HAWASSA UNIVERSITY

WONDO GENET COLLEGE OF FORESTRY AND NATURAL RESOURCES

TRAINING MANUAL ON:

FOREST INVENTORY AND MANAGEMENT IN THE CONTEXT OF SFM AND REDD+

Compiled by:

Zerihun Asrat (MSc) and Yemiru Tesfaye (PhD)

November, 2013

Wondo Genet, Ethiopia

Table of Contents

List of Tables

List of Figures

SECTION-I: FOREST INVENTORY

1. Introduction

Protection and rational utilization of natural resources become more and more important in order to meet the increasing demand for raw wood material and agricultural crops. Among the resources, forests are important not only as a source of wood but as the means of protecting the hills thereby regulating stream flow, and reducing the rate of soil erosion, among many others. Maximum advantages and benefits from forests can only be secured provided that the existing forests are properly managed. Sound forest management depends on the quantity and quality of information available on the forest. Basic data and information is required if a renewable natural resource such as forest is to be managed in a reasonable and sustainable manner. This information is obtained from forest inventories. Forest inventory is described/defined in different forms by different authors, but essentially with more or less the same meaning.

Forest inventory: is the activity of data collection that helps generating the required information base on the forest resource within an area of interest. Forest inventory: is a tool that provides the information about size and shape of the area as well as qualitative and/or quantitative information of the growing stock.

Forest inventory: is the tabulated, reliable and satisfactory tree information, related to the required units of assessment in hierarchical order. It is an attempt to describe quantity, quality, and diameter distribution of forest trees and many characteristics of land upon which trees are growing.

Forest inventory information is obtained either from measurements of individual trees or stand. The information may be obtained from measurements taken from ground or on remote sensed imagery (aerial photographs, satellite imagery, etc.). Forest inventory information obtained from the entire forest is called complete or 100% inventory. In contrast, when the measurements are taken from a representative sample of the forest it is a sampling inventory.

The information requirements regarding the forest resource are as manifold as are the interests in forest as an ecosystem. Interested parties are above all decision makers and researchers in forestry and related fields. Forest owners, forest managers and forest politicians are those who demand information about the forest resource, but also regional planners, the wood industry, conservation biologists, tourism people, etc. When the group of actually and potentially interested parties can clearly be identified, it is straight forward to plan an inventory in a flexible manner to serve many different potentially interested experts without yet knowing all of them exactly.

This training material is prepared to give insight into forest inventory (forest resource assessment) from planning and implementation point of view. Hence it shall help everyone to understand the principles of forest inventories. It is believed that at the end of the training participants should be able to plan a forest inventory in a methodologically sound manner and also according to statistical principles. They should know also how to write a good inventory reports; how to critically read inventory reports of others.

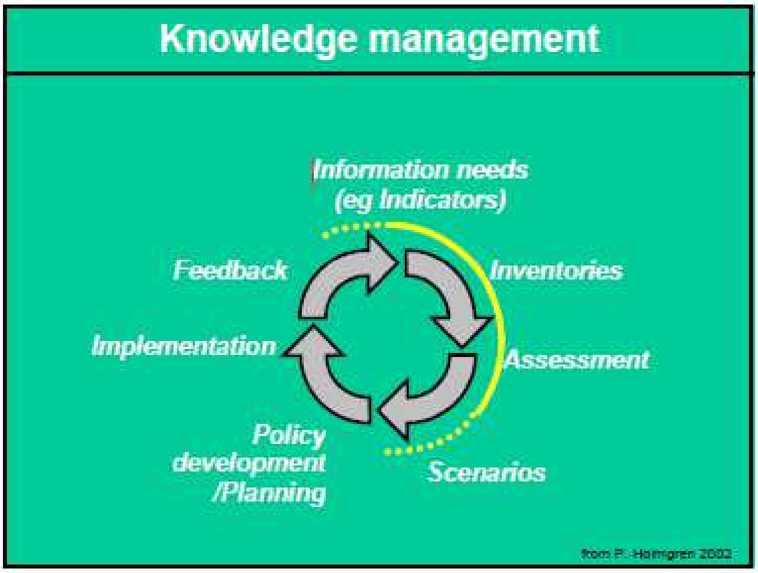


Figure 1: knowledge management in forestry

2. Brief history of forest inventory

The first inventories were carried out in Europe in the 14th and 15th centuries. The rise of forest inventory was due to intensive mining activities which in the vicinity of the mines depleted the forest resources severely. It does actually not make wonder that it was a mining engineer (Carl von Carlowitz) who did also manage the forest resources around his mines was the first to describe in 1712 the principles of sustainability which is now days used in many context also outside forestry. The early inventories are crude assessment and not to compare with today's inventory exercises.

In 19th century, forest inventories were an established component of forest planning. Data gatherings were based mainly on visual estimation. During this period statistical sampling was not available yet. It was only developed around 1900. The first large area inventories took place in Sweden around 1840 on provincial level and the first large area forest inventory in the tropics was carried out in Burma around 1860 (by Dietrich Brandis). Beginning in the 1910s national forest inventories were carried out in the Nordic countries Norway, Sweden and Finland. In these times the forest inventories gave considerable inputs to the development of statistical sampling theory. Changes and progresses in forest inventory were largely fostered by the developments in the fields of statistics (sampling and modeling), remote sensing (air photos and satellite images), computers, measurement devices and also road infrastructure (increased accessibility to remote areas) and means of transportation which facilitated reaching field plots in the forest.

2.1. Geographical levels of forest inventory

Forest inventories at local level: Forest information is required on different geographical levels. For forest stands, forest inventories are carried out to plan forest operations or to prepare selling standing timber. For forest enterprises, forest inventories are periodically carried out to prepare forest management plans which define silvicultural treatments such as thinning, harvest, etc. for a planning period.

Forest inventories at national level: General estimates of all elements are normally recorded in such type of forest inventory. A complete picture of the forests of the nation including their potential without detailed analysis of any one area or characteristics is given.

It represents a response to support increasing demands for additional information on forest resource attributes; for policy, national & international reporting, and for reports on:

- Climate change

- Criteria and indicators of sustainable forest management
- Biodiversity and forest health
- Sustainability

Forest inventory at International level: FAO has carried out global forest assessments from the 1940s onwards. In the 1960s UNESCO expressed the urgent need for integrated resources assessments with the objective to promote the conservation of nature. UNCED 1992 made obvious that there is a great gap regarding natural resources information.

Types of forest inventory:

Three broad classes of forest inventories can be considered based on the depth of the investigation:

1. Reconnaissance inventory: this class of inventory is based upon an exploratory investigation of the forest population. The information derived is primarily intended for preliminary management decisions. The inventory data are summarized on a regional or total area basis.

2. Management inventory: this inventory represents a low intensity investigation of a large tract of forested area; for example, a forest reserve. The information produced is primarily intended for broad-based management decisions, allowable cut calculations and long range planning.

3. Operational inventory: an operational inventory is based upon an intensive investigation of a relatively small area. The information produced is primarily intended for use in short term or "operational" planning, e.g. related to the harvesting of timber volumes within local cutting compartments or logging units.

Costs of a forest inventory

Forest inventory is generally a costly undertaking, hence explicit planning and real need is a necessary. There are three main factors, which influence the cost of an inventory: Type of information required; Standard of accuracy; Size of area to be surveyed and the minimum size of unit area in the forest.

a) Type of information Required: General information on areas of the important forest types can be obtained relatively cheaply from aerial photographs. In contrast terrestrial forest inventory is very expensive particularly if various detailed information is sought. Hence, the intensity and quality of the selection of representative samples requires careful supervision.

b) Standards of Accuracy: The greater the degree of accuracy required, the greater the percentage of the forest that has to be sampled. The reduction of the standard error by half requires approximately four times as many samples.

c) Size of Area to be surveyed: The cost per unit area for aerial photography will be less the larger the zone photographed. If individual estimates to a prescribed degree of accuracy are required then it is cheaper to have large blocks of forest rather than small ones.

2.2. Planning a forest inventory

The main task of forest inventory is to collect information efficiently and present it in a form, which is readily understood. This requires, however, much thought and preparation, i.e., planning. Forest inventories like any other projects require planning. There must be an explicit information requirement that justifies the need for an inventory to be carried out. Make discussions with decision makers or others who request the information in order to make clear & illustrate options and limitations of a forest inventory.

A good forest inventory;

- Should be conform to the objectives
- Should provide adequate precision
- Methodologically sound & follow statistical sampling criteria
- Have comprehensive & transparent reporting & documentation
- Overall credibility

Procedure of planning a forest inventory

- Setting the foundations
    - Justification, funds, objectives, defining mandates, etc
- Inventory planning
    - Definition of technical objectives, development of inventory design, inventory protocol (Write the field manual, which gives a detailed information of the measurement procedure in the field; and design form sheets.), etc.
- Data collection

  - Remote sensing (selection of imagery – map products) and/or
  - Field data: organization, training, implementation, supervision, etc
- Data management & analysis
  - Database development, data entry, data analysis, database maintenance, etc
- Reporting

The following planning principles can be used as checklist

1) Objectives

The objectives of the inventory must be clear right at the beginning of the planning stage including the variables/parameters to be estimated (e.g. diameter, girth & heights). Furthermore the units of measurement, desired precision at a specified level of probability, the kind of recording forms and the style of presentation of the results must be worked out before the commencement of the inventory. The amount of time and cost involved need to be studied thoroughly in relation to the importance of the forest to be surveyed and its profitability, or whether it is cost efficient or not.

2) Standardization

Most inventories are undertaken as separate and distinct projects. As a result, little or no attempt has been done so far to ensure that the results are presented in such a way that they could either be combined or compared with results from other inventories. Some of the specifications, which could be standardized in order to facilitate easy comparison of forest inventory results, are:

a) Definition of terms and symbols

b) Forest type classification

c) Inventories to be designed to give an expression of sampling errors and its probability level

d) Use of the metric system and volume expressed in cubic meters under bark

e) Standardization of size classes and limits of merchantability

f) The concept of "accessibility" should be based on economic and not physical considerations. A better word would be "operability" based on costs and financial returns

3) Time and Funds

The size of the sample and the degree of precision of forest inventory task are governed by the time and fund available. In many cases an inventory design that gives the desired information with an acceptable limit of error for the lowest cost is chosen. Thus, make sure that there is sufficient resource to carry out the work (of a reasonable forest inventory).

4) Forest classification

The classification of a very large forest area into smaller sub-divisions enables the observer or the surveyor to have a better understanding of the forest. Furthermore, this sub- division allows more efficient sampling and maps can also be prepared showing the different forest and land types.

5) Sampling and plot designs

The information collected by an inventory is obtained either by observations and measurements in the field or aerial photographs or by a combination of both methods. In most cases the combined approach is used.

6) Maps

Before the commencement of the inventory work, maps must be adequately available.

7) Field measurement procedures

Organize logistics (transport, measurement devices), Make a time table for field work and for image interpretation.

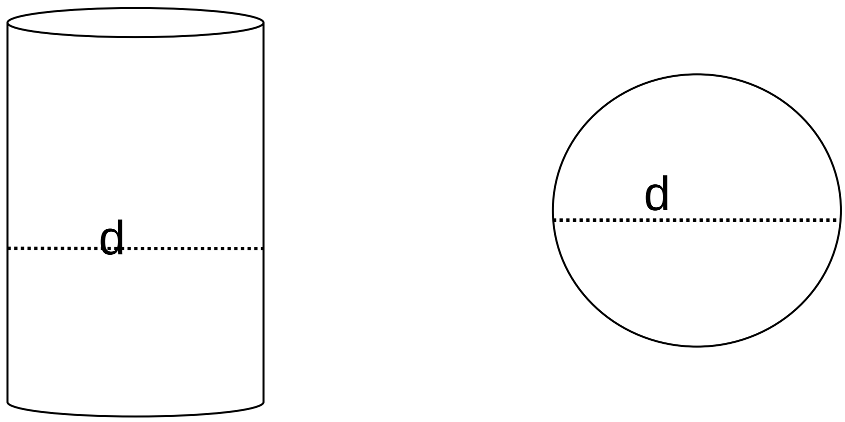
8) Calculation and compilation

Design a data base and make a “pseudo”-analysis with dummy data in order to be sure that you can analyze the data as you would like it.

3. Basics of mensuration (Tree variables measurement)

3.1. Diameter measurement of a single standing tree

Diameter of a stem is a length from the outside of the bole through the centre to the opposite side of it.



A. Longitudinal/side view B. Cross-sectional view

Figure 2: Different views of tree diameter

Usually diameter is measured with bark so that a reduction needs to be applied if only the wood is of interest.
Sometimes instead of diameter tree girth is measured. It is the circumference/perimeter of the stem.

