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. Volume of forest crops at present

Forest Inventory

Definition

- F. I. is :
  - Tabulated , reliable and satisfactory tree information, related to the required unit of assessment
  - An attempt to describe **quantity, quality, diameter distribution of trees and many of the characteristics of land** upon which trees are growing

Objective

- Natural Resources Survey
- Management plan for a forest - long term and short term
- Assessment of potential for forest and wood based industry development

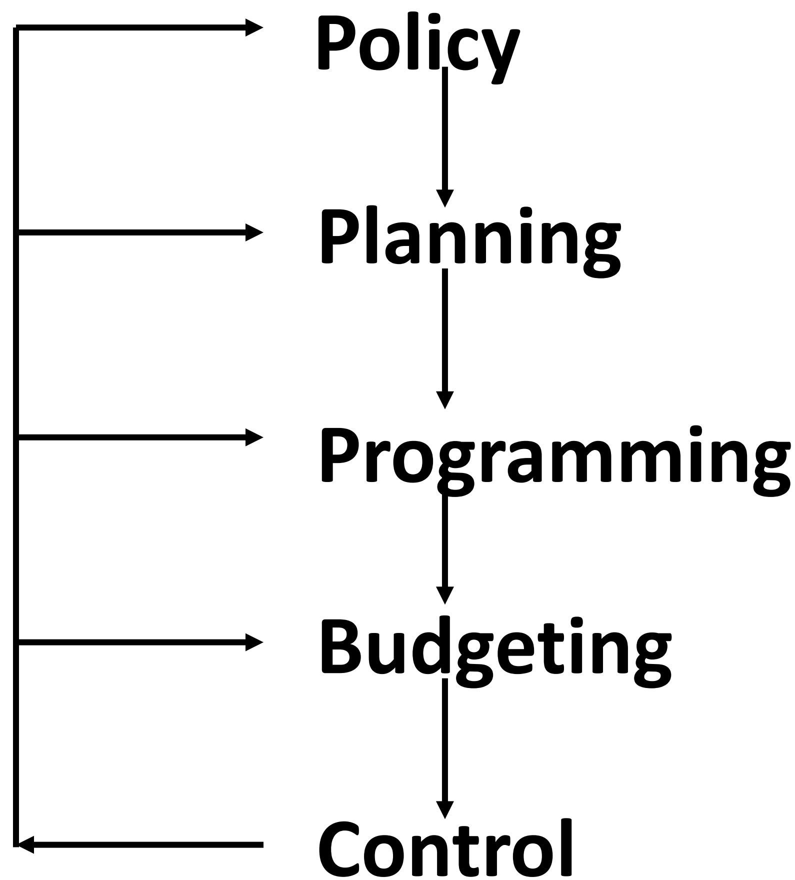
Types of Inventory

1. Current Inventory
   – current growing stock etc

2. Recurrent or Continuous Inventory
   – Inventory repeated at regular interval
   – Monitoring growth rate and other changes

Planning and execution of Inventory

3 PBC



Kinds of enumeration

1. Total or Complete enumeration
   - Expensive & time consuming
   - Very small area of valuable and intensively managed forest
2. Partial or Sample enumeration
   - Enumeration only in a representative portion
   - Sample
     - part of population
     - May consist one or more sampling unit
   - Ratio of sample to whole population is called ‘sampling fraction’ or ‘intensity of sampling’
     - Expressed as a percentage

