the same or nearly the same age. A stand is even aged if the range of tree age does not exceed 20 or 25 percent of the rotation length.
- Even-aged stands have definite beginnings and endings

The typical lifeline of an even-aged stand is:

- Stand initiation (plant or seed) – a series of intermediate treatments (vegetation control, fertilization, thinning) –harvest – initiate a second rotation
- In even-aged stands, a growth equation might predict the growth of diameter, basal area or volume in units per annum as a function of age and other stand characteristics.
- A yield equation will predict *the diameter*, *stand basal area or total volume* production attained at a specified age.
- Most even aged stand characteristics are related to stand age and these relationship are used to guide decisions about when to treat or harvest the stand.



Large number of growth and yield models exist for prediction for even aged stand.

- Normal yield tables
- Empirical yield tables
- Variable density growth and yield equations
- Size class distribution models
- Individual tree models

Normal Yield Table

- A normal yield table is based on two independent variables, age and site (species constant), and applies to fully stocked (or normal) stands.
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- Since only two independent variables are involved, normal yield tables are conveniently constructed by graphical means.

Empirical Yield Table

- In contrast to normal yield tables, empirical yield tables are based on average rather than fully stocked stands. This simplifies the selection of stands for sampling.
- The resulting yield tables describe stand characteristics for the average stand density encountered during the collection of field data.

Variable Density growth and Yield equations

- A multiple regression approach to yield estimation, which takes stand density into account.
- Basal area/area, mean diameter or other stand density indices are used to define the density classes.

Size class distribution models

- The distribution of volume by size classes, as well as the overall volume is needed as input to many forest management decisions.
- A variety of approaches providing the distribution of volume by size classes (generally dbh classes) has been taken in the development of growth and yield models.
- One widely applied technique for even aged stands is a diameter distribution modeling procedure.

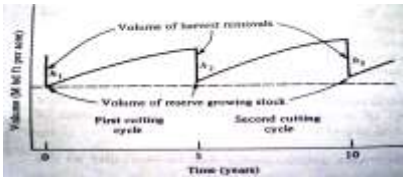
Individual tree models

- Approaches to predicting stand growth and yield which use individual trees as the basic unit are referred to as individual tree models.
- The components of tree growth in these models are commonly linked together through a computer program which simulates the growth of each tree and then aggregates these to provide estimates of stand growth and yield.
- Individual tree models may be divided into two classes, distance independent and distance dependent, depending on whether or not individual tree locations are required tree attributes.

Growth and yield of uneven aged stands

- Trees on any given ha vary by age as well as size and frequently can be of several different species. Throughout most of their lives, trees compete for light or moisture with larger overtopping or nearby trees.
- Uneven-aged stands generally lack a definite beginning or end in time.
- Trees on any given area of an uneven-aged stand vary by age, size and end in time.
- Management of uneven-aged forest is basically a periodic cycle of partial harvests which influence the species composition and size structure of residual stand.
- The interval between harvests in an uneven-aged stand is called the cutting cycle.

- The system favours the tolerant climax species.
- A cycle starts with a harvest that leaves a specified volume of reserve growing stock. This volume grows for the number of years in the cycle.
- In an uneven-aged stand, **yield** is the total production over a given time period while **growth** is the rate of production.
- Age is an indeterminable parameter in an uneven-aged stand.



- Growth and yield models without age as a variable, and without site index for assessing site quality, have been developed for uneven aged stands.

Few growth and yield models exist for uneven-aged stands.

- **Growth and yield equations** - volume growth rate equation for uneven aged stands of mixed forest
- **Size-class distribution models** – diameter distribution in regular uneven aged stands are inverse j shape. Another approach to size class distribution modeling in even aged stands is the stand table projection models.
- **Individual tree models-** individual tree as the basic unit have been developed for mixed species, uneven aged stands.

Different growth and yield modeling approaches

- a forest growth and yield model describes the development of tree crops as they increase in age or as time changes.
- The design of a growth model for use in a particular situation depends on

- the resources available,
- the uses to which it will be put and
- the structure of the forest stands whether even or uneven aged of a single species or mixed species.

Commonest uses of a growth and yield model are to predict the

- Growth of the forest so that the manager may match his harvesting and selling plans.
- Growth on a particular site to enable the land manager to make rational decisions.
- Growth of crops under different management regimes and silvicultural practices in order to make comparisons and a choice.
- Work programs when budgeting costs and revenues.
- Many types of model exist for growth and yield prediction ranging from a simple linear equation or table to complex computer simulation.
- The yield table may also be expressed graphically as a series of curves, with the horizontal axis indicating age and vertical axis indicating volume produced.
- It may also be expressed more concisely as a mathematical equation.

Common growth models

- Simple linear, Yt = a + b (t)
- Linear transformation, Yt = a tb
- Exponential model, Yt = a ebt
- Polynomial models, Yt = a + bh +ch2…..