$C = 2\pi r$ $C = \pi d$

Tree diameter and girth measurement are the most important tree variables because:

- They are in most cases easily and directly measured
- From the diameter the basal area (which is closely correlated to tree volume) is directly calculated
- The diameter distribution of a stand gives a good insight to the stands structure and potentially necessary silvicultural treatments

The diameter at breast height (dbh)
The standard position for diameter measurement at standing tree is at breast height. It is defined at 1.30 meter above ground in most countries, but there are some countries where diameter at breast height is measured at different heights.

Why dbh is preferred?
At breast height the instrument is easily handled (convenience and ease). Also on most trees the influence of buttress on the stem form is already much reduced at

breast height. However, irregularities of tree stems do sometimes prevent the measurement of diameter at breast height.

The followings are some of the cases:

Trees on slope: measure dbh at the standard height above the floor/ground on the uphill side of the tree.

Leaning tree: measure parallel to the lean on the lower side of the lean

Buttress tree: if the buttress height is more than one meter then measure dbh from the point where buttress ends, otherwise measure normally.

Abnormalities at breast height: swellings, knots, crooks, etc

Measure the dbh above or below the abnormalities and indicate the height at which diameter is measured. Sometimes measurement is done at equal distance above and below breast height and then dbh is estimated by taking the mean of the two readings.

Bifurcation: If a tree bifurcates above breast height then measure dbh as usual. But, if a tree bifurcates below breast height then measure dbh on each stem separately.

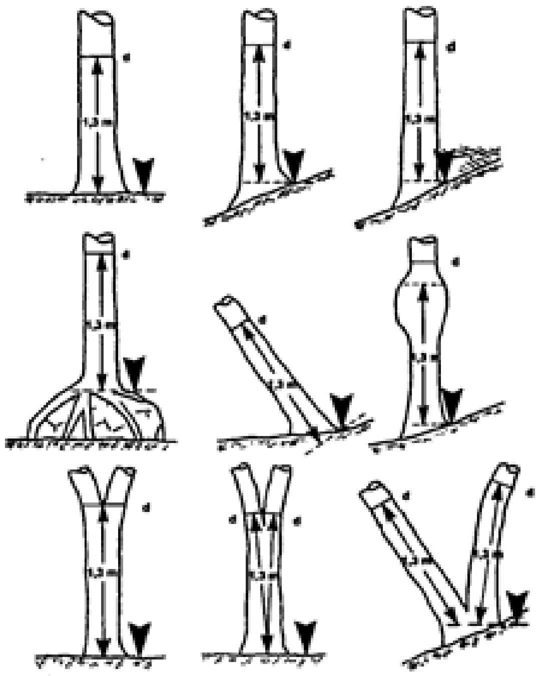


Figure 3: Positions of diameter measurement different conditions

Instruments used for measuring

Calipers and diameter tape are the most commonly used instruments. But also Biltmore stick can be used (very rare presently).

Caliper

Is the most efficient to measure dbh directly whenever there is direct access to the tree. It can be made of wood, metal or aluminum. It has two arms one fixed and a graduated bar/beam on which the second arm slides.

To measure with a caliper, hold it firmly and horizontally as well as perpendicular to stem axis at the same time. Usually two readings are taken perpendicular to each other rat breast height and then the average value will be recorded.

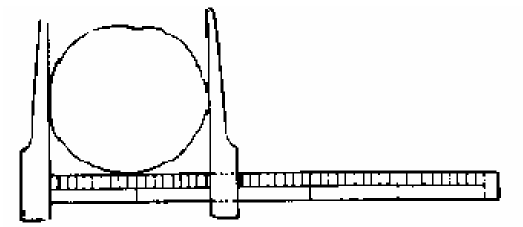


Figure 4: Tree diameter measurement with caliper

Diameter tape

There are diameter tapes from which the tree diameter can be directly read. Tree diameter can also be determined from circumference measurement which can be done by diameter tape or any tape since circular tree stem shape is assumed.

$$C = 2\pi r = \pi d; \quad d = C/\pi$$

Calipers Vs diameter tape

- Tapes are easy to carry than calipers (especially in dense forest)
- Measuring with caliper is faster than with tape.
- Bigger trees can be measured with tapes easily (calipers have an upper bound) tapes can be extended by joining them
- Tapes are good to maintain consistency in measuring diameter regularly.

Measuring upper stem diameter

Upper stem diameter of a tree is measured for instance to describe the shape of a stem (derive taper curve). It is measured at various heights. Upper stem diameters are most easily observed on felled trees; however there are situations in which upper stem diameter need to be measured on a standing tree. Upper stem diameter is measured either at a fixed point (X meter) or at relative height (X% of height).

Methods

1. Using Finn caliper (Finnish parabolic caliper)

- Used to measure diameter up to 7m
- Difficult to carry mostly beyond this height

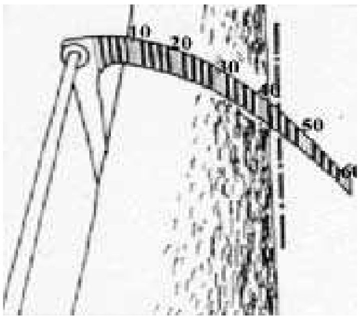
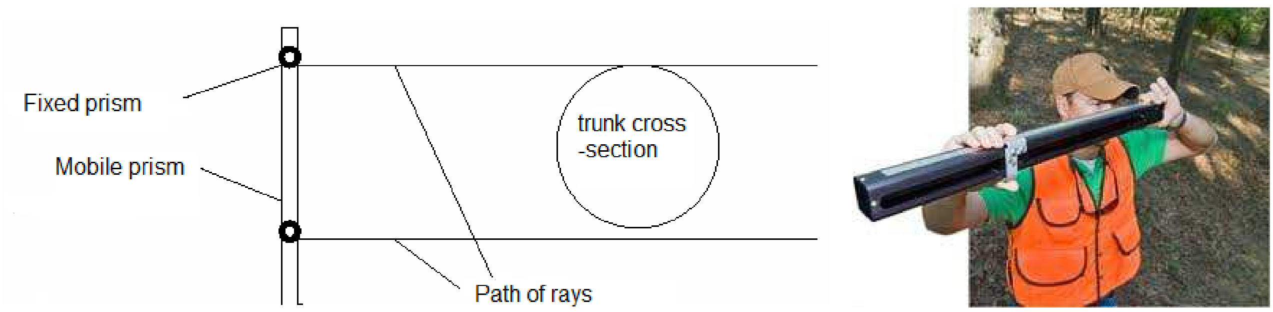


Figure 5: Upper stem diameter measurement with Finn Caliper

2. Optical caliper (parallel beams)

- Needs determination of height before or after diameter measurement
- Read diameter when the two images of the trunk coincides
- It is independent of distance measurement



A B

Figure 6: Upper stem diameter measurement with optical caliper

3. Measuring upper diameter with angle measurement technique

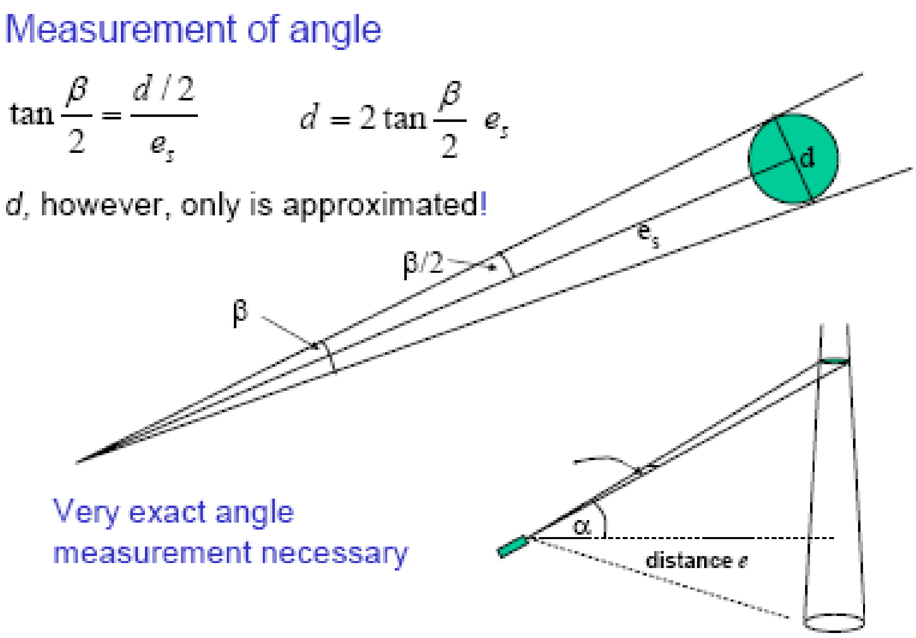


Figure 7: upper stem diameter measurement by angle measurement techniques

4. Measuring upper stem diameter with mirror relaskop

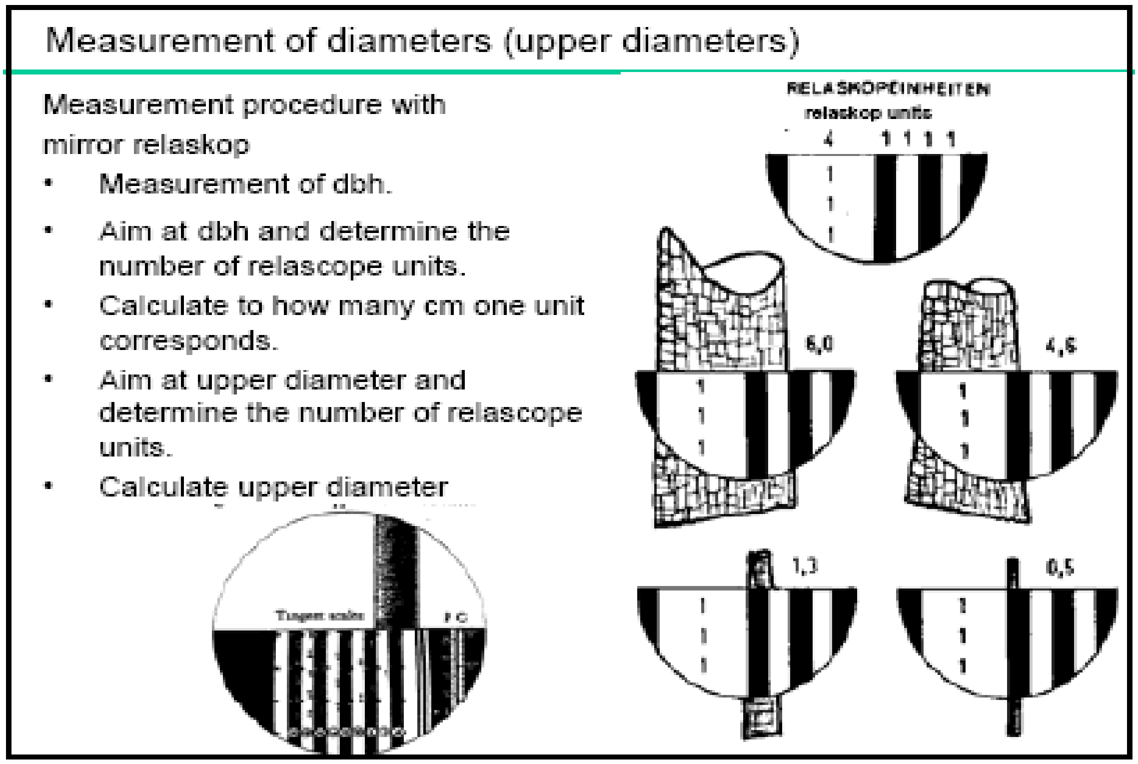


Figure 8: Upper stem diameter measurement using mirror relaskop

3.2. Tree cross-sectional area estimation

If the cross-section of a tree is determined using the diameter at breast height, then it is called basal area. It is denoted by "g".

g = (π d2)/4

Basal area is commonly expressed in square meter (m^2)

Importance of basal area measurement:

- The sum of the basal areas of all trees in crop is a useful measure of stocking.
- In a uniform plantation of a single species volume is closely related to basal area.

3.3. Tree Height Measurement

Why tree height is needed to be measured?
Height is a tree variable that is used to estimate or determine the volume of a tree. It (dominant height) also helps to deal with the issues of site classification.

Tree height Vs tree length
Tree height is defined to be the perpendicular distance between the ground level and the top of the tree. While, Tree length is the distance between the stem foot and the top along the stem

Types of tree height:

- *Total height*: the distance between the ground and top of the tree.
- *Bole height*: the distance between the ground and the crown point.
- *Merchantable height*: the distance between the ground and the terminal position of the last useable portion of the tree stem.
- *Stump height*: the distance between the ground and the position where a tree is cut.
- *Merchantable length*: is the distance between the top of the stump and the terminal position of the last useable portion of the tree stem.
- *Dominant height*: is the average height of 100 thickest trees per hectare.

