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

3PBC

Policy(objects)

Planning(methods)

Programming(proce., odrer, time table)

Budgeting

Control

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

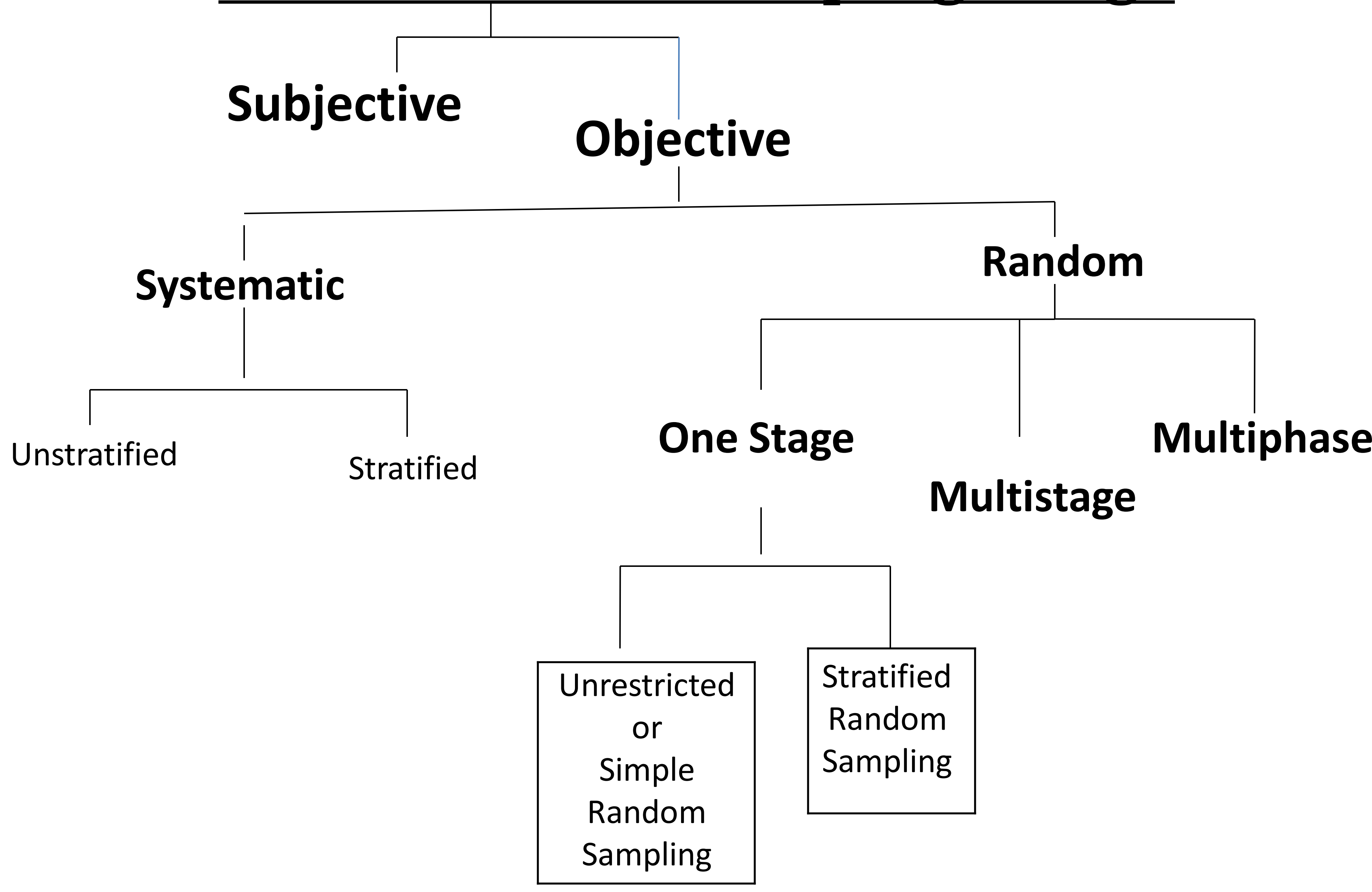
Choice of kind of enumeration

