Biometry

Course content

- **Measurement of forest crop** – diameter, height, age and volume,
- **Stand structure** – even aged and uneven aged
- **Management of sample plots**
- **Forest inventory** – planning and design alternatives, sampling, execution, compilation and reporting,

- **Forest sites**- classification and evaluation, quality classes and site index models,
- **Stand growth** and its current estimation and production – various methods.
- **Yield Tables** - Calculation of current annual increment and mean annual increment of stand, mathematical models.
- **Plant Biomass Estimation**: Basic concepts, simple indices of biomass, estimators for actual biomass estimation, sample counts.

Measurements of Forestry Crops

1. Height
2. Diameter
3. Age
4. Volume

Some Learnings from Mensuration

- Measurement of individual tree
  - Diameter, height, age, form, volume, growth etc.
- Basal Area is very well co-related with volume

Some Learnings from statistics

- Trees should be selected, areas should be selected in such a way that statistical analysis can be carried out

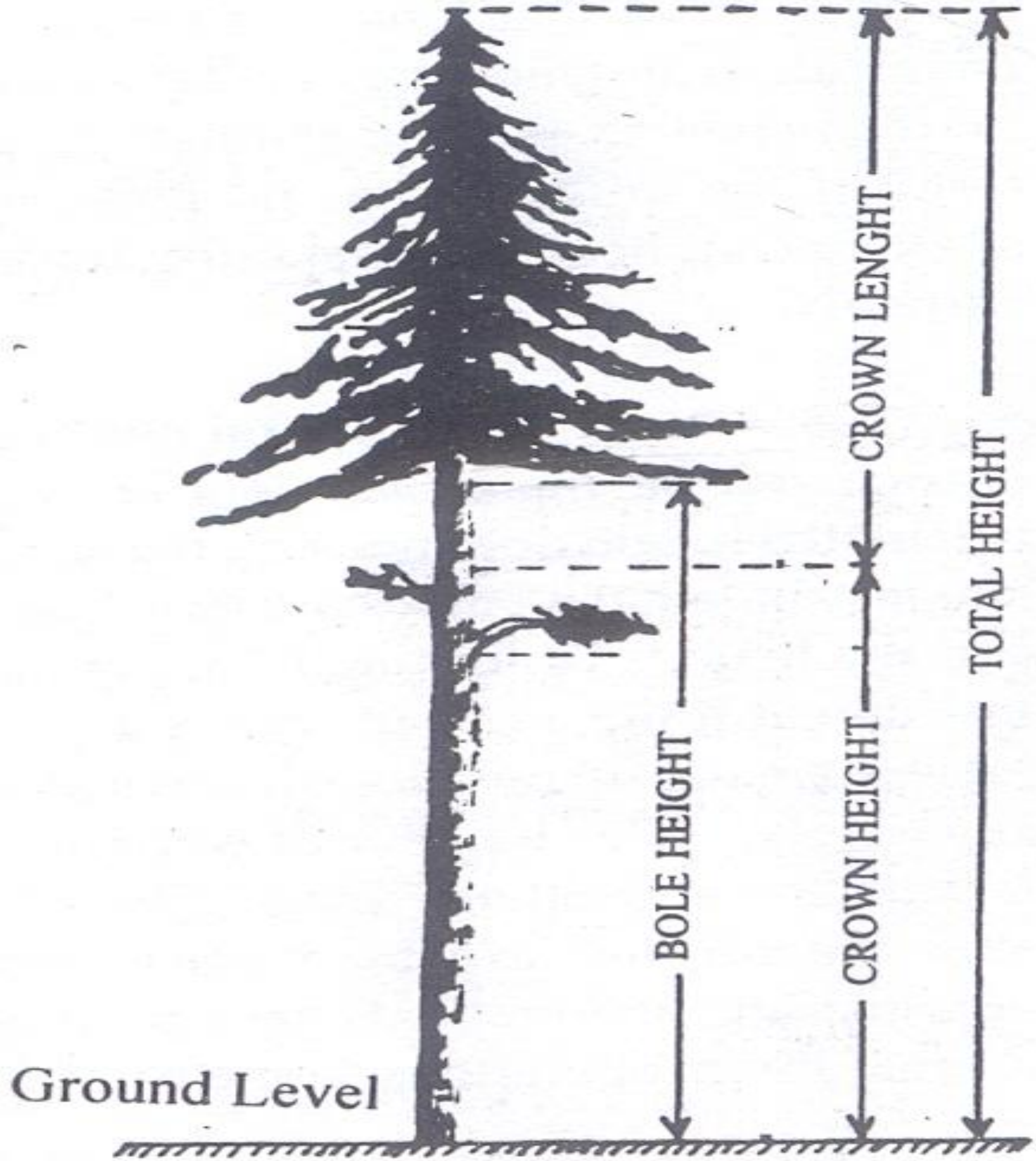
Diameter

- BH – 1.37m (4 ft 6 inch)
- D.B.H
- G.B.H
- D.B.H/G.B.H(O.B)
- Callipers & Tape

Height

- To find out the volume
- To read volume table, form factor table, yield table
- To find out the productive capacity of the site
- Index of the fertility

- Instruments: Abney’s Level, Haga Altimeter, Ravi Multimeter, Spiegel Relaskop



CROWN LENGHT
TOTAL HEIGHT
BOLE HEIGHT
CROWN HEIGHT
Ground Level

Form

- Rate of taper of a stem or log
- Taper: decrease in diameter of a stem/log from base upwards
- Geometrical Solids of tree form:
  - Neloid
  - Paraboloid
  - Cone
- Form Factor $F = \frac{V}{Sh}$

V is the tree volume
S is the basal area at BH
h is the height of the tree

AGE

- For knowing the rate of growth

- How to know the age??
- Existing Records
- Ocular Estimates
- Pressler's Borer
- Periodic Measurements
- Stem & Stump Analysis

Volume

- Most important Measure
- Ultimate object is to calculate the quantity of wood in trees and crop
- Commercial, research, predicting future yields, estimating increment to assess return on capital *etc*

Calculation of Volume of Logs

Form of solid	Volume of full solid	Volume of a frustum of solid	Remarks
(1) Cylinder	sl	sl	---
(2) Paraboloid	$\frac{sl}{2}$	(i) $\frac{s_1 + s_2}{2} \times l$	Smalian's formula
		(ii) $s_m \times l$	Hubers's formula
(3) Cone	$\frac{sl}{3}$	$\frac{(s_1 + s_2 + s_1 s_2)}{3} \times l$	
(4) Neiloid	$\frac{sl}{4}$	$\frac{(s_1 + 4 s_m + s_2)}{6} \times l$	Prismoidal or Newton's formula

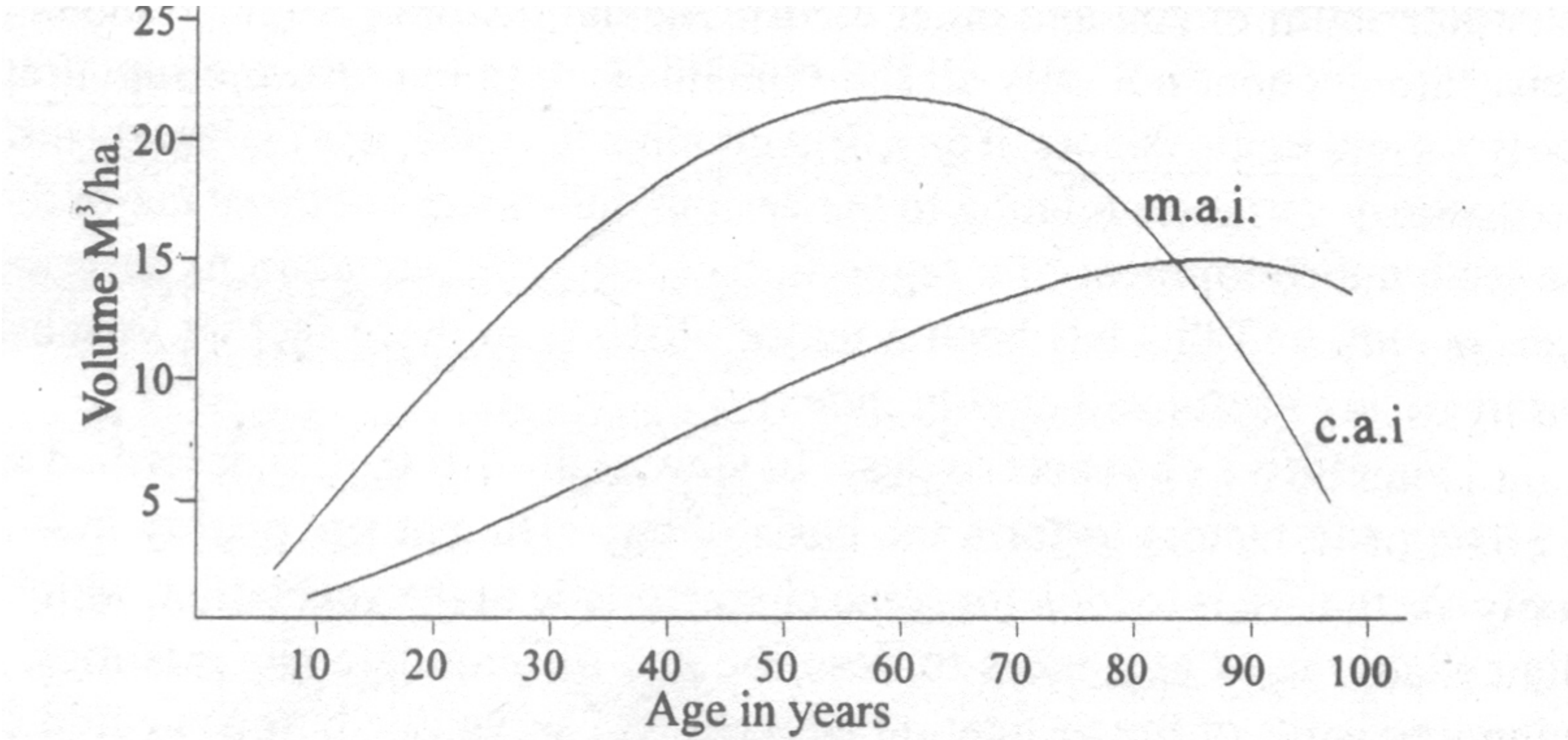
Volume

- Quarter Girth Formula:(Hoppu's Rule)

- $$V = \left[\frac{g}{4} \right]^2 \times L$$

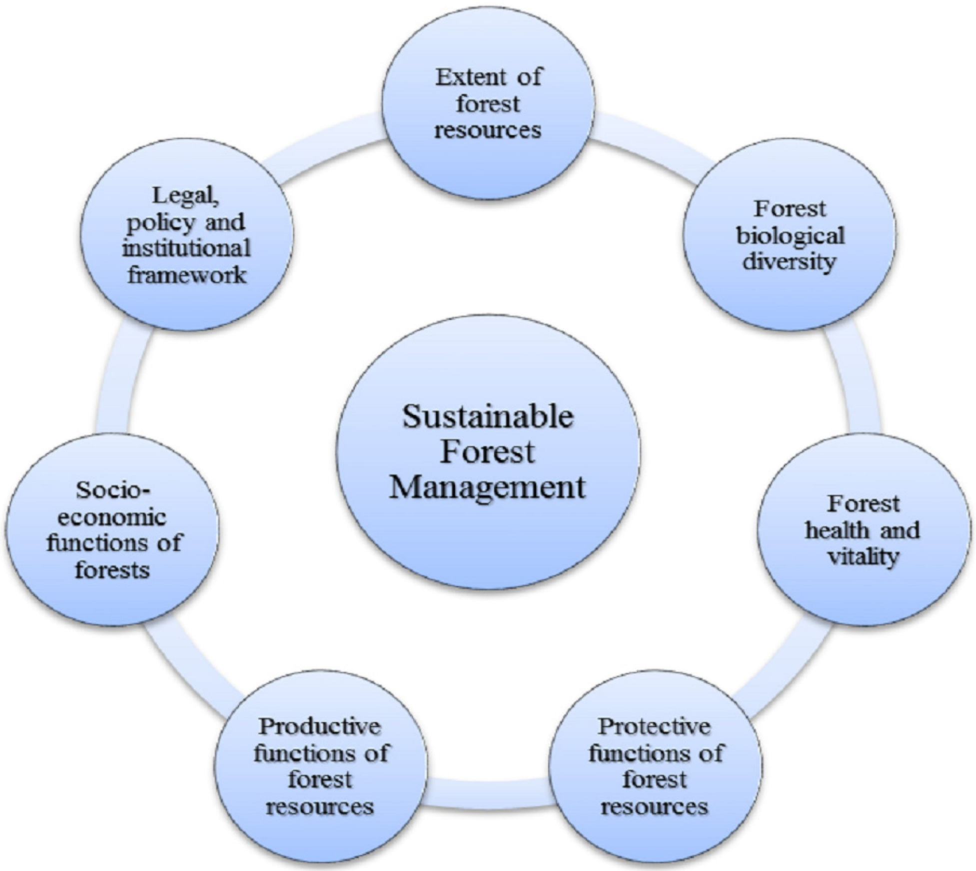
g- girth at the middle of the log

Growth



25
20
15
10
5
Volume M³/ha.
m.a.i.
c.a.i
10
20
30
40
50
60
70
80
90
100
Age in years

Ultimate Objective ?



Sustainable Forest Management

Object of Sustainable Forest Management

"Perpetuate Forest

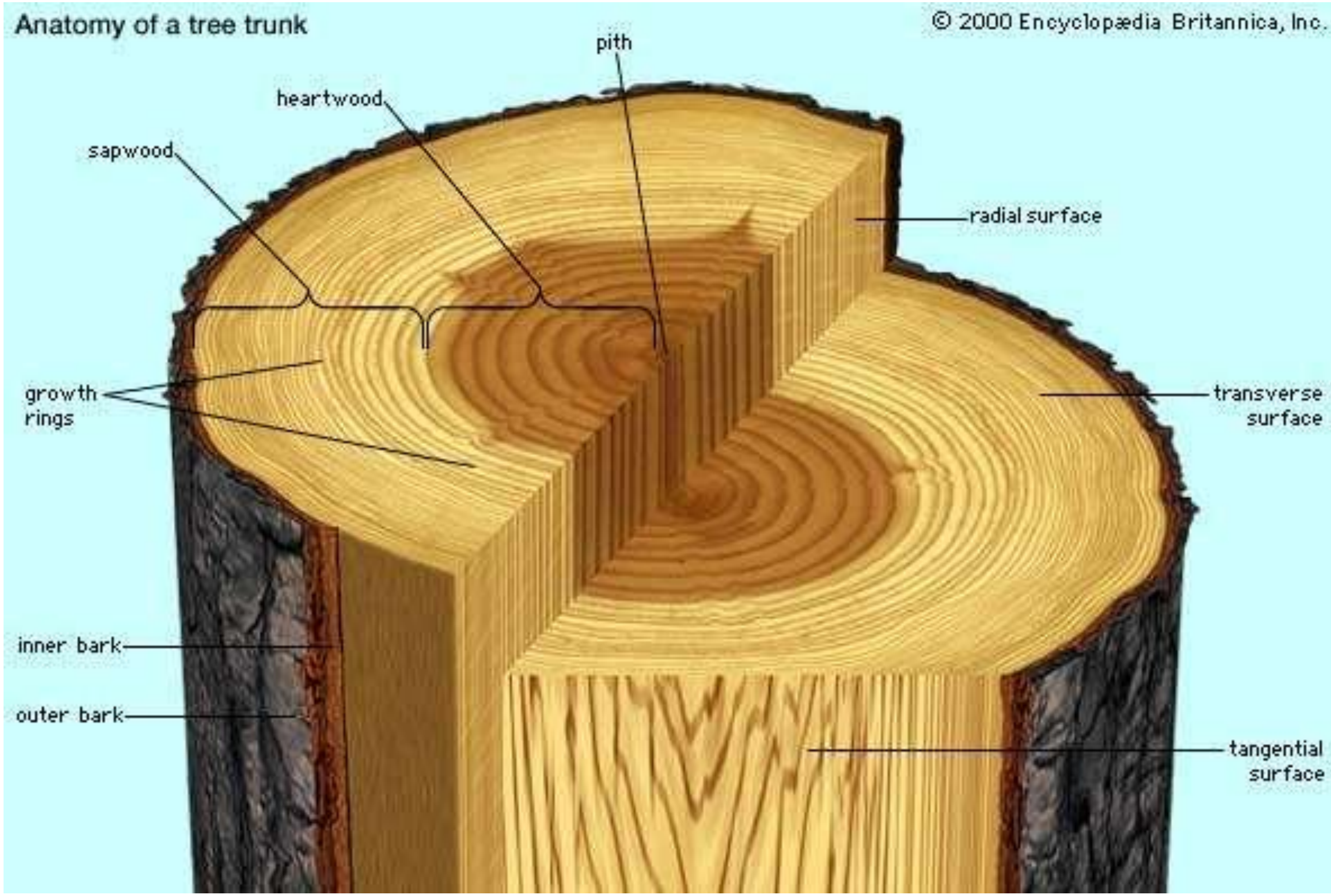
and

Harvest Economic Yields too"

(Sustained Yield)

Pre-requistes

1. **Estimate of Present Growing Stock:**
   - Build by individual trees
   - Survey/Sampling techniques
   - Use statistics
2. **Growth Models for Future Production:**
   - Mathematical
   - Empirical



Anatomy of a tree trunk
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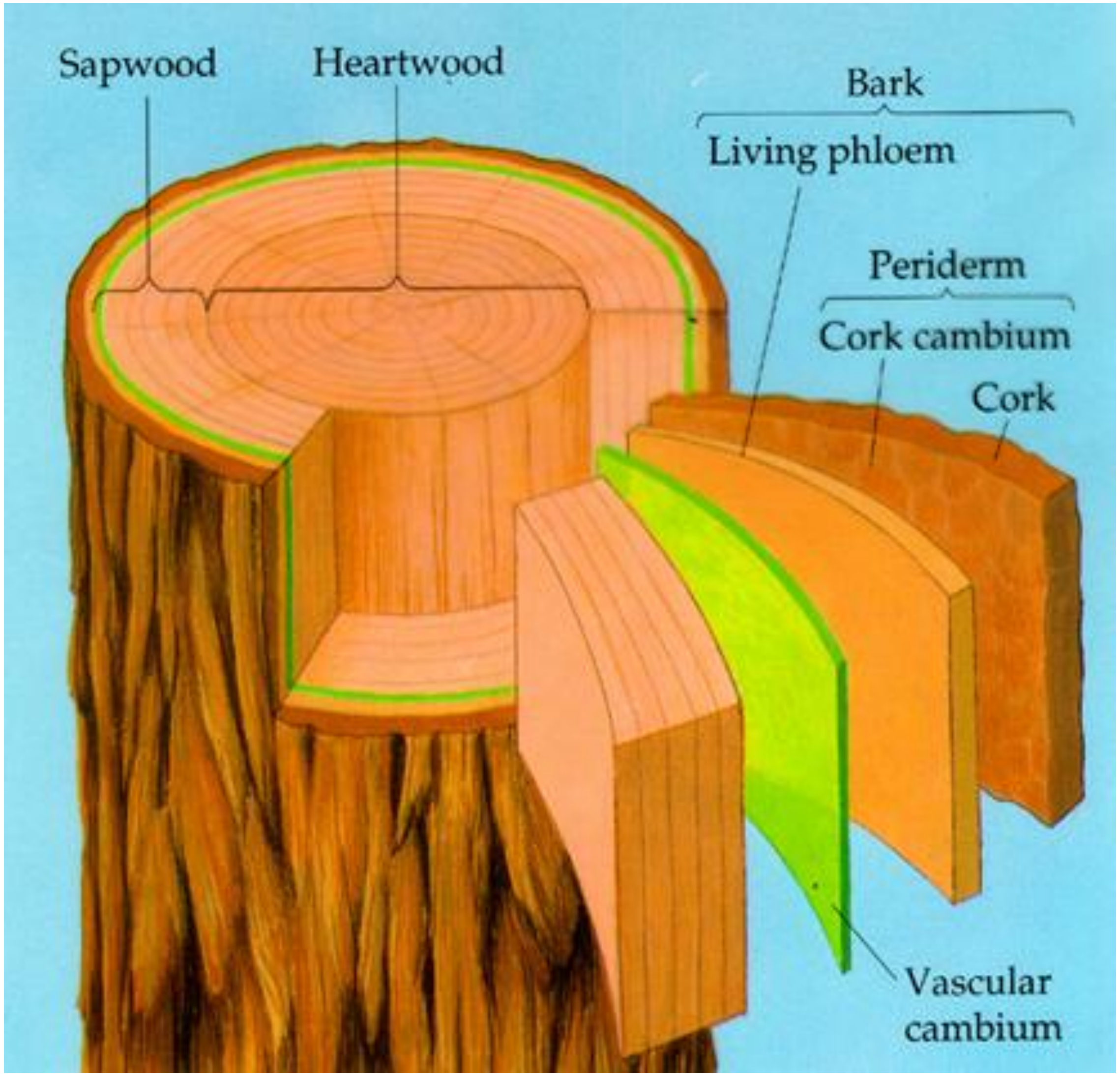
pith
heartwood
sapwood
radial surface
growth rings
transverse surface
inner bark
outer bark
tangential surface



Sapwood
Heartwood
Bark
Living phloem
Periderm
Cork cambium
Cork
Vascular
cambium

Hollow Log

Anatomy of wood

- In dicotyledonousIn dicotyledonous and coniferous (i.e., woody) trees and shrubs, is a layer of meristematic cells, called the vascularIn dicotyledonous and coniferous (i.e., woody) trees and shrubs, is a layer of meristematic cells, called the vascular cambium

- vascularvascular cambium organizes between the primary xylem and primary phloem of the vascular cylinders.

