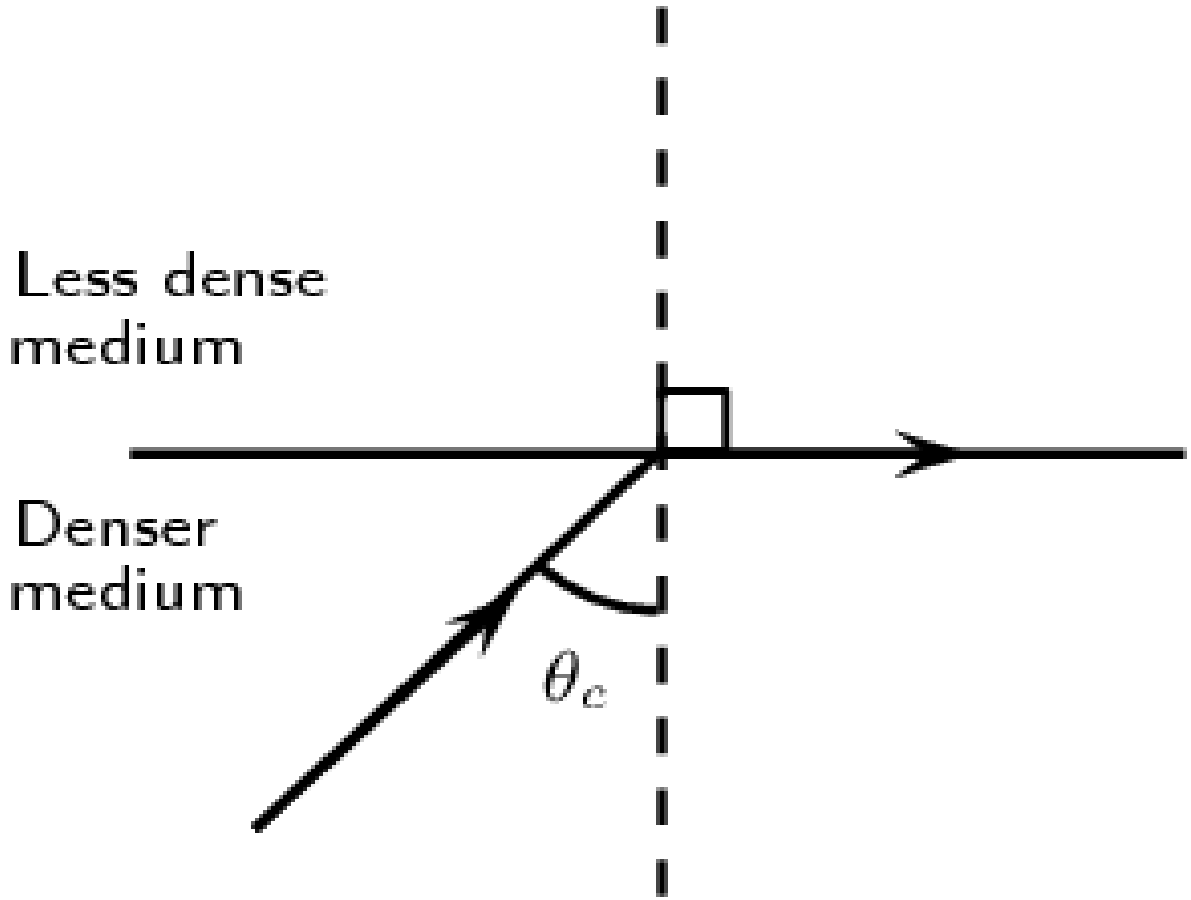
POINT SAMPLING (PS)

Horizontal PS

- 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 or greater than the critical angle of instrument are counted (at a specified radius).

Critical Angle is the angle of incident in an optically denser medium for which the angle of refraction is 90.



- Please, note that even if all the trees are of the same basal area, some might be included and counted while others are not, because being far away from the sampling point, they might not form an angle bigger than the critical angle of the instrument.