3.3.1. Methods of tree height measurement

1. Direct method:

It involves climbing or using height measuring rods. It is rarely used and only for small trees.

2. Indirect method:

  2.1. Using geometric principle

  2.2. Using trigonometric principle

Method using geometric principle

A christen hypsometer or ruler of a certain length (30cm for example) and a pole of constant length/height used to estimate/measure tree height.

Technique:

- ❖ Place a pole of known length at upright position against the tree to be measured.
- ❖ Hold ruler (of known length) vertically and parallel to the tree to be measured.
- ❖ Find the sighting position by moving back and forth and/or right and left so that the top of the ruler exactly aligned with the tip of the tree and the bottom of the ruler with the base of the tree.
- ❖ Take ruler reading in line with the top of the pole. Then apply the following formula.

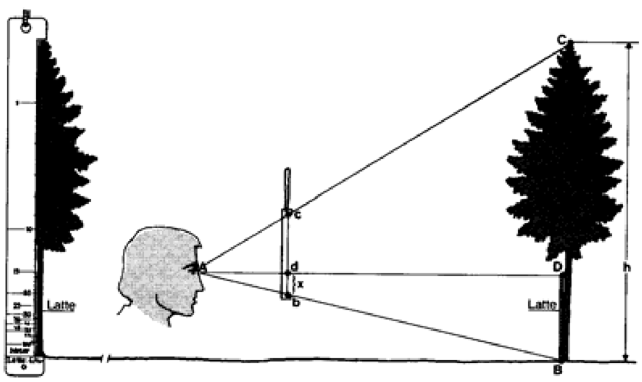


Figure 9: Tree height measurement technique by geometric principles

$\Delta ABC \cong \Delta Abc$

$(BD/BC) \cong (bd/bc)$; $(bc/BC) = (bd/BD)$

$$\text{Tree height (BC)} = \frac{\text{Known ruler length (bc) X Known length of pole (BD)}}{\text{Ruler reading on the pole (bd)}}$$

Advantages:

+ no distance measurement is required

+ height reading is not influenced by slope

Drawbacks:

- In dense forest it is difficult to find suitable point of observation

- Only with a steady hand can serious misreading be avoided.

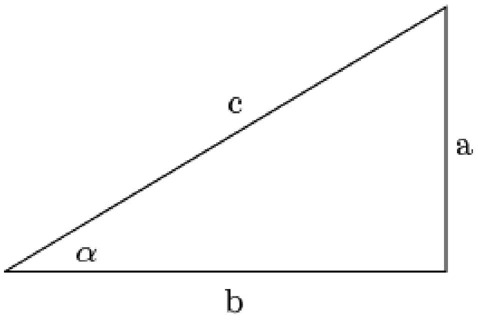
Methods employing trigonometric principles

The followings are some of the instruments used to measure tree height based on trigonometric principles.

1. Sunto hypsometer
2. Silva hypsometer
3. Haga altimeter
4. Blume-leiss
5. *Sunto clinometers: measure inclination angle in degree or percent*

General steps (for the first 4 instruments mentioned above)

- ❑ Stand at a fixed horizontal distance from the base of the tree (usually 10, 15, 20, 25 meters, and so on)
- ❑ Sight at the top of the tree and read the value 'A' (top reading)
- ❑ Again sight at the bottom of the tree and read the value 'B' (bottom reading)
- ❑ Then the total height of the tree is top reading 'A' minus bottom reading 'B'
- ❑ Bottom reading +ve or –ve (above and below eye level)



Sin α = opposite / hypotenuse; (a/c)

Cos α = adjacent / hypotenuse; (b/c)

Tan α = opposite / adjacent; (a/b)

Case 1: If the observer is on a flat terrain

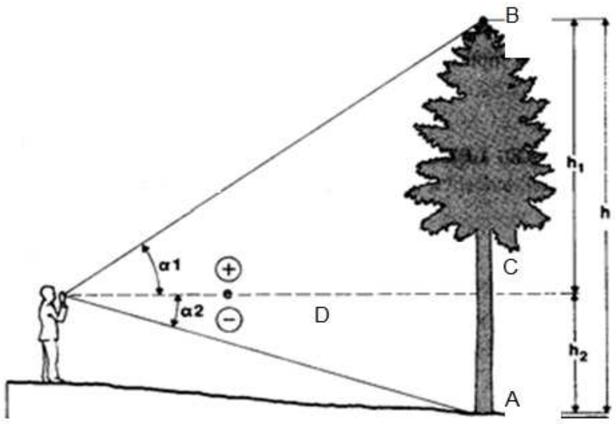


Figure 10: Tree height measurement on a flat terrain.

$\tan \alpha 1 = BC / D$

$BC = \tan \alpha 1 \cdot D$

$\tan \alpha 2 = AC / D$

$AC = \tan \alpha 2 \cdot D$

AB (height) = BC + AC

$AB = \tan \alpha 1 \cdot D + \tan \alpha 2 \cdot D$

$AB = D (\tan \alpha 1 + \tan \alpha 2)$

Case 2: upslope

AB = BC - AC

AB = tan α1 . D - tan α2 . D

AB = D (tan α1 - tan α2)

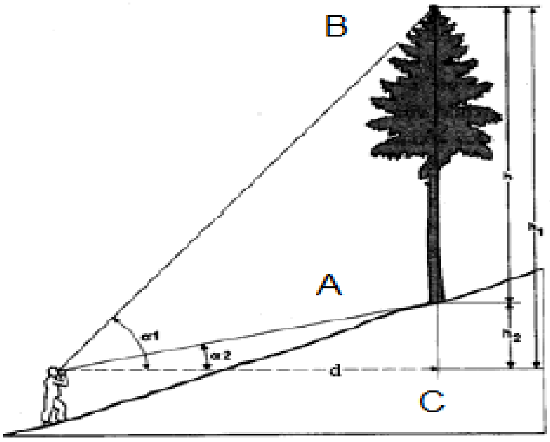


Figure 11: Tree height measurement on uphill terrain

Case 3: down slope,

When the tree base is below the eye level of the observer

AB = AC + BC

AB = tan α1 . D + tan α2 . D

AB = D (tan α1 + tan α2)

Clinometer method

- It follows the same principles as above, but in this case we measure/read the inclination angle and then calculate height after knowing the horizontal distance between the observer and the tree.

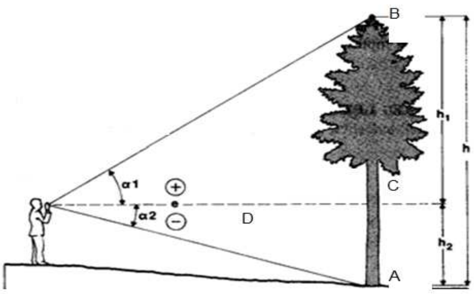


Figure 12: Tree height measurement using clinometers

- If measured in percent:

  $$Ht = \frac{(TR - BR)}{100} \times D$$

- Or if measured in degree:

  $H = D (\tan \alpha 1 \; +/- \; \tan \alpha 2)$

3.3.2. Possible sources of error in height measurement

1. Error from failure to correctly identify the top of the tree

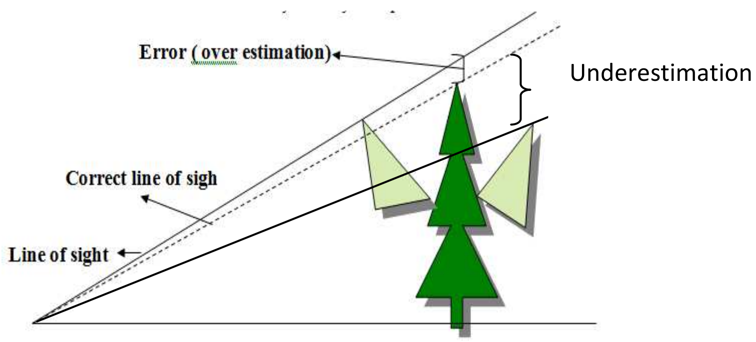


Figure 13: Error during height measurement (failure to detect correct tree top)

2. Lean tree

- ❑ When the leaning is away from the observer then the value will be under estimation and the vice versa.

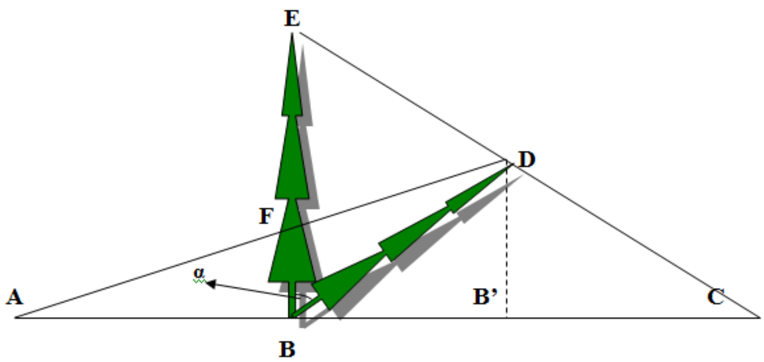


Figure 14: Error during measuring height of a leaning tree

The correct length/height BD can be calculated after the angle of the lean is determined

BD = DB' / cosα

DB' is equal to the average of EB and FB

3. If the distance is not correctly measured
   - ❑ If not reading is taken according to the scale
   - ❑ If slope distance is measured instead of horizontal distance

Other important tree variables to be measured include:

- Bark thickness
- Crown attributes
- Form factor
- Etc

3.4. Forest measurement

While thinking of forest crop/stand measurement there are some central questions to be dealt with:

- How many samples?
- How to select the samples?
- How to take what observations?
- How to calculate the estimations?

Thus, there are three basic design elements, which are actually dependent on each other, to answer the questions:

- Estimation design;
- Response/plot design &
- Sampling design.

Estimation design

It explains and defines how the estimations are calculated. There are two types of estimations:

1. Estimations of the variable(s) of interest (= point estimates); and
2. Estimations of the precision of the point estimates (interval estimates)

- *Example:*
  - Volume = 200 m^3/ha ± 15%
  - 200 m^3/ha ± 30 m3/ha

Estimator is the calculation algorithm (formula) that eventually delivers the estimation.

Estimator   Estimation

Example: $s_{\bar{y}} = \sqrt{\hat{\mathrm{var}}(\bar{y})} = \sqrt{\frac{s^2}{n}} = 0.4982$

The followings are some of the estimators that are frequently used or applied in forest mensuration and inventory.

Mean

i) The simple arithmetic mean

This is the most commonly used measure of location

Sample mean = sum of the observations / number of observations

$$\bar{x} = \frac{x_1 + x_2 + \text{-----} + x_n}{n}$$

Where: x1…. Xn = observations
n = total observations
x bar = mean

ii) Weighted arithmetic mean

If a forester selects randomly two trees from a stand for height measurement and the estimated heights are 20m and 25m, the mean height would be (20 + 25) /2 = 22.5m

Nevertheless if the same forester selects five trees and the estimated heights are 20m, 20m, 20m, and 30m then the mean height is (4x20+ 1x30) / 5 = 110 / 5 = 22m

This is called a ***weighted mean*** because it "gives weight" to the fact that there are 4 of 20 and 1 of 30. In forestry we frequently use weighted means and a very good example is Lorey's mean height or weighted crop mean height. You will see from the above example given that the word
"weighting" is synonymous with frequency; We can also deal with classified or grouped data in a similar fashion. All we have to remember is to use the mid – point (or class mark) of the class when multiplying by the frequency.

iii) Geometric mean

When a series of numbers are multiplied or divided by a constant number we get a geometric progression. For example, starting from 1 and multiplying progressively by 2 gives the geometric progression 1, 2, 4, 8, 16, 32, and so on. The point of particular interest to us is how we find the mean value in a geometric progression. This is of importance when we construct volume tables using logarithmic values. Let us take a simple example to explain the basic principles. In the geometric series 2, 4, 8, 16 and 32 the most meaningful average is the value that lie at the midpoint of the series, in this case, 8. The arithmetic mean of this series is 12.4, which tends to be unduly biased towards the largest test numbers in the series.