- **The cambiumThe cambium forms the wood and the inner bark of the tree and is responsible for thickening the plant**, whereas the apical meristems are responsible for forming and elongating the primary plant body

Measurements of Crops

- Different from individual tree measurements:
- Special characteristics of the crop

1. Gradual Diminution of # of Trees

   Smaller trees: Competition – death-average dia & ht increase

   Mature trees: death – average dia.& ht decreases

2. Crop Structure (stand Constitution)

   Even & Uneven aged; Pure & mixed

   Growth also depends on the Size & form of the neighbouring trees

3. Object of Measurement – no of trees, crop dia., crop ht., crop vol., distribution size –wise.

Determination of Crop Parameters

1. Crop Diameter
2. Crop Height
3. Crop Age
4. Crop Volume

Few Important Terms …

Stand

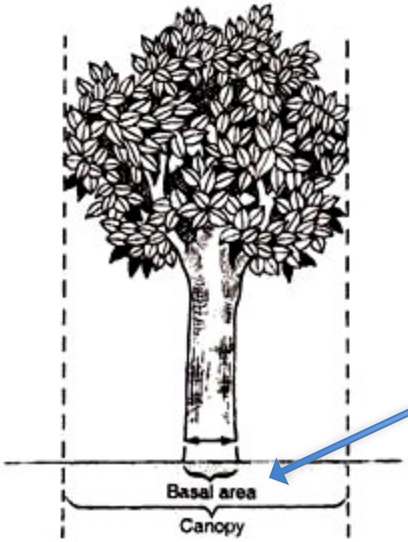


Fig. 3.3: Basal area is a small fraction of land area but the canopy of a tree occupies a large area

Basal area

1. <u>Stand</u> :

- Some area of forest having common crop characteristics/homogeneous(species composition, size, age) and require **same treatment & planning attention.**
- **Studied or managed as a single unit**

Definition: An area of forest that **<u>can be treated as a unit</u>** because it has uniform land quality, topography, species composition etc

- Typically, a stand is no less than 1 ha and no more than 20 ha in area

Forest types – too varied

divided into

Stand Type - Collection of Stands

Forest Crop: The collection of trees growing on a given area

main features that influence separation of stands

1. Extent of stand management
    - Intense management
    - Extensive working
2. Age of stand
    - Age class interval

3. Treatment of stand

- Use development or treatment class instead of age class
- Mainly 6 development classes:

i. Seedling stage

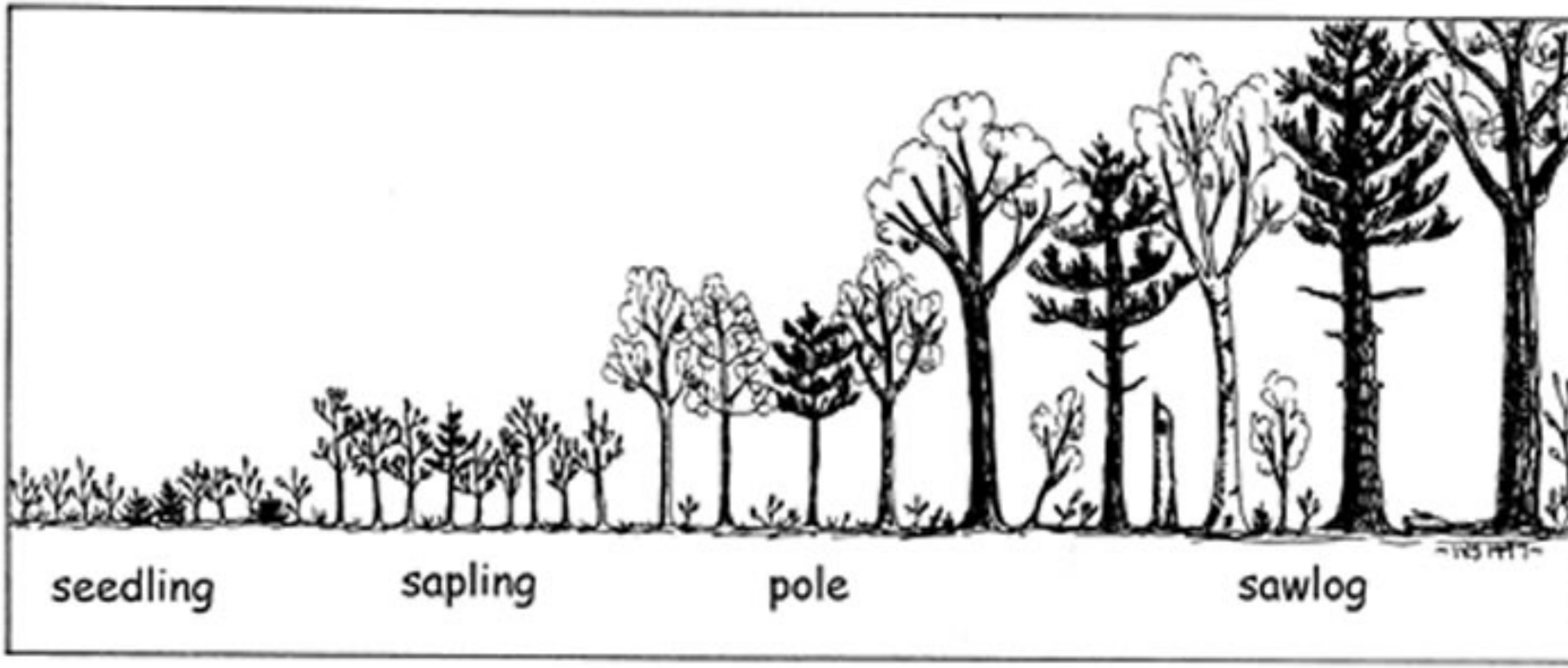
ii. Young pole stage

iii. Large pole stage

iv. Young timber stage

v. Mature timber stage

vi. Over mature timber stage


seedling
sapling
pole
sawlog

4. Health of stand

- Areas which are damaged by wind, fire, insects etc.
- Their future prospect demands special attention

Difference between Forest & Stand:

Stand – An aggregation of trees or other growth occupying a specific area and sufficiently uniform in species composition, size, age, arrangement, and condition as to be distinguished from the other growth on adjoining areas.

Forest – A plant association predominantly of trees or other woody vegetation, a collection of stands.

Stand Parameters

- Stand Composition
- Stand Structure
- Stand Density
- Stand Stocking

Stand Parameters:

Stand Composition – The composition of stands is conceived of as being either pure or mixed. These are defined as:

(a) Pure Stand – A stand in which at least 80% of the trees in the main canopy are of single species.

(b) Mixed Stand – A stand in which less than 80% of the trees in the canopy are of a single species.

Stand Parameters:

Stand Structure – distribution of species and tree sizes on a forest area.

depends on:

- ✔species' growth habits
- ✔environmental conditions
- ✔management practices

Traditionally, stand structures are classified on the basis of tree ages . These are:

- (a) Even-aged stands – Stands in which there exists relatively small age differences between individual trees.
- (b) Uneven-aged stands – Stands in which there exists relatively large age differences between individual trees.

Stand Parameter

- **Stand Density** – quantitative measurement of a stand expressed in terms of number of trees, basal area, volume, or other criteria, on unit area basis
  - Describes the degree of stem crowding within an area
  - Quantitative measurement of a stand

    BA/ha, No. of trees/ha, Vol./ha

Stand Parameters

- **Stocking**: Adequacy of a given stand density to meet the management objective
- Measure of relative completeness of tree stocking

- (a) Fully stocked stands – Stands in which all the growing space is effectively occupied but which still have ample room for development of the crop trees.

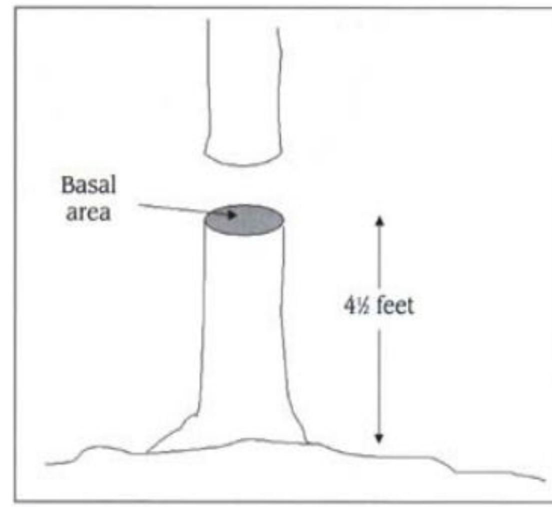
- (b) Overstocked stands – Stands in which the growing space is so completely utilized that growth has slowed down and many trees, including dominants, are being suppressed.

- (c) Understocked stands – Stands in which the growing space is not effectively occupied by crop trees.

2. **Basal Area**

- Definition: The cross sectional area estimated at breast height expressed in m^2, symbol is g.

- on per ha basis G $m^2 ha^{-1}$



Example:

- for young plantations 10-20 m^2/ha
- tropical average good crop 35 m^2/ ha

  maximum exceptional 60 m^2/ ha

How to Calculate ?

1. Using Sample Plots:- for plantation

Steps:-

a) Select representative sample plots

b) Lay out plots in field

c) Measure and record diameter frequency in a table.

   - By measuring all trees in **dia class**

d) Total B.A. calculated for each plot by ∑ B.A. in each dia class.

e) Avg. B.A./ha calculated by proportion to plot area.

- **Problem:**

  Estimating basal area per hectare using four plots

A=0.01 ha

d class cm	f1	f2	f3	f4	g/ tree m^2	f1g m^2	f2g m^2	f3g m^2	f4g m^2	Total for 4 plots m^2
0-10	1	-	2	-	0.00196	0.00196	-	0.003925	-	0.005888
10-20	1	1	-	1	0.01766	0.01766	0.01766	-	0.01766	0.052988
20-30	2	3	2	2	0.04906	0.09812	0.14718	0.09812	0.09812	0.441563
30-40	5	4	4	4	0.09616	0.48081	0.38465	0.38465	0.38465	1.634763
40-50	3	3	4	5	0.15896	0.47688	0.47688	0.63585	0.79481	2.384438
50-60	-	1	-	2	0.23746	-	0.23746	-	0.47492	1.187313
60-70	2	1	2	2	0.33166	0.66332	0.33163	0.66332	0.66332	2.32163
70-80	-	-	1	-	0.44156	-	-	0.44156	-	0.441563
Total	**15**	**13**	**15**	**17**		**1.73875**	**1.59546**	**2.227425**	**2.43348**	**7.99522**

Cont…

$$G = \frac{\sum^{n}\sum^{m} g_{ij}}{\sum^{n} A} \ m^2/ha$$ and

$= 7.99522/0.04$

$= 199.88\ m^2/ha$

Determination of Crop Parameters

1. Crop Diameter

2. Crop Height

3. Crop Age

4. Crop Volume

1. Crop Diameter

- Main object is to find out volume

- Volume is dependent on basal area (well correlated)

Crop diameter : Even aged crop

Mean diameter : any group of trees or any forest

Steps:

1. Tabulate field data in dia-classes

Dia class	# of trees	Basal area of mid pt.	Total basal area in dia class
10-20	n1	g1	n1 . g1
20-30	n2	g2	n2. g2
30-40	n3	g3	n3. g3
40-50	n4	g4	n4. g4
50-60	n5	g5	n5. g5
ith	ni	gi	ni. gi
Total	**∑ ni**		**∑ ni.gi**

M.B.A. = ∑ ni gi / ∑ni

$$\text{M.B.A.} = \frac{n1g1+n2g2+\ldots\ldots\ldots\ldots\ldots nigi}{n1+n2+n3+\ldots\ldots\ldots\ldots\ldots ni}$$

$$\text{M.B.A.} = \pi \left(\frac{\text{crop diameter}}{2} \right)^2$$

$$= \frac{\pi}{4} \times (\text{crop dia.})^2$$

$$\text{Crop dia.} = \sqrt{\frac{(4 \times \text{M.B.A.})}{\pi}}$$

$$\text{Crop dia.} = 2 \times \sqrt{\frac{\text{M.B.A}}{\pi}} \qquad (1)$$

- **Problem:**

  Calculate crop diameter using four plots.

A=0.01 ha

d class cm	f1	f2	f3	f4	g/ tree m^2	f1g m^2	f2g m^2	f3g m^2	f4g m^2	Total for 4 plots m^2
0-10	1	-	2	-	0.00196	0.00196	-	0.003925	-	0.005888
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60-70	2	1	2	2	0.33166	0.66332	0.33163	0.66332	0.66332	2.32163
70-80	-	-	1	-	0.44156	-	-	0.44156	-	0.441563
Total	**15**	**13**	**15**	**17**		**1.73875**	**1.59546**	**2.227425**	**2.43348**	**7.99522**

Cont….

$$M.B.A. = \frac{\sum n_i . g_i}{\sum n_i} = \frac{7.99522}{60} \; m^2 \quad \text{in } 0.04 \text{ ha,}$$

and….

$$\bar{d}_g = 2 \times \sqrt{\frac{MBA}{\pi}} = 2 \times \sqrt{\left[\frac{7.99522}{60}\right] \times \frac{1}{\pi}}$$

$$\bar{d}_g = 0.412 \text{ m}$$

$$\bar{d}_g = 41.2 \text{ cm}$$

- Similarly from above table arithmetic mean dia. can be calculated

- **Arithmetic Mean dia. =** $\dfrac{\sum ni\ di}{\sum ni}$

ni- no. of trees in each dia. class

di- average diameter of the dia. class

Top diameter :-

- diameter corresponding to the M.B.A.

of 250 biggest diameters per ha

- Used in determining the top height of the crop assessing the site quality.

Determination of Crop Parameters

1. Crop Diameter
2. Crop Height
3. Crop Age
4. Crop Volume

Crop Height

- Height is another widely used parameter.

- Height is widely used as a measure of site quality and stand productivity.

- Vertical structure (i.e., the height distribution) is an important factor in many silvicultural prescriptions and in assessing wildlife habitat.

Crop Height

- For an even-aged stand, the variation in heights in typically less than the variation in diameter.

- For uneven-aged stands, the height distribution is often similar to the diameter distribution, although generally not as wide.

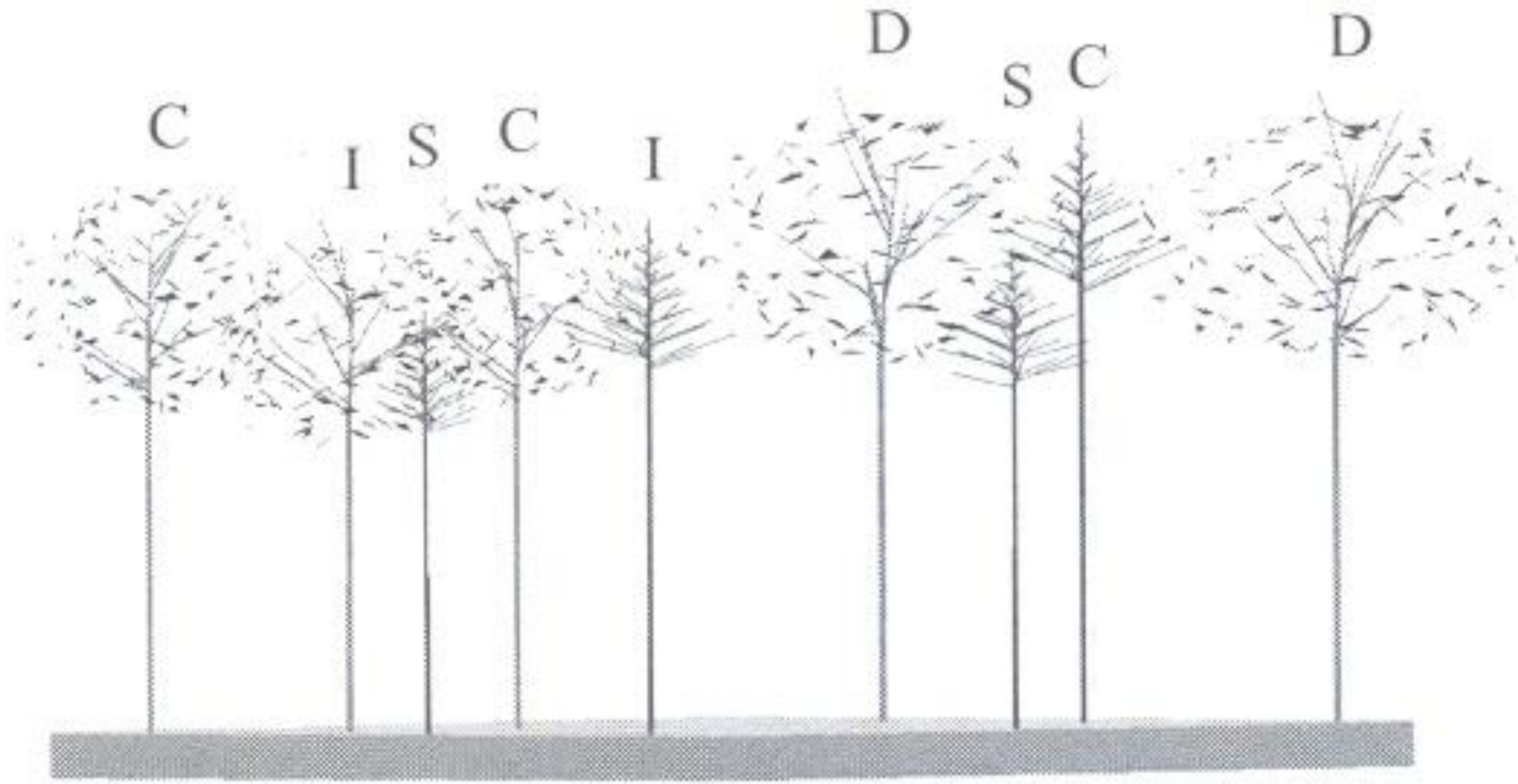
Classification based on crown position

- Dominant :-
  - crowns extend above the general level of crown cover of others of the same stratum
  - not physically restricted from above
  - somewhat crowded by other trees on the sides.
- Co-dominant:-
  - Crowns form a general level of crown stratum
  - not physically restricted from above,
  - more or less crowded by other trees from the sides.