- 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

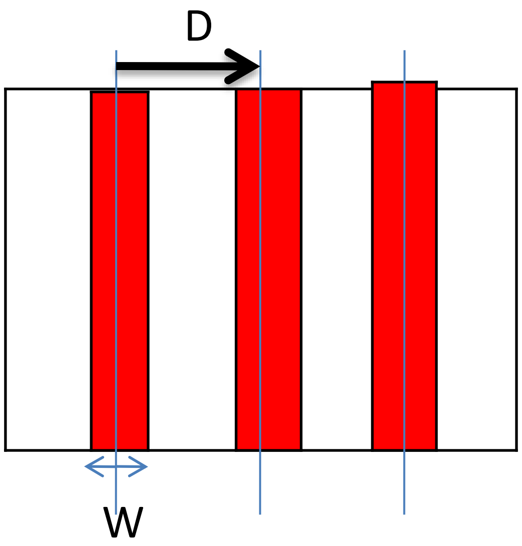
2. Shape :

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

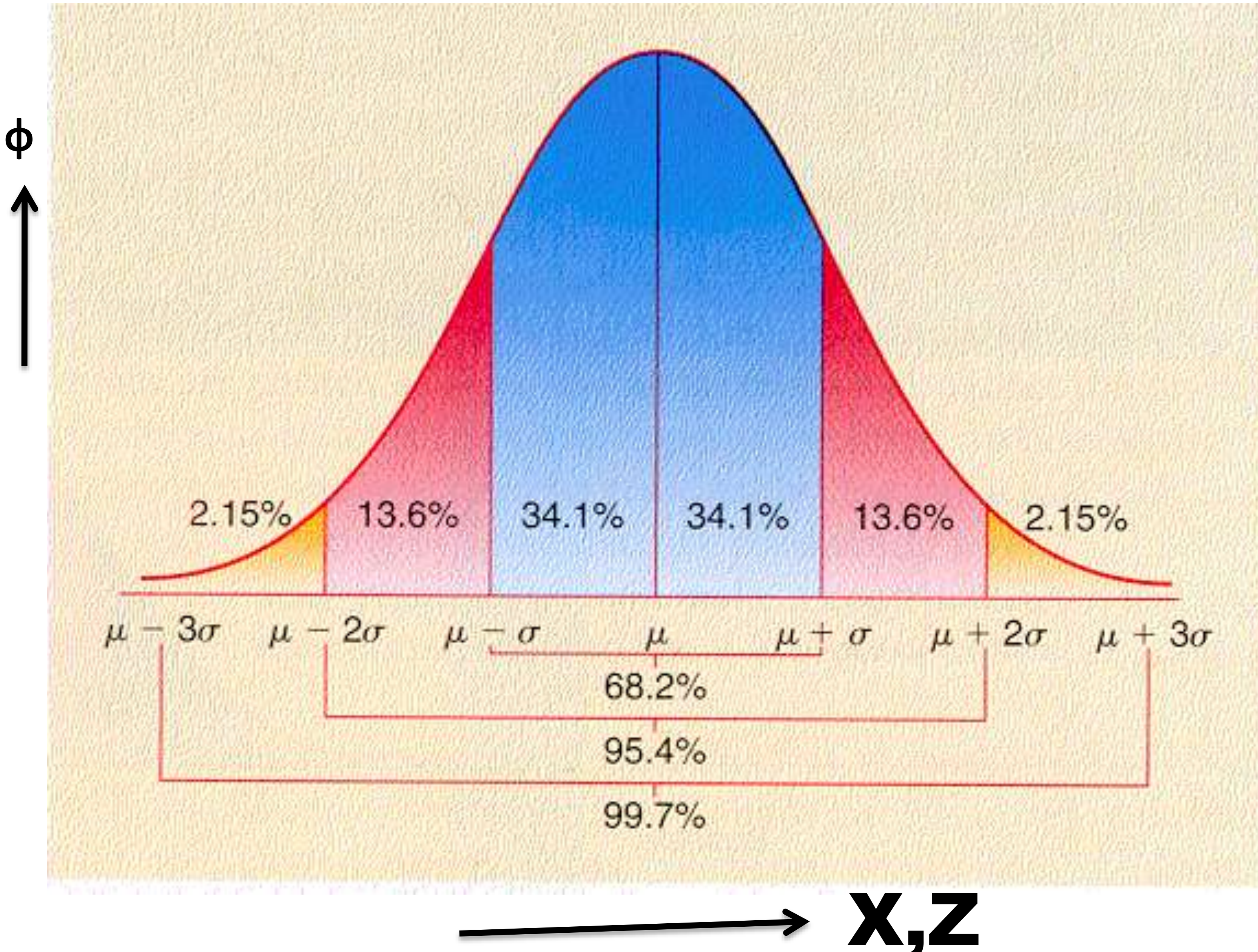
$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