When the above series of numbers are plotted against time, we will see that the plotted line is a curve. But if we plot the same data on a logarithmic scale, the curve becomes a straight line. Now, because it is a straight line, the arithmetic mean of the logarithmic values will be a truly representative average for this data log2 = 0.3010

log4 = 0.6021

log8 = 0.9031

log16 = 1.2041

log32 = 1.5051

Total = 4.5154

The arithmetic mean of these logarithmic values is 4. 5154 ÷5 = 0.9031 and the antilogarithm of 0.9031 is 8 which is precisely the figure which we thought to be the most meaningful average value of the series. This average is called the geometric mean. In general terms we can calculate it as follows:

$$GM = \sqrt[n]{X_1 * X_2 \ldots\ldots\ldots X_n}$$

Or $= \text{Antilog}\left(\frac{\log X1 + \log X2 + \log X3 \ldots\ldots + \log Xn}{n}\right)$

iv) Quadratic Mean

This is used principally for calculating mean diameters where "weight " is given to the fact that volume of a stem varies as the square of the diameter and not to the diameter itself.

$$Q.M. = \sqrt{\frac{x_1^2 + x_2^2 + x_3^2 + \ldots + x_n^2}{n}}$$

Range, standard deviation, coefficient of variation

Let us first consider three sets of tree heights (m) data taken from three small plots.

Sample 1: 19, 21, 17, 23, 18, 22, 24, mean = 20.6

Sample 2 : 27, 15, 24, 21, 18, 19, 20, mean = 20.6

Sample 3: 19, 16, 25, 31, 18, 14, 20, 22, mean = 20.6

Each of these samples has a mean equal to 20.6m. Nevertheless the dispersion of the observations in the three samples differs greatly. Dispersion refers to the way in which the observations are spread out on either side of the mean. In the first sample there is little variability (or variation) among the observations as they are all grouped within three units of the mean. In the second sample only one observation (21) is closer to the mean and some are as far away as six units. In the third sample only one observation (20) is closer to the mean and some are as far away as ten units.

If we describe each of these samples only by its arithmetic mean of 20.6 we are not able to convey the information about the degree of reliability that exists in each sample. Clearly it would be desirable if we had some single numerical measure that would indicate the dispersion of the data. Two of the commonly used measures of dispersion are the range and the standard deviation.

Range

This is the simplest measure of dispersion. The range equals the value of the largest sample observation minus the smallest sample observation.

Variance

Variance is also termed the mean squared deviation.

$$S_x{}^2 = \sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2 \Big/ n-1$$

Standard deviation

This is the unit of measurement used to measure the dispersion of individual observations about their arithmetic mean. In a normally distributed population approximately 2/3 (68 per cent) of the observation will be within ± one standard derivation of the mean; about 95 percent will be within 1.96 (approx. 2) standard directions and roughly 99 per cent within 2.58 standard derivations.

$$S = \sqrt{\sum_{i=1}^{n} \left(X_i - \overline{X}\right)^2 \Big/ n-1}$$

Coefficient of variation (CV)

The ratio of the standard deviation to the sample mean is known as the coefficient of variation.

$$CV\% = \frac{Sx}{\overline{X}} * 100$$

Where, Sx is standard deviation.

It is difficult to compare the variation that exists between two populations if the means are different. But if we calculate the coefficient of variations for two populations with different sized means we can compare the relative variability.

Standard error of the mean

When we calculate the standard deviation of the means of samples we call it the “standard error of the mean". Thus standard deviation is a measure of the variation of individual sample observations about the mean whereas the standard error is a measure of the variation among means calculated from different samples of these individuals.

For simple random sampling

$$s_{\overline{y}} = \sqrt{\hat{\text{var}}(\overline{y})} = \sqrt{\frac{s^2}{n}} = \frac{s}{\sqrt{n}}$$

or

$$S_x = \sqrt{\frac{s2}{n} * \left(\frac{N-n}{N}\right)}$$

The finite population correction factor (i.e. (N-n) / N) serves to reduce the standard error of the mean when relatively large samples are drawn without replacement from finite populations.

Confidence Limits

Suppose that the mean height of a sample of ten trees was 15.25 m. This mean height is an estimate of the true population mean. We do not know the population mean, but we hope that our sample estimate is close to the true figure. Perhaps it is likely that population mean lies in the interval from 13.8 to 16.9 meter. This interval is known as the confidence interval and the figures 13.8 and 16.9 are known as the confidence limits. Usually we express confidence limits with a certain level of probability (95%, 99%). It is important to note that the statement, "we are 95% confident that population mean lies in the interval 13.8 to 16.9, "does not mean that the probability that population mean lies in the interval 13.8 to 16.9 is 0.95.

When setting up confidence limits we use the standard error of the mean and multiply it by a value obtain from t – table. For simple random samples from normally distributed population, the confidence limits for the true but unknown population mean are computed by

Mean ± t * Standard error

Sampling Error per cent (E%)

It is a common practice to express the ratio of the confidence limits to the sample mean as a percentage.

$$E\% = \frac{S_{\bar{x}}t}{\bar{X}} * 100$$

In this way it shows the width of the confidence interval and as such lets you see just how precise is your estimate of the population mean. For estimation of timber in a uniform plantation a sampling error percent of ± 10% would be considered good whereas in natural forest where there would be greater variation an E% of ± 20% would be satisfactory.

Required sample size

If one defines the width of the confidence interval A = t $_{\alpha,v}$ S_y and the error probability α, then we can calculate the necessary sample size:

$$A = t_{\alpha,v}\, s_{\bar{y}}$$

$$A = t_{\alpha,v} \frac{s}{\sqrt{n}} \rightarrow n = \frac{t^2 s^2}{A^2}$$

Or alternatively,

$$n = \left(\frac{CV\% * t}{E\%} \right)^2$$

Where :

n	=	Number of sample plots
CV%	=	Coefficient of variation (%)
t	=	Student statistics
E%	=	Standard of precision required

Response design/plot design/observation design:

It defines what the "observation units" are and what is observed. Observations are taken on observation units. Basic types of observation units in forestry include:

- Individual objects: trees, stands, properties, etc
- Points (no dimension): area estimation with dot grids.
- Lines (one dimension): transects.
- Areas (two dimensions): fixed area (circular, square, rectangular) or "variable" area (nested plots, relascope sample, distance methods).

In forest inventories, rarely individual trees are the sampled elements, usually "some type of cluster of trees" (sample plots) is selected and the individual trees measured. The independent observation unit is then the plot (not the individual tree!).

Plot shape

Shape of a plot in forest inventory could be circular, square or rectangular/strip plot. Most relevant characteristics when comparing circular, square, rectangular/strip plots are:

- The practical aspects: laying out the plots, border trees, etc.; and
- The statistical characteristics.

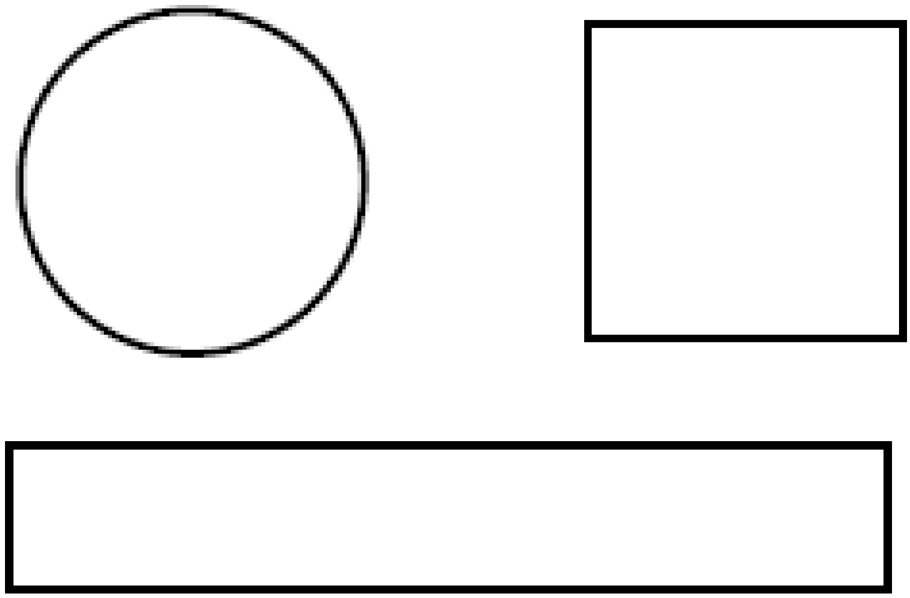


Figure 15: Various plot shapes

Plot size

Although there is no consensus, as a rule of thumb on the average there should be about 15-20 trees on the sample plot. The table below suggests a reasonable plot size based on the stocking density of the stand.

Table 1: Suggested plot size based on the stocking

STOCKING RATE (STEMS/*HECTARE*)	PLOT SIZE (*HECTARES*)	RADIUS OF CIRCULAR PLOT (METRES)
100	0.2	25.2
200	0.1	17.8
400	0.05	12.6
500	0.04	11.3
600	0.033	10.2
800	0.025	8.9
1000 +	0.02	8.0

Nested sub-plots

Sometimes in fixed area plots a large number of small trees may enter. Thus, using a set of sub-plots of different sizes for different size (diameter) classes might be a solution. Not only for trees, but also used for litter and soil observation purposes. Nested plots can be designed for all plot shapes.

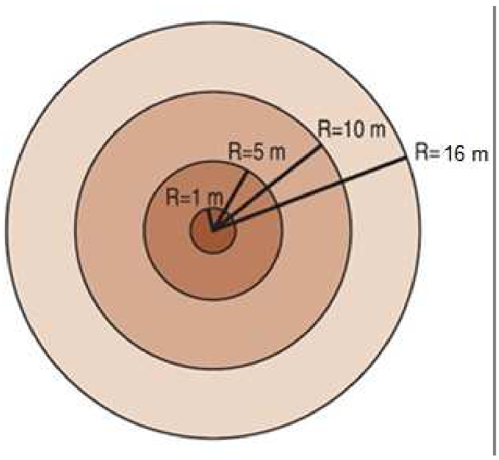


Figure 16: Example of circular nested sub-plots

Sampling design:

Sampling design refers to the method of selecting sampling units to be included in a sample. There are many forest inventory designs. As such there is not a specific pattern of design, which can be used in all inventories as each forest area varies. Nevertheless, basic inventory designs generally fall into the following categories: probability and non-probability sampling designs.

It defines the distribution and number of "observation units". Sampling is essentially an "information collection tool". It is done to produce *estimates,* wherever a census is not possible. Types of common sampling designs in forest inventory are given below.

Simple random sampling

It is the basic theoretical sampling technique. All sampling methods have their roots in simple random sampling. They are modification of simple random sampling method designed to achieve greater economy or precision. Every possible combination of sampling units from the population has an equal and independent chance of being selected.

The fundamental idea in simple random sampling is that, in choosing a sample of n units every possible combination of n units should have an equal chance of being selected. To state it in another way, the selection of a particularly unit should be completely independent of the selection of all other units. The best way to do this is to assign every unit in the population a number and then draw n number from a table of random digits. The units may be selected with or without replacement. If selection is with replacement, each unit is allowed to appear in the sample as often as it is selected. In sampling without replacement, a particular unit is allowed to appear in the sample only once. Most sampling is without replacement. This is an easy sampling technique to implement as long as there is an explicit sampling frame (list or map).

Use simple random sampling design when:

- The population is finite
- There is frame (sampling frame refers to the list of sampling units that might be drawn in the population and sampling units are units from where we are going to collect information)
- The characteristics of the population we are interested in is homogenous
- There is no much emphasis on precision

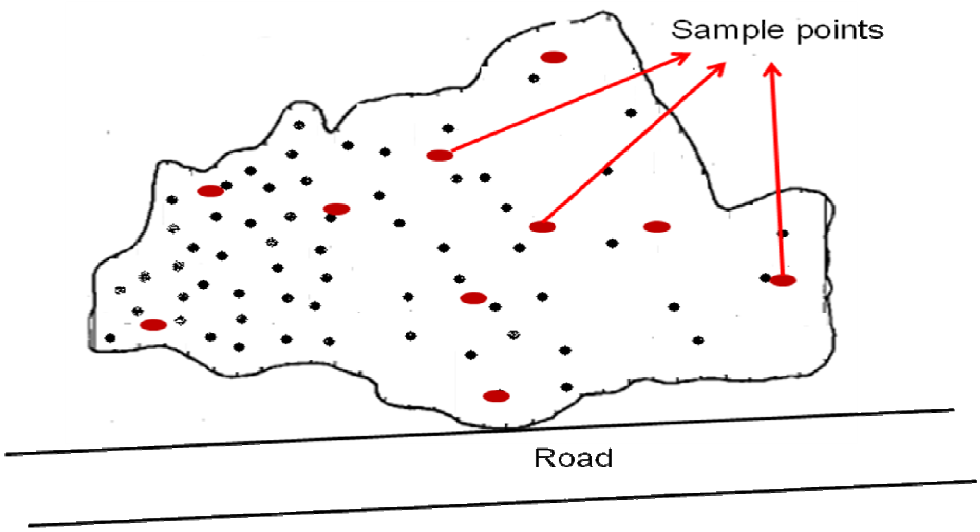


Figure 17: samples taken using simple random sampling techniques

For the computational issues see the exercises material provided during the training.