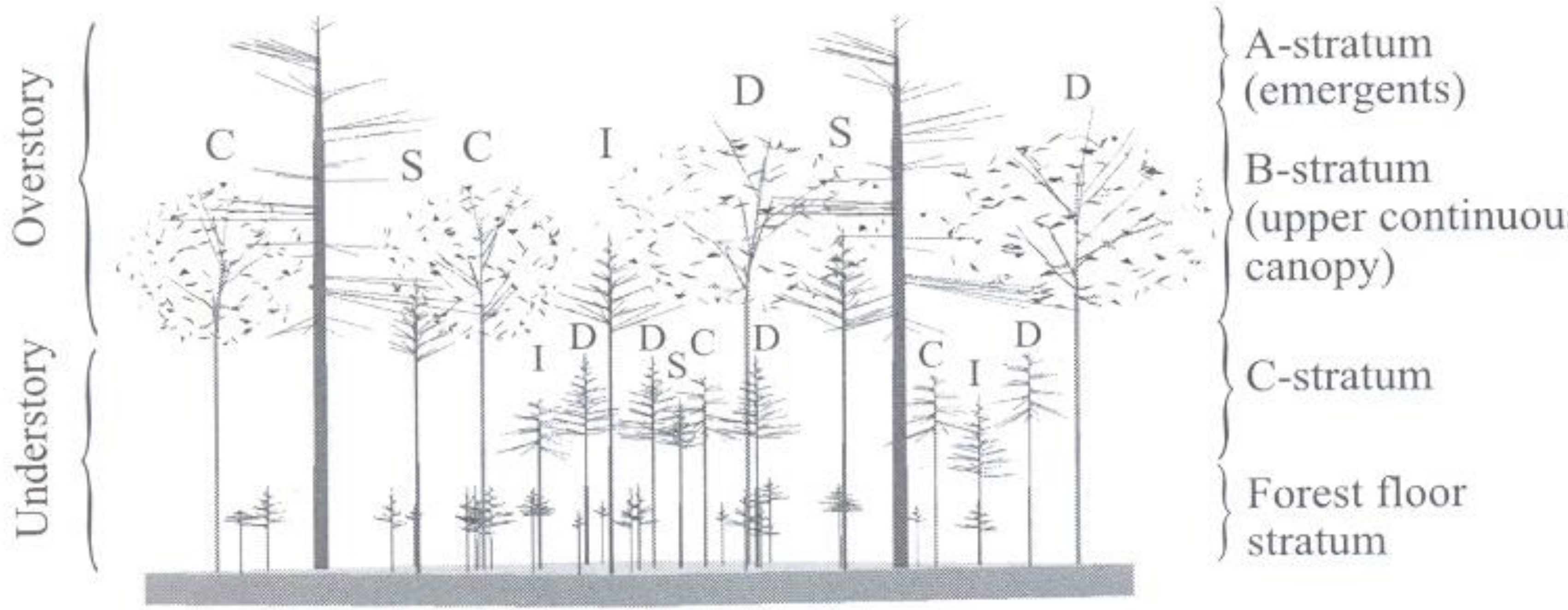
Classification based on crown position

- Intermediate:-
  - shorter, but their crowns extend into the general level of dominant and co-dominant trees
  - free from physical restrictions from above, but quite crowed on the sides.

- Suppressed (overtopped):-
  - Crowns are entirely below the general level of dominant and codominant trees
  - physically restricted from immediately above.



Single Stratum Canopy



Muti-strata Canopy

Determination of Height of Crop

1. Crop height:

- Weighted avg (basal area) ht. of a regular crop **(Lorey's formula)**

2. Mean Height:

- Ht. corresponding to the mean dia. of a group of trees or crop dia. of an even aged stand.

Lorey's Mean Ht. / Crop Ht.

- This method weights the contribution of trees to the stand height by their basal area.

- Lorey's mean height is calculated by multiplying the tree height (h) by its basal area (g), and then dividing the sum of this calculation by the total stand basal area:

$$h_L = \frac{\sum g * h}{\sum g}$$

Determination of Crop Height :

Steps-

Tabulate data:

Dia. classes	Basal area observed	Average height	$G_{i} * h_{i}$
10-20	G1	h1	G1*h1
20-30	G2	h2	G2*h2
30-40	G3	h3	G3*h3
40-50	G4	h4	G4*h4
50-60	G5	h5	G5*h5
60-70	G6	h6	G6*h6
ith	Gi	hi	$\sum G_i h_i$

Gi - Total basal area in each of the diameter classes (Calculated from measured values)

hi – average (Arithmetic mean) height of trees in each dia. class

<u>Lorey's Formula :</u>

$$\textbf{Crop height} = \frac{\sum Gi\,hi}{\sum Gi}$$

$$= \frac{(G_1h_1 + G_2h_2 \ldots\ldots\ldots\ldots\ldots\ldots\, Gihi)}{(G_1 + G_2 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\, Gi)}$$

2. **Mean Height:**

It is the height corresponding to the mean diameter of a group of trees or crop diameter of an even aged stand

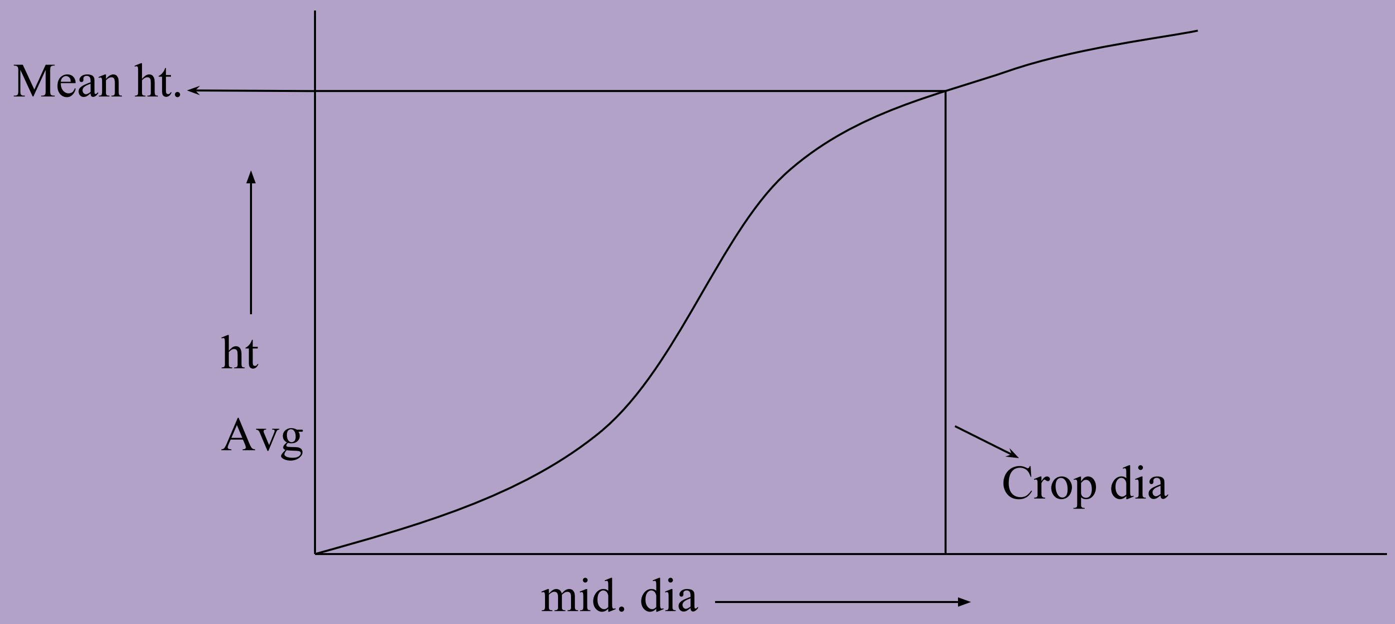
Steps:

a) draw **ht. *vs* dia. curve** for the stand

b) In order to draw the graph, first tabulate the data - diameter class wise:

Col 1 Dia. Class	Col 2 ht	Col 3 Avg. Hts.
10-20	h1' h2'....hi	$\bar{h}$1'
20-30	h1'' h2''...hi''	h1''
30-40	h1''' h2'''...hi'''	h1'''
h^{th}	$h1^n h2^n$.... hi^n	$h1^n$

Plot mid point of dia class Vs Avg. ht.



c) Calculate M.B.A. for stand

d) Then calculate crop diameter

e) Read height from graph mean height

- **Crop and/or mean height – used for Volume calculation**

- **For site quality – Top Height…**

Top height

'Height corresponding to the Top Diameter (calculated from basal area of 250 biggest diameters per ha) as read from height diameter curve'

- To assess the quality of the locality
- This relates only 250 biggest dia. (or about 125 trees)

Determination of Crop Parameters

1. Crop Diameter
2. Crop Height
3. Crop Age
4. Crop Volume

3. **Determination of Age of Crop**

- Even aged
- Un-Even aged

Even aged and Un-even aged Stand

Even Aged Stand:

- ✔ Trees approximately of same age
- ✔ Age variation less than 25% rotation age

Un-even Aged Stand:

- ✔ Individual stem vary widely in age
- ✔ Age variation is more than 25% of rotation age

Uneven-aged: a stand with trees of three or more distinct age classes, either intimately mixed or in small groups.

Two-aged: a stand with trees of two distinct age classes separated in age by more than plus or minus 25% of the rotation age.

Even-aged: a stand composed of a single age class of trees in which the range of tree ages is usually plus or minus 25% of the rotation age.


<u>Age (for even aged)</u>

- The age of even aged crop is described by the term "Crop Age"
- **<u>Crop Age</u>**: Age of regular crop corresponding to its crop diameter

- **Two situations**
  - **very small age difference**
  - **greater age difference**

- When the difference in ages of trees is very small as in plantation crop, **crop age** is the age corresponding to the age of the tree of mean diameter.

- This age can be found out by felling it, if it has clear rings or
- age corresponding to crop dia. from age-diameter curve.

$$\textbf{Mean dia.} = \frac{\sum \textbf{ni di}}{\sum \textbf{ni}}$$

ni- no. of trees in each dia. class

di- average diameter of the dia. Class

Steps:

1. Tabulate field data in dia-classes

Dia class	# of trees	Basal area of mid pt.	Total basal area in dia class
10-20	n1	g1	n1 . g1
20-30	n2	g2	n2. g2
30-40	n3	g3	n3. g3
40-50	n4	g4	n4. g4
50-60	n5	g5	n5. g5
ith	ni	gi	ni. gi
Total	**∑ ni**		**∑ ni.gi**

M.B.A. = ∑ ni gi / ∑ni,

$$\text{M.B.A.} = \frac{n1g1+n2g2+\ldots\ldots\ldots\ldots\ldots nigi}{n1+n2+n3+\ldots\ldots\ldots\ldots\ldots ni}$$

$$\text{M.B.A.} = \pi \left(\frac{\text{crop diameter}}{2} \right)^2$$

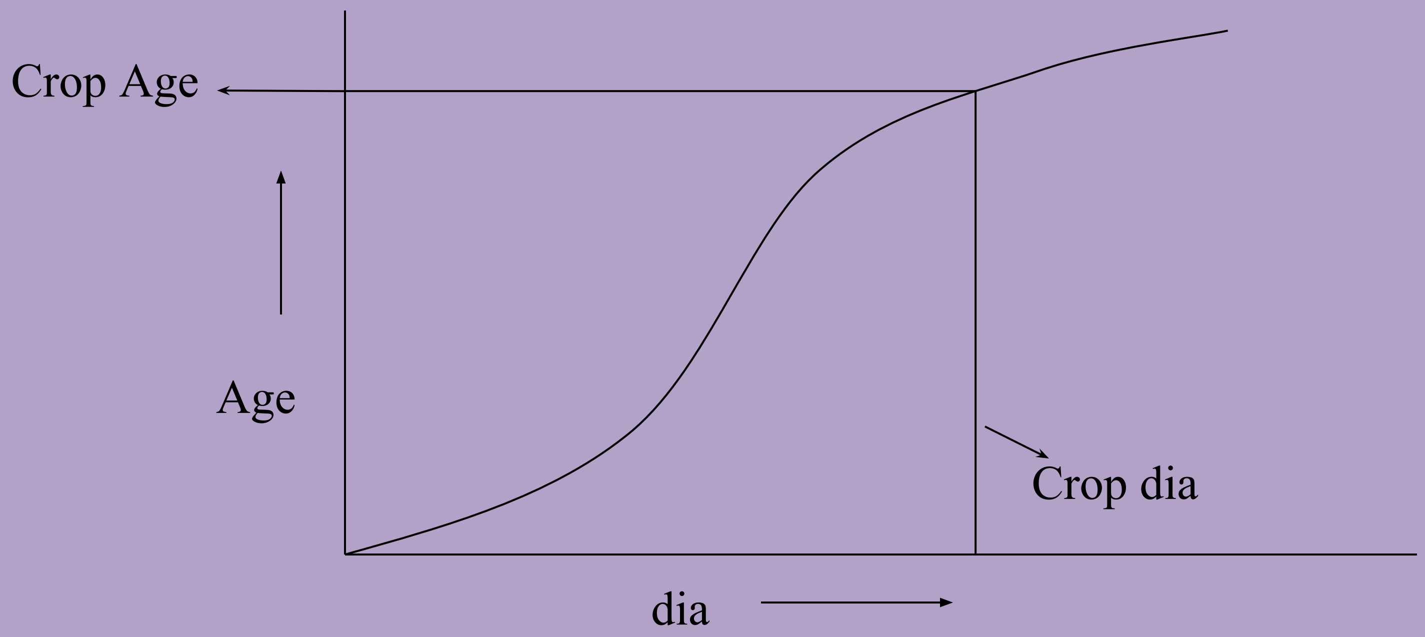
$$= \frac{\pi}{4} \times (\text{crop dia.})^2$$

$$\text{Crop dia.} = \sqrt{\frac{(4 \times \text{M.B.A.})}{\pi}}$$

$$\text{Crop dia.} = 2 \times \sqrt{\frac{\text{M.B.A}}{\pi}}$$

.

Plot mid point of dia class Vs Avg. Age



a) Get basal area of the crop

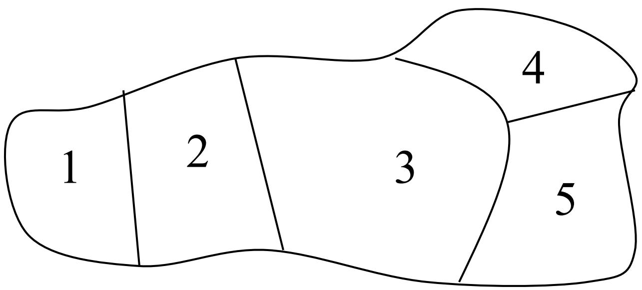
b) Get crop dia

c) Plot Age-dia curve

d) Read age corresponding crop dia.

- **If Age variation in crop is more:-**
- **Method for even aged crop:**

a) Break Area into smaller area of even aged group



b) Get gi, basal area of the eve aged groups (each plot)

c) Get ai, age of each age group

(as dealt in Crop age.)

$$\text{Crop Age} = \frac{\sum gi\ ai}{\sum gi}$$

gi - basal area of each of the even aged group

ai - age of each age group

Age (for Un-Even aged)

- Difference of opinion

a. Indian Forest and Forest Products Terminology, Part I- Forest

  - The average age of dominant trees in a crop

b. Europe

  - That period which an even aged wood requires to produce the same volume as the un-even aged wood

Determination of Crop Parameters

1. Crop Diameter
2. Crop Height
3. Crop Age
4. Crop Volume

4. Determination of Volume

By means of small sampling units :

Two Methods-

Method 1 : direct measurement of Volume by felling or

measuring volume of each standing tress: 1 (A) & 1 (B)

Method 2 : indirect estimate using volume table

Method 1

(A)

$$V = \frac{\sum^{n} \sum^{mi} Vij \left(\quad \right)}{n \cdot a}$$

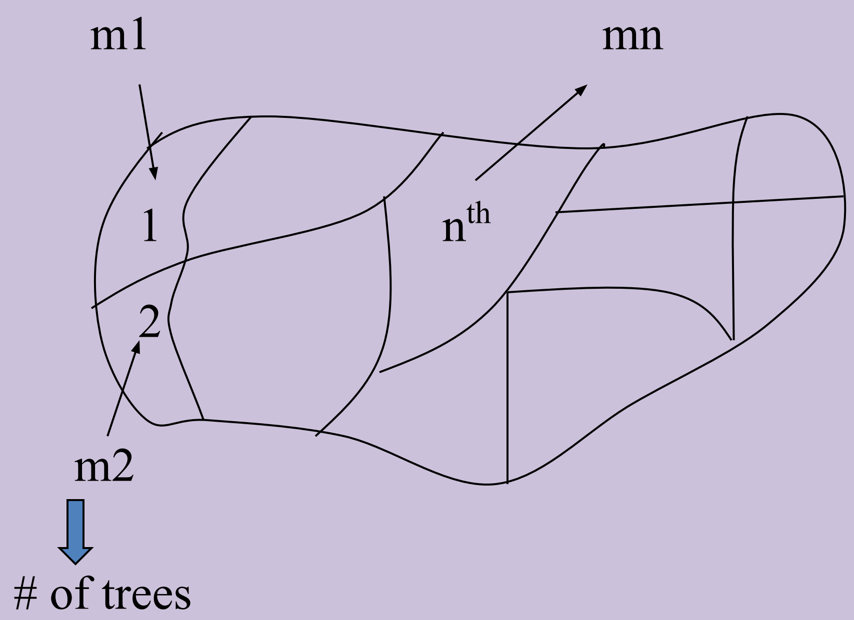
V : Avg. Vol. per ha, m^3

Vij : Volume of individual tree in *i*th plot

$\sum$ **mi** : Total no. of trees in i^{th} plot

n : Total no of plots.

a : Area of samples plot m^2



- **Problem 1 : Calculation of volume per hectare**

- **Solution:-**

In an inventory of a stand of *Pinus patula* the following data were collected.

n=5

a=0.005 ha

Trees	**1**	**2**	**3**	**4**	**5**	**Total**
Plots	**Volumes (m^3/tree)**					
1	0.42	0.36	0.39	0.27	-	1.44
2	0.38	0.37	0.41	0.40	0.41	1.97
3	0.29	0.36	0.31	0.34	-	1.30
4	0.41	0.36	0.34	0.33	-	1.44
5	0.30	0.40	0.39	0.27	-	1.36

$$\sum^{n}\sum^{m} v_{ij} = 7.51 \text{ m}^3$$

$$V = \frac{\sum^{n}\sum^{m} v_{ij}}{na} \qquad \frac{7.51}{(5)(0.005)} \qquad = \quad 300 \text{ m}^3/\text{h}$$

Method 1 (B)

- If sub sampling for volume is practised:

3 methods

1. Mean tree method
2. Mean Form Height method
3. Regression of volume on basal area method

1.Mean tree method

- Sub-sample
- Average vol. of all trees in sub-sample plot is calculated.
- From this & no of trees in each plot

↓

Volume of each plot

↓

Volume Per Hectare

1. **<u>"Mean tree method"</u>**

Steps:

a) Layout sample plot (SP)

b) Count trees in SP

c) Select a sub sample

d) Measure all trees in sub sample for **v,** volume

e) Calculate volume of average tree in sub sample

f) Multiply number of trees in sample plot with volume of average tree in sub sample

1. Calculate for sub-sample:

- ➡ $$\bar{v}_i = \frac{\sum v}{s_i} \text{ m}^3 \text{ per tree}$$

(s_i : no of trees in sub sample in plot i)

- **Multiply this avg vol. with no. of trees in the plot i**

$$\boxed{v_i = m_i \bar{v}_i}$$ m^3 in plot i, **(m_i: no of trees in sample plot)**