In general, growth and yield models might be classified into following three types based on their application scope

- Stand table projection
- Whole stand modeling

- Individual tree modeling

Stand table projection

- Stand table projection uses a current diameter distribution (stand table) and recent past growth (usually from increment borers) to project or estimate future diameter distribution.
- This method can be used for projecting diameter, height, basal area and volume.
- It is unlikely to yield table as it can be applied to any kind of stand, even-aged or uneven-aged.
- However, this method is best suited to uneven aged low density and immature stands. In dense or over mature forests where mortality rates are high, this method may not be reliable.
- **Stand projection** is a direct method of estimating stands growth based on an analysis of a given stand from measured variables.
- The basic elements of stand growth are accretion/cut, mortality and ingrowths.
- **Accretion** is the growth of all trees that were measured at the beginning of the growth period. It includes the growth on trees that were cut during the period plus tree that died and were utilized.
- **Cut** is the number or volume of trees periodically felled or salvaged, whether removed from the forest or not.
- **Mortality** is the volume of trees initially measured that died during a growth period and were not utilized.
- The volume of those trees that grew into the lowest inventoried diameter class during the growth period is termed **ingrowth**.
- **Gross growth** is a measure of the change in total volume from a given stand. In any given diameter class, it is the change in volume, plus mortality during the growth period.
- **Net growth** represents the stand volume increment based on the initial trees after mortality has been deducted.

Procedure of growth prediction by stand table projection

- Determining present stand condition (by inventory);
- Determining past periodic growth (by increment boring)
- Forecasting increment in the future period based on increment in the past period (determined from permanent sample plot or stem analysis of individual trees);
- Determining both present and future stock tables.
- Determining periodic stand growth (difference between total volume of the present stand and that of future stand).
- Stand table method is also known as traditional diameter class model/method that estimates future stand table of a subject stand on the basis of present one.

$M = g/i \times 100$

where, m = movement ratio (or growth index ratio) of trees in larger dbh classes, g = average periodic dia. Increment of a dbh class, and i = diameter class interval.

Examples from below table,

M (for 6 in dbh class) = 2.2/2 x 100 = 1.1 x 100 = 110

- That is 100 % of trees in 6 inch dbh class move up one dbh class and 10% of these advance two classes i.e. 90% of trees move to 8 in dbh class and 10 % to 10 in classes.

Present stand table, mortality and expected 10 year dia growth

Dbh class (in)	Present stand (no. of stems)	Expected mortality (%)	Expected survival (no.)	10 yr. dbh growth, (in)
6	522	40	313	2.2
8	352	35	229	2.3
10	179	25	134	2.4
12	88	20	70	2.2
14	40	15	34	2.4
16	11	10	10	2.6
18	10	10	9	2.1
20+	8	20	6	1.8
Total	1210		805	

Dbh class (in)	Present stand surviving no. of stems	Growth index ratio (g/i)	No. of stems moving up by dbh classes			Future stand table no. of stems
			No change	1 class	2 classes	
6	313	1.1	0	282	31	0
8	229	1.15	0	195	34	282
10	134	1.2	0	107	27	226
12	70	1.1	0	63	7	141
14	34	1.2	0	27	7	90
16	10	1.3	0	7	3	34
18	9	1.05	0	8	1	14
20	6	0.90	1	5	0	12
22	0	…	0	0	0	6
Total	805		1	694	110	805

Application of growth index ratio in deriving a future stand table

- Stand table projection is much less successful for projecting volume because time changes in the height/dbh relationship and form are rarely taken into account properly.
- If reliable growth functions are available, an alternative to predicting stand volume is to forecast future volume from the growth equations using as independent variables those stand characteristics (eg. Dbh and height) which are correlated with volume and which can be projected readily and reliably.

Whole stand modeling

- Stand level models are most generalized forest vegetation models.

- Whole stand models are models where the basic components are stand level parameters such as stocking, volume, site quality and diameter distribution of the stand.
- Usually, whole stand level models are specific to species, region or locality.
- These models are constructed from simple data.
- A whole stand model looks like the following:

$$V=f\,(A, SI, D, N, G \ldots)$$

Where, V = volume, A = age,
SI = site index, D = diameter, G = basal area

There could be two classes of stand level model for

- Prediction of current yield
- Prediction of future yield

Normal yield table can be applied for whole stand modeling.

Individual tree modeling

- Approaches to predicting stand growth and yield which use individual tree as the basic unit of growth prediction.
- The components of tree growth in these models are commonly linked together through a computer program which stimulates the growth of each tree and then aggregates these to provide estimates of stand growth and yield.
- 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.
- Model based on individual tree growth provide detailed information about stand dynamics and structure, including the distribution of stand volume by size classes.

Two classes of individual tree models depending on whether or not individual tree locations are required tree attributes.

- Distant dependent model and
- Distance independent model

Distance independent model

- Estimate tree growth either individually or by size classes, usually as a function of present size and stand level variables (age, site index and BA per unit area).
- 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.
- It is not necessary to know individual tree locations when applying these models.
- Models assume that spatially all spp. and sizes of trees are uniformly distributed throughout the stand

Three components of distance independent models

- A diameter growth
- A height growth and
- Mortality

$\Delta D = f\,(RB, HD, Td)$

Where, ΔD=dia. Increment,
RB=Relative BA,
Hd=Dominant ht, and
Td=Tree dominance