Stratified random/systematic sampling

In many forests there is great variability in timber volumes throughout the forest area. We describe such a forest as being heterogeneous. If random samples were taken in such a forest the standard error would be very large due to the large range of volume and as a result the estimation of volume in the forest could not be precise. In such instances it is useful to subdivide (stratify) the population in to sub-population (stratum). In fact the stratification can be done either for practical or statistical reasons. The corresponding sampling technique is called stratified sampling.

Stratification criteria could be:

- Forest types,
- Ecozones
- Site conditions
- Political or property boundaries
- Tree sociological classes
- Species, etc

Use stratified random sampling design when:

- The population is finite
- There is frame
- The characteristics of the population we are interested in is heterogeneous
- High precision is required

Sample allocation in stratified random sampling

Having decided the total number of sample sizes (e.g. n observations), the way in which many of these observations are distributed in each stratum need to be determined. There are different ways/procedures to do this:

1. Uniform allocation: equal samples to each stratum
2. Proportional allocation: allocating proportion to the stratum size
3. Neiman allocation: consider variation within the stratum and the stratum size
4. Optimal allocation: takes cost in to consideration

Uniform allocation:	$n_h = \frac{n}{L}$
Proportional allocation:	$n_h = n \frac{N_h}{\sum_{i=1}^{L} N_i} = n \frac{N_h}{N}$
Neyman allocation:	$n_h = n \frac{N_h \sigma_h}{\sum_{i=1}^{L} N_i \sigma_i}$
Optimal allocation:	$n_h = n \frac{\frac{N_h \sigma_h}{\sqrt{c_h}}}{\sum_{i=1}^{L} \frac{N_i \sigma_i}{\sqrt{c_i}}}$

Where, n is sample size; n_h is stratum sample size; L is number of strata; N_h is stratum size; c is cost of sampling.

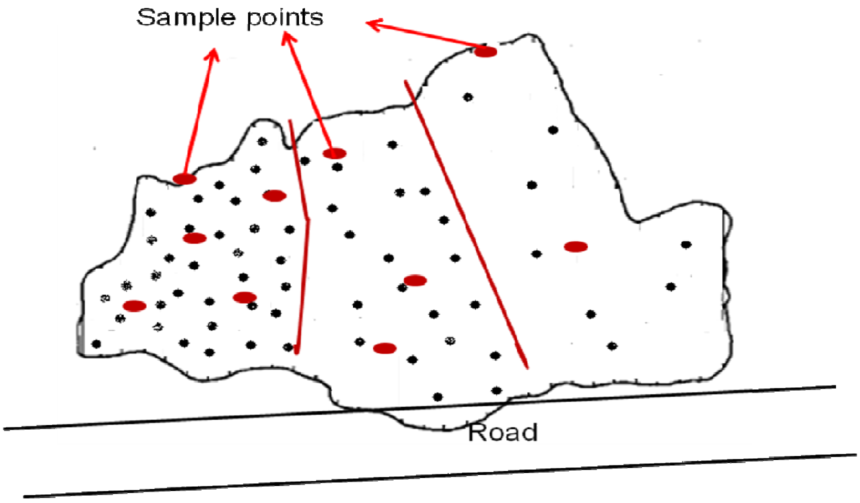


Figure 18: Sample points selected using stratified random sampling techniques

For the computational issues see the exercises material provided during the training.

Systematic sampling

It is a sampling technique in which selection of sample is following a systematic pattern. After the first sample is selected randomly all others are fixed/automatic.

It is the most frequently used sampling technique in forest inventory because:

- The procedure is easily applied in the field and it is easily explained to the field crew;
- It is also easy for those who are interested in the results to understand the sampling procedure
- It yields more precise results than simple random sampling with the same number of sample points.

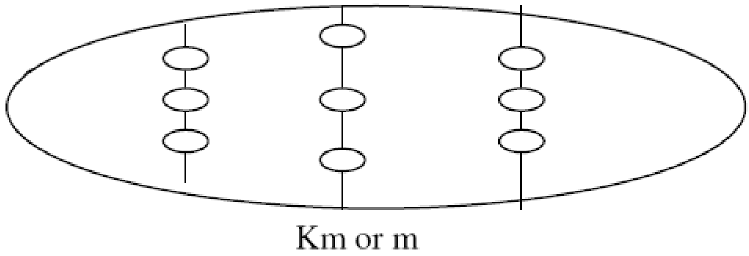


Figure 19: an example of systematic (line plot) sampling technique

For the computational issues see the exercises material provided during the training.

Reporting a forest inventory

As a general principle:

- The report should contain all information required to meet the inventory's objectives.
- The report should be understandable for those who need the information provided and who will use the results.
- There should be a detailed technical section for the possibly interested expert.

There is no as such a standard content of a forest inventory report. However the structure of a typical forest inventory report shall contain:

- Introduction (justification, legal basis, users etc.)
- Data sources, sampling and plot design.
- Organization and implementation.

- Data analysis and algorithms.
- Inventory results (totals and broken down to smaller reporting units (strata):
    - Areas, Growing stock, Forest structure and composition, Age classes, Assortments, Damages, Road infrastructure.
- Technical *discussion of results and inventory. Description of* problems encountered. Comparison with earlier studies.

More specifically:

- Include an executive summary
- Give precision statements for the all estimations, i.e. for all variables and all reporting units
- Give a clear description of the methods used, and specify the reasons why this method and not another has been chosen.
- Spell out practical or other problems encountered. There is NO forest inventory in which not something went differently than planned - it is simply to complex an issue.
- Attach field manual and form sheets to the reporting documents.
- Provide maps whenever possible.
- (Do not forget the acknowledgements.)
- Give budget information or indications, or at least information on time consumption for the different planning and implementation steps.
- Graph the sampling and plot design.
- Make the reasons transparent that lead to a specific sampling design.
- Describe the overall organization of the exercise, training measures and composition of field crews.
- State the models used.

SECTION-II: FOREST MANAGEMENT PLANNING

1. Definitions of Forest management

Forest management is the process of applying the **scientific**, **technical** and **economic** principles of forestry in the **planning**, **organization** and **implementation** of forestry activities in order to achieve the **objectives** of forest owners (society).

FAO definition

Forest Management deals with the overall administrative, economic, legal, social, technical and scientific aspects related to natural and planted forests. It implies various degrees of deliberate human intervention, ranging from actions aimed, at safeguarding and maintaining the forest ecosystem and its functions, to favouring specific socially or economically valuable species or groups of species for the improved production of goods and services. Sustainable forest management will ensure that the values derived from the forest meet present-day needs while at the same time ensuring their continued availability and contribution to long-term development needs.

2. Objectives of forest management

Objectives are desired points the forest organization wishes to reach or the purpose that an organization strives to achieve. Objectives are fundamental elements of an organization. Organizations often have more than one objectives. Forest management objectives can be defined on a nationwide, project or compartment level. Each will have different level of specificity with the nationwide objectives being stated in more general terms.

Examples of forest management objectives:

Nation Wide: (often provide the overall goals of forest resources management that influence policy decisions and strategies)

- Produce enough forestry products for the need of the people on a long term base
- Increase the forest cover and prevent desertification
- Maintain or enhance the biodiversity resources

Project level:

- Production of lumber, construction poles and fuel wood for the local market
- Generate enough revenue to cover the cost of the project and allow additional investment

Compartment level:

- Production of maximum volume of good quality saw timber.
- Production of round wood up to maximum diameter.

When the forest management objective/ target/ for a compartment is decided, then the decision can be made on:

- Species to be planted
- Rotation period
- Spacing
- Tending operations
- Thinning out put
- Harvesting out put

To be able to take these decisions we have to know more about.

- Tree growth
- Quality of the forest site
- Yield of the forest.
- Tending operations
- How to determine allowable cut
- The management plan
- Basic economy.

Planning: is the determination of the goals and objectives of an organisation and the selection, through a systematic consideration of alternatives, of the policies, programmes and procedures of achieving them. It comprises clearly identifying, defining and determining courses of action necessary to achieve predetermined goals.

Organizing : is the process of engaging two or more people in working together in a structured way to achieve a specific goal or set of goals. It involves dividing the overall management task in to a variety of processes and activities and establishing means of ensuring that these processes are carried out effectively and the activities are co-coordinated.

For example, in forestry one can generally categorize management activities in to two – Silvicultural Operations & Harvesting/Utilisation Operations -

Silvicultural operation has different components: Establishment (Site Classification and Assessment, Seedling raising, Planting, Beating up, etc), Tending operations (Weeding, Climber cutting, Singling, pruning etc).

Harvesting operation could include thinning, selection thinning, clear felling, processing, transporting, etc. After one has understood all the involved activities, he/she has to classify every activity in to appropriate categories and also determine the required resources both human and material. In addition the relationship and sequence of activities must also be determined and co-coordinated.

3. Principles of Sustainable Forest Management

Forest resources and forest lands should be sustainably managed to meet the **social, economic, cultural and spiritual human needs of present and. future generations**. These needs are for forest **products and services**, such as wood and -wood products, water, food, fodder, medicine, fuel, shelter, employment, recreation, habitats for wildlife, landscape diversity, carbon sinks and reservoirs, and for other forest products. Appropriate **measures** should be taken **to protect forests** against harmful **effects of pollution**, including air-borne pollution, **fires**, **pests** and **diseases** in order to maintain their full multiple values.

Primary considerations:

I. Sustainable forest management should be practiced on an operational and not an experimental scale.
II. It should embrace a balanced and comprehensive range of management activities that include working plans, yield prediction and control and other technical requirements.
III. It should include the wider political, social and economic criteria without which sustainability is probably unattainable.

3.1. Elements of Forest Management: prescriptions land classification, growth and yield predictions

a. Land Classification

Land classification is the first prescriptions element since it **sets the stage and context** of the activities and yield prediction. The forest area is **heterogeneous** in terms of various characteristics that are relevant for management planning and implementation. Therefore, classifying the forest management unit into homogeneous units with regard to these characteristics is necessary. Classifying land in to strata also **allow us to generalize results** from observed or studied areas to similar but unstudied areas.

Land classification is done by considering some relevant features of the forest area related to physical characteristics, vegetation characteristics, and development characteristics. **Physical characteristics** includes the set of attributes used to **characterize the permanent, physical nature of forest land**, including topography, soils, bedrock, climate, hydrology, etc. **Vegetation characteristics** are the set of attributes used to characterize tree and other vegetation currently growing on forestland, including height, age, basal area, volume, diameter, etc. **Development characteristics** include the set of attributes used to characterize the **organization, development and accessibility** of forest land for human use, including ownership, roads, building etc. The combination of these set of attributes can give rise to huge number of unique classes. As a result it is important to decide on the number of classes to be made by selecting only those attributes that have great influence on the outcome of prescriptions.