Choice of kind of enumeration

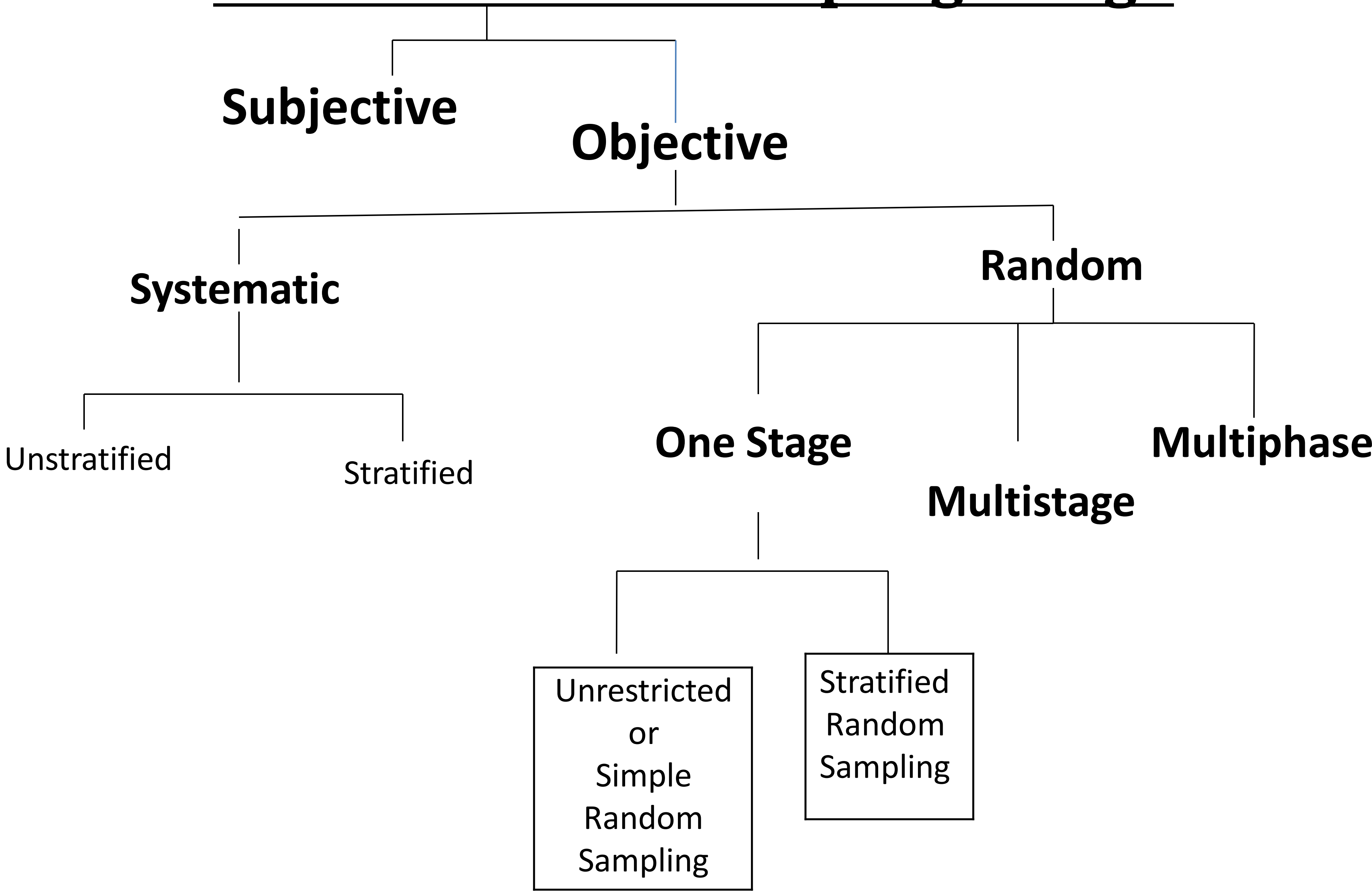
- Depends upon :

  1. Extent of area to be covered
  2. Variation in composition & density
  3. Intensity of management & consequent accuracy required
  4. Resource of labour , time and funds available

Relative advantage of Sampling

1. Reduced cost and saving of time
2. Relative accuracy- when planned, appropriate intensity, qualified personnel can be employed.
3. Knowledge of error- calculated and kept within limits by stat. methods
4. Greater scope- sophisticated instruments & highly skilled techniques

Classification of Sampling Design



SAMPLING DESIGNS

Guided by

- Objective of the inventory
- Desired precision
- Time and money available
- Topography & accessibility
- Availability of personnel and equipments
- Availability of satellite imageries, aerial photographs, and maps, data processing units.
- Results of previous survey

Types of sampling plots

1. Temporary sampling plots
2. Permanent sampling plots

1. **Temporary sampling plots:**
   – Generally used for the enumeration surveys
   – Measurements carried out once only

2. Permanent sample plots

- can be used for:
  - Repeated measurements at regular interval
  - Used for preparation of yield tables.
  - To study the all stages of development of even aged crop
    - Including crop volume and increment.
  - To study the same type of crops in different localities.
  - To study the influence on crop increment of different methods of regeneration.

