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 and Animal 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, 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

Ultimate Objective ?

Sustainable Forest Management

Object of Sustainable Forest Management

"Perpetuate Forest

and

Harvest Economic Yields too"

(Sustained Yield)

Sustained Yield

3 types :

1. Integral Yield
2. Intermittent Yield
3. Annual Yield

Commonly,

Sustained Yield ~ Annual 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

Measurments of Crops

- Different from individual tree measurments
- Special characteristics of the crop

1. Gradual Diminution of # of Trees
2. Crop Structure
3. Object of Measurement

Determination of Crop Parameters

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

Few Important Terms …

1. Stand

2. Basal area

1. Stand :

- Some area of forest having similar crop characteristics and Require **same treatment & planning attention**

Definition - An area of forest that can be treated as a unit because it has uniform land quality, topography, and species composition

- 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

4 main features that influence separation of stands

1. Extent of stand
    - 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:
    1. Seedling stage
    2. Young pole stage
    3. Large pole stage
    4. Young timber stage
    5. Mature timber stage
    6. Over mature timber stage

4. Health of stand

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

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 table.

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

d) Total B.A. calculated for each plot by $\sum$ 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…

$$G = \frac{\sum^{n}\sum^{m} g_{ij}}{\sum^{n} A} \ m^3/ha \text{ and}$$

$= 7.99522/0.04$

$= 199.88\ m^2/ha$

Determination of Crop Parameters

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

1. <u>Crop Diameter</u>

- Main object is to find out volume
- Volume is dependent on basal area (well corrected)

Crop diameter : <u>Even aged crop</u>

Mean diameter : any group of trees or 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,

$$\text{M.B.A.} = \frac{\text{n1gi+n2g2+}\ldots\ldots\ldots\ldots\text{nigi}}{\text{n1+n2+n3+}\ldots\ldots\ldots\ldots\text{ni}}$$

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

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

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

$$\text{Crop dia} = 2 \text{ x} \sqrt{\frac{\text{M.B.A}}{\pi}} \quad \text{——— (1)}$$

- **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
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….

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

and

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

$$d_{\bar{g}} = 0.412 \ m$$

$$d_{\bar{g}} = 41.2 \ cm$$

- Similarly from above table arithmetic mean dia can be calculated

$$\text{Arithmetic Mean dia} = \frac{\sum ni\ di}{\sum ni} \qquad (2)$$

Crop dia < = > Arithmetic Mean dia ?

<u>Top diameter</u> :- diameter corresponding to the M.B.A. of 250 biggest diameter/ha

2. “Determination of Height of Crop”

2 terms :

1. **Crop height:**
   - avg weighted(basal area) ht of of a regular crop **(Lorey’s formula)**

Determination of Crop Height :

Steps-

Tabulate data:

Dia classes	Basal area observed	Average height
10-20	G1	h1
20-30	G2	h2
30-40	G3	h3
40-50	G4	h4
50-60	G5	h5
60-70	G6	h6
ith	Gi	hi

Gi - Total basal area in each group

(Calculated from measured values)

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

Lorey's Formula :