- On the other hand, at the same distance from the sampling point a bigger tree is counted while a smaller tree is not.

- Thus, the inclusion of trees in the tally for a given angle depends upon the sizes of trees and their distances from the observer, or sampling point.

Non-Sampling Errors in Horizontal PS

- The following non-sampling errors often occur in horizontal point sampling:

i) ***Instrumental errors and personal bias:***

In making a 360^{o} sweep the starting tree is often either left out or counted twice. This error can be avoided by marking the first tree, and following one procedure of counting it, either in the beginning or at the end.

ii) ***Deviation from the prescribed sample point:***

While making a sweep or turn with instrument held in hand, the viewer often does not keep the instrument at the same point. This gives an over estimation of the tally trees. With an error of 0.5 m in circle radius, there could be bias in basal area estimate.

iii) ***Bias due to concealed trees:***

Concealed trees are the most serious source of bias in stands of high density. Concealed trees should be seen by shifting, such that distance between the tree and the observer does not change.

iv) ***Error due to incorrect inclusion or exclusion of borderline trees:***

Borderline trees should be checked carefully by measuring distance, if necessary. In quick surveys, the best way is to count each borderline tree as half tally tree.

v) ***Bias due to imaginary circle extending outside the stand:***

Slop-over occurs, when any part of a trees associated with imaginary circular plot extends beyond the boundary of the stand being sampled. This causes a bias, which should be avoided by shifting the sample point to the interior of the stand. However, this would at the same time increase the edge bias, since the boundary zone will not be adequately represented.

Vertical PS

- Within a full 360^{o} sweep around the sample point, all trees appearing taller than a critical angle are counted and measured at a specified radius.

- This principle is used in construction of an instrument called a conimeter. For tree height, the height at which the instrument is kept will require to be added.

- This instrument subtends a critical angle of 45^{o}.

AGE OF TREES

- The determination of the age of individual trees is a very important factor to be considered after the determination of volume or biomass, because it indicates the time required to produce that volume or biomass.

- Since ages of individual trees form the basis of determination of age of woods, its study assumes added importance because in the absence of knowledge of age, it is neither possible to know at which rate the wood capital is growing, nor is it possible to compare financial results of forestry with comparable and competing land uses, like agriculture.

Methods of Determining Tree Ages

- While the diameters and heights of individual trees can be measured easily and fairly-accurately with the help of instruments, the determination of age of trees is not so simple.

- Except for the trees, which produce annual rings and whose ages can be determined by counting rings, if the trees are felled, the age of trees has to be estimated by certain methods, which vary with situations, whether the tree is standing or felled.

- Therefore, the methods of determination of age of standing trees and felled trees need separate considerations.

Determination of Age of a Standing Tree

- The age of individual trees, when standing can be estimated using the following methods:

1) From existing records:

- In the case of trees raised by sowing or planting, the records of the year of such operation is very useful in finding the age of trees, as the difference between the year of determining the age and the year of sowing or planting will be the age of the tree.
- In case of trees raised by natural regeneration, under systems of concentrated regeneration, the difference in the year of seeding felling and the year of estimating the age gives the age of trees.

- This method, however, is not very accurate as the record of artificial and natural regeneration pertains to the tree crops or entire stand, and not individual trees.

- In a plantation, all trees are not of the same age, as some are raised in beating-up operations. Similarly, in naturally-regenerated areas, the year of seeding felling cannot give the age of trees correctly because regeneration comes gradually over a period of years, which may be up to 40 years.

2) From general appearance:

The age of standing trees can also be found by ocular estimation, taking the following into consideration:

a) *The size and relative taper of the stem*: E.g., young trees have very tapering boles, while older trees have relatively less-tapering boles.

b) *The size and shape of the crown*: In certain species, the size and shape of the crown changes with advancing age. If knowledge of such developments exists, the age of trees can be estimated by looking at the crown.

c) *The colour and condition of bark*: E.g., the colour and condition of the bark changes with age. For example, the older trees have generally smooth and light-coloured bark, while the younger trees have rough, fairly-cracked and darker-coloured bark.