We can transform the original variate to

Z= (x - μ) / σ

When x= μ $\rightarrow$ 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%
μ − 3σ
μ − 2σ
μ − σ
μ
μ + σ
μ + 2σ
μ + 3σ
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)

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

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

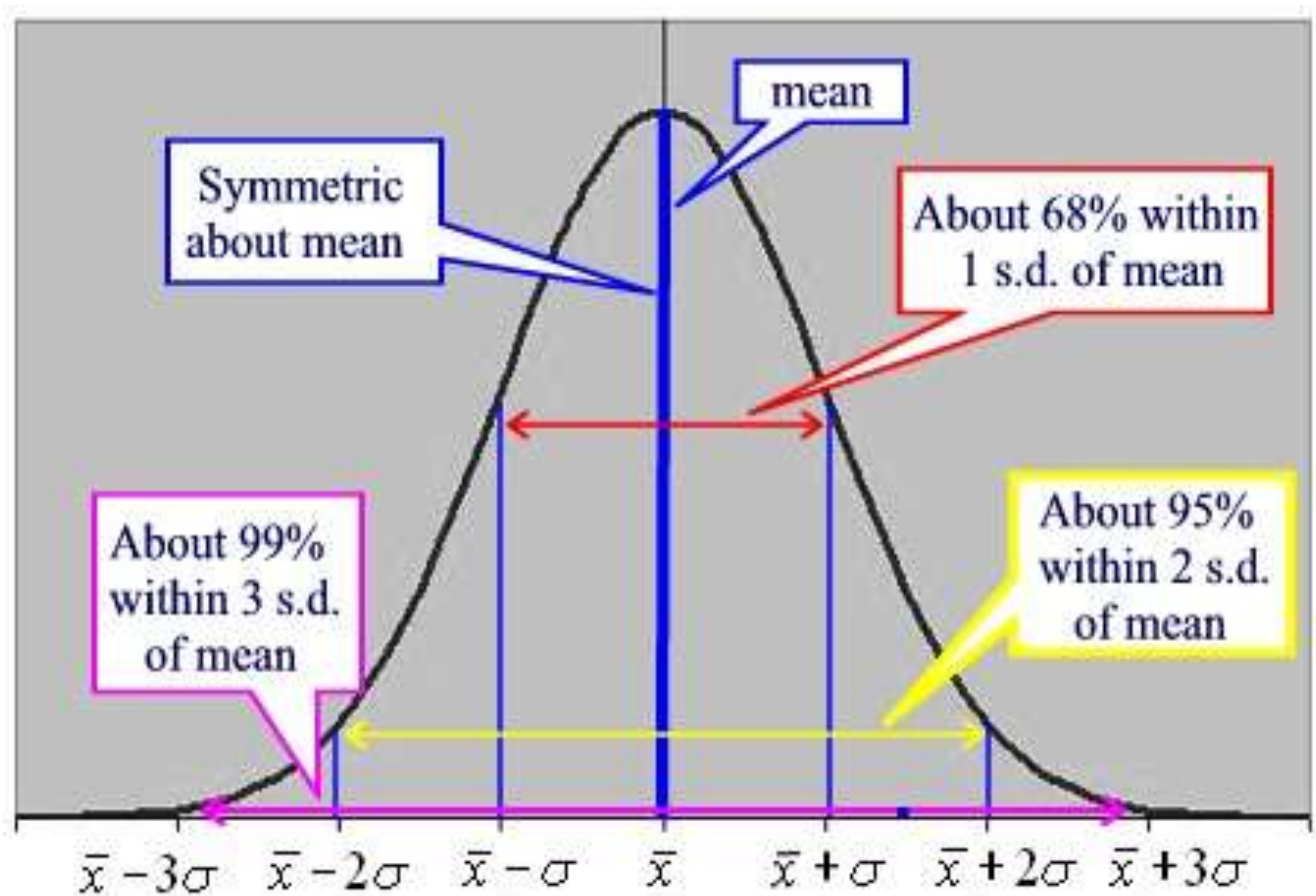
$= 0.9749$

- **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
$\bar{x}-3\sigma$
$\bar{x}-2\sigma$
$\bar{x}-\sigma$
$\bar{x}$
$\bar{x}+\sigma$
$\bar{x}+2\sigma$
$\bar{x}+3\sigma$

Method :

- If probability is given, then finding out value of variable ?
  - Probability is ‘P’, find ‘ X ‘ ?
  - First, find ‘Z’ value of ‘P’ from table
  - Calculate ‘X’ from , $Z = (X - \mu) / \sigma$

$$X = \sigma . Z + \mu$$

Q : If $\mu = 100$ and $\sigma = 15$;

what ‘ X’ falls at the probability 95% ?

Sol : first, Z value at P = 0.95 is 1.64 (from table)

$$X = \sigma \, . \, Z + \mu$$

$$X = (15 * 1.64) + 100 = 125$$

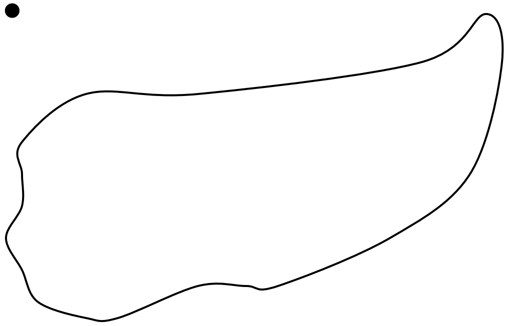
Simple Random Sampling

- 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 ?

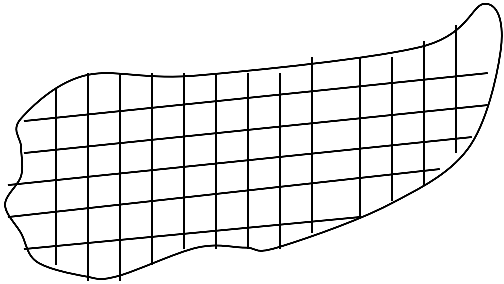
- Assign every unit a unique #
- Draw lots or generate random #
- Two cases possible
  - Sample without replacement
  - Sample with replacement.

- **Practical example:**



- **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