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

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

2. Mean Height:

It is the height corresponding to the crop diameter of the stand

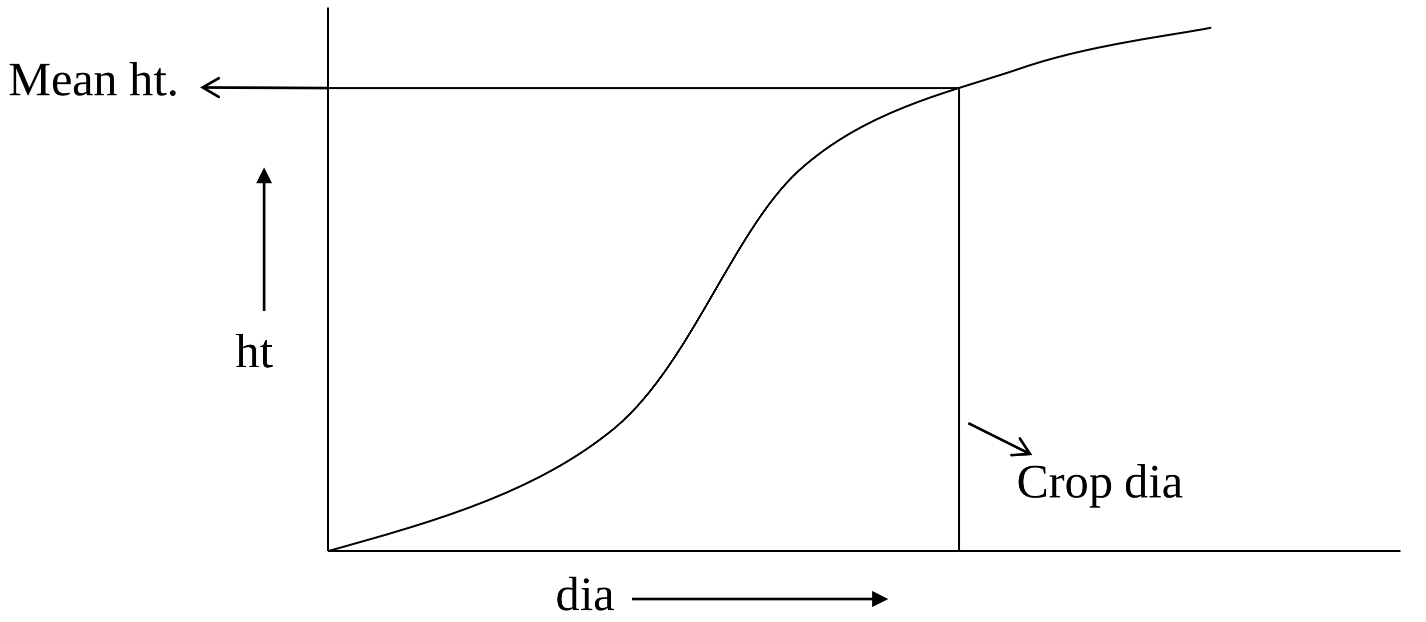
Steps:

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	Col 2 ht	Col 3 Avg. Hts.
10-20	h1' h2'….hi	h1'
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

‘Height corresponding to the mean diameter(calculated from basal area) of 250 biggest diameters per ha as read from height diameter curve’

3. Determination of Age of Crop

- Even aged
- Un-Even aged

Even aged and Un-even aged Stand

Even Aged Stand:

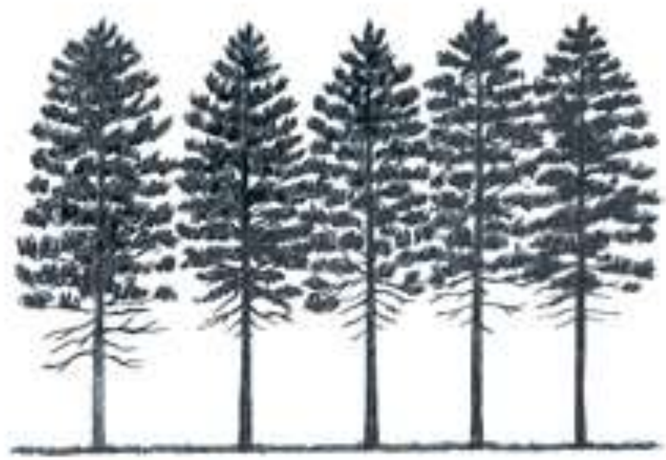
- ✓ Trees approximately of same age
- ✓ Age variation less than 25% rotation age

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.


Even aged and Un-even aged forest

- Even aged forest :
  - Has stands of different ages till 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