<u>Example:</u>

Physical characteristics:

Slope: Gentle (G), moderate (M), steep (S)

Vegetation characteristics

Forest type: Natural (N) vs Plantation (P)

NaturalForest vegetation: closed (NC), disturbed (ND), open (NO)

Plantation forestVegetation: Cupressus (PC), Eucalyptus (PE), mixed (PM)

Development Characteristics

Accessibility to roads: close (<1km) (RC), far (> 1km) (RF)

Settlements: close (<5km) (SC), far (>5km) (SF)

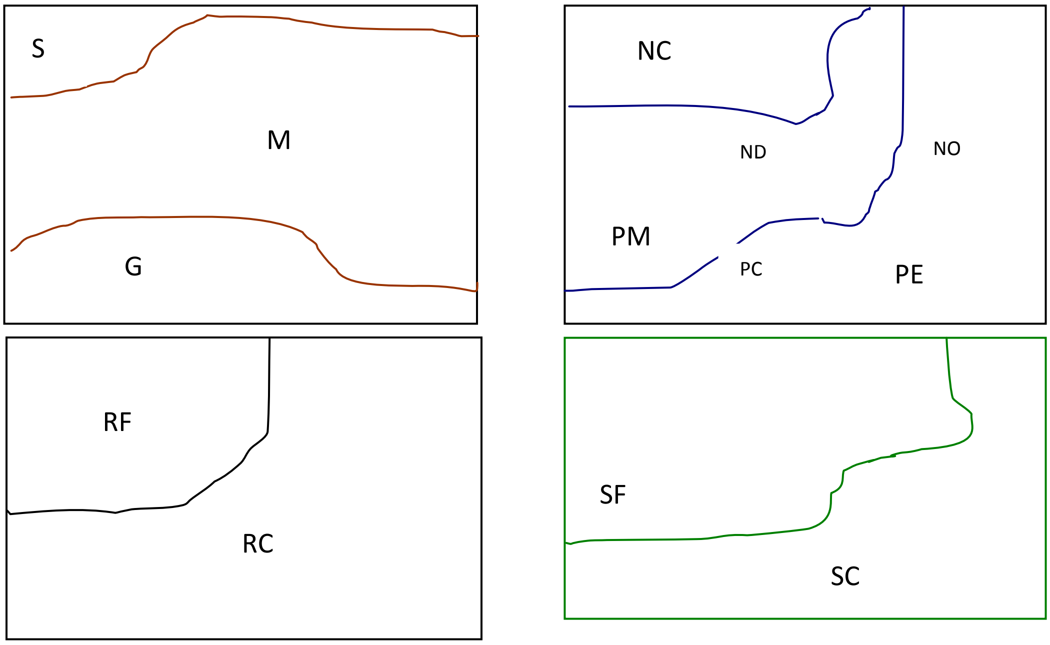


Figure 20: Land Classification

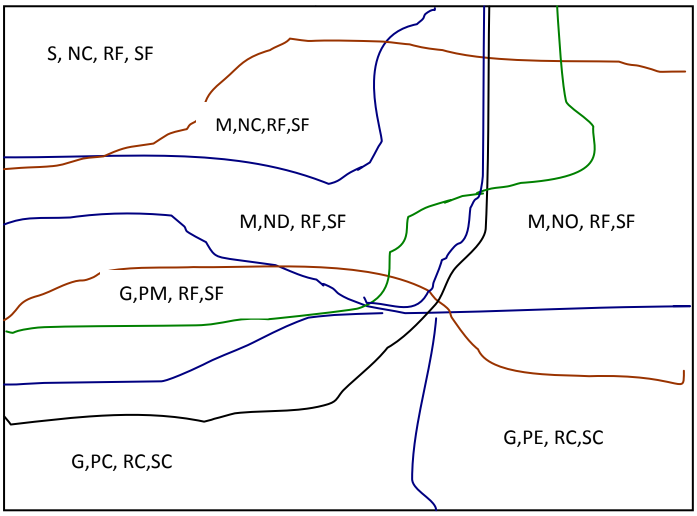


Figure 21: Forest map

Stands type: All forestland that has the **same defined combination and attribute range of the physical, vegetation, and development** characteristics chosen to classify the forest into homogeneous types with regard to some basic land characteristics in order to predict timber yield and other responses of the land to treatments with confidence. e.g., Land type, site type, forest type

E.g. All open natural forests situated on gentle slope area (at the foot of the mountain) that are close to the roads and surrounded by settlements

All closed natural forests located on the mountains sides situated in the remotest parts of the forest and away from the surrounding communities

Management unit/Block: An area of forest for which an approved Forest Management Plan is in operation. It is a geographically contiguous parcel of land containing one or more stand types and usually defined by watershed, ownership, or administrative boundaries for purposes of locating and implementing prescriptions. It is a permanent portion of the forest used mainly for administrative purposes. Blocks organize the forestland into logical spatial units for purposes of implementing the plan and to deal with concerns or impacts that are inherently spatial in character. They are more autonomous unit with a separate technical unit. Usually very large forest will be divided into blocks (not more than 500 ha) to facilitate management activities.

Compartment: is usually the smallest permanent subdivision (management units) of a forest. Compartments are permanently defined for the purpose of locating, describing, and record keeping and as a basis for the planning and management of all forest activities. Areas of forests being managed for different purposes, or have clearly different functions or values should as much as practicable placed in separately defined compartments – **Customary land Rights, Industrial Tree Plantation, Reduced Impact ground Skidding, Long Distance Cable Crane System, Natural Forest Management, Non-wood Forest Products**. The whole forest area will be divided in to various compartments and each compartment will be identified with a number on the operational map. There is not any constant size definition for compartments. Their size depends on the size of the forest, the intensity of management and the holding – whether it is a scattered or contiguous forest. However, it is preferable that compartments should not be less than 10 hectare in size.

Being a permanent unit the compartment should be clearly demarcated on the ground and its boundaries should, as much as possible, follow natural features such as roads, rides, main ditches, banks or other surveyed lines. The shape of compartments should preferably be compact and in flat, featureless country where artificial delineation is necessary, compartments may usefully be rectangular or square and have convenient area. The size of a compartment depends primarily on the intensity of working and also on topographic or site variations that may affect the type of management and its intensity.

The composition and state of the growing stock shouldn't be a factor in distinguishing a permanent forest subdivision. A compartment is not necessarily a unit of treatment even though treatments can be planned per compartment basis.

Therefore, different parts of a compartment may be subjected not only to different methods of treatment but also different objects of management. Such parts of a compartment are called sub-compartments.

The sub-compartment is a subdivision of a compartment, generally of a temporary nature, differentiated for special description and treatment (preferably designated by small letter a, b, c, etc). Variety of site and treatment of the growing stock results in the formation of different stands which can be defined as collections of trees or other vegetation which are sufficiently homogenous in specific composition, structure age and rate of development or health to differentiate them from each other for purposes of description or treatment. Accordingly the sub-compartment is usually synonymous with the stand and has a silvicultural and utilization functions while the compartment has a managerial, administrative function. Being temporary, sub-compartments do not need demarcation on the ground although they should be delineated in maps and their areas calculated and recorded.

b. Yield_prediction

Predicting growth and yield of managed and unmanaged stands is absolutely essential to credible forest management planning.

Stand growth is measured as the change in a selected stand attribute over some specified time. As an example, a stand might increase in volume by 2000m^3 over 10 years. Its average periodic annual volume growth equals 200m^3/ year.

In general, the maximum that a forest can yield at any time is the growth that has accumulated up to that time, and the maximum yield that can be removed perpetually per period equals the growth per period.

Components of stand growth

Growth of a stand or a tree is the result of:

- increase in diameter
- increase in height; and
- change in form.

The growth rate achieved by any given forest stand is largely determined by two factors.

1. The productive capacity of the site
2. The amount and composition of the growing stock present in the stand.

Specific growing stock characteristics of importance are;

1. The species present
2. The number of trees by species class categories; and
3. The spatial distribution of trees

All three of these characteristics are subject to control by the forest manager. This control is achieved through the managers selection of silvicultural and harvesting strategies.

The structure of a stand i.e the distribution of trees by diameter classes changes from year to year because of the growth, death and cutting of the trees. Thus many problems of stand growth are best understood considering stand population of trees and by studying the changes in the structure of this population.

Monitoring stand growth

A network of permanent sample plots (PSPs) in a continues Forest Inventory (CFI), if correctly laid out as representative samples of the forest and assessed, provide the most reliable data for estimation of:

1. Change in the forest stand over time, in number, size and species.
2. Variations in composition and production with size.
3. The relationship between individual tree variables, stand variable and increments, which may be used for predicting future stocking and.
4. Long term changes (improvements, degradation) in the site and it is productive capacity.

Permanent sample plots should be placed with equal frequency in:

- Poor sites
- Average sites
- Good sites ,

and ;

- Low density
- Stands of average density
- high density

and ;

- Young or recently logged stands
- mid- rotation or midway through felling cycle
- at rotation age or at the end of the felling cycle.

If two estimates are made for the same stand at different times, the difference is an estimate of net growth. To understand the composition of net growth it is necessary to recognize what happens to individual trees during the period between estimates, Some trees are alive and are measured at both times. Some are present only at the first and others only at the second time. These classes identify three significant elements of net growth: **accretion-** material added to trees measured at both occasions; **mortality-** the volume, at time of death, of trees that died during the period between measurements; and **ingrowth-** the volume of trees that grow to measurable size during the interval between measurements. The other change of stand is also the volume of trees felled during the measurement period or **cut**.

Gross growth is the total amount of material produced on an area. A skillful forest manager will harvest essentially all of gross growth in trees large enough to be marketable. Gross growth consists of accretion and ingrowth.

Combining these measures of stand change (accretion, mortality, ingrowth and cut) with the volume of living trees at the end gives the components normally used to estimate stand growth.

The stand components can be represented by:

V_1 = Volume of living trees at the beginning of measurement period

V_2 = Volume of living trees at the end of measurement period

M= Volume of mortality over period

C = Volume of cut over period

I = Volume of in growth over period

Given these components, the following different measures of increment over the growth period can be defined by equation:

Gross growth of initial volume = $V_2 + M + C - I - V_1$

Gross growth including in-growth = $V_2 + M + C - V_1$

Net increment = $V_2 + C - I - V_1$

Net increment including in-growth = $V_2 + C - V_1$

Net change in growing stock = $V_2 - V_1$

Where,

V_1 volume at the beginning of growing period

V_2 volume at the end of growth period

M Mortality volume

C Cut volume

I ingrowth volume

Living trees make increment, but its assumption does not give stand increment because some trees die, rot and are cut. For example, consider an even-aged stand measured at two succeeding inventories 10 years apart. The distribution of stem number changes from time to time as time passes. In most cases as a result of low selective thinning and death due to high competition, the shift is towards the bigger diameter classes. To estimate the growth or increment of the volume over successive time a number of growths parameters must be known, clearly understood and estimated. The appropriate definition depends on the user's purpose:

The forest owner who simply wants to know how much wood is actually being produced would use definition 3, net increment, including ingrowth. A system ecologist interested in total biomass would include small trees and use definition 1. The forest researcher concerned with thinning and reduction of mortality would look to definition 2, while the national accountant monitoring the condition of the forest resource might use definition 5.

Table 2: Stand growth measurements

	First measurement	**Second measurement**			
Tree no	Volume (m^3)	Volume (m^3)	Mortality	Cut	In-growth
1	0.292	0.670			
2	1.314	H		1.314	
3	0.154	0.387			
4	0.027	D	0.027		
5	NM	0.107			0.107
6	0.130	0.367			
7	0.387	0.782			
8	1.031	H		1.031	
9	0.045	D	0.045		
10	0.060	0.210			
11	NM	0.045			0.045
12	0.107	0.328			
13	NM	0.130			0.13
14	NM	0.087			0.087
15	0.210	0.567			
Total	**3.758**	**3.682**	0.072	2.345	0.369

	V2	V1	M	C	I	
Gross growth of initial volume	3.682	3.758	0.072	2.345	0.369	1.972
Gross growth including in-growth	3.682	3.758	0.072	2.345		2.341
Net increment	3.682	3.758		2.345	0.369	1.9
Net increment including in-growth	3.682	3.758		2.345		2.269
Net change in growing stock	3.682	3.758				-0.076

Methods of yield prediction

Using Past growth percentage

The assumption in this case is future growth will proceed at the same rate as the past growth period of years. The recommended period for such type of prediction is between 3 to 5 years.

$$\text{Growth \%} = \frac{V_2 - V_1}{n \times V_1} \times 100$$

Where, V_2 = Volume at the end of growth period

V_1 = volume at the start of growth period.

n = Number of years in growth period

Example

Volume of the stand has $100m^3$/ ha, and 2 years later the volume reaches 150 m^3/ ha. What will be the volume after 3 years from now. Assume that the pattern of the volume growth follow past growth.

Solution. $$\text{Growth percent} = \frac{V_2 - V_a}{n \times V_1} \times 100$$

$V_2 = 150m^3/ha$

$V_1 = 100m^3/ha$

n = 2 years

$$\text{Growth percentage} = \frac{150 - 100}{2 \times 100} \times 100 = 25\ \%$$

Initial volume for the next growth is 150m3/ha, percentage growth for the next three years is 25%

Therefore , V = $150m^3/ha$ + 3 (150m3/ ha * 25%) = <u>262.5m/ha</u>

The final volume can also be found by compounding the growth rate.

Stand Table Projection

Stand table projection is a traditional diameter class method that estimated the future stand table of a subject stand on the basis of the present one, using actual diameter growth and other information which is collected from the subject stand for each diameter class.

A tree population/diameter class distribution is compiled using PSP summary data. DBH classes are in 5 or 10 cm intervals. Stratification of the tree population can be made on the basis of species groups. Average diameter growth and average tree mortality rates are determined from periodic measurements of PSP, for each diameter class. Growth is projected for a five-year period for each diameter class per hectare by applying growth and mortality rates.

Table 3: Growth projections

Item	Definition	Example value
N_{it}	Number of trees in class i at time t	83
I_i	Number of trees growing into class i in growth interval (ingrowth)	47
U_i	Number of trees growing out of class i in growth interval (upgrowth)	61
M_i	Number of trees in class i dying in interval (mortality)	7
C_i	Number of trees in class i being cut in interval (harvest)	12
$N_{i,t+1}$	Number of trees in class i at the end of growth interval	50

$$N_{i,t+1} = N_{it} + I_i - U_i - M_i - C_i$$

The past increment in different tree sizes are obtained from estimates obtained from permanent plots or estimates made on increment borings. But this assumes that tree growth follows past rates and also there are distinct growth rings that can easily be associated with number of years. The estimate should apply for a short period (not more than 5 years). However, the growth conditions for each tree might significantly change either by change in stand structure or other randomly occurring factors. Mortality among different tree sizes must be established from past experiences or applying models developed for the site.