- Vol. per ha. $$V = \frac{\sum V_i}{n \times a}$$

n : no of Sample Plots

- In an inventory of a stand of *Pinus petula* the following data were collected
- **N=5, a= 0.01 ha.** **m_i = Total # of trees in i^{th} plot, s_i = no of trees in sub sample of plot i**

i	m_i	s_i	v_{ik} m^3	$\sum v_{ik}$	v_i m^3 m^3	v_i	m^3
1	10	4	0.14	0.48	0.120		1.2
			0.12				
			0.13				
			0.09				
2	12	4	0.13	0.52	0.130		1.56
			0.12				
			0.14				
			0.13				
3	9	3	0.11	0.43	0.143		1.29
			0.12				
			0.20				
4	11	4	0.10	0.45	0.113		1.24
			0.13				
			0.13				
			0.09				
5	12	2	0.28	0.48	0.240		2.88
			0.20				
Tot=54		**17**		**2.36**		**8.17**	

2.36/17
=0.139

0.139 x 54
=7.51

$$V = \frac{8.17}{(5)(0.01)} = 163 \text{ m}^3 \text{ ha}^{-1}$$

OR using a pooled mean Volume:

$$V = \frac{7.51}{(5)(0.01)} = 150 \text{ m}^3 \text{ ha}^{-1}$$

1.Mean tree method

- Accuracy of this method depends upon the sample tree reflecting the true plot mean volume per tree.
- This may be facilitated by sample trees having the mean basal area.
- A sub-sample of 20 trees per plot is necessary for precise estimate of tree of mean volume in a plot

Method 1 (B)

- If sub sampling for volume is practised:

3 methods

1. Mean tree method
2. Mean Form Height method
3. Regression of volume on basal area method

2. “Mean Form Height method”

Steps:

a) Layout sample plot (SP)

b) Measure diameter of each tree in SP

c) Select a sub-sample

d) Measure all trees in sub sample for **d, g, v,** (i.e. dia, basal area, volume)

e) Calculation may be done in 2 ways

1. Calculate $\sum g$, $\sum v$

$$\text{mean form height, } \overline{fh} = \frac{\sum v}{\sum g}$$

(for each plot)

$$\sum Vi = \sum(g) \times \overline{fh}$$

$$\text{Vol. per ha, } V = \frac{\sum Vi}{n \times a},$$ n : no of Sample Plots

with a mean form height pooled over all plots

d) $$\bar{\bar{fh}} = \frac{\sum\sum V_{ik}}{\sum\sum g_{ik}}$$

↑ pooled mean

or

$$V = \frac{(\sum g_{ij}) \times \bar{\bar{fh}}}{n \times a}$$

- **Problem 2: Calculation of volume per hectare**

- In an inventory of a stand of *Pinus petula* the following data were collected
- N=5, a= 0.01 ha. m_i = Total # of trees in i^{th} plot, s_i = no of trees in sub sample of plot i

i	**m_i**	**$\sum^{m_i} g_{ij}$ (m^2)**	**s_i**	**d_{ik} (cm)**	**g_{ik}**	**v_{ik}**	**$\sum^{s_i} g_{ik}$ (m^2)**	**$\sum^{s_i} v_{ik}$ (m^3)**	**fh_i**
1	10	0.124	4	13.4	0.014	0.14	0.049	0.48	9.80
				11.8	0.011	0.12			
				13.4	0.014	0.13			
				11.3	0.010	0.09			
2	12	0.132	4	12.9	0.013	0.13	0.053	0.52	9.81
				12.4	0.012	0.12			
				13.8	0.015	0.14			
				12.9	0.013	0.13			
3	9	0.119	3	11.3	0.010	0.11	0.044	0.43	9.77
				12.9	0.013	0.12			
				16.4	0.021	0.20			
4	11	0.100	4	10.7	0.009	0.10	0.044	0.45	10.23
				11.8	0.011	0.13			
				13.4	0.014	0.13			
				11.3	0.010	0.09			
5	12	0.140	2	19.9	0.031	0.28	0.048	0.48	10.00
				14.7	0.017	0.20			
Tot=54		**0.615**	**17**				**0.238**	**2.36**	

Cont…

i	$\sum^{mi} g_{ij}$	fh_i	v_i
1	0.124	9.80	1.22
2	0.132	9.81	1.29
3	0.119	9.77	1.16
4	0.100	10.23	1.02
5	0.140	10.00	1.40

total: 0.615 **6.09 m^3 in 0.05 ha**

$$V = \frac{6.09}{(5)(0.01)} = 121.8\ m^3\ ha^{-1}$$

$$fh = \frac{\sum^{n}\sum^{s_i} v_{ik}}{\sum^{n}\sum^{s_i} g_{ik}} = \frac{2.36}{0.238} = 9.92$$

using a pooled mean form height of 9.92

$$V = \frac{(0.615)\,(9.92)}{(5)\,(0.01)} = 122.0\ m^3\ ha^{-1}$$

Mean Form Height method

- As basal area is highly correlated with volume, use of basal area rather than no of trees as multiplying factor to convert sub-sample volume to plot volume will provide more precise estimate.

- UK Forestry Commission has adapted this method.

Method 1 (B)

- If sub sampling for volume is practised:

3 methods

1. Mean tree method
2. Mean Form Height method
3. Regression of volume on basal area method

3. Regression of Volume on Basal Area Method:

As in previous problem

- Steps:

a) Take a Sample plot and sub samples

b) Measuring of **d , g ,v** on sub sample trees

c) Pool the data of all sub sample from all plots

e) Hypothesize linear fit

$$v_{ik} = a + b\,(g_{ik}) \qquad m^3/\text{tree}$$

$$v_i = m_i\, a + b \sum^{m_i} g_{ij} \qquad m^3/\text{plot}$$

Cont….

$$V = \frac{\left(\sum^{n} m_i . a + b \sum^{n} \sum^{m_i} g_{ij} \right)}{n \times r} \ m^3/ha$$

Here- a , b are regression const.

r= Area of sampling units

m_i= Total # of trees in i^{th} plot

n= Total no. of plots.

Regression eq.

Y = a + b. x.

Formula for least squares estimate of x and y:

$$\begin{cases} a = \dfrac{\left(\sum y\right)\left(\sum x^2\right) - \left(\sum x\right)\left(\sum xy\right)}{n\sum x^2 - \left(\sum x\right)^2} \\ b = \dfrac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{n\sum x^2 - \left(\sum x\right)^2} \end{cases}$$

- **Problem 2 : Calculate of volume per hectare**

- In an inventory of a stand of *Pinus petula* the following data were collected
- N=5, a= 0.01 ha. m_i = Total # of trees in i^{th} plot, s_i = no of trees in sub sample of plot i

i	m_i	$\sum^{m_i} g_{ij}$ m^2	s_i	d_{ik}	g_{ik} cm	v_{ik}	$\sum g_{ik}$ m^2		$\sum v_{ik}$ m^3		fh_i m^2	s_i	s_i m^3
1	10	0.124		4	13.4	0.014		0.14	0.049		0.48	9.80	
				11.8	0.011		0.12						
				13.4	0.014		0.13						
				11.3	0.010		0.09						
2	12	0.132		4	12.9	0.013		0.13	0.053		0.52	9.81	
				12.4	0.012		0.12						
				13.8	0.015		0.14						
				12.9	0.013		0.13						
3	9	0.119		3	11.3	0.010		0.11	0.044		0.43	9.77	
				12.9	0.013		0.12						
				16.4	0.021		0.20						
4	11	0.100		4	10.7	0.009		0.10	0.044		0.45	10.23	
				11.8	0.011		0.13						
				13.4	0.014		0.13						
				11.3	0.010		0.09						
5	12	0.140		2	19.9	0.031		0.28	0.048		0.48	10.00	
				14.7	0.017		0.20						
Tot=54		**0.615**		**17**				**0.238**		**2.36**			

- **Solution:-**
- Using the same data as in the previous examples, the volume on basal area regression is calculated and volume per hectare derived using the regression:

N=17

V_{ik}	g_{ik}	$(g_{ik})^{2} \cdot 10^3$	$(v_{ik}g_{ik}) \cdot 10^2$
0.14	0.014	0.196	0.196
0.12	0.011	0.121	0.132
0.13	0.014	0.196	0.182
0.09	0.010	0.100	0.090
0.13	0.013	0.169	0.169
0.12	0.012	0.144	0.144
0.14	0.015	0.225	0.210
0.13	0.013	0.169	0.169
0.11	0.010	0.100	0.110
0.12	0.013	0.169	0.156
0.20	0.021	0.441	0.420
0.10	0.009	0.081	0.090
0.13	0.011	0.121	0.143
0.13	0.014	0.196	0.182
0.09	0.010	0.100	0.090
0.28	0.031	0.961	0.868
0.20	0.017	0.289	0.340
2.36	0.238	3.778	3.691

Cont…..

$$b = \frac{\sum^{n} vg - \frac{\sum^{n} v \sum^{n} g}{n}}{\sum^{n} g^2 - \frac{\left(\sum^{n} g\right)^2}{n}}$$

$$= \frac{\left(3.691 - \frac{(2.36)(0.238)(10)}{17}\right)}{\left(3.778 - \frac{(0.238)^2 (10)^3}{17}\right)} = \frac{(0.38)(10)}{0.446} = 8.677$$

a = v – b g = 0.14 – 8.677 x 0.014 = 0.018

V = 0.018 + (8.677) (g), m^3 per tree

Cont…… result of previous problem :

$$\sum_{}^{n} v_i = \sum_{}^{n} m_i \quad a + b \left(\sum_{}^{n} \sum_{}^{m} g_{ij} \right)$$

$= 54\ (0.018) + (8.677)(0.615) = 6.308, \qquad m^3$ in 0.05 ha

$V = 6.308/\ ((5)\ (0.01)) = 126\ m^3\ ha^{-1}$

Method 2 : with the help of volume tables

Steps:

a) Take a sample

b) Make a frequency table

s.n.	**dia classes**	**# of trees**
1.		
2.		

c) Read volume corresponding to mid point of dia class

d) Multiply volume by # of trees and sum to arrive at volume of the sample plot.

e) Get an estimate of volume of whole forest.

Estimation of Growth and Yield of Stands

Scope of Forest Biometry…

1. Volume of forest crops at present

+

2. Forecast of future yields

1. Volume of forest crops at present

- Not always possible to calculate for whole forest

↓

Sample plots (Area + Point sampling)

↓

For obtaining forest inventory

2. Forecast of future yields…

Require tables which may give Yield of Stand on unit area basis

depends mainly on ↓

1. Stand structure
2. Stand growth
3. Stand density
4. Productive capacity of site, "site quality"

1. <u>Stand structure</u>

Definition :

– Distribution and representation of age and / or size classes of trees in a stand

↓

Keeps changing

↓ depends on

1. Factors of locality
2. Management practices

Stand structure…

- Classified in 2 groups :

  1. Even aged

  2. Un-even aged

Even aged Stand

- ✔ Trees approximately of same age
- ✔ Age variation less than 25% rotation age

Un-even aged stand

- ✔ Individual stem vary widely in age
- ✔ Age variation is more than 25% of rotation age

Uneven-aged: a stand with trees of three or more distinct age classes, either intimately mixed or in small groups.

Two-aged: a stand with trees of two distinct age classes separated in age by more than plus or minus 20% of the rotation age.

Even-aged: a stand composed of a single age class of trees in which the range of tree ages is usually plus or minus 20% of the rotation age.

Even aged and Un-Even aged forest

Even aged forest :

- Has stands of different ages to maturity but one stand has trees of one age

Un Even aged forest:

- Each stand has trees of all ages –**Selection Forest**

Silvicultural system

- Broadly classified in to 2 main groups :

I. **Even aged system**
   - Clear cutting
   - Shelterwood
   - Management based on **Age & Area**

II. **Un-Even aged system**
   - Selection
   - Management based on **Size**

- ✔ **<u>Mathematically</u>**

Even aged Stand

→ Normal distribution

- Peaking at mean BH size

Un-Even aged Stand

→ Inverse J curve

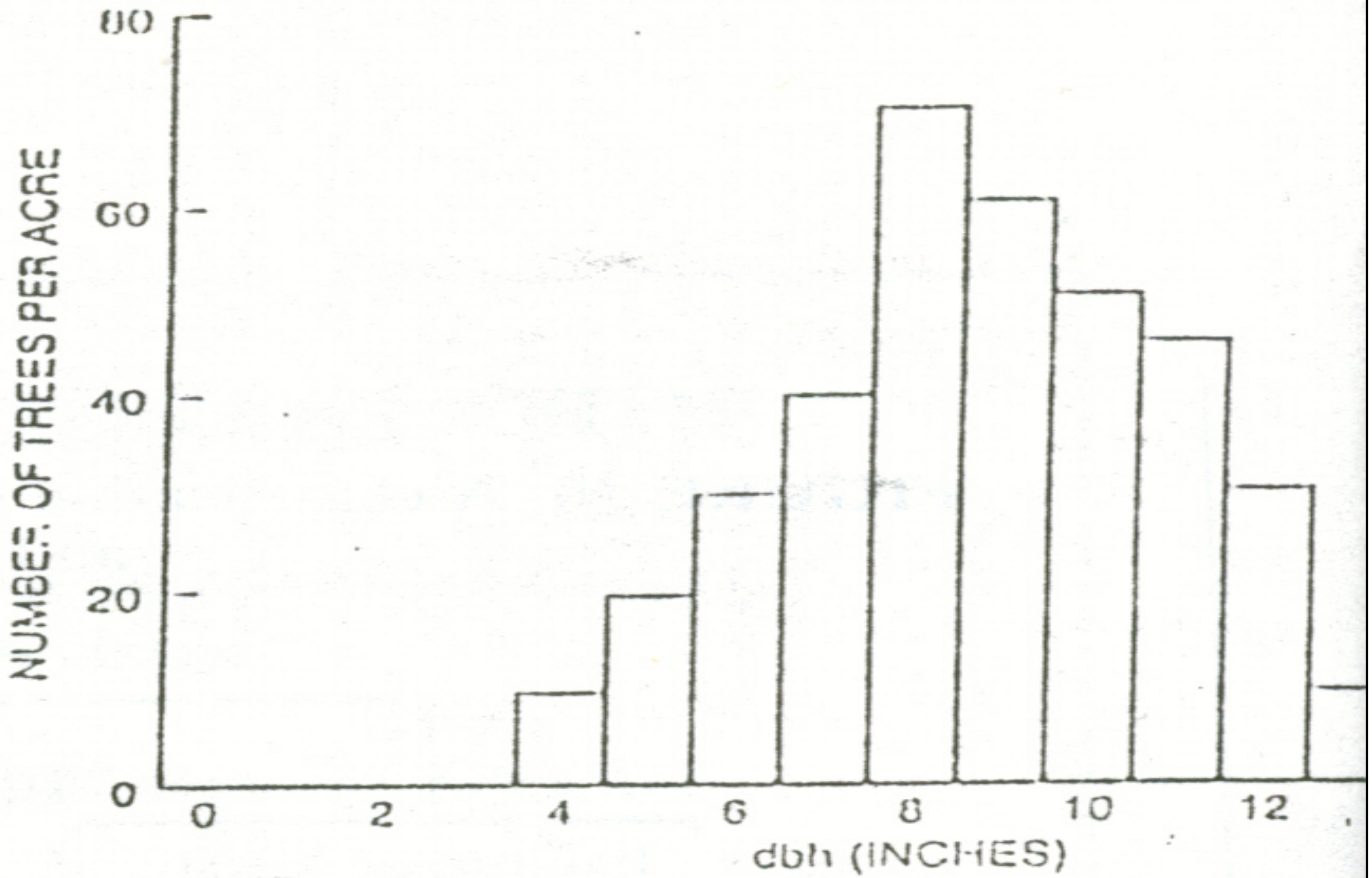


FIGURE 16-2
A typical dbh distribution for pure, even-aged stands.

A typical dbh distribution for pure, even-aged stands

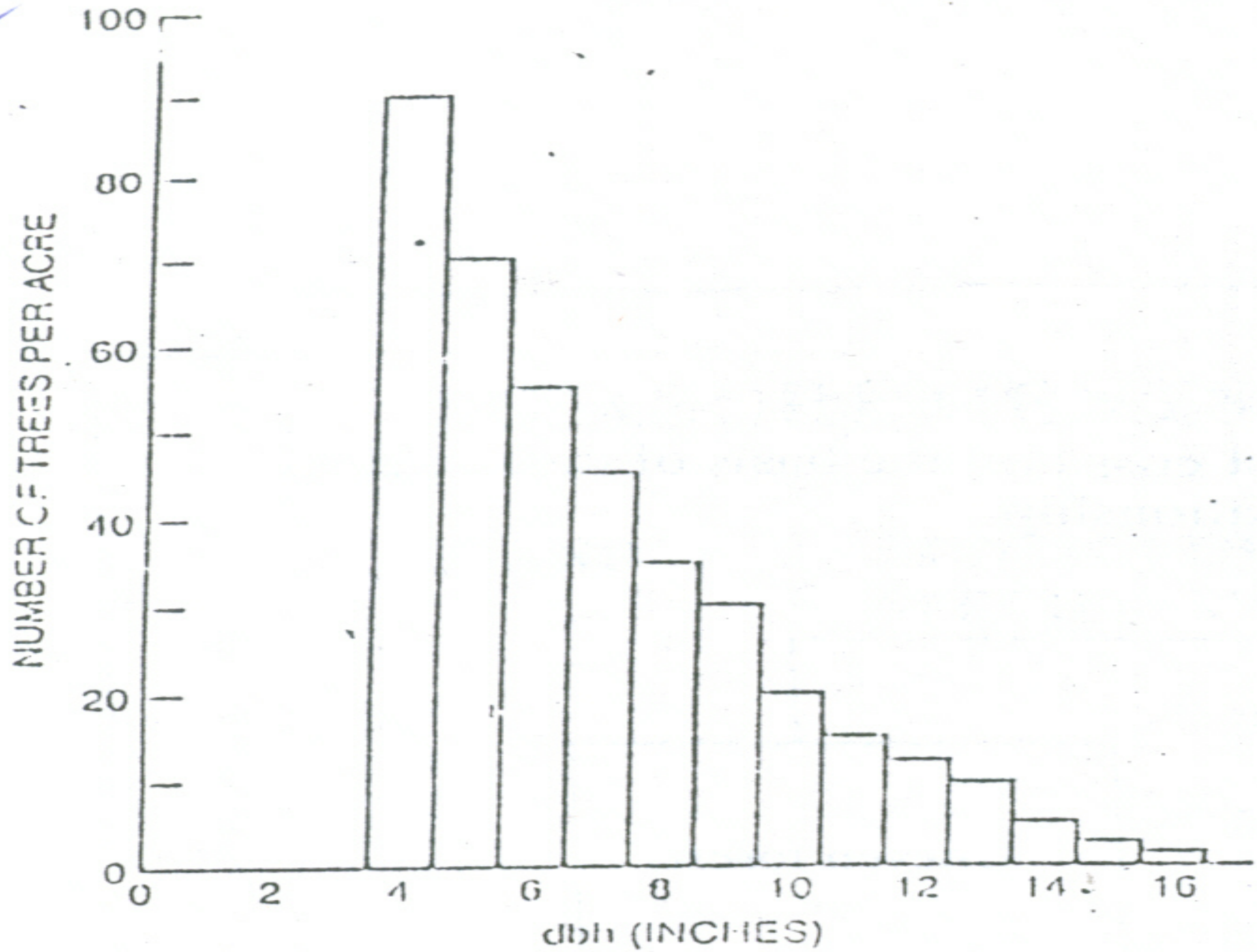
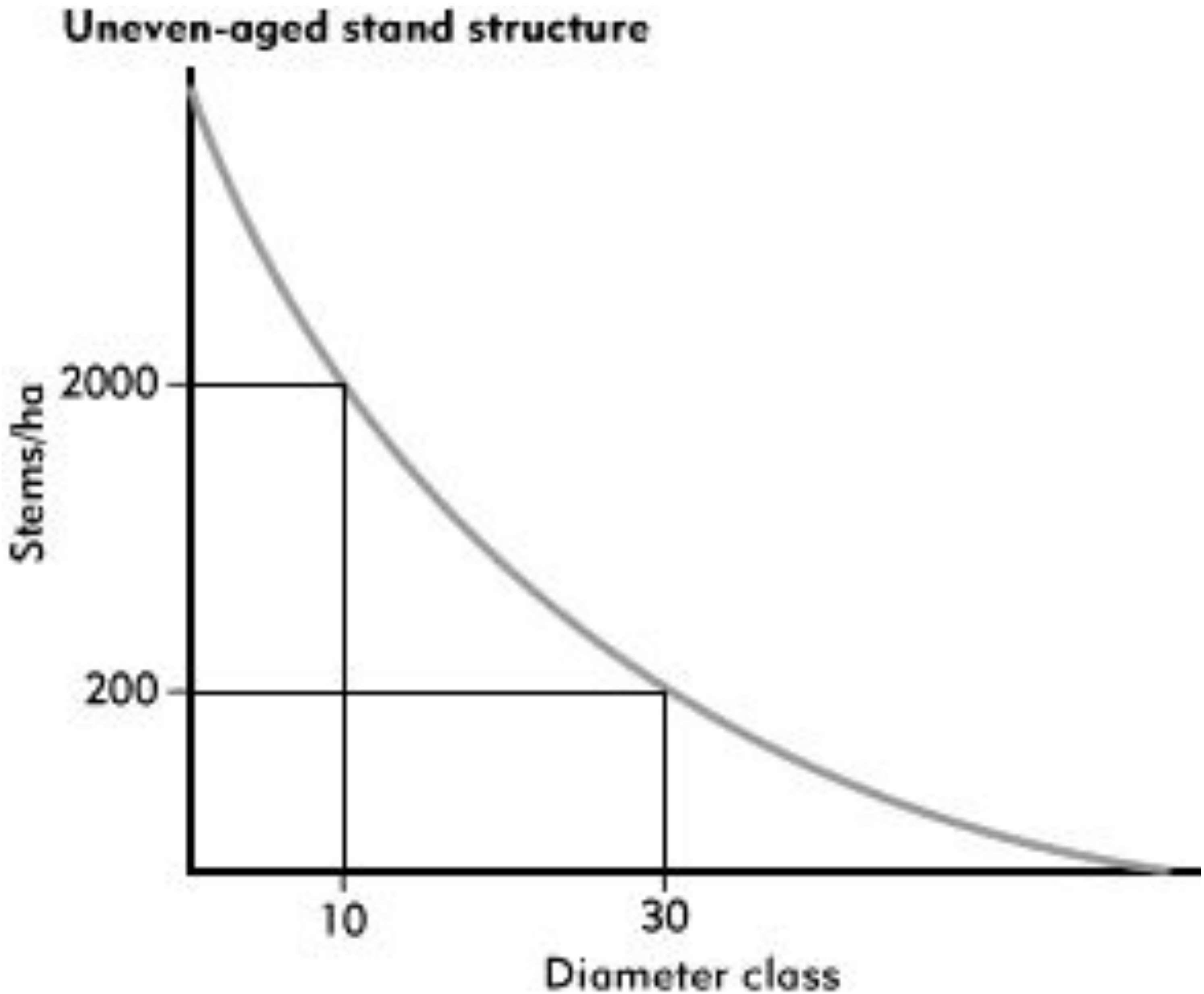
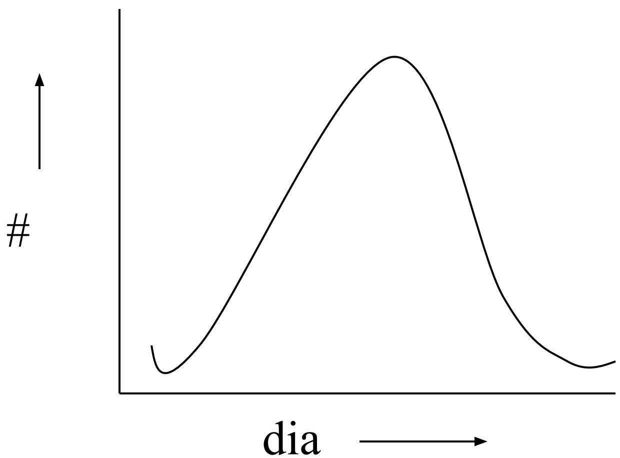