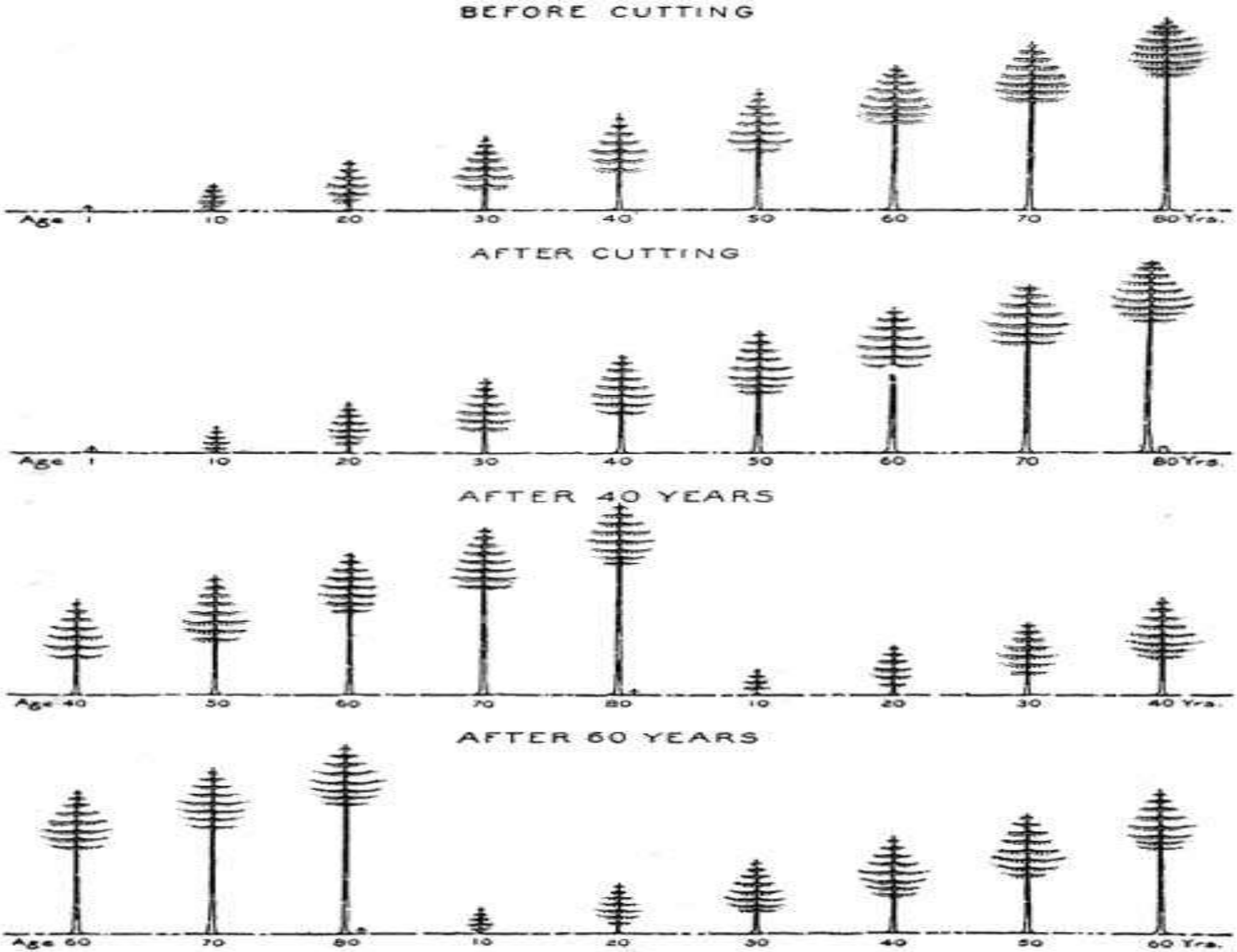
– **Age**

II. **Un-Even aged system**

- Selection

– Management based on

– **Size**


BEFORE CUTTING
Age 1
10
20
30
40
50
60
70
80 Yrs.
AFTER CUTTING
Age 1
10
20
30
40
50
60
70
80 Yrs.
AFTER 40 YEARS
Age 40
50
60
70
80
10
20
30
40 Yrs.
AFTER 60 YEARS
Age 60
70
80
10
20
30
40
50
60 Yrs.

- After rotation period **Even aged forest** needs regeneration
- **Uneven aged forests**: new recruits continuously coming

  - ✓ Productivity (Timber) (Quantity) wise even aged is better than uneven aged.

Quality wise uneven aged may be better.