Size & Shape of sampling units

1. Size :
   - Compromise between maximum efficiency, cost and convenience
     - Small sampling units – more efficient than larger ones
     - Large sampling units – fewer sampling units , hence lesser time required for travel & hence lesser cost

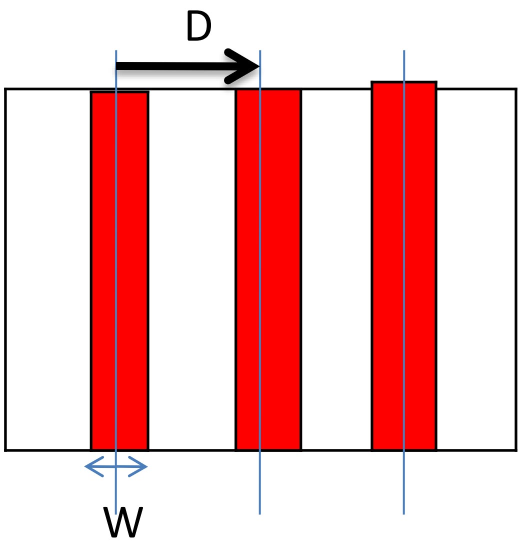
2. Shape :

a) Plots

- Square , rectangular or circular

b) Strips

- Base line
- Enumeration is done on the both side of central line



Intensity of sampling,

I =(W /D) x 100

W= width of strip

D = distance between the central lines of 2 adjacent strips

c) Topographical units

- Natural / artificial features form boundaries
- Used in hills
- Units first identified on maps then on ground
- Calculate area from the map

d) Clusters

- A group of smaller units
  - Cluster – statistical unit
  - Small unit – record unit

Sampling Intensity

- Defined as:

  (Area sampled/Total area) x 100

- In order to keep the sampling error less than 10%, following intensities have been recommended:

Type of forest	Percentage
Tropical wet ever green	10
Tropical moist deciduous	2.5
Sub-tropical pine forest	5

Sampling Intensity

- The percentage usually recommended for different terrains:-

Terrain	Method	% of sampling
Plains	Strip sampling Linear plot	5 to 10 2 to 5
Hills	Topographical Units	20 to 25 if the area of the forest is more than 2000 ha.

This is only a rough guide

Sampling Intensity

- Circular plot method
  - Circular plot size 0.05 ha (radius 12.62 m)
  - For plains following table can be used

Net area of the forest unit	**Enumeration intensity**
Up to 10 ha	Total enumeration
11 to 50 ha	Minimum of 30 circular plots
51 ha and above	30 to 100 circular plots

Sample

- Sample
  - Part of population
  - Representative of population
  - May consist one or more sampling unit

Parameters and Statistic

- Used to describe quantitative characteristic of population and sample
  - Statistical constants of population are called ‘**Parameters**’
  - Statistical measures calculated from the sample observations are ‘**Statistics**’

Variables

  - Discreet
  - Continuous
- Distribution ?
- Discreet
  - Binomial distribution
  - Poisson distribution
- Continuous
  - Normal