This method, however, requires great practice and experience before age can be estimated within reasonable limits of accuracy. These conditions, however, change due to locality factors.

3) By the number of annual shoots or whorls of branches:

- In species, which have clear marks of annual shoots, age of tree can be ascertained by counting these shoots from top downwards and adding a proportionate number of years for that part in which these are not visible.

- Some other species form only one whorl of branches every year. Counting the whorls or stubs thereof and making an increase of proportionate number of years for portion in which such whorls are not visible, gives an approximate idea of the age of the tree.

4) By means of increment borer:

Age of trees with annual rings can also be determined using increment borer. This instrument is used for extracting a narrow cylinder of wood, and consists of a hollow auger, which is fitted to a hollow handle that serves as a lever, when the instrument is used.

The instrument is available in different lengths up to 40 cm, and can be used with ease in softwood species.

5) By taking three periodic measurements:

- The age of trees without annual rings can be determined by three periodic measurements. Suppose d_1 was the initial diameter of the tree, and d_2 and d_3 are diameters at subsequent periodic measurements. Let p_1 be growth per unit diameter per year during first two periodic measurements and p_2 the growth per unit diameter per year, during the period between the second and third periodic measurements.

The age of tree can then be determined using:

$$\text{Age} = \frac{1}{p_1 s}, \text{ where 's' is a constant equal to } \frac{\log p_1 - \log p_2}{\log d_2 - \log d_1}$$

6) By reading age from diameter-age curve prepared from periodic measurements of trees in an area:

- Diameter of trees in the area are recorded class-wise, and the average diameter determined. The same trees are measured at an interval of 5 or 10 years, and the average diameter of each diameter-class is found.

- The difference between the two averages gives the periodic diameter increment, which is plotted against Dbh, and a smooth curve drawn. The increment curve is then transformed into diameter-age curve by the following steps:

i) The lowest diameter on the increment curve is taken and its increment is read-off directly from the curve. This is added to the original diameter to obtain final diameter at the end of the period. Increment against this diameter is read-off again, and added similarly. The process is repeated for the whole range of values available from the curve.

ii) The diameter values so obtained are plotted against a succession of equidistant points spaced at intervals corresponding to the number of years in the period and diameter growth curve drawn through the plotted points.

iii) The time axis of the curve is corrected to read age by shifting the zero point to the left by the necessary number of units corresponding to the estimated time required to reach lowest diameter plotted.

If the time required to reach the lowest point cannot be estimated or is not known, the curve may be produced backwards on the basis of experience of similar curves and the age corrected from where the curve cuts the x-axis. The age of the tree can then be read from this curve with reference to its diameter.

7) Mathematical relationship:

The age of tree can also be determined if an equation showing relationship between age and diameter has been prepared for the species.

Determination of Age of Felled Trees

- The age of a felled tree can be determined, if the stump shows annual rings. The only thing that has to be done is to count the rings on stump and add the estimated period the tree would have taken to grow to stump height. This method is however, replete with the following difficulties:

i) *Incidence of false rings:* There are often false rings, i.e., rings, which do not run right round the tree. Therefore, the ring count has to be done carefully so as not to count false rings.

ii) *Closed formed rings:* Certain trees, which are very slow-grown or have been suppressed, have rings very close and care has to be taken not to miss any ring.

iii) *Absence of growth ring in certain years:* In certain years, when the tree is subjected to a heavy defoliator attack, ring formation may not take place. In spite of these difficulties, it is the best and the quickest method of determining age of a tree and can be used, even several years after felling of the tree.

DETERMINATION OF GROWTH OF TREES

- Tree growth shows in elongation and thickening of roots, stems and branches.

- Linear growth takes place as a result of the direct activity of the original tissue, or primary meristem.

- Subsequent radial growth is brought about by division and enlargement of secondary meristem, or cambium, which produces new wood and bark between the old wood and bark.

- Root growth is not given enough importance in forest mensuration, though in some tree species, the root portion is very valuable.