FIGURE 16-4
Typical dbh distribution for regular, uneven-aged stands.

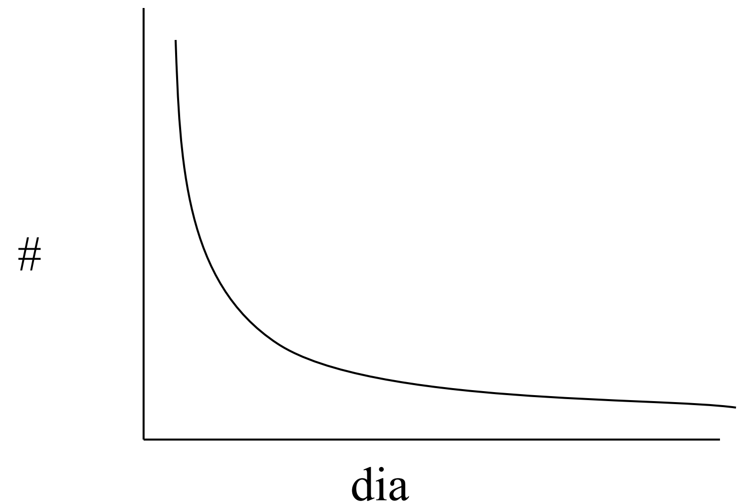
Typical dbh distribution for regular, uneven-aged stands


Uneven-aged stand structure
Stems/ha
2000
200
10
30
Diameter class

1. Dia Distribution Curve is different



Even aged Stand



Uneven aged Stand

Uneven aged stand

De Liocourt diameter distribution:

– Stem numbers in successive diameter classes had a fixed ratio within a stand

$$\frac{N1}{N2} = \frac{N2}{N3} = \frac{N3}{N4} = q$$

(Di Liocourt quotient)

Where, N1, N2, N3 etc. are # of stems in successive dia class.

– Geometric series

Even aged & Un-Even aged Forest structure

- Reverse J shaped curve
  - Even aged Forest
    - Curve applies to the whole forest
  - Un-Even aged Forest
    - Curve applies to each small unit of area throughout the forest

Even Aged Stand (of one species) are Characterized by:

1. # of Stems /ha
2. Basal Area
3. Crop dia
4. Height
5. Age
6. Form
7. Crown size and Canopy

Un-even Aged Stands are Characterized by:

1. Diameter and # of stem distribution

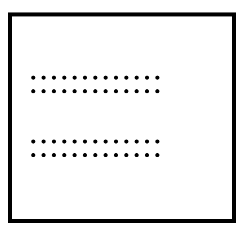
Number of Stems per ha:

- A useful description

- Alone it is not sufficient

(Along with **ht, Age** or **dia** it gives picture of crop)

Example:



Young crop
#200/ha may be
quite open or
light stocked

Mature crop
200/ha near
rotation age may
be densely stocked

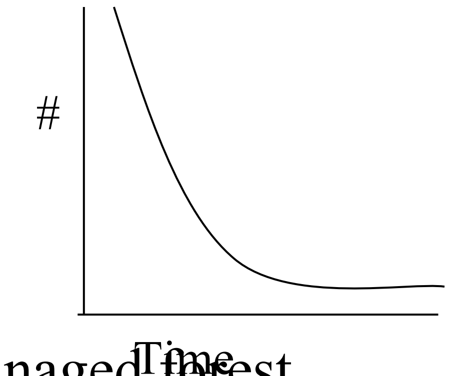
>Plantation usually done at 2.5x2.5m or 3.3x 3.3m

→ 1600 or 1000 plants /ha

at Maturity ↓

200 – 500 trees /ha

- In natural forests



  - Even in even aged well managed forest
    - # decrease due to

      - Natural Mortality

      - Thinning

Estimate # of Trees/ha:-

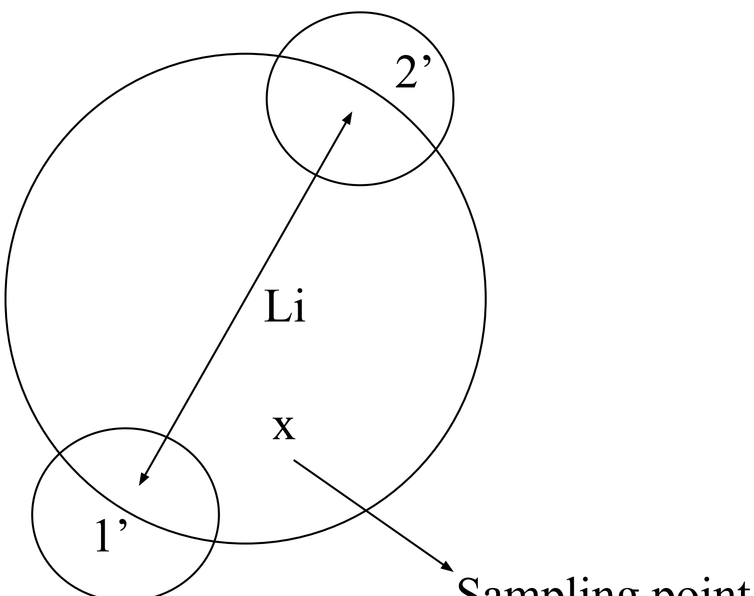
Method 1:

- Lay out small plot of known area, a
- Count the # of trees in each plot, n
- Calculate

No of trees per Ha,	**N=n/a**

Method 2:

a) At representative points measure the length Li



1’ = closest neighbour
2’ = second closest neighbour

b) No. of trees per Ha,

$$\mathbf{Ni = A/a_i}$$

where,

$$\mathbf{A} = 1 \text{ ha} = 10{,}000 \text{ m}^2 = \mathbf{10^4} \text{ m}^2$$

$\mathbf{a_i}$ = area of circle with **'Li'** as diameter

i.e. $\mathbf{a_i} = \prod \times (Li/2)^2$

$$= \prod \times \frac{Li^2}{4}$$

$$\Rightarrow \mathbf{Ni = A/a_i = [(4/\prod) * 10^4]* \left[\frac{1}{Li^2}\right]}$$

$$= \mathbf{K * (1/Li^2)}$$

c) This is for one sample point if we take sample at 'm' points, then

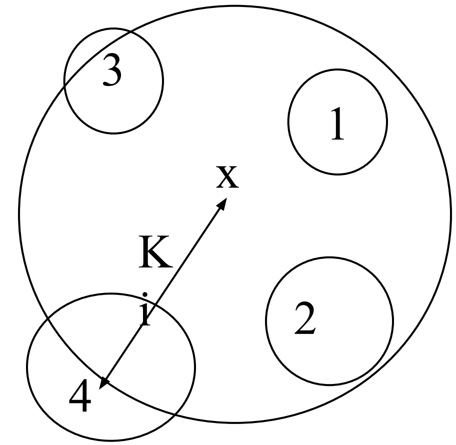
$$\Rightarrow N = \frac{\sum Ni}{m}$$

$$N = [(4/\pi) * 10^4] * \frac{\sum (1/Li^2)}{m}$$

$$= K * \frac{\sum (1/Li^2)}{m}$$

Method 3 :

-Extension of method 2.



$$N = \frac{[(n-1/2) * 10^4] *}{\wedge \quad m} \sum^{m} (1/ki^2)$$

1,2,3,4 = nearest, 2nd,3rd & 4th nearest neighbour

n = nth nearest neighbouring tree.

ki = distance from the sampling point to the nth nearest tree.

m = # of sampling points.

Example of number of trees /ha Calculation

- **Problem 1:**

  At 10 points in a plantation chosen systematically, the following data were collected on the number of trees –n- in circular plots of area 0.01 ha. Calculate number of trees per Ha.

  Data: n=16,14,18,13,12,9,17,15,16,14

- **Solution:-**

$$\sum^{10} n_i = 144 \qquad n = 14.4$$

$$N = n/a \qquad = 14.4/0.01$$

$$= 1440 \text{ stems ha}^{-1}$$

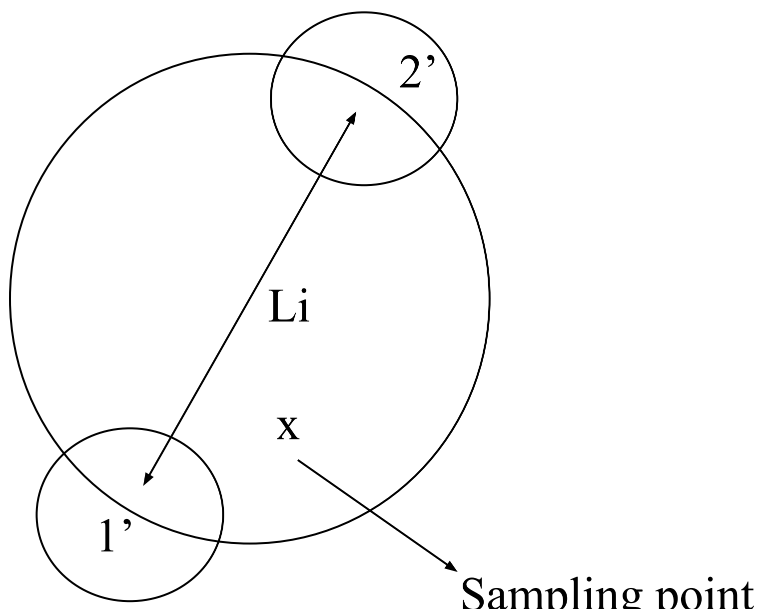
- **Problem 2:**

In a similar plantation and at a similar ten points chosen systematically, the distance-L,- between the nearest two trees (n=1) was measured and recorded in m.

Data: L_i= 2.25, 3.75, 1.95, 3.65, 2.75, 2.90, 3.10, 3.45, 3.60, 2.85.

Method 2:

a) At representative points measure the length Li



1' = closest neighbour
2' = second closest neighbour

b) No. of trees per Ha,

$$\mathbf{Ni = A/a_i}$$

where,

$\mathbf{A}$ = 1 ha = 10,000 m^2 = $\mathbf{10^4}$ m^2

$\mathbf{a_i}$ = area of circle with **'Li'** as diameter

i.e. $\mathbf{a_i} = \prod \times (Li/2)^2$

$$= \prod \times \frac{Li^2}{4}$$

$$\Longrightarrow \mathbf{Ni = A/a_i = [(4/\prod) * 10^4]* \left[\frac{1}{Li^2}\right]}$$

$$\mathbf{= K * (1/Li^2)}$$

c) This is for one sample point if we take sample at ‘m’ points, then

$$\Longrightarrow \mathbf{N} = \frac{\sum \mathbf{Ni}}{\mathbf{m}}$$

$$N = [(4/\pi) * 10^4] * \frac{\sum (1/Li^2)}{m}$$

$$= \mathbf{K} * \frac{\sum (\mathbf{1/Li^2})}{\mathbf{m}}$$

- **Solution:-**

$$\sum^{10} (1/L_i^2) = 1.246$$

$$N = \frac{(1.273)10^4}{10} (1.246)$$

$= 1586$ stems ha^{-1} Where $n=1$

- **Problem 3:**

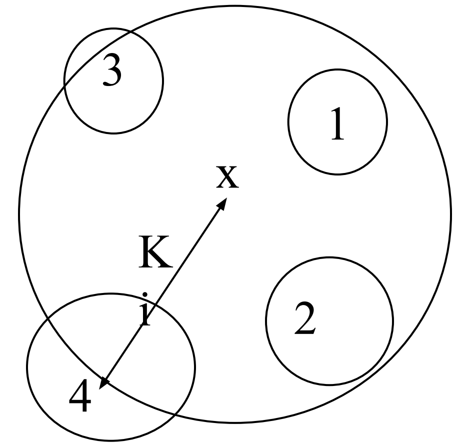
In a similar manner but in another older plantation the distance from the sampling to the 4^{th} nearest tree (n=4) was measured and recorded to the nearest 0.1 m.

Data: 4.8, 6.2, 5.4, 6.1, 5.7, 6.0, 5.8, 5.6, 6.2, 6.0

Method 3 :

-Extension of method 2.

$$N= \frac{[(n-1/2) * 10^4] * \sum^{m} (1/ki^2)}{\wedge \qquad m}$$



1,2,3,4 = nearest, 2nd,3rd & 4th nearest neighbour

n = nth nearest neighbouring tree.

ki = distance from the sampling point to the nth nearest tree.

m = # of sampling points.

- **Solution:-**

$$\sum^{10} (1/K_i^2)=0.3045$$

$$N=\frac{(3.5)10^4}{10\ (3.14)}\quad(0.3045)$$

$$= \quad 339 \text{ stems ha}^{-1}$$

CROWN CLASS

- **Crown class** is a term used to describe the position of an individual tree in the forest canopy.

- In the definitions below, “general layer of the canopy” refers to the bulk of the tree crowns in the size class or cohort being examined.

- Crown classes are most easily determined in evenaged stands
-
- In an unevenaged stand, a tree’s crown would be compared to other trees in the same layer.

- Kraft's Crown Classes are defined as follows (Smith et al. 1997 and Helms 1998 modified for clarity):

- **Dominant trees** These crowns extend above the general level of the canopy. They receive full light from above and some light from the sides. Generally, they have the largest, fullest crowns in the stand

- **Codominant trees** These crowns make up the general level of the canopy. They receive direct light from above, but little or no light from the sides. Generally they are shorter than the dominant trees.

- **Intermediate trees** These crowns occupy a subordinate position in the canopy. They receive some direct light from above, but no direct light from the sides. Crowns are generally narrow and/or one-sided, and shorter than the dominant and codominant trees.

- **Suppressed trees (Overtopped trees)** These crowns are below the general level of the canopy. They receive no direct light. Crowns are generally short, sparse, and narrow


C D I D S C I S C D

- Crown classes are a function of tree vigor, tree growing space, and access to sunlight. These in turn are influenced by stand density and species shade tolerance.
- A shade tolerant "suppressed" western hemlock on the other hand, may survive very nicely and be able to take advantage of increased sunlight if a neighboring tree were to fall over.
- Crown class distribution can also infer overall vigor of an evenaged stand.
- If most trees are in the intermediate crown class, then the stand is likely too crowded and the trees are stagnated.
- A stand with nearly every tree in the dominant category is either very young, with all of the trees receiving plenty of sun, or very sparse and may be considered "understocked."
- A typical evenaged stand has the majority of trees in the codominant class, and the fewest trees in the suppressed class.