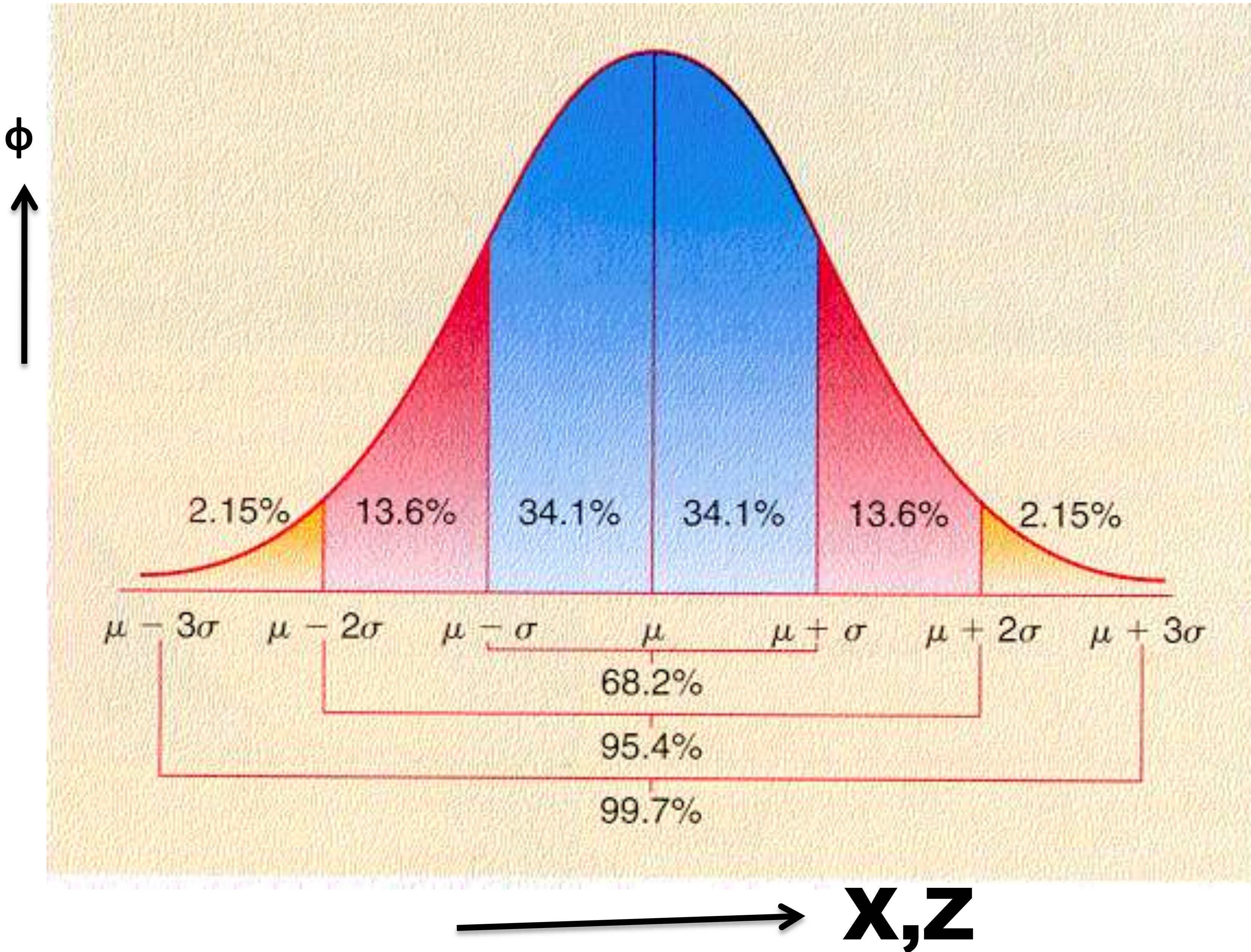
$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

We can transform the original variate to

$Z = (x - \mu) / \sigma$

When $x = \mu \rightarrow$ Mean $Z = 0$

$$\phi(\mathbf{z}) = \frac{1}{\boldsymbol{\sigma}\sqrt{2\pi}} e^{-\frac{1}{2}\mathbf{z}^2}.$$



ϕ
2.15%
13.6%
34.1%
34.1%
13.6%
2.15%
$\mu - 3\sigma$
$\mu - 2\sigma$
$\mu - \sigma$
μ
$\mu + \sigma$
$\mu + 2\sigma$
$\mu + 3\sigma$
68.2%
95.4%
99.7%
x,z

Characteristics of Normal distribution

- The curve is bell shaped and symmetrical about line $x = \mu$
- Mean, Median and Mode of the distribution coincide
- Total area under graph = 1
- Probability of a continuous variable falling within x_1 and x_2 : $P_1 - P_2$

Method :

- Calculate $Z_1 = (x_1 - \mu) / \sigma$

  $Z_2 = (x_2 - \mu) / \sigma$

- Calculate P_1 at Z_1 and P_2 at Z_2

- Probability of a continuous variable falling within x_1 and x_2 : $P_1(Z_1) - P_2(Z_2)$

Q : If $\mu = 485$ and $\sigma = 25$;

what is the probability that $x <= 460$?