- The radial growth and height growth of stem together with the resulting changes in stem form must be measured to determine growth in volume.

- Fluctuations in growth occur both daily and seasonally.

- The daily changes cannot generally be measure in trees.

- Unlike the tropics, the seasonal variations in temperate forests are of particular importance in forestry since they are responsible for the formation of growth rings.

- The spring wood is lighter and more porous while summer wood is darker and denser.

- Thus, the annual growth of a tree as observed on a cross section of the stem forms a pattern of concentric rings. By measuring the width of these rings, the annual radial growth of the tree may be determined.

- This radial growth is not the same along the entire length of the stem.

- The height and radial growth do not start and end at the same time.

- In most of the tree species, height growth starts and accumulate earlier than the radial growth.

- Tropical species, as well as broad leaved trees in temperate climates barring few exceptions, do not generally form annual rings, though they may have pronounced seasons of high and low growth activity.

- *Tectona grandis* is examples of broad leaved tropical species, which show annual growth rings.

- Several other broad leaved species show growth rings but these may not be annual (e.g., *Mansonia altissima*, *Milicia excelsa)*.

- In some cases, several rings may be produced in a year, while in other cases one ring may be formed after several years.

CLASSIFICATION OF INCREMENT

- The increment, whether in diameter, height or volume is classified as follows, depending on the period to which it relates:

i) *Current annual increment* (CAI) – An increment, which a tree or a crop puts on in a single year. Because of the very slow rate of growth in certain tree species, in practice, CAI often refers to average annual rate of increase over a short period or the periodic annual increment.

ii) *Periodic annual increment* (PAI) – An average annual increment for any short period.

iii) *Total increment* – An increment that a tree or a crop puts on from origin up to the age at which the tree or crop is cut. It is the sum of the CAI, and therefore represents the volume of the tree or the stand.

iv) *Mean annual increment* (MAI) – It is the mean volume of a tree at the desired age.

In other words, it is the total increment up to a given age divided by that age. If the MAI is calculated for a portion of the total age, it is called periodic mean annual increment. If it is calculated at the rotation age, it is called the final mean annual increment.

Relationship between CAI and MAI

- The MAI, whether in a tree or in a stand, is the expression of the average yearly response in the past to the growth factors of the site, while the CAI is the actual response in any one year.

- As the MAI is the average and the CAI is the individual item from several of which the average is drawn, the two do not coincide with each other throughout the life of the tree or stand except twice viz., one at the end of first year, and the second in the year of the culmination of the MAI.

- The CAI is not uniform throughout the life of a tree or a stand.
- It rises to a maximum and then gradually falls off.
- In the case of some species, it is small to start with; then, it rises steeply to a climax and then falls off.
- In either case, falling off is not as steep as the rise. The MAI also increases to a maximum, but at a much lower rate, because the effect of increase of a single year is distributed over all the years that the tree or stand has existed.
- The MAI continues to rise towards a maximum even after the CAI has started falling because the amount of growth added to the tree or stand volume during the year, although less than before, is still greater than the average or the mean.

- When CAI finally falls to such an extent that it is equal to the average of the entire life of the tree or the stand, the MAI reaches its highest point. This is the year of the culmination of the mean annual increment.
- During the following and subsequent years, the CAI is less than the mean, and so the mean also begins to drop. But this drop, too, is not as rapid as that of the CAI because the effect of the decrease of CAI is spread over the whole life of the tree or stand.
- The MAI therefore drops only to the extent it is being pulled down by the effect of the lesser CAI for single years upon the fraction, total volume/age in years.

- A time may come, when there may be no growth at all and so the CAI will be zero.

- Unless the tree or the stand is cut, loss in volumes may start taking place due to rot or other damages and then the CAI will become negative.

- But the value of MAI is never zero and in no circumstance, it is negative like the CAI. In other words, until the tree or the stand is cut or destroyed, the MAI is always positive.