Sample theory

- Distribution of sample mean is "Normal distribution" i.e.

$$Z_i = (X_i - \mu_x) / \sigma_x$$

Where, σ_x = Standard deviation of sample mean or std error

$$= \sigma / \sqrt{n},$$

σ = population std deviation;

Finally, our aim is , sample mean = population mean

i.e. $\mu_x = \mu$

Hence ,

$$Z = \frac{(X - \mu)}{\sigma/\sqrt{n}}$$

$$\sigma_x = \sigma/\sqrt{n}$$

- As 'n' increases,
  - Variability among sample mean decreases

Q: Population mean, $\mu = 500$, $\sigma = 10$

What is the probability that out of 5 sample, all measurments will be between 490 & 510 ?

Sol : $Z_1 = \dfrac{(490-500)}{10/\sqrt{5}} = -2.24$; $P_1(-2.24) = 0.01255$

$Z_2 = \dfrac{(510-500)}{10/\sqrt{5}} = 2.24$; $P_2(2.24) = 0.98745$

$P(490 <= X <= 510) = 0.98745 - 0.01255 =$ **0.9749**

Sampling Errors

- Occur due to enumeration in samples and result applied to population
- 'Error of estimate' is :
  - Difference between 'estimate' and the ' population parameter (true value)'

$$E = (M - Y)$$

Where, E = error of estimate,

M = population mean

Y = sample mean

$$Z = \frac{(X - \mu)}{\sigma/\sqrt{n}} = \frac{E}{\sigma/\sqrt{n}}$$

$$n = \left[\frac{\sigma . Z}{E} \right]^2$$

Q: The SD of a population is 2.70 cms. Find probability that in a sample size of 66 the sample mean will differ from the population mean by 0.75 or more.