Sol : $Z = (x - \mu) / \sigma$

$= (460 - 485)/ 25 = -1$

$P (x <= 460) = P (z <= -1)$

$= 0.1587$ (from table)

Q : If $\mu = 500$ and $\sigma = 4.47$

what is the probability that $490 <= x <= 510$?

Sol : $Z_1 = (x_1 - \mu) / \sigma = (490 - 500)/ 4.47$

$= - 2.24$

$P_1 (Z_1) = P_1 (-2.24) = 0.01255$ (from table)

$Z_2 = (x_2 - \mu) / \sigma = (510 - 500)/ 4.47$

$= 2.24$

$P_2 (Z_2) = P_2 (2.24) = 0.98745$ (from table)

$P (490 <= x <= 510) = P (-2.24 <= z <= 2.24)$

$= P_2 (2.24) - P_1 (-2.24)$

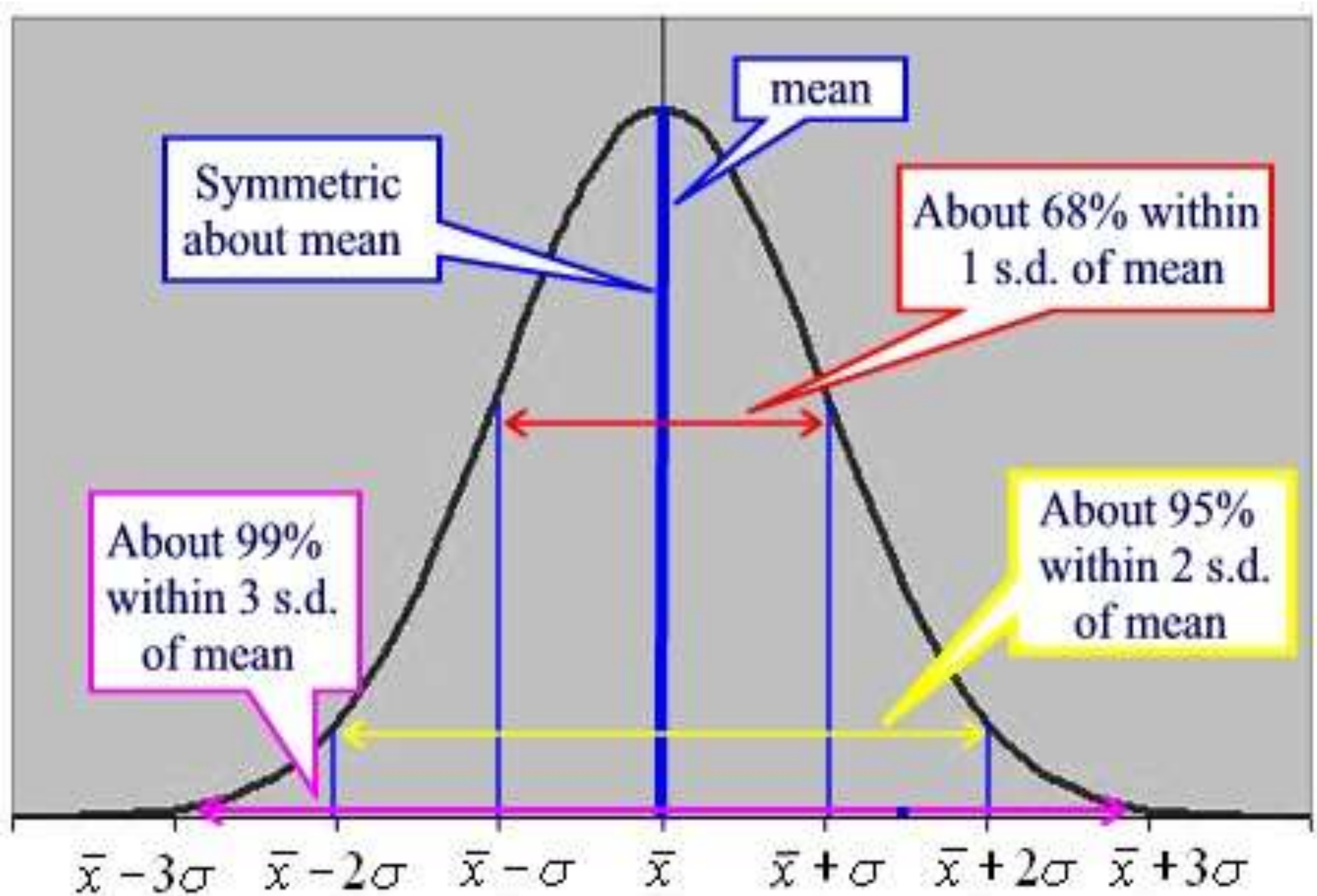
$= 0.9749$

- **Problem :**

  A population is deemed to have a normal distribution of diameters defined by the estimated mean of 50 cm with a standard deviation (S) of 5 cm. Expected diameter distribution for a population of 900 stems per hectare ?

- **Solution:-**

CM		**Probability**	**N, stems ha^{-1}**
<40	(d-2s)	0.0228	21
40-45	(d-2s) to (d-1s)	0.1359	122
45-**50**	(d-1s) to (d)	0.3413	307
50-55	(d) to (d+1s)	0.3413	307
55-60	(d+1s) to (d+2s)	0.1359	122
>60	(<d+2s)	0.0228	21
		Total	900


mean
Symmetric about mean
About 68% within 1 s.d. of mean
About 95% within 2 s.d. of mean
About 99% within 3 s.d. of mean
$\bar{x}-3\sigma$
$\bar{x}-2\sigma$
$\bar{x}-\sigma$
$\bar{x}$
$\bar{x}+\sigma$
$\bar{x}+2\sigma$
$\bar{x}+3\sigma$

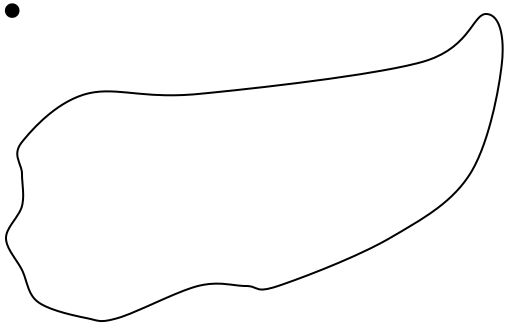
Simple Random Sampling

- Every possible combination of n units should have an equal chance of being selected.
- Selection of one units does not effect selection of another unit.

How to do ?

- Assign every unit a unique #
- Draw lots or generate random #
- Two cases possible
  - Sample without replacement