Increment Percent

- Increment percent is defined as the average annual growth in diameter, basal area or volume over a specified period expressed as a percentage of diameter, basal area or volume either of the beginning or more usually halfway between the beginning and end of the period.

- This is an expression of increment from the business man's point of view. The statement that the tree or a crop has been growing in diameter, basal area or volume at a certain rate during a period omits reference to the capital on which the increase is taking place.

- If the increase per year is expressed as a percentage of the diameter, basal area or volume of the tree to which it relates, it indicates the rate of growth clearly, and makes it comparable to other forms of investments, on which interest accrues.

- But the analogy of the interest and principal does not apply to the increment on wood capital, wholly and correctly.

- The increment percent of a tree cannot be compared with the percent of interest earned annually on a fixed capital since this increment is not separable from the wood capital on which it is laid, and thus causes this capital or base volume to increase annually.

- To maintain the same rate of growth or increment percent on this increasing volume, the amount of annual growth must continue to increase at a geometric rate.

- Although the increase in volume of a tree or a stand during the period of most rapid current growth for a time does approach a geometric rate, when compared to a given or fixed initial volume, yet even here the effect of the constantly and rapidly increasing volume of accumulated wood capital on the current annual rate of increase would cause this rate of increment percent to drop consistently throughout the entire life of a tree or a stand.

METHOD OF DETERMINING GROWTH OF TREES WITH ANNUAL RINGS

- The growth of trees with annual rings can be determined by the following methods:

a) Stump Analysis

b) Stem Analysis

c) Increment Boring

- Of these methods, stump analysis and increment borings give only diameter increment, but *stem analysis* is used to determine diameter, height and volume increment throughout the life of the trees analyzed.

a) Stump Analysis

- It is the analysis of a stump cross-section by measuring annual rings in order to estimate the age of the tree and its past rate of diameter and basal area growth.

Advantages of Stump Analysis

- As compared to other methods, stump analysis offers the following advantages:

i) 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 felling.

ii) Data can be collected any time with minimum of manual labour.

iii) The data can be multiplied to any desired extent with no objection other than the time taken in measuring.

iv) Field work is simple and easily learnt.

v) Each stump provides data for the whole life of the tree.

b) Stem Analysis

- Stem analysis is defined as the 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.

Advantages of Stem Analysis

- Stem analysis offers the following advantages:

i) The data are collected from standing trees carefully selected and so it is more reliable. This is 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 or in increment boring.

ii) It gives complete information about the growth of trees in respect of diameter, height and volume, and so it is self-contained.

c) Increment Boring

- Increment boring is defined as the boring of a tree stem with increment borer to determine increment of trees with annual rings.

DETERMINATION OF INCREMENT IN TREES WITHOUT ANNUAL RINGS

- The only way to determine increment in trees without annual rings is to make periodic measurements.

- This can be done for the individual trees for which the investigation is to be made, or it can utilize data of linear increment plots or sample plots situated in comparable localities.

- Though both kinds of plots give same information, they differ in their applicability and treatment.

- While the tree increment plot is applicable to (i) uneven-aged crops, (ii) irregularly-stocked forest, (iii) mixed forest and (iv) isolated trees, the sample plot is applicable to pure, even-aged, uniformly-stocked crops.

- Very often, it forms a line of trees of selected species maintained for the purpose of assessing diameter/age relationship for species not characterized by annual rings.
- It is also used for the following purposes:

i) Determination of the average time required for typical trees growing under typical conditions to pass through each recognized diameter class. This information is used for determination of rotation and yield.

ii) Comparison of increment of trees of different age, diameter and crown classes as a guide for suitable treatment.

iii) Comparison of effect of adverse or favourable influences on diameter increment with the object of determining whether sufficient response is obtained to justify expenditure involved in the operation.

iv) Collection of data for determination of crop increment in irregular forest. In this respect, it differs from stem analysis in one important respect, and it is that while stem analysis requires the felling of trees, linear increment plot does not require felling of the concerned tree. Thus, it is used where continuous observations at regular intervals are possible.