Age (for even aged)

- The age of even aged crop is described by the term "Crop Age"
- Crop Age: Age of regular crop corresponding to its crop diameter
- Method:

a) Get basal area of the crop

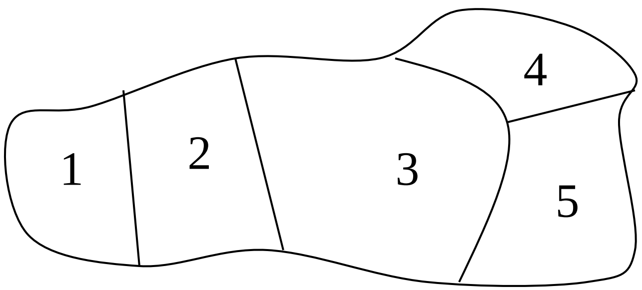
b) Get crop dia

c) Plot Age-dia curve

d) Read age corresponding crop dia

- **If Age variation in crop is more:-**
- **Method:**

a) Break Area into smaller area of even aged group



b) Get Si, basal area of each plot

c) Get ai, age of each age group

(as dealt in Crop Age)

d)

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

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 measurment 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)

$$V = \frac{\sum^{n} \sum^{m} (Vij)}{n \cdot a}$$

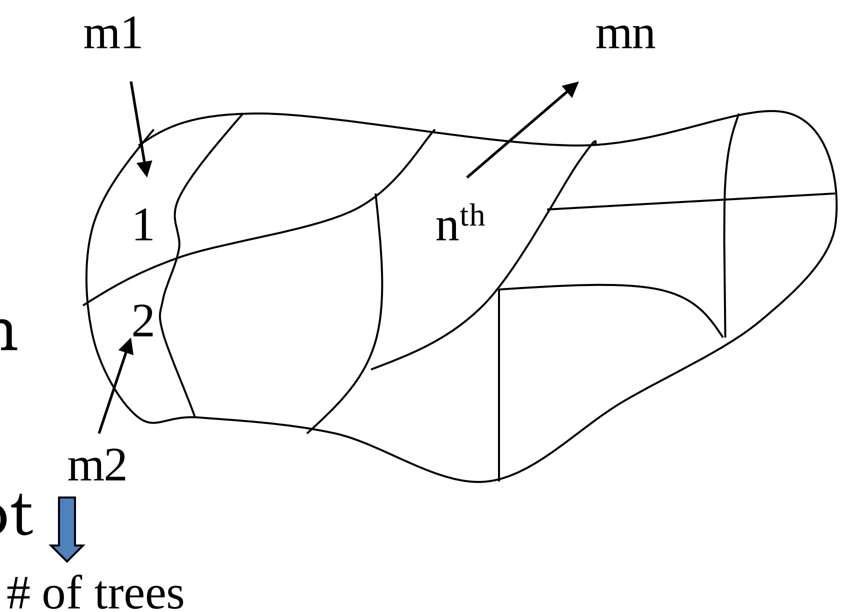
V : Avg. Vol. per ha, m^2

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

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

$$V = \frac{\sum^{n}\sum^{m} v_{ij}}{na} = \frac{7.51}{(5)\ (0.005)} = 300\ m^3\ ha^{-1}$$

Method 1 (B)

- If sub sampling for volume is practised:

<u>3 methods</u>

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

1. “Mean tree method”

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

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

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

$$v_i = m_i \bar{v}_i$$

m^3 in plot I, (m: no of trees in sample plot)

vol. per ha, $V = \frac{\sum Vi}{n \times a}$

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	$\sum v_{ik}$ m^3	$\bar{v}_i$ 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**

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

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 $\sum g$, $\sum v$

→ mean form height, $\overline{fh} = \dfrac{\sum v}{\sum g}$

(for each plot)

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

vol. per ha, $V = \dfrac{\sum Vi}{n \times a}$, n : no of Sample Plots with a mean form height pooled over all plots

d) $$\overline{\overline{fh}} = \frac{\sum\sum Vik}{\sum\sum gik}$$

↑ pooled mean

or

$$V = \frac{(\sum gij) \times \overline{\overline{fh}}}{n \times a}$$

- **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} m^2**	**v_{ik} m^3**	**$\sum^{s_i} g_{ik}$ m^2**	**$\sum^{s_i} v_{ik}$ m^3**	**$\overline{fh_i}$**
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	$m_i \sum g_{ij}$	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**

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

OR,

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

using a pooled mean form height of 9.92

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

3. Regression of Volume on Basal Area Method:

As in previous problem

- Steps:

a) Take a Sample and sub samples

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

c) Pool the data

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….

$$V = \frac{\sum_{i}^{n} m_i . a + b \sum^{n} \sum^{m_i} g_{ij}}{n \times r} \quad m^3/ha$$

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

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

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

- **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 = $\bar{v}$ – b $\bar{g}$ = 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, 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.