Canopy density

- Measure of relative completeness of canopy
- Expressed as decimal coefficient (closed canopy as 1)
- No bearing with crop volume, basal area or no. of trees
- Important for forests which do not have yield tables
  - Gives indication of stand density

Classification of canopy density

i. **Closed** - density 1

ii. **Very Dense** - density between 0.7 and 1

iii. **Moderately dense** - density between 0.4 and 0.7

iv. **Open** - density between 0.1 and 0.4

Calculation of canopy density for Pure Even Aged Crops :

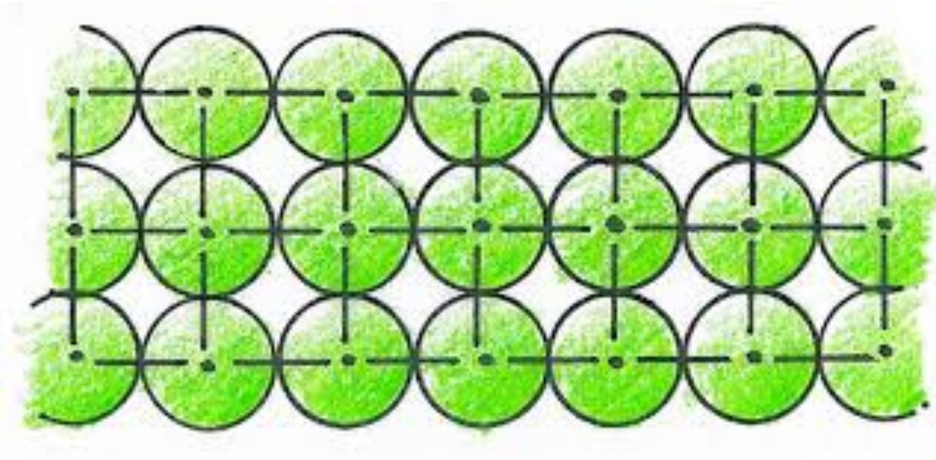
Assumption :

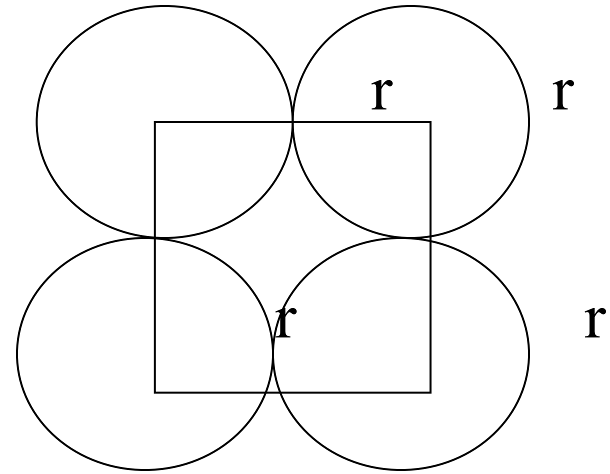
Canopy as - non overlapping circles of same size

2 methods :

1. For square spacing
2. For triangular spacing

1. **For Square Spacing**

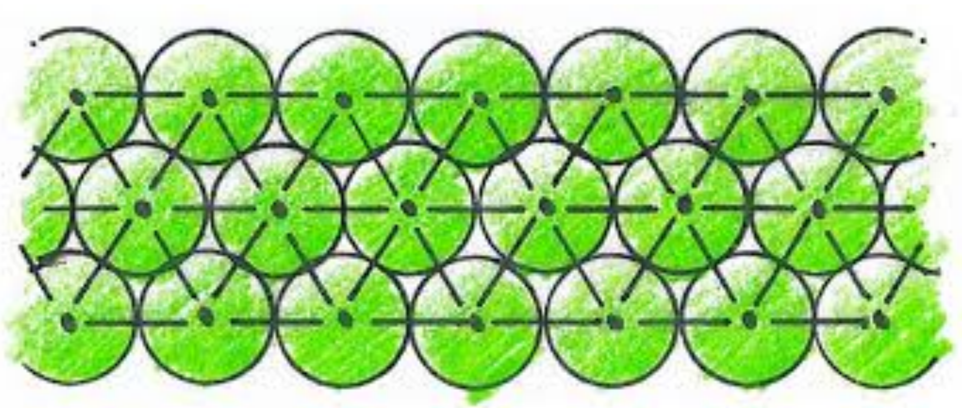


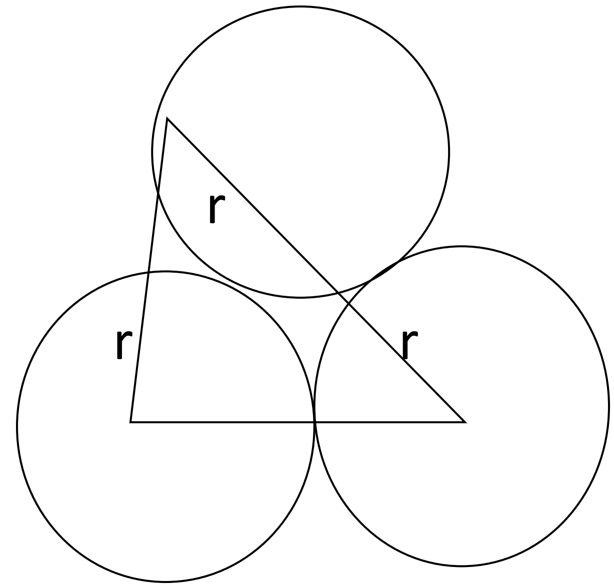


Maximum canopy closer is

$$= \frac{\pi r^2}{4r^2} \times 100\% = \left(\frac{\pi}{4}\right) \times 100\% = 78.54\ \%$$

2. For triangular spacing





Maximum canopy closer is

$$= \frac{3 \times \frac{1}{6} \times \pi r^2}{\frac{1}{2}(2r)^2 \sin 60^0} \times 100\%$$

Cont…..

$$= \frac{1}{2} \, \frac{\barwedge}{2} \, \frac{2}{\sqrt{3}} \times 100\%$$

$$= \frac{\barwedge}{2\sqrt{3}} \times 100\% = 0.9068 \times 100\%$$

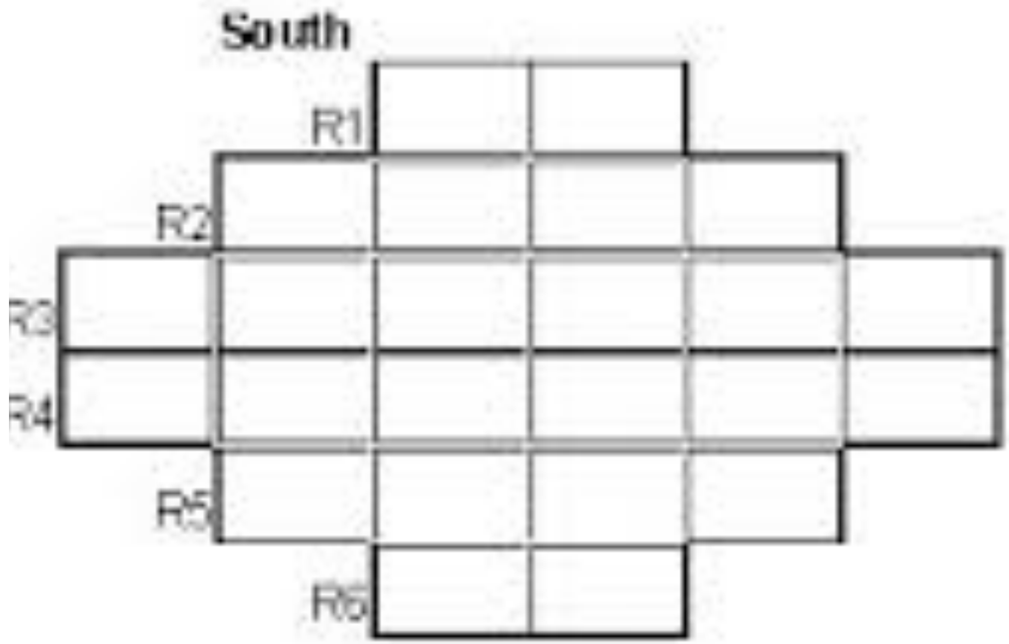
$$= 90\%$$

Measurement of canopy density in field

- Instrument - Spherical Densiometer

Properties :

- Spherical surface
- 24 square blocks



- Each square block has 4 equi spaced dots
- Total dots = 24 * 4 = 96

Procedure

1. Open the densiometer
2. Hold it about 12" in front of you and at elbow height
3. Identify a rock in the channel directly below the densiometer
   - Throughout this entire procedure, the densiometer should remain above this rock
4. The top of your forehead should be visible in the mirror but not the grid area

6. Close one eye and get your sighting eye in line with the grid centerline

7. Make sure the densiometer is level by getting the bubble inside of the circle

8. You will have a view of canopy cover

9. Maintain this position while you count

Calculation

1. There are four dots in each square of the grid
2. Count either the dots that are more than half shaded or less than half shaded, depending on which is easier to count.
3. Count systematically, from top row to bottom row, left to right.
4. Record the number of shaded dots on your data sheet
5. If you counted unshaded dots, subtract that number from 96 to get shaded dots.

6. Multiply the count by 1.04
7. This is the percentage of area covered by canopy

Estimating maximum basal area per hectare for known spacing and K/d ratio.

Where: N – number of stems per hectare at full stocking

K- crown diameter, m

d- stem diameter, m

$$z = \frac{K}{d}$$, the crown/bole diameter ratio

The maximum number of stems per hectare N, assuming **square spacing** , for trees of a given diameter is given by:

$$N = \frac{100 * 100}{K * K} = \frac{10^4}{K^2}$$

$$G_{max} = N * \frac{\pi}{4} d^2 = \frac{10^4}{K^2} \frac{\pi}{4} d^2 = \frac{\pi}{4} 10^4 \left[\frac{d^2}{K^2}\right] = \frac{10^4}{z^2}\left[\frac{\pi}{4}\right]$$

$$= 0.7854 \text{ x } \frac{10^4}{z^2}$$

Q: For a crown/bole diameter ratio of 10, crown diameter and bole diameter in m, the maximum feasible basal area per hectare, G_{max}, with square spacing is :

$$G_{max} = \frac{(0.7854)*\ 10^4}{10^2} = 78.5\ m^2\ ha^{-1}$$

or, for a **K/d** ratio of 15 of square spacing;

$$G_{max} = \frac{(0.7854)\ 10^4}{15^2} = 34.9\ m^2\ ha^{-1}$$

Forecast of future yields…

1. Stand structure
2. Stand growth

↓

3. ***Stand density***
4. Productive capacity of site, “site quality”

Normal forest

"Ideal state of perfection"

↓

Complete , ideal stocking of all stands

– satisfy the purpose of management to the full

Basic factors of Normality

General attributes :

1. Species grown & methods of silviculture adopted must fully suit all peculiarities of site
2. Growing stock of trees must be so constituted that it provides regularly the greatest possible quantity
3. General organization of forest must appropriate for its purpose
   - Road network, extraction method, sales organization
4. General administration must be the best possible

Historical background of the Normal forest

- Late 18th and earlier 19th century, when the principal of **sustained yield** took root

↓

'Forest should be capable of continuous, regular yields'

↓

Even aged stands & Even aged forestry – Essence of good forestry

2 main types of Normal Forest

1. Normal Even aged forest
2. Normal Un-Even aged forest

1. Normal Even aged forest

3 Norms :

1. Normal series of age gradation
   - Presence of as many uniform aged stands as there are years in the rotation
     - Ages of stand differs by one year up to rotation age
     - Each yield capacity is equal

   (When trees of each age occur on separate areas – age gradations)

2. <u>Normal growing stock (</u> with normal age gradation & normal increment)

- Fully & ideally stocked
- Normal volume for each age

  ↓

  Stocking and volume deemed to be ideal to achieve objects of management

3. <u>Normal increment</u>

- Growing at a rate consistent with normal age and normal stocking

All 3 norms must be present for the forest to be normal as a whole

Trinity of norms

1.Normal series of age gradation

(presence in forest, in appropriate quantity, trees of all ages from one year old to rotation age)

2. Normal increment.

(best increment attainable for a given species, for a given rotation, per unit area on a given site)

3. Normal growing stock

(volume of stands with normal age class and a normal increment; *in practice* volume indicated in Yield Table for each age class)

2. Normal Un-Even aged forest

- Un-Even aged forest
  - Trees of all ages(& sizes) are intermingled on every small unit of area
  - Age & rotation – meaningless
  - Normality is judged by
    - No. of trees in each size class
      - Must have normal series of size gradation instead of age gradation

3 Norms :

1. Normal growing stock
2. Normal increment
3. Normal series of **size gradation**

Normal Un-Even aged forest

- Difficult to devise a simple model to :
  - represent either the no. or volumes of trees in several size classes
- No Yield tables
- Normal growing stock – which produces permanently the most valuable increment
- Ideal state can only be found by long experience of working – Method of control inventory

3 ways to know Normality in un-even aged forest :

1. **Inverse J curve (N-D curve)**
   - Normal Un-Even aged forest
   - Normal Even aged forest

 Derive inverse J curve for un-even aged forest from yield table for even aged forest

 Get Coefficient of diminution

SIZE- FREQUENCIES AND COEFFICIENT OF DIMINUTION ON 1 HA

Dia. Class	No of Stems	Coefficient of diminution
0-10	185	1.54
10-20	120	1.41
20-30	85	1.36
30-40	62	1.25
40-50	50	1.25
50-60	40	1.22
>60	34	1.15

2. De Liocourt diameter distribution:

– Stem numbers in successive diameter classes had a fixed ratio within a stand

$$\frac{N1}{N2} = \frac{N2}{N3} = \frac{N3}{N4} = q \quad \text{(Di Liocourt quotient)}$$

Where, N1, N2, N3 etc. are # of stems in successive dia class.

Or, Geometric series

$N_1, N_1 . q^{-1}, N_1 . q^{-2}, N_1 . q^{-3}$.............

3. **Meyer's exponential expression**

– Simplified De Liocourt's law
– Used exponential form :

$$y = K e^{-a\chi}$$

Where,

Y = no. of stems in dia interval

χ = mid of dia class

'K' =relative stand density which is dependent on site conditions

and 'a' = percentage reduction in no of stems for each dia. class.

K & a are constants vary with site & species

e = 2.71828 , the base of Napierian Logarithm

3. **Stand density** or **Crop density**

- Measure of relative completeness of tree stocking
- Expressed as a decimal coefficient
  - Taking Normal no. of trees, basal area or volume as unity

- Overstocked
- Full stocked
- understocked

Tree density illustrates the horizontal distribution of trees. The top photo shows a dense forest with many trees (or stems) per acre. The lower photo is less dense, with fewer trees per acre.

$$\text{Stand density (SD)} = \frac{\text{Actual stand vol.}}{\text{Normal stand vol.}}$$

Over stocked , SD > 1

Under stocked, SD < 1

Normal stocking, SD = 1

Growth Prediction for Normal Even Aged Stand using Yield Tables

$$Iv = p\,(Y_f - Y_p)$$

Iv : Volume growth /ha

$$p : \left[\frac{\text{Actual stand vol.}}{\text{Normal stand vol.}} \right]$$

Y_f = future vol/ha from yield table

Y_p = present vol/ha from Yield table

Ex

Year	Age	Vol. (according to YT)
1980	70	11,900
1990	80	13,360

In 1980 inventory data showed avg. vol. of stand 7” dia and over to be 8920 ft^3. Stocking in 1980 ?

$$\Rightarrow \text{stocking in 1980} = \frac{8920}{11900} = 75\%$$

Cont…

1. Assuming constant stocking for next 10 yrs :

→ Iv = (13,360 - 11,900) x 0.75

= 1095 ft^3

2. Suppose 4% increase in stocking in next 10 years: ‘**p**’ in year 1990 = 0.79

→ Iv = (13,360) x 0.79 - (11,900) x 0.75

= 1629 ft^3

2. Forecast of future yields…

1. Stand structure
2. Stand growth
3. Stand density

↓

4. ***Productive capacity of site, "site quality"***

Forest Site Quality Determination

Forest Site

- An area
  - considered in terms of its environment – determine the type and quality of the vegetation it can carry
  - – Affected by the Factors like
    - Rock
    - Soil
    - Climate
    - Topography
    - Vegetation

Site Quality

- Forest site quality – "Relative Productive Capacity"
- Site productivity :
  - Site quality + management inputs
  - Management inputs like
    - Growing stock manipulation
    - Site treatment
    - Fertilizer/irrigation inputs
    - Soil compaction (grazing)
    - Biomass and nutrient cycling

Measurement of Site quality

- Using Multiple variables
  - Forest productivity depends on various parameters
  - Attempts are made to quantify forest productivity in terms of these parameters.

– 2 methods

1. CVP Index
2. Using vegetative characteristics

Measurement of Site quality

1. **CVP (climate, vegetative & productivity) Index**

   – Tries to quantify climatic , edaphic and biotic factors

   – Given by Paterson - Weck

CVP Index

$$I = \left[\frac{T_v}{T_a}\right](P)\left[\frac{G}{12}\right](E)$$

I = CVP Index. Varies from 0 – 30,000. Forest growth possible in I > 25

T_v = Mean monthly temp. of the hottest month in ^{0}c

Ta = Difference between the mean monthly temp ^{0}c of the hottest and coldest month

P = mean annual precipitation in mm

G = Length of growing season in Months

E = Evapo-transpiration defined as = Rp/Rs

Rp = Radiation at pole, 10^3 g cal $cm^{-2}min^{-1}$

Rs = Radiation at site, 10^3 g cal $cm^{-2}min^{-1}$

- Potential Productivity Y = 5.2 log I – 7.25

Contd.

  - Y has units m^3/ha/year
- For Dehradun
  - I = (28.4/15.6) (2160) (6/12)(47/100) = 924.09
  - Y = 5.2 log 924.09 – 7.25 = 8.17 m^3/ha/year
- Short comings
  - Too broad based
  - Soil conditions, aspects, topography, slopes not considered
  - Biotic factors not considered
  - Applicable only over very large forest areas

Measurement of Site quality

2. Using vegetative characteristics
   i. Plant indicators
   ii. Trees characteristics
      - BA, Volume, Height etc.

ii. Plant indicators

– Match species to different sites
   - *Casia tora* indicator of degraded forest

– Applicable to simple compositions of forest

– Requires considerable knowledge of ecology

ii. Trees characteristics

- Important characteristics of tree which reflect productivity:
    - Vol., Dia or BA, Height,
- Volume best indicator but –
    - when to know volume?

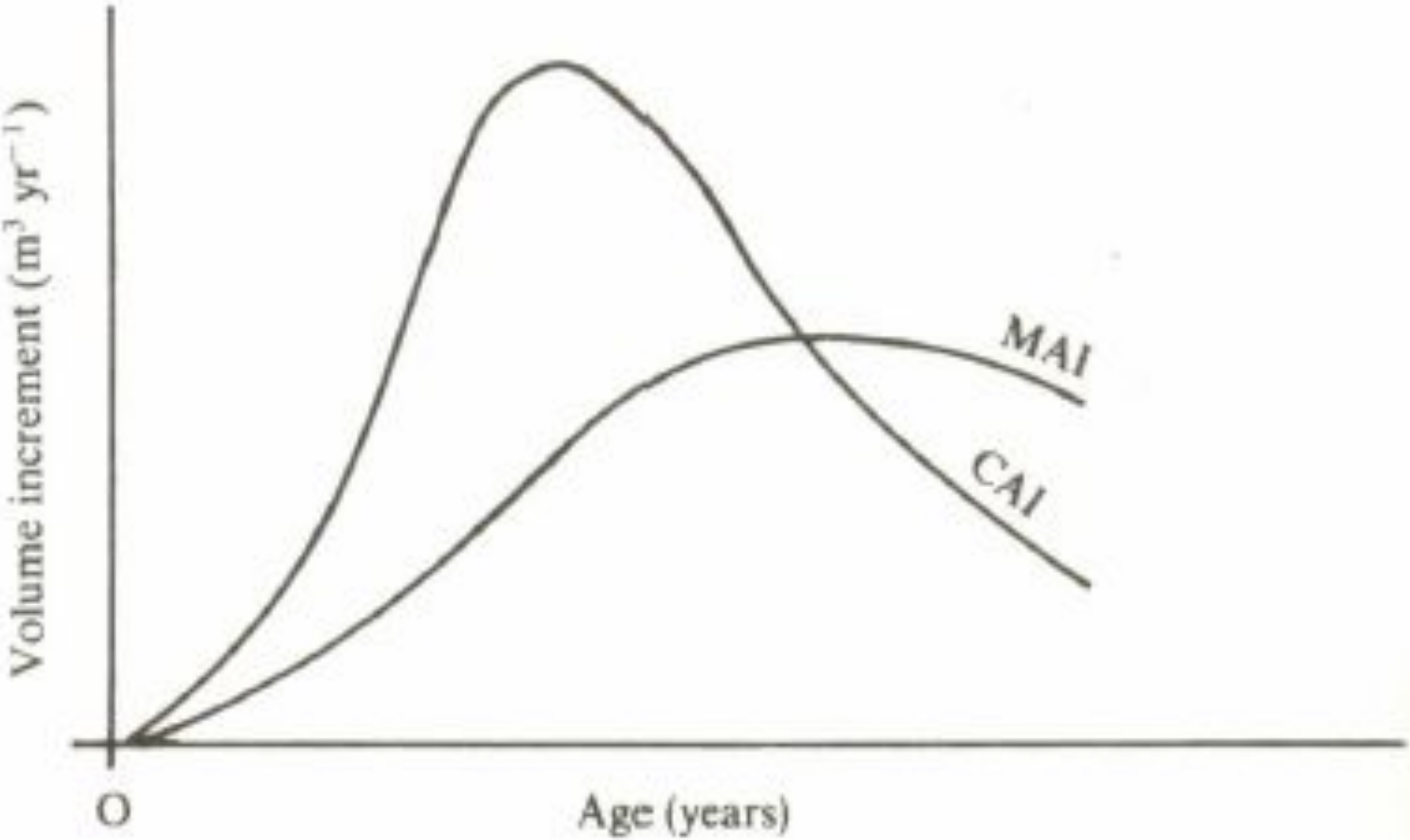
Yield class system of classifying growth potential

MAI & CAI curve intersection

↓

Maximum average rate of volume increment(MAI) which a particular species can achieve on a particular site

FIGURE Current and mean annual increments; single trees



- Yield Class : based on maximum MAI
  - 'Yield class 12' means it has maximum MAI of $12 m^3$/ ha
- But for preparing yield class for a site , one has to wait for the period till the crop reaches its maximum MAI

Other tree characteristics…

Diameter or basal area

- Reflects the effects of site quality
- Affected by stand density

Height

- Reflects the effects of site quality
- Least affected by stand density

- Relationship of tree ht and age - used in most countries as a measure of site quality
    - In America – relationship between tree ht and age is called " **site index**"

↓

Avg ht that a dominant and codominant trees will attain at key ages, such as 50 or 100 years

Ex : site index 70 on a 50 yr basis means ?