  - Sample with replacement.

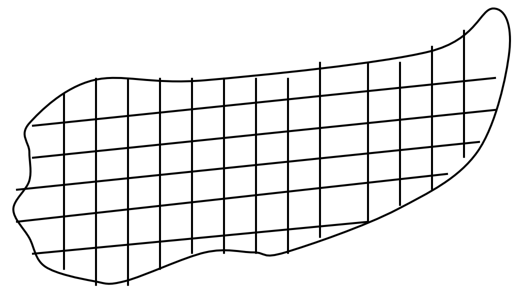
- **Practical example:**



250 acre forest

- **Object:** get volume/ acre of trees in dia more than 5” dbh over bark

- Sample size = 0.25 acre



a) Make 1000 equal div. on map

b) Assign no. 1 to 999 to each plot .

000 - corresponds to 1000

c) Draw lot, or generate random no. Measure the selected plot for required value (sample without replacement)

d) Now it becomes a population with no. of units in population = **N = 1000**

e) If 25 quarter acre plots are taken for sampling at random

- Each value of one plot is one unit,
- After selecting these 25 units; the sample size is now **n = 25.**
- We can get the standard error for simple random sampling

- In forestry, Population parameter are not known
  - Hence it is not possible to know true value of sampling error in forest inventory
  - Alternatively, sample data are used to obtain a measure of sampling error which must fulfill the condition of consistency

- Since the estimate of population parameter is based on sample statistics – it can’t be a single figure but a range
  - ➢ Forest inventory estimates are expressed in terms of a range with an associated probability

Range : - within which true value is expected to lie at a given probability

- known as **“Confidence Interval”**

- values which define limit of this interval are called **“Confidence Limits”**

For Large Sample (n > 30):

Generally it is true that most of forest parameter follow **Normal Distribution**.

i. Confidence Interval for 95% prob. is :

= **Sample mean ± 1.96 (Standard error of estimate)**

ii. Confidence Interval for 98% prob. is :