There are three choices for applying the growth estimate for diameter classes: the first is by applying average diameter increment to the midpoint of diameter class, second is application of average diameter increment assuming uniform distribution over the diameter class, third is application of variable diameter increment to actual diameter. The third method requires a lot of data hence is costly.

Using the second method, we first determine movement ratio which is calculated as the ratio of average growth for the diameter class to the size of class width. Then the number of trees in the diameter class is multiplied by this ratio to determine the number of trees that have moved to the next higher diameter class. This value constitute up growth (trees that have grown to the next larger diameter class) and will be subtracted from the diameter class. Trees that have moved from the next lower diameter growth will constitute in growth and thus will be added to the diameter class. If the ratio is greater than one then the value after the decimal point indicates the proportion of trees that have moved two diameter classes while the difference have move one diameter class.

Example:

1. if diameter class size is 2cm, and the average growth is 1.3cm, then movement ratio is 1.3/2 = 0.65, which means that 65% of the trees have moved to the next higher diameter class while 35% have remained in the same diameter class. If average growth was 2.4cm, then movement ratio will be 2.4/2 = 1.2, indicating that 20% have moved up two diameter classes, while the remaining 80% have moved to the next higher diameter class, therefore all the trees in the diameter class have grown to the next two higher diameter classes.

Consider the following table and determine the growth of the stand.

<u>Example</u>

For a certain *Eucalyptus saligna* plantation, established for fuelwood and transmission poles production, the volume increment for the coming three years is going to be predicted. As there is not any appropriate yield table for the species, stand table projection was found to be the next best alternative. Accordingly, the average diameter growth per diameter class in the past three years is estimated as shown on the table. Assuming mortality to be negligible fill in the following table and calculate the net increment.

1.Diameter class (d_i) (cm)	2.Present stand table	3.Present volume/ diameter class	4.Average growth (cm)	5.Movement Ratio	6.Percentage of trees moving			7.Number of trees moving			8.Future stand table	9.Future volume/diameter class
					0 classes	1 class	2 classes	0 classes	1 class	2 classes		
-5-	21	0.189	0.96	0.48	0.52	0.48		10.92	10.08	0	10.92	
7	25	0.145	1.2	0.60	0.4	0.6		10	15		20.08	
9	70	2.80	1.3									
11	105	5.88	1.6									
13	360	39.96	1.8									
15	230	32.20	1.8									
17	132	30.76	2.0									
19	33	9.31	1.9									
21	5	1.94	1.5									
23	-											
	Present volume/ha = [illegible]										Future volume/ha	

<u>Local volume table for *Eucalyptus saligna*</u>

D (cm)	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
V (m^3)	0.009	0.012	0.018	0.024	0.040	0.043	0.056	0.077	0.111	0.125	0.140	0.178	0.233	0.244	0.282	0.325	0.389	0.441	0.497

c. Prescription Development

Prescription is a schedule of activities for some stand or parcel of forestland. A concisely written specification in a forest management plan that translates an objective or a part of one, into an operational activity. **Developing, evaluating and implementation of prescriptions** are central activities in forestry. As a result, in some texts they equate prescription development with forest management plan development.

Prescription formulation integrates:-

- the strategies of **land classification**;
- the basic and applied biological **knowledge of silviculture**;
- the growth **prediction** techniques of mensuration;
- **economic** values, and
- the **decision analysis** techniques of the management economist.

Example 1:

- For the *Cupressus lusitanica* stands close to the rotation age and on erosive soils but less steep slopes (less than 30%), site indices over 30, and basal area greater than 30m^2/ha, undertake commercial thinning using tractor logging to reduce basal area to 20m^2/ha followed by a final harvest in 5 years.
- Site preparation should be made with spot hoeing and planted the same year and weeding by spot weeding

The three essential elements of a prescription are:

i. A land type classification: which describes parcels or types of land by **location, timber size, stocking, species, soils, slope**, and other land attributes
ii. A management "**activity schedule**" describing the timing, methods, and conditions by which the vegetation and other resources will be manipulated or disturbed to achieve desired outcomes, including:
    a. Logging rules
    b. A timber thinning and harvest schedule
    c. Regeneration techniques for the next tree crop
iii. A quantitative growth and yield projection, which numerically describes how much timber is expected for commercial harvest: specifically, volumes removed at each thinning and final harvest entry for both the existing and subsequent regenerated stands

The following guidelines for formulating management plan prescriptions are suggested:

- Prescriptions should be **concisely written**, **specific to the issue** being addressed and should be r**elated to specific management objectives**. They should not be vague or ambiguous. Prescriptions should not be too long or too technical. Lengthy or excessively technical prescriptions are likely to be misunderstood or simply ignored. Only include material that is directly relevant to support the implementation of forest management objectives.
- Prescriptions must be **measurable**, or capable of being monitored easily, so that progress can periodically be reported.
-
- Although a need for precisely written prescriptions should be recognized, it also needs to be acknowledged that there may be occasions where a manager should be allowed some discretion in the implementation of a prescription if local conditions or common sense indicate that a degree of flexibility is desirable. Losses of forest through **fire**, **additions** or **losses** of forest area, **changes in the definition** of forest resources or changes in **community interests** in a forest are cases of unforeseen events which may influence the progress of the management plan.

3.2. Forest Regulation

Forest Regulation: determines what, *where* and *when* timber harvesting takes place on the managed forest. The regulation decisions indicate ***what species and how much of them should be cut***. ***A regulated forest is one that yields an annual or periodic crop of about equal volume, size and quality***. Thus, forest regulation consists of manipulating forestlands and growing stock to best achieve the forest owner's yield objectives. Sustained yield management, allowable cut, and normal forest are important concepts in forest regulation. Sustained yield is the yield a forest can produce continuously at a given intensity of management. Allowable cut implies the need to keep a balance between increment (growth) of the forest and amount of cutting (harvest). Normal forest is the ideal forest structure which foresters strive to achieve and commonly applied in relation to even-aged forests. Preferred approaches for forest regulation can differ for even-aged and uneven aged stands owing to the difference in the structure of these forest types.

d. Even-aged and uneven-aged stands

As a natural stand or plantation grows, it usually becomes vertically stratified, as different groups of trees develop canopy layers. Single-storied stands are often described as even-aged stands and multi-storied stands as uneven-aged stands. In even-aged stands, individual trees originate at about the same time, either naturally or artificially. In the theoretical description of even-aged management, all trees in a stand are assumed to be identical and of the same age. There is usually a small amount of variation in tree heights in even-aged stands, and since tree ages are relatively the same, the resulting forest structure is, by comparison, relatively simple. In addition, stands have a specific termination date at which time all remaining trees are cut. This complete harvest is called a clear-cut. An even-aged forest consists of a mosaic of even-aged stands of different age and size called management units or compartments. Each unit must be big enough for practical management, but size may vary greatly, depending on the management objectives.

The diameter distribution will represent a bell-shaped curve. Thus, once one knows the growth function of a single tree and the number of trees in a given stand or land unit, one also knows the volume of the stand at any point in time. The growth functions of any tree on any site have common features; namely, growth follows a sigmoid or S-shaped path when the volume of wood in the trees is graphed over time. Sigmoid growth means that volume first increases at an increasing rate and then eventually increases at a decreasing rate. A typical time-line of volume accumulation within an even-aged stand is represented by a sigmoid curve. Several characteristics of the growth dynamics in even-aged stands set them apart from uneven-aged stands and other types of stand structures. As the even-aged stand canopy closes, inter-tree competition for resources(light, water, nutrients) will lead to the weakening and mortality of some trees. As a result, mortality rates are generally high in younger even-aged stands than they are in older even-aged stands.

In an uneven-aged (or selection) forest, many trees of different age and size coexist on small tracts of land. In contrast with the even-aged forest, distinct areas of homogeneous age-classes cannot be distinguished. Uneven-aged stands are sometimes referred to as all-aged stands, but generally are considered those containing more than two or three distinct age classes or age cohorts. However, the ideal uneven-aged forest, where trees of all ages appear on the same acre, is rare. Trees may be grouped in patches of similar age, but these patches are usually too small to be administered like the even-aged compartments. These types of stands may be sustainable through active management if the associated harvesting schedule can be designed to remove the appropriate types of trees (size and species) that will result in a diameter distribution that can be maintained. Large contiguous tracts are never clear-cut in the uneven-aged forest. Rather, one selects single trees or group of trees within stands. Consequently, unlike even-aged stands, uneven-aged stands have no beginning and no end. There are always trees left on each hectare of the uneven-aged forest, even immediately after harvest.

The target forest structure of an uneven aged stand is one where equilibrium in volume growth has been reached. The equilibrium is a theoretical state where a sustainable timber increment (accretion) is developed over a period of time using a diameter distribution of trees that remains roughly constant. One of the assumptions of this Silvicultural system is that an adequate amount of regeneration is provided, which will maintain the system indefinitely. The rules that are used to manage uneven-aged stands are not based on age, as they might be with even-aged-stands, but rather are based on measures of stand density and a desired diameter distribution. The structural trajectory of an uneven aged stand will depend on the treatments applied to different diameter classes within the stand. An understanding of the shade-tolerance of desired tree species may help determine how large the gaps need to be with each logging entry to promote regeneration and growth. As a result, an extensive examination of the distribution of shade tolerant and shade intolerant trees, and the advanced regeneration that may be present in the stand, would seem necessary prior to scheduling management activities in uneven-aged stands. Forest growth in uneven-aged forests is measured as an increase in the number of trees in each diameter class. The concepts of ingrowth and upgrowth are used to describe the transition of trees from one diameter class to another.

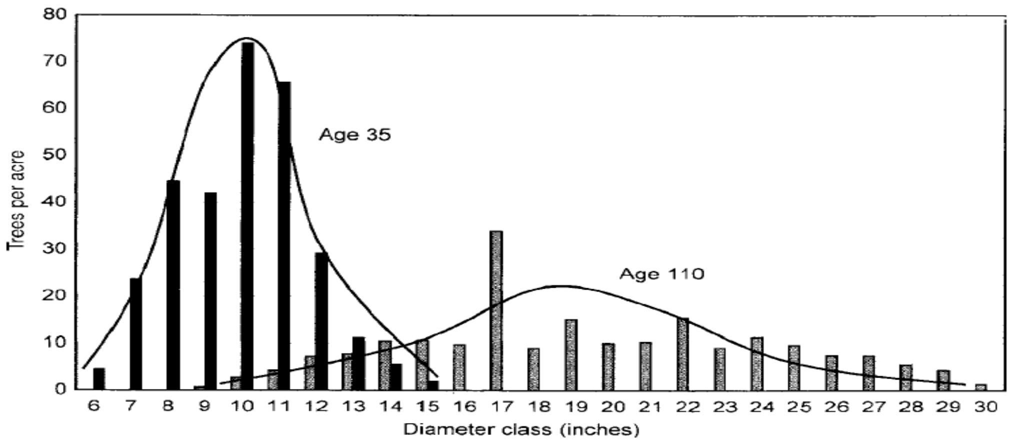


Figure 22: Diameter distribution of trees in even aged stands

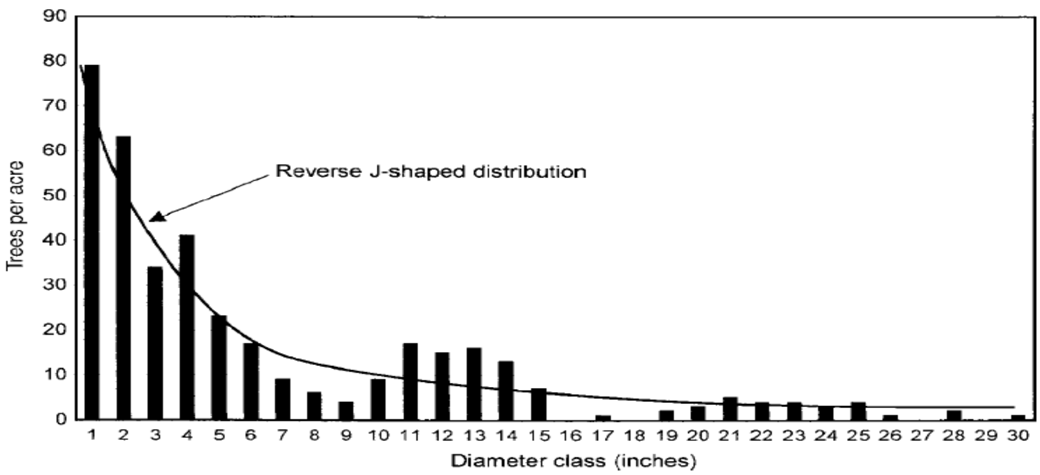


Figure 23: Diameter distribution of trees in uneven-aged stands

Growth and development characteristic	Even-aged stands	Uneven-aged stands
Trees per unit area	Decreases with age	Varies through time
Mortality rate of stems	Decreases with age	Stays relatively constant over time
Mortality of volume	Increases with age	Stays relatively constant over time
Height of canopy	Increases with age, then plateaus	Stays relatively constant over time
Canopy cover	Ranges from none to full	Ranges from full to one containing gaps
Average tree diameter	Increases with age	Fluctuates with harvest entries and mortality
Diameter distribution	Bell-shaped curve	Reverse J-shaped curve
Basal area	Increases with age, then plateaus	Fluctuates with harvest entries and mortality
Timber growth rate	Rises, peaks, then declines	Stays relatively constant over time
Timber yield	Increases with age, then plateaus	Fluctuates with harvest entries and mortality

e. **<u>Regulation of Even-aged stands</u>**

In even-aged stands management regulation of forest uses the model of 'normal forest' to achieve a forest structure that produces a sustained yield. A normal forest is a forest consisting of stands of all age classes distributed on equal area of the same productivity giving maximum production of the required product on a perpetual basis.