Q: The SD of a population is 2.70 cms. Find the sample size if it is 95% probable that sample mean differs from the population mean by 0.75 or less.

1.

$$Z = \frac{E}{\sigma/\sqrt{n}} = \frac{0.75}{2.70/\sqrt{66}}$$

$$= 2.24$$

P (2.24) = 0.98745

Probability that sample mean will differ from the population mean by 0.75 or more = 1 – 0.98745

= 0.01255

2.

$$n = \left[\frac{\sigma \,.\, Z}{E} \right]^2$$

$$= \left[\frac{2.70 * 1.96}{0.75} \right]^2$$

$$= 49.78 \quad \text{or} \quad 50$$

- 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_γ = 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)	Ṽ - V	(Ṽ - 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,

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

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

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

Eg:

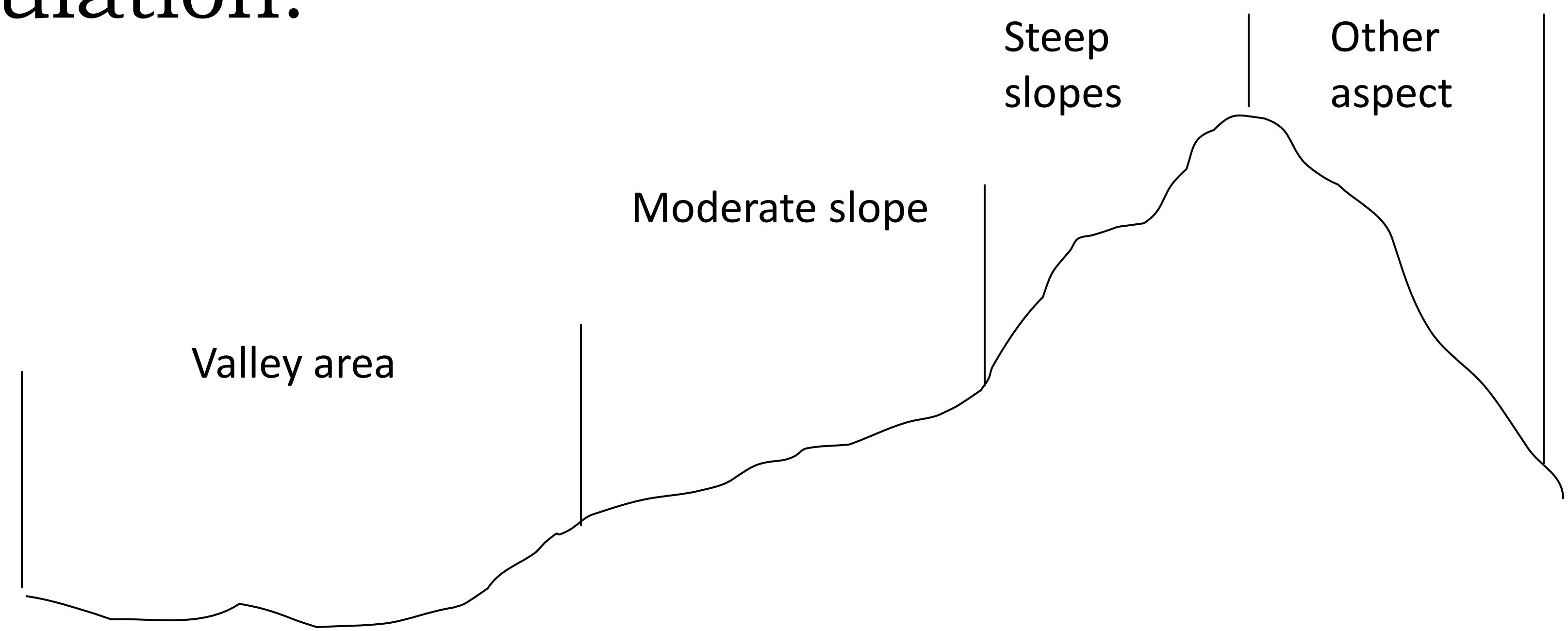
If volume measured in 25 plots of the previous example, we can get

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.