In India….

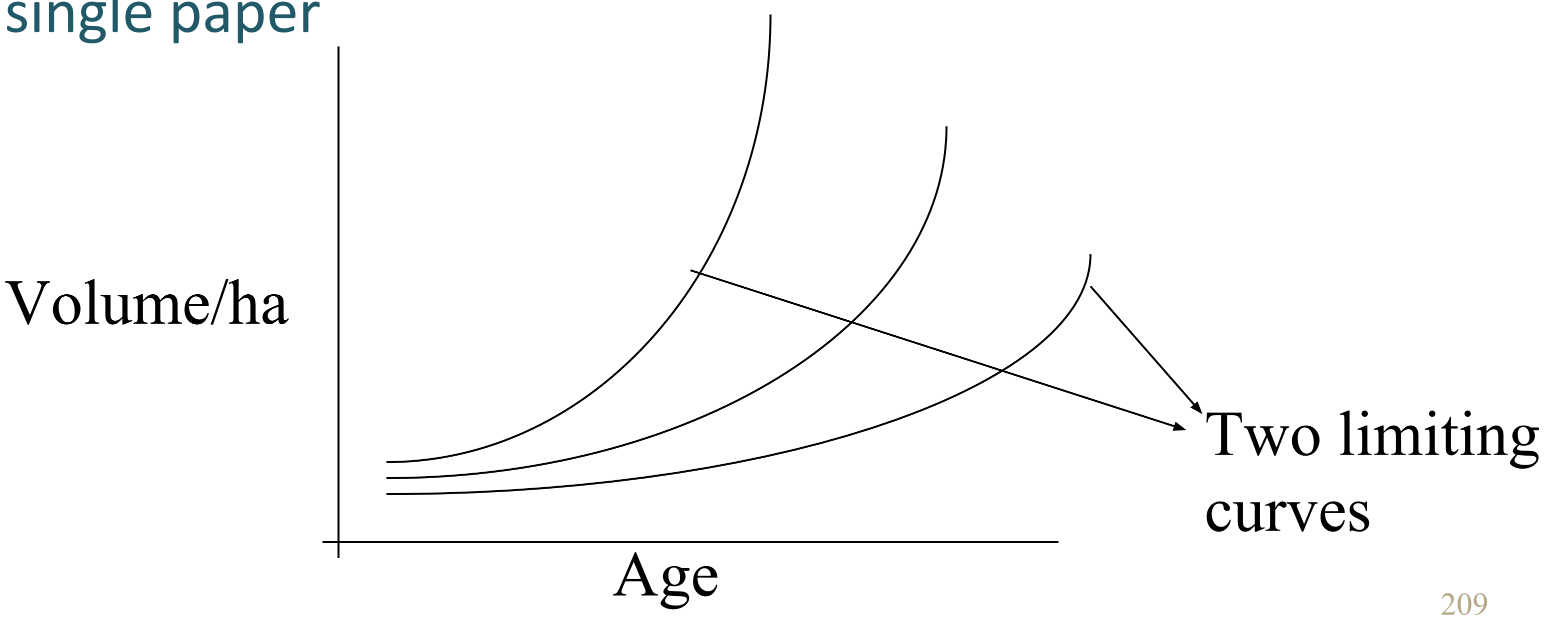
- Before 1930,
  - Average ht of all trees used
- Since 1930,
  - Site quality assessed based on top ht
  - Top hts of all sample plots – plotted against age
  - Then site classes are delimited by following methods :
    1. **Baur’s method**
    2. **British Forestry Commission(BFC) method**

Measurement of Site quality

1. Strip – Height Method (Baur's Method)

- Steps

1. Identify various plots
2. Plot volume/ha Vs age curve for each of the plot on a single paper



Contd.

3. Two limiting curves are drawn

4. Space between the two limiting curves is divided into strips of equal width

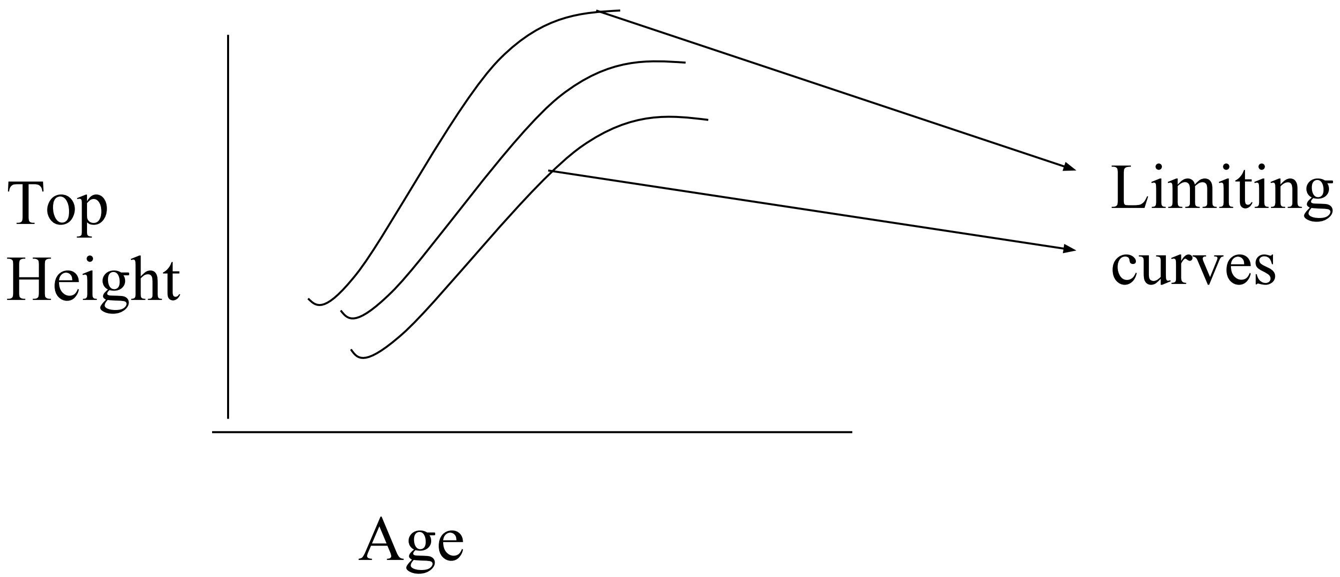
5. These strips represent different site quality classes

- **In India -** Volume is replaced by Height

Baur's method with height

- Steps

1. Identify various plots
2. Draw 'top height Vs age' curve for each of the plots



Contd.

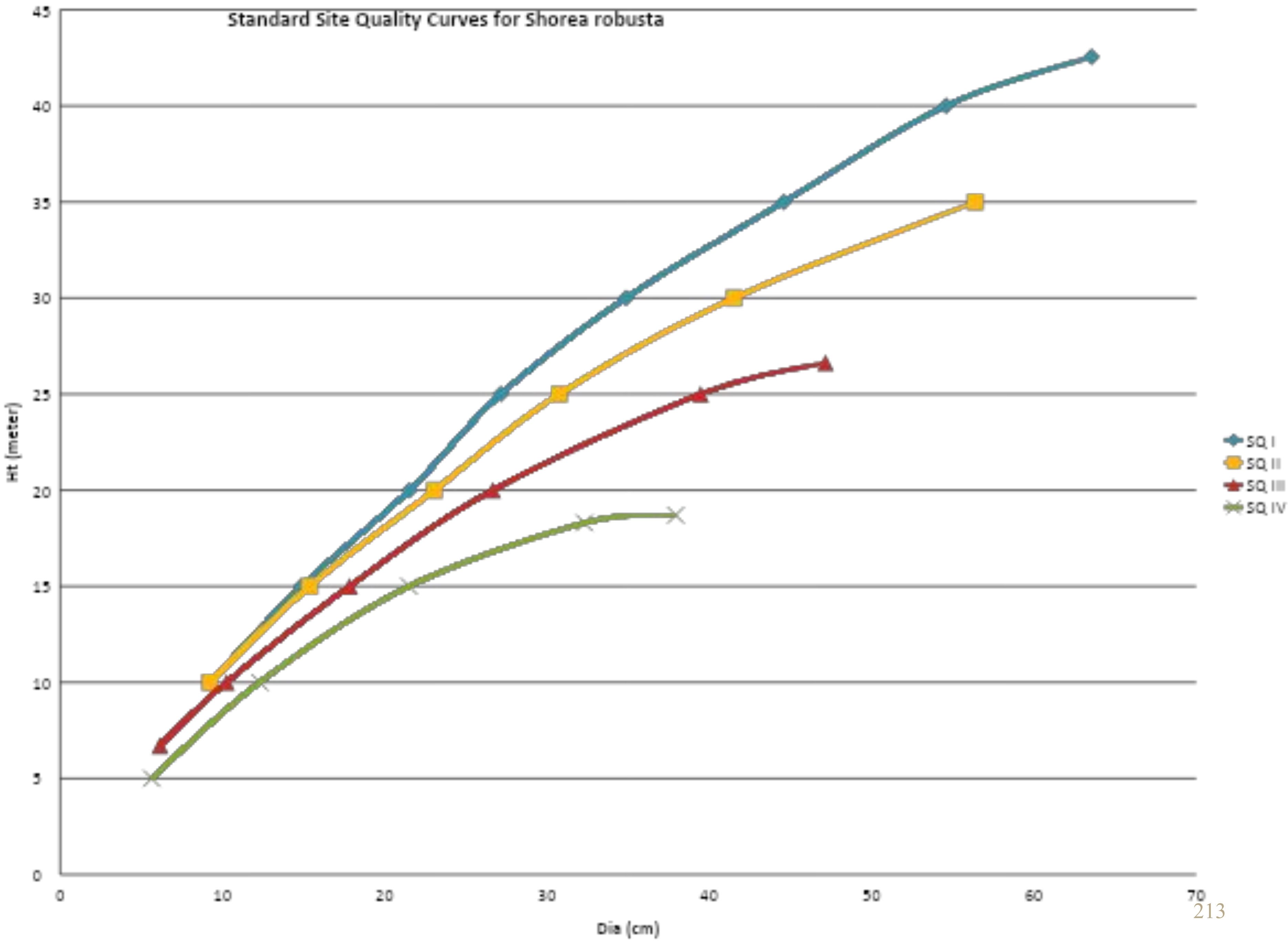
3. After neglecting the abnormal points limiting curves are plotted through the guiding points

4. No. of qualities to be differentiated are decided by considering:-

   - ✔ Difference between the limiting curves
   - ✔ Practical limits of accuracy in ht determination

5. Space between limiting curves divided symmetrically

   1. For sal Four quality classes : divided by three curves
   2. For teak five quality classes : divided by four curves


Standard Site Quality Curves for Shorea robusta
Ht (meter)
Dia (cm)
0
5
10
15
20
25
30
35
40
45
0
10
20
30
40
50
60
70
SQ I
SQ II
SQ III
SQ IV

2. British Forestry Commission method

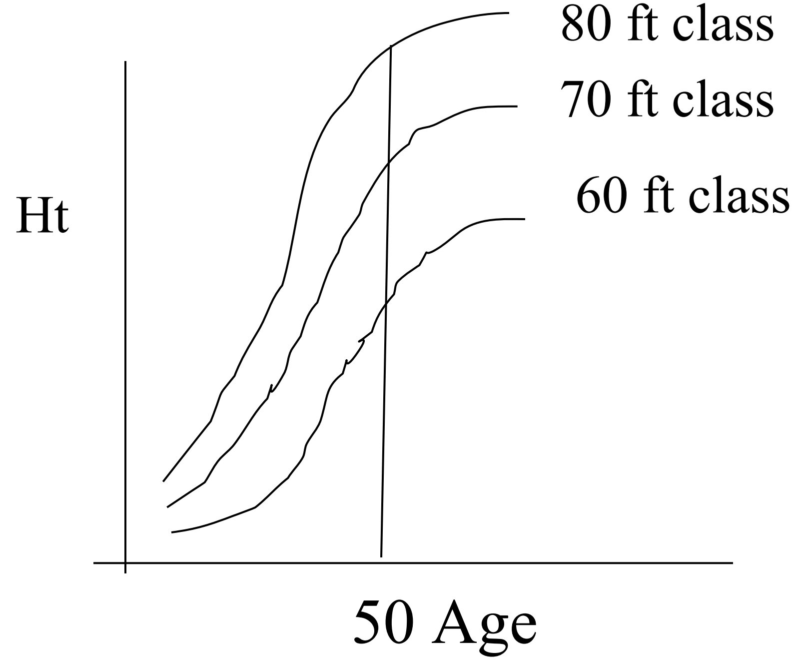
- Here also height taken as index
- Site trees
  - Dominant or co-dominant
  - Even aged
  - No evidence of crown damage, disease, crook, or forking etc.
- Measurement taken of site trees only
- Data on height development obtained from both temporary and permanent sample plots

Contd.

Steps

1. Index age fixed (25,50 or 100 years) fixed on the basis of estimation of age of site*
2. From each plot over index age three stems of approx. mean heights are selected.
3. Selected trees are subjected to stem analysis; age Vs ht curve from stem analysis prepared for each plot on a single paper.

4. Heights at index age are observed. And divided into 10 feet divisions representing Quality classes.



5. In this way number and range of quality classes is determined

6. All the plots over the age of index age are then allotted to a site quality.

Fractional site qualities

- Quality classes has high range of heights
- Lower limiting curve of a quality class is signified by 0.0, the mean curve as 1.0 and the upper curve as 2.0
- If age and top height are known fractional site qualities can be calculated

... This falls on ... quality and therefore can be said to be 1.0 III. If the

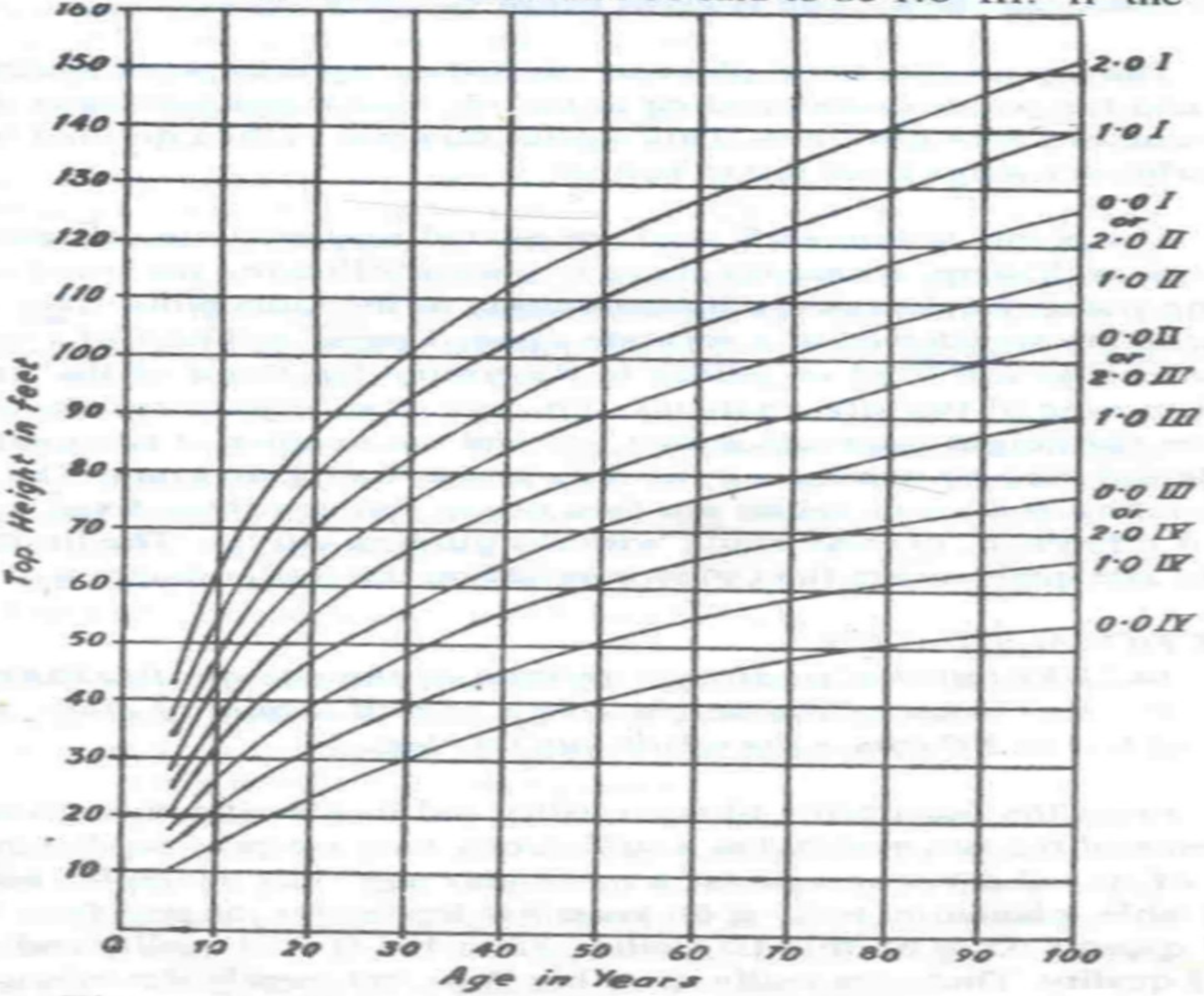


Fig. 117 Age-top height curves for plantation teak

Example of fractional site quality

- At 60 years and top height = 75 ft
  - Site Quality = 1.0 III
- At 60 years and top height = 65 ft
  - Site Quality = 0.0 III
- At 60 years and top height = 69 ft
  - Site Quality = 0.4 III
- At 60 years and top height = 80 ft
  - Site Quality = 1.5 III

Estimating the site quality of a Compartment

Method 1 (by Top Height) :