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
16	17	18	19	20
21	22	23	24	25

Example: Let assume

- V_i = volume per hectare in age class i
- V_{ti} = total volume in age class i
- a = area per age class
- G = total annual growth for the forest
- H = total annual harvest for the forest
- MAI_R = mean annual increment for rotation age stands
- A = total area of the forest
- R = rotation age

Then

- The number of hectares in each age class (a) = A/R
- Total volume in age class i $(V_{ti})=(a)\times(V_i)= av_i$
- The total volume of growing stock in the forest is
  - $V_{gs} = V_{t1} + V_{t2} + V_{t3} + \ldots + V_{tR}$, or
  - $V_{gs} = av_1 + av_2 + av_3 + \ldots + av_R$
  - The annual harvest (H) = $V_{tR} = av_R$
- Total annual growth of the forest (G) = H = $V_{tR} = av_R$
- Annual harvest (H) = $av_R = (A/R)\ v_R = (A)(v_R/R)$
  - $H = (MAI_R) \times (A)$

Example: assume a forest established with a species that grows according to the following yield table

Age	Vol/ha (v_i)	MAI
6	143.1	23.8
7	189.1	27.0
8	237.8	29.7
9	288.0	32.0
10	338.7	33.9
11	389.2	35.4
12	438.8	36.6
13	487.0	37.5
14	533.6	38.1
15	578.1	38.5
16	620.5	38.8
17	660.6	38.9
18	698.4	38.8
19	733.8	38.6
20	767.0	38.4
21	797.9	38.0
22	826.7	37.6
23	853.4	37.1
24	878.1	36.6
25	900.9	36.0

A sugar factory intends to establish a plantation with a species growing according to the previous table and planned to harvest and consume fuelwood amounting to 20,000m^3 per year. Assuming stands less than 6 years old to be non-harvestable, determine the following values for each of the options of managing the forest with rotations between 6 – 22 years.

1. Annual cutting area (a) at each rotation age
2. Total forest area (A) required for sustained yield
3. Total growing stock (V_{gs}) in the forest
4. If forestland has to be leased, which rotation will require the smallest area of land for rent?

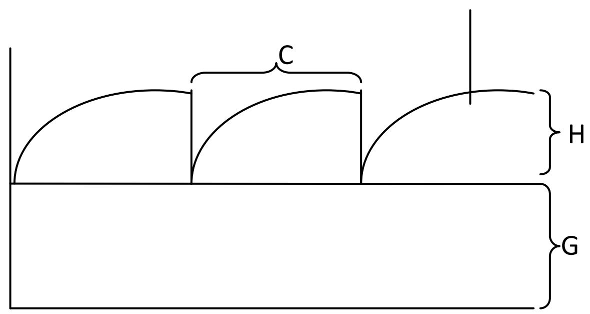
Age	Vol/ha	MAI	a	A	GS	%GS
6	143.1	23.8	139.8	838.6	20000+	
7	189.1	27.0	105.8	740.4	35134.27	56.9%
8	237.8	29.7	84.1	672.9	47941.56	41.7%
9	288.0	32.0	69.5	625.1	59585.59	33.6%
10	338.7	33.9	59.1	590.5	70660.12	28.3%
11	389.2	35.4	51.4	565.3	81493.67	24.5%
12	438.8	36.6	45.6	547.0	92279.71	21.7%
13	487.0	37.5	41.1	533.8	103137.9	19.4%
14	533.6	38.1	37.5	524.8	114144.8	17.5%
15	578.1	38.5	34.6	518.9	125351.1	16.0%
16	620.5	38.8	32.2	515.7	136790.5	14.6%
17	660.6	38.9	30.3	514.7	148485.6	13.5%
18	698.4	38.8	28.6	515.5	160451.4	12.5%
19	733.8	38.6	27.3	517.8	172697.5	11.6%
20	767.0	38.4	26.1	521.5	185229.4	10.8%
21	797.9	38.0	25.1	526.4	198049.5	10.1%
22	826.7	37.6	24.2	532.2	211158.2	9.5%

f. Regulation of uneven aged stands

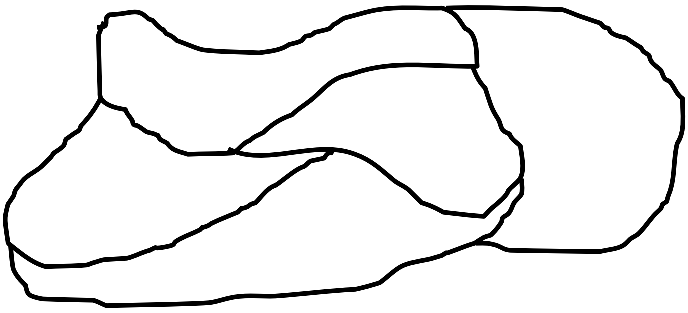
Uneven aged forest is when there is a significant difference in the age of trees composing the forest and when three or more age classes are represented.

Cutting cycle (C) and reserve growing stock are important concepts in regulating uneven-aged forest. A cutting cycle is the planned interval between major felling operations in the same stand

Reserve growing stock (G)is the growing stock in the forest that is reserved (uncut) to produce the growth for future cuts (H).



The conceptual regulation model for uneven-aged forest is a forest divided into a series of stands that are regularly harvested on the cutting cycle. The stand all provide an equal volume of harvest and thus may vary in size depending on site productivity. Therefore, there will be as many stands in the forest as there are cutting cycles.



There are four important questions to be answered in regulating uneven-aged forests.

I. How much growing stock should be carried?

II. What should be the diameter distribution on the stand?

III. What should be the species composition of the stand?

IV. What should be the cutting cycle length?

The reserve growing stock should be determined as the volume that maximizes the growth of the forest. This is obtained by long years of experience and expert judgment. There is no widely used formula to determine the reserve growing stock.

As many younger trees (usually those with the smaller diameters) do not survive as a result of either mortality or cutting, many more trees are needed in order to obtain larger ones in the future. Therefore, the inverted J-shaped diameter distribution is preferred.

The important point in species composition is balancing the species that will reproduce and grow well on the site with those that are desirable for reaching the management objectives. There are also limitations of site variables as soil, fertility, moisture, and altitude. As in most case, uneven-aged forests are natural forests, appropriate species to the site are already known. Species desirability is also affected by such things as marketability, owner's aesthetic values, and other non-timber production.

Though there are many factors determining the cutting cycle, the most important will be species composition, financial needs, and the site. For example, shade tolerant species can have a longer cycle because open stand conditions are not required for successful reproduction, and vice versa for intolerant species. Faster growing species can have a shorter cycle and slower growing species a longer cycle because of the time needed to reach merchantable size. The financial need of the owner might also determine the length of harvest periods.

The operational conceptualization of uneven-aged management is dominated by the diameter size structure of a stand rather than its age structure. Management operates by periodically harvesting some of the trees on each hectare, and the key decision variable is how many trees of particular sizes and species to remove. This requires a good knowledge of the stand structure and effective methods to predict growth by diameter class.

Conceptually regeneration in uneven aged stands is assumed to be continuous. The diameter distribution of uneven aged stands is also assumed to take the form of negative exponential distribution while the ratio of the number of trees in successive diameter classes, going from the largest to the smallest, is also assumed to be a constant value – q. Besides, for a given species and certain diameter class size, this value will take a particular value and can be estimated from empirical data. Once this value – q – is known it can be used as a way to conceptualize and describe diameter distribution for uneven-aged stands. Accordingly, a balanced (regulated) uneven aged stand is one in which growth can be removed periodically (cutting cycle) while maintaining the diameter distribution and initial volume of the forest. Therefore, this balanced diameter distribution for a stand can be defined by defining the following stand parameters.

q = desired quotient (ratio) between successive diameter classes

B = desired stand density, measured in basal area, volume or other density measure

D_{min} = the smallest measurable diameter class

D_{max} = largest desired diameter class

N_{max} = number of trees in largest diameter class

Using these parameters, the stand structure is described by the set of N – 1 equations for all pairs of adjacent diameter classes

$q = N_{i-1}/N_i$, for i = D_{min}, . . . , D_{max}

Stocking constraint = the desired density of stand measured in Basal area or Volume

$$\sum_{i=min}^{max} b_i N_i = B$$

Where bi is the contribution of volume, basal area, or other density measure per tree of size class i, and B is the stand density defined in units of volume, basal area or other measure.

Once the quotient (q) and the optimum basal area (B) for the species are known, and the minimum measurable diameter size and the maximum desired diameter size are decided, and the planned number of trees in the largest diameter class is known, then the desired structure of the forest stand can be determined using the following formula.

$$N_{max} = \frac{B}{\sum_{i=min}^{max} b_i q^{(D_{max}-D_i)/w}}$$

Where D_i = midpoint of diameter class i, and w = diameter class width, other as defined above

The denominator of this expression is the density per hectare of a stand with exactly one tree in the largest diameter class.

For a regulated uneven-aged forest stand that will give a sustained volume of harvest, the number of trees in each diameter class is determined and the excess number of trees in the merchantable sized diameter classes can be removed at each cutting cycle.

<u>Example</u>

If the largest desired diameter class is 45cm, the measurable minimum diameter size is 7.5cm, the quotient is 1.6, and the desired basal area per hectare for the forest stand is 30m2 per hectare, then the desired diameter distribution for a regulated uneven-aged stand can be determined as follows:

Diameter class (cm)	Mid diameter class (cm)	b_i (=Basal area in m^2)	N_i (when N_{max} = 1)	$b_i \times N_i$ (when N_{max} = 1)
>47.5	-			
42.5 – 47.49	45	0.159043	1	0.159043
37.5 - 42.49	40	0.125664	1.60	0.201062
32.5 – 37.49	35	0.096211	2.56	0.246301
27.5 – 32.49	30	0.070686	4.10	0.289529
22.5 – 27.49	25	0.049087	6.55	0.321699
18.5 – 22.49	20	0.031416	10.49	0.32942
12.5 – 17.49	15	0.017671	16.78	0.296478
7.5 – 12.49	10	0.007854	26.84	0.210829
			$\sum_{i=min}^{max} b_i q^{(D_{max}-D_i)/w}=$	2.05

Then the number of trees in the largest diameter class for a basal area of $30m^2$ is determined as follows:

$$N_{max} = \frac{30}{2.05} = 14.63$$

Taking the number of trees in the largest diameter class determined above, we can determine the required diameter distribution for a regulated forest structure as follows:

Diameter class (cm)	Mid diameter class (cm)	N_i (for regulated structure)	Actual diameter distribution	Excess N_i	% of excess N_i
≥47.5	-	0	6	6	100%
42.5 – 47.49	45	14.63	11	-3.63	-33%
37.5 - 42.49	40	23.41	22	-1.41	-6%
32.5 – 37.49	35	37.45	38	0.55	1%
27.5 – 32.49	30	59.92	70	10.08	14%
22.5 – 27.49	25	95.88	105	9.12	9%
18.5 – 22.49	20	153.41	185	31.59	17%
12.5 – 17.49	15	245.45	285	39.55	14%
7.5 – 12.49	10	392.72	470	77.28	16%

Therefore, about 174 trees per hectare are in excess of the required distribution for a regulated structure Therefore, about 174 trees per hectare need to be removed in the next cutting cycle to achieve the regulated forest structure.

The diameter distribution of the actual (Niu) and regulated forest (NiR) looks likes as follows