= **Sample mean ± 2.33 (Standard error of estimate)**

iii. Confidence Interval for 99% prob. is :

= **Sample mean ± 2.58 (Standard error of estimate)**

$$Z = \frac{(X - \bar{x})}{s_y / \sqrt{n}} = \frac{E}{s_y / \sqrt{n}}$$

Or, $s_y / \sqrt{n} = E / Z$

$$\boxed{\mathbf{n = (s_y . Z / E)^2}}$$

coefficient of variation, $CV = (s_y / \bar{x}) * 100$

Problem

Q : The mean girth of a random sample of 60 trees was found to be 145 with SD of 45. Construct 95% confidence interval for true mean. Assume sample size large enough to be normal population.

What sample size required for mean to be within 5 units of the true mean ?

Sol 1: n = 60, mean girth , $g_\gamma = 145$; SD = 45

$$CI = g_\gamma \pm 1.96\,(45 / \sqrt{60})$$

$$= 145 \pm 15$$

$$= 130 \text{ and } 160$$

Sol 2: E = 5;

$$\mathbf{n = (s_y . Z / E)^2}$$

$$\mathbf{= (45 * 1.96 / 5)^2}$$

= 311 samples

Biometry Exercise

PLOT NUMBER	LEAST VOLUME (V)	$\tilde{V}$ - V	($\tilde{V}$ - V)^2
PLOT# 1	24.72	-0.96	0.92
PLOT# 2	21.65	2.11	4.46
PLOT# 3	27.25	-3.49	12.17
PLOT# 4	43.92	-20.16	406.39
PLOT# 5	40.92	-17.16	294.43
PLOT# 6	31.69	-7.93	62.87
PLOT# 7	14.82	8.94	79.94
PLOT# 8	14.37	9.39	88.19
PLOT# 9	19.85	3.91	15.30
PLOT# 10	26.15	-2.39	5.71
PLOT# 11	21.18	2.58	6.66
PLOT# 12	9.58	14.18	201.10
PLOT# 13	19.5	4.26	18.16
PLOT# 14	17.26	6.50	42.26
PLOT# 15	17.26	6.50	42.26

PLOT# 16	19.37	4.39	19.28
PLOT# 17	16.58	7.18	51.57
PLOT# 18	16.44	7.32	53.60
PLOT# 19	18.9	4.86	23.63
PLOT# 20	25.49	-1.73	2.99
PLOT# 21	35.31	-11.55	133.38
PLOT# 22	27.19	-3.43	11.76
PLOT# 23	28.74	-4.98	24.79
PLOT# 24	33.19	-9.43	88.91
PLOT# 25	16.01	7.75	60.08
PLOT# 26	18.3	5.46	29.82
PLOT# 27	43.27	-19.51	380.60

PLOT# 28(Gr 12)	21.72	2.05	4.19
PLOT# 29(Gr 12)	13.85	9.92	98.32
PLOT# 30(Gr 12)	12.06	11.70	136.91
PLOT# 31(Gr 13)	17.13	6.63	43.99
PLOT# 32(Gr 13)	20.17	3.59	12.87
PLOT# 33(Gr 13)	24.55	-0.78	0.62
PLOT# 34	19.85	3.91	15.30
PLOT# 35	25.18	-1.42	2.01
PLOT# 36	22.24	1.52	2.31
PLOT# 37	17.71	6.05	36.61
PLOT# 38	42.32	-18.56	344.44
PLOT# 39	37.07	-13.31	177.13
PLOT# 40	27.69	-3.93	15.44
TOTAL	**950.44**		3051.36

MEAN ($\tilde{V}$)	23.76	
STANDARD DEVIATION	8.845	
ERROR %	5.00	6.00
NO OF PLOTS	213	148

For Small Sample:

- Sample distribution not normal
- But fundamental assumption that the parent population follows normal distribution
- For such distributions **student's 't'** can be calculated for C.I.