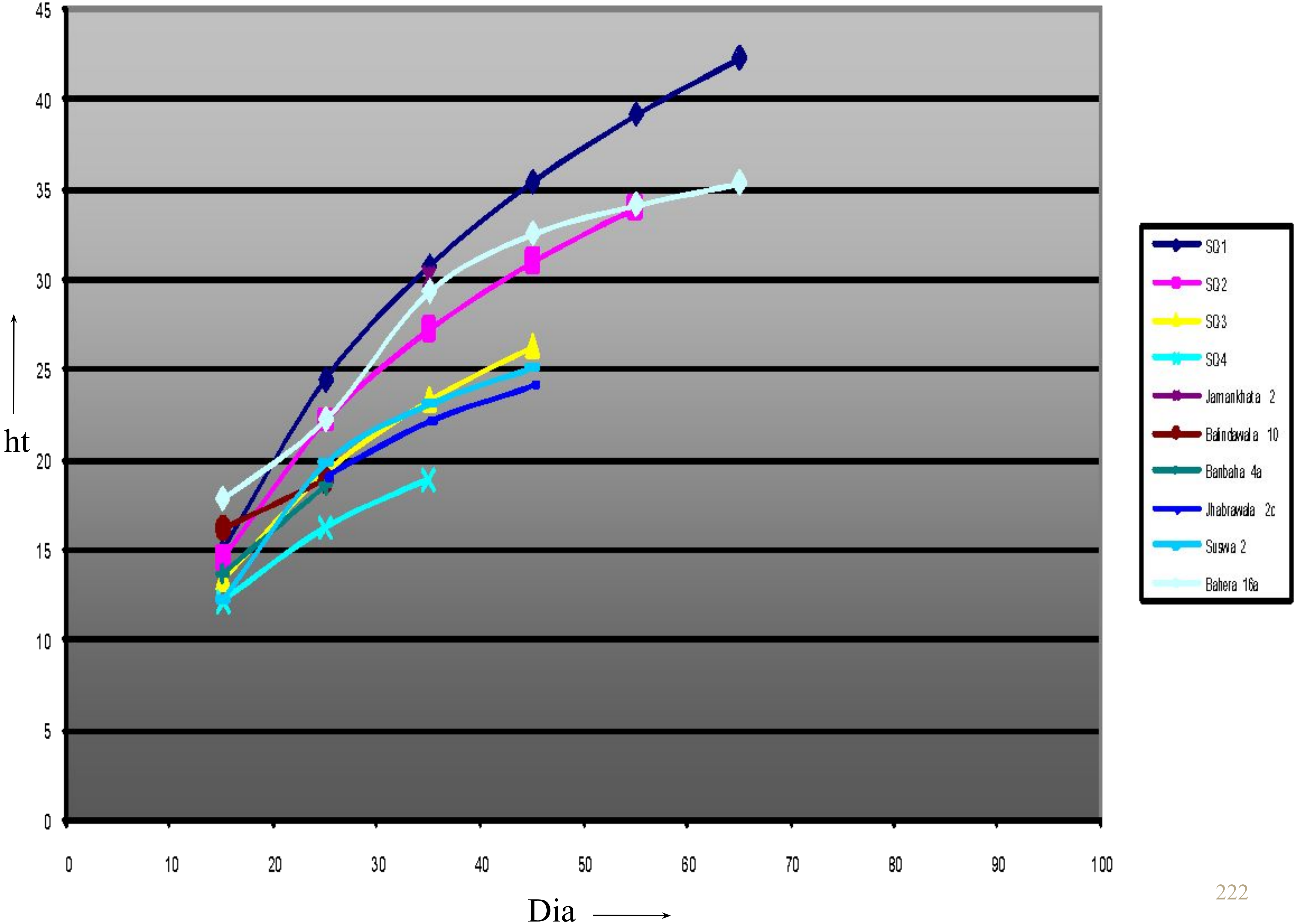
- Steps
  - Get Crop age
  - Get top height
  - Use yield tables to find out the site quality

Age - Difficult to know ?

Estimating the site quality of a Compartment

Method 2 (By Sample Plots) :

- Steps
  - Lay a Representative Sample plot
  - Get data for plotting **ht vs dia** curve
  - If data for all dia class is not available go out side the sample plot to get the data
  - Plot **ht vs dia** curves for various site qualities
  - Overlay the field data curve with the site quality curves (yield table) to see the site quality


45
40
35
30
25
20
15
10
5
0
ht
0
10
20
30
40
50
60
70
80
90
100
Dia
SQ1
SQ2
SQ3
SQ4
Jamankhata 2
Balindawala 10
Banbaha 4a
Jhabrawala 2c
Suswa 2
Bahera 16a

2. <u>Forecast of future yields…</u>

1. Stand structure

↓

2. ***<u>Stand growth</u>***

3. Stand density

4. Productive capacity of site, “site quality”

2. Stand Growth

- *Development of tree crops as they increase in age*

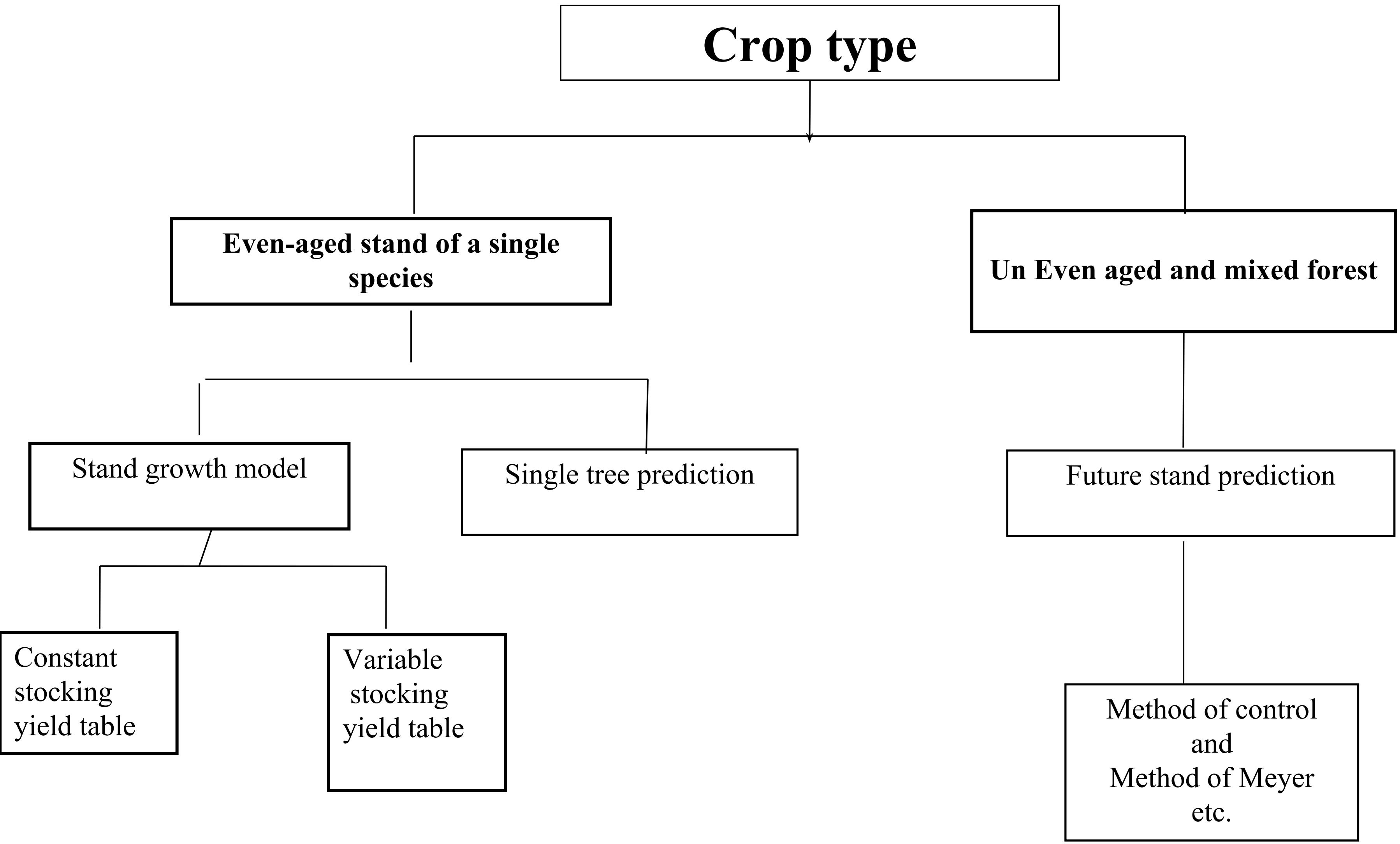
- 'Design of growth model' depends on :
  - Resource available
  - Uses to which it will be put
  - Structure of tree crops

    Even or Uneven aged

    - Changes from year to year

- Even aged stand
  - Simplest models
- Un Even aged or mixed species stand
  - Very complex

A classification of growth models



Stand prediction
in
Un-Even aged or mixed species stand

 Factors affecting stand structure

- Growth
- Death
- Cutting of trees

- **Definitions:**
  - **Ingrowth:**
    - volume of new trees growing into the minimum measurable size class during the measurement period.

Mortality:

- the **#** or **vol.** of trees periodically dying from natural causes as:

  - Old age, Disease, Insects etc.

Cut:

- the # or vol. of trees periodically felled or salvaged

- **Types of Stand Growth (in terms of vol.)**

$$Gg = V_2 + M + C - I - V_1$$

Gg= Gross growth of initial vol.

V_2= Stand Vol. at end of growth period

V_1= Stand Vol. at beginning of growth period

M = Mortality Volume

C = Cut volume

I = Ingrowth Vol.

Gn = Net growth of initial volume

$$\longrightarrow \quad Gn = (Gg - M) = V_2 + C - I - V_1$$

G_d = Net increase in standing vol.

$$\longrightarrow \quad G_d = V_2 - V_1$$

Stand prediction in Un-Even aged crops

- Method of measuring growth of un-even aged crops
  - evolved from those developed in France & Switzerland in last century
  - Swiss forester , M Henri Biolley introduced **“ Methode du Controle”**
    - Established the increment of forest over successive 100 % inventories by 3 categories
      - Large , Medium & small sized trees
    - This data then used to predict or plan future felling

Method of Control ...

- Depends on the following factors:

1. 100% inventories
2. Well defined procedure of measuring and re-measuring the diameter of standing trees
3. Measuring and determining the volume of felled trees and mortality trees
4. A simple method of determining ingrowth
5. Use of permanent local volume tables

- Initial inventory
  - Entire area is enumerated
  - Trees are classified by Dia- class
  - Record all trees removed till the next inventory

    (dia class as well as volume)
- Next Inventory
  - Entire area is again enumerated

- Volume calculation
  - Using LVT
  - For each dia –class
  - Add volume of each dia class to obtain volume of each inventory
- Cut and mortality together constitute trees removed

a) Vol at time t = V_1

b) Vol at time (t + 5) yrs = V_2

c) Account total vol. removed during the period = C

Then, net growth, including ingrowth, of initial volume

$$\mathbf{Gn+i = V_2 + C - V_1}$$

The Calculation of increment in the Methode du Controle

		2001		2006		Felled		Recruits		Revised 2006 total		Volume inc./ha in 5 yr	Annual volume increment per ha	
Dbh	Vol./tree	No./ha	Vol./ha	No./ha	Vol./ha	No./ha	Vol./ha	No./ha	Vol./ha	No./ha	Vol./ha			%
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
75	5.56	–	–	1	5.56	–	–			1	5.56		*Large trees*	
70	4.93	1	4.93	–	–	–	–			–				
65	4.32	–	–	–	–	–	–			–				
60	3.72	2	7.44	5	18.60	–	–			5	18.60			
55	3.20	5	16.00	6	19.20	2	6.40			2	6.40			
Total large trees		8	28.37	12	43.36	2	6.40	6	19.20	8*	30.56	2.19	0.44	1.6
									Recruits	6	19.20		*Medium trees*	
50	2.70	11	29.70	7	18.90	1	2.70			8	21.60			
45	2.22	13	28.86	17	37.74	5	11.10			22	48.84			
40	1.66	27	44.82	27	44.82	1	1.66			28	46.48			
35	1.14	32	36.48	41	46.74	4	4.56			19	21.66			
Total medium trees		83	139.86	92	148.20	11	20.02	26	29.64	83*	157.78	17.92	3.58	2.6
									Recruits	26	29.64		*Small trees*	
30	0.12	66	47.52	52	37.44	5	3.60			57	41.04			
25	0.37	69	25.53	83	30.71	13	4.81			96	35.52			
20	0.16	117	18.72	94	15.04	19	3.04			73	11.68			
Total small trees		252	91.77	229	83.19	37	11.45	40	6.4	252	117.88	26.11	5.22	5.7
Total		343	260.00	333	273.75	50	37.87			343	306.22	46.22	9.24	3.6

Methode du Controle

(volume increment by dia class)

1. the classes of diameter at breast height were grouped into three major categories of large, medium and small trees. A separate increment % was calculated for each.
2. data derived from a one parameter volume table.
3. from an inventory of the compartment made in 2001
4. col. 2 X col. 3
5. From an inventory of the compartment made in 2006

Contd…

6. col. 2 X col. 5
7. From the compartment records of outturn for the period 2001-2006
8. col. 2 X col. 7
9. only to be completed in the line of the totals for the large and medium trees = total of col. 5 + total of col. 7 – total of col. 3, i.e. $V_2 + F - V_1$ or the number of trees of medium size in 2001 recruited to the large tree category, etc.
10. col. 2 X col. 9 for totals only.

11. has to be completed for the total line of the large trees first and must equal the corresponding total in col. 3.

- Then starting with the largest diameter class of the large trees, col. 11 = col. 5 + col. 7 until the sum of these totals equals the figure previously entered in the total line. The balance of trees in the large tree diameter classes has been recruited from the medium category and this balance is entered in the blank line at the head of the medium tree category in col. 11 and labelled ‘recruits’ in the adjoining space in col. 10

12. col. 2 X col. 11

13. completed for the total line of the large, medium and small tree category only = col. 12 – col. 4

14. col. 13 divided by the period of years between the inventories

15. column 14 expressed as a % of col. 4

- **Meyer (1953)** reviewed the Stand Prediction Method
  - Developed new system was similar to Methode du Controle but
    - Predicted the future structure of a stand either from increment measured from successive inventories or in sample plots

Methodology

1. Current diameter increment by diameter classes
   - Use of data collected
2. Predict future structure of stand and growth in volume

1. Diameter increment by diameter classes

- Takes in to account
  - no. of trees rising into a diameter class,
  - Trees remiaining stationery in the class
  - Trees going out of the class

in successive inventories

- Increment in each dia class,

$$I = (DR/DE) * C$$

where,

DR = double rising (sum of trees rising out and rising into a class)

DE = double effective (sum of trees in the first and second inventories after correction for trees removed)

C = width of dia class

Table
Calculation of Periodic Annual Diameter Increment by Diameter Classes by the Method of Control

(1) dbh Class (inches)	(2) Inventory Spring 1999 (number)	(3) Trees Removed (number)	(4) Inventory Spring 1999 Minus Trees Removed (number)	(5) Inventory Spring 2009 (number)	(6) Trees Rising (number)	(7) Double Rising (number)	(8) Double Effective (number)	(9) DR/DE	(10) Periodic Diameter Increment (inches)	(11) Periodic Annual Diameter Increment (inches)
					0					
32	0		0	1	1	1	1	1.000	2.00	0.200
30	2		2	4	3	4	6	0.667	1.33	0.133
28	3		3	0	0	3	3	1.000	2.00	0.200
26	3	2	1	9	8	8	10	0.800	1.60	0.160
24	10	1	9	7	6	14	16	0.875	1.75	0.175
22	10	4	6	21	21	27	27	1.000	2.00	0.200
20	23	4	19	39	41	62	58	1.069	2.14	0.214
18	37	7	30	72	83	124	102	1.216	2.43	0.243
16	73	5	68	169	184	267	237	1.127	2.25	0.225
14	194	17	177	234	241	425	411	1.034	2.07	0.207
12	249	9	240	379	380	621	619	1.003	2.01	0.201
10	418	15	403	507		864	910	0.949	1.90	0.190
					484					
Total	1022	64	958	1442		2420	2400			

$$\frac{\Sigma DR}{\Sigma DE} = 1.008$$

Average = 2.02   0.202

Number of trees ingrowth = 1442 − 958 = 484 (checks with last figure in Column 6). Trees were removed (Column 3) immediately following t 1999 inventory. Data from 143 permanent sample plots of ⅕ acre located on Morgan-Monroe State Forest, Indiana. Sample area: 28.6 acres. Growth period: 10 years.

- No. of trees rising in to class =

  (# of trees in 2nd Inv)

  - (# of trees in 1st Inv)

  + (# of trees rising out of the class)

→ $C6_{i+1} = C5i – C4i + C6_{i-1}$

→ $C7i = C6_{i+1} + C6_{i-1}$

→ $C8i = C4i + C5i$

2. Predict future structure of stand and growth in volume

- **STAND PREDICTION METHOD**

Dbh Cm	Vol. per tree (Cum)	Inventory - No. of Stems Per Ha	Diameter increment in 5 years Cm (i)	Ratio i/c*	Station ary	1dia. Class	2 dia. Class	Future stand No. of stems per Ha	Present Volume (Cum per ha)	Volume prediction (Cum per ha)
1	2	3	4	5	6	7	8	9	10	11
42	1.80	-	-					1.10	-	1.98
40	1.58	2	1.1	0.55	0.90	1.10	-	2.70	3.16	4.27
38	1.38	3	1.2	0.60	1.20	1.80	-	5.45	4.14	7.52
36	1.19	5	1.7	0.85	0.75	4.25	-	10.55	5.95	12.55
34	1.02	8	2.0	1.00	-	8.00		8.50	8.16	8.67
32	0.88	9	2.4	1.20	-	7.20	1.80	11.70	7.92	10.30
30	0.76	13	2.2	1.10	-	11.70	1.30	17.10	9.88	13.00
28	0.65	18	1.9	0.95	0.90	17.10	-	13.70	11.70	8.90

Dbh Cm	Vol. per tree (Cum)	Inventory - No. of Stems Per Ha	Diameter increment in 5 years Cm (i)	Ratio i/c*	Stationary	1dia. Class	2 dia. Class	Future stand No. of stems per Ha	Present Volume (Cum per ha)	Volume prediction (Cum per ha)
1	2	3	4	5	6	7	8	9	10	11
26	0.55	16	1.6	0.80	3.20	12.80	-	22.80	8.80	12.54
24	0.46	28	1.4	0.70	8.40	19.60	-	28.90	12.88	13.29
22	0.38	41	1.0	0.50	20.50	20.50		58.20	15.58	22.12
20	0.31	58	1.3	0.65	20.30	37.70		70.90	17.98	21.98
18	0.25	92	1.1	0.55	41.40	50.60		99.45	23.00	24.86
16	0.18	129	0.9	0.45	70.95	58.05		70.95	23.22	12.77
	Total	**422**						**422.00**	**152.37**	**174.75**

c = class interval = 2 cm

5 years' total increment = (174.75 – 152.37) = 22.38 ;

current annual increment 4.48 per year or 2.9%

Notes on calculation in Example of the

STAND PREDICTION METHOD

COLUMN

1 Classes of diameter at breast height

2 From a one parameter volume table

3 From an inventory

4 From repeated measurements on sample trees

5 Col.4 divided by the diameter class interval

COLUMN

6,7,8 If the increment is 1/n of the class interval, then on average 1/n of the trees will move out of the class in to the next larger dia class;

However, if the increment is more than the class interval, then all the trees will move up

If the increment is 1 ¼ times the class interval, all the trees will move up and ¼ will move beyond into the next but one diameter class

Co.6= 0, if Col.5 is greater than 1, or else = (1- col.5) (Col.3)

Col.7 = Col.3 - (col.6+ col.8)

Col.8 = 0, if col.5 is less than 1, or else = (col.5 - 1) (col.3)

Column 9 Col6 + (the entry in Col.8 of 2 diameter classes lower) + (the entry in col.7of 1 diameter class lower), e.g.

Dbh 42 col.9 = 0+1.10 =1.10

Dbh 40 col.9 = 0.90+1.80 = 2.70

10 col.2 X col.3

11 col.2 X col.9

- The total of column 3 must equal that of column 8 .

Q: Following inventory data has been collected in two different years in the same forest area:

Dia class (in cm)	Volume per tree	Initial inventory in 2001 (number)	Second inventory in 2011 (number)
1	**2**	**3**	**4**
42	1.8	0	1
40	1.58	2	3
38	1.38	4	5
36	1.19	6	11
34	1.02	12	20
32	0.88	18	26
30	0.76	22	30
28	0.65	26	33
Total		**90**	**129**

Calculate annual diameter increment in each dia class, overall annual diameter increment and also future volume in year 2016 using Method of Control.