- The linear increment plot is selected so as to be representative of the whole range of quality, type and geographical distribution of the species to be studied.
- It should also be typical as regards uniformity and density of stocking of the area, which it represents.
- All trees in the plot are not necessarily kept under detailed observation.
- Only some trees suitable for the purpose are selected to cover all diameter classes, crown classes, age classes.
- These trees are given cross marks, and serially numbered.
- The centre line of the plot is cleared if necessary and durable pegs or posts are driven in at every 20 m.

- Measurements of the selected trees are taken periodically and compiled to draw curves, which indicate increment in those trees.

MEASUREMENT OF CROPS OR STAND

Determination of Age of Stand

- Depending on the variation in age of trees constituting a stand, forest stands are classified into even-aged and uneven-aged crops.

- The term *even-aged* is applied to crops consisting of trees of approximately the same age, but differences up to 25% of the rotation age may be allowed, in case where a crop is not harvested for 100 years or more.

- On the other hand, the term *uneven-aged* is applied to crops in which the individual stems vary widely in age, the range of difference being usually more than 20 years, and in the case of long rotation crops, more than 25% of the rotation.

- In view of these differences, different methods are used for determination of age of these two classes of crops.

Even-Aged Stand

- The age of an even-aged stand is described by the term stand age, which is defined as the age of a regular stand corresponding to its stand diameter.

- Thus, when the difference in ages of trees is very small, as in case of plantation stand, or the stands raised under uniform system of forest management, stand age is the age corresponding to age of the tree of mean diameter.

- The age of such a tree can be found out either by felling it, if it belongs to a species, which produces clear annual rings, or by reading age corresponding to stand diameter from the age diameter curve.

- If, however, the difference in ages of trees is appreciable, they should be grouped into even-aged groups. Then, the total basal area of each group is found and also the age of the group.

- Then, the following formula gives stand age:

$$\text{Stand age} = \frac{s_1a_1 + s_2a_2 + s_3a_3 + \ldots\ldots}{s_1 + s_2 + s_3 + \ldots\ldots}$$

- Where, s_1, s_2, s_3, ….. are the basal areas of the even-aged groups, a_1, a_2, a_3 ….. are the ages of the even-aged groups.

Uneven-Aged Stand

- There is a difference of opinion about the definition of mean age of uneven-aged crops.

- For instance, while some defined mean age as the average age of dominant trees in a stand, some others defined mean age of an uneven-aged stand as that period, which an even-aged stand requires to produce the same volume as the uneven-aged stand.

- The difference of opinion is reflected in the methods of determining mean age. A few formulae commonly used are given as follows:

i) As already stated, MAI is equal to volume divided by age. Therefore age is equal to volume divided by MAI. Depending on this, Smalian and Heyers defined mean age of an uneven-aged stand as the sum of the volumes of the groups of different age-classes divided by the sum of the MAIs of those groups:

$$\text{Thus, mean age} = \frac{V_1 + V_2 + V_3 + \ldots\ldots\ldots\ldots}{V_1/a_1 + V_2/a_2 + V_3/a_3 + \ldots\ldots}$$

- Where, V_1, V_2, V_3, ….. are the total volumes of even-aged groups, a_1, a_2, a_3 ….. are the average ages of the groups.

- As the ages of standing trees are difficult to ascertain, age classes may be substituted by diameter classes. Theoretically, this formula gives most accurate results as it correctly correlates volume with age.

- But this method is very cumbersome, as it requires previous calculation of volume of the various groups of different age-classes.

ii) As volume depends, to a large extent, on basal area, the ages may be correlated with it, and thus the mean age can be determined by the following formula:

$$\text{Mean age} = \frac{s_1 a_1 + s_2 a_2 + s_3 a_3 + \ldots}{S}$$

- Where, s_1, s_2, s_3, … are the total basal areas of even-aged groups, a_1, a_2, a_3, ….. are the average ages of these groups, ‘*S* ‘ is the total basal area of the whole forest.

- This formula is simple and easy to apply, and it works well, if form heights of the diameter classes are equal.