- In order to estimate **'t'** , two parameter are needed

 1. degrees of freedom
 2. degree of certainty (probability level)

Then,

$$C.I. = \text{Estimate} \pm t \ .(S.E.)$$

$\mathbf{C.I. = x \pm t_{0.05} \ . \ s_x}$ (for 95% confidence interval)

$\mathbf{C.I. = x \pm t_{0.01} \ . \ s_x}$ (for 99% confidence interval)

Eg:

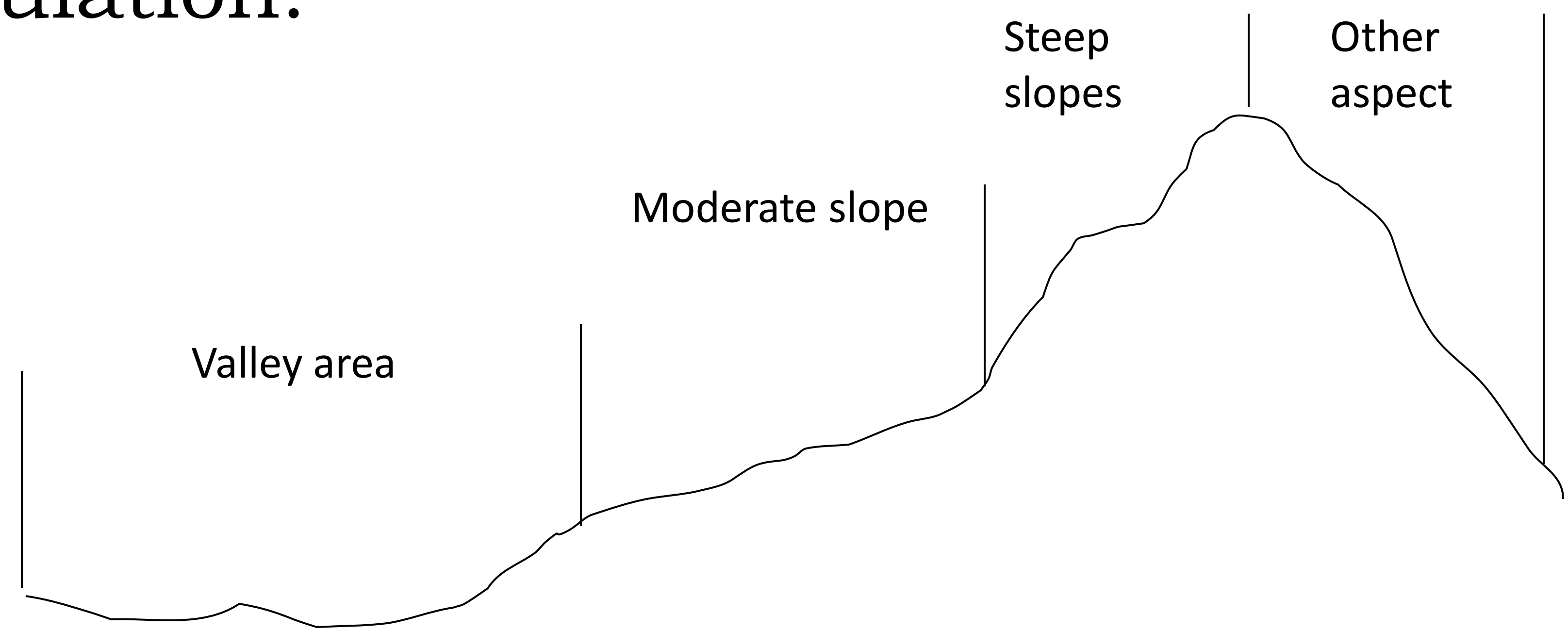
If volume measured in 25 plots of the previous example, we can get

1. Standard error of mean volume
2. Read ‘t’ against 24 df and 95 %
3. Then confidence interval per acre area basis can be calculated
4. C.I. = v + t (Standard error of mean volume)

- **Stratified Random Sampling:**

  - In this groups are made based on similarity of characteristics of units.

  - Variability within group should be less than the variability through out the population.



Q. Total area of a plantation is 37 ha. Measurements of volumes have been taken in 12 sample plots of 0.02 ha area each. Data gathered is as follows:

Plot	1	2	3	4	5	6	7	8	9	10	11	12
Vol.	4.7	4.4	3.8	5.1	4	4.6	4	4.6	4.8	6.1	5.6	4.3

(in cum)

Find out confidence limit for total volume with 95% probability. Assume that population and sample distribution is normal.