Tropical Rainforest Inventory

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Course Outline

Course Design Objectives:

The basic objective of the course is to introduce the participants to the subject of forest inventory, with an emphasis on applications in tropical rainforest. The course will contain two topics:

- Basic Forest Mensuration
- Tropical Rainforest Inventory

Each topic will be designed to elaborate on information presented in the preceding topic. The topics are designed in a manner that will allow the presentations to be modified as suits the participants. For example, basic details of forest mensuration can be presented as a refresher if the class level indicates so, or as an introduction, should this be required.

Each topic will be designed to present information on a range of levels, in order that those to whom the material is new will gain an understanding of the material, yet those who have a higher level of understanding will be challenged. This will be done by the inclusion of a simple example and a more complex example. The simple example will serve as a refresher for the more advanced participants. The more complex example will show challenge the more advanced, and demonstrate the breadth of the subject to the less advanced participant.

The structure of the presentation will be formal lecture sessions, followed by group discussion of the material presented. The participants will be presented with opportunities to carry out exercises, followed by a group discussion of the exercises.

Course Topics

Basic Forest Mensuration

The objective of this topic is to ensure that participants are aware of the basic techniques used in forest assessment. The participants will be expected to know how to measure the diameter and height of a tree, how to measure the dimensions of a log, and how to establish a bounded plot in an area of forest. The following sub topics will be presented

- Tree Measurement
- Log Measurement
- Area Measurement

These skills may already be established, in which case the presentation will be abbreviated.

Tropical Rainforest Inventory

The objective of this topic is to introduce the participants to the methodology of tropical rain forest inventory. Participants will be expected to gain and understanding of the techniques used in tropical rainforest inventory. The following sub topics will be presented.

- Objectives
- What to measure
- Integration
- Stratification
- Field plots
- Plot types
- Inventory plot layout
- Attribute sampling
- Field plot measurement
- Random sampling design
- Systematic sampling design
- Calculations
- Computer systems for processing field data
- Integration
- Remote sensing
- Geographical information systems
- Complete systems integration
- People

At the end of the course, the more advanced participants will be expected to be able to take part in the planning of an inventory. The less advanced participants will be expected to understand the inventory process, and will know what steps to take to advance their knowledge.

The participants will be given a number of exercises to complete that will be graduated, from simple to complex.

Reading List

The following list of general references may be of value to the participants.

Bitterlich, W. 1984: The Relascope Idea. Commonwealth Agricultural Bureau

Cochran, W.G. 1977: Sampling Techniques. John Wiley & Sons

Cochran, W.G, Cox, G.M. 1957: Experimental Designs. John Wiley & Sons

Freese, F. 1962: Elementary Forest Sampling. USDA Forest Service Agricultural Handbook 232

Freese, F. 1967: Elementary Statistical Methods for Foresters. USDA Forest Service Agricultural Handbook 317

Hogg, R.T, Craig, A.T. 1970: Introduction to Mathematical Statistics. Macmillan Publishing

Raj, D. 1968: Sampling Theory. McGraw-Hill

Spurr, S.H. 1952: Forest Inventory. Ronald Press.

Basic Forest Mensuration

Introduction

All forest management information is derived from information collected from individual trees. The process of collection such information is called **mensuration**.

Information from individual trees can be combined to provide statistics that provide information about a forest. Forest information cannot be collected directly, and must be calculated from tree information. The large number of trees in a forest means that trees must be sampled, which means that forest information relies heavily on statistical calculations. Such calculations are meaningless unless the information collected from each tree is accurate.

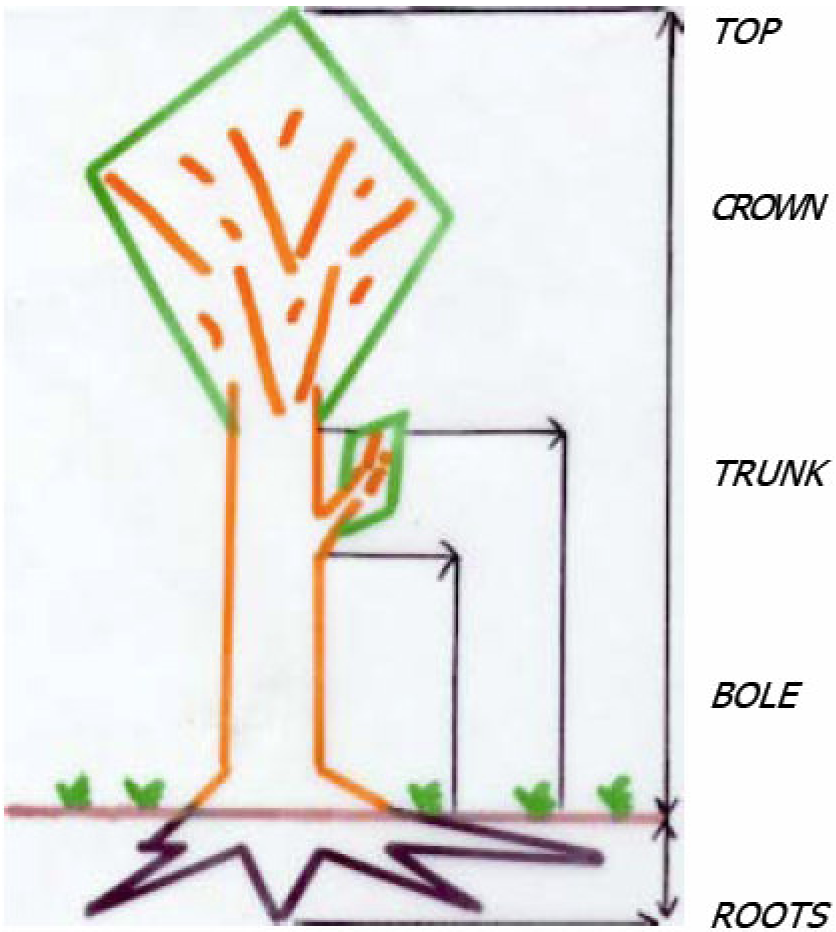

Figure 1The component parts of a tree

Tree Measurement

Count

The most basic measurement that can be taken from a tree is the presence of absence of the tree. The simplest form of forest mensuration is an enumeration of the number of trees in an area. Such an enumeration can be done in a variety of ways, such as counting trees in a plot on the ground, counting trees within a certain distance of a path, or counting trees in some part of an aerial photograph.

Species

After establishing the presence or absence of a tree, the next most important feature of the tree is the species. In some cases, such as plantation forestry, the species is clearly defined, as a decision will have been made to plant a certain species. In other cases, such as natural forest inventory, there may be a wide range of species.

Species identification should be given careful consideration when any form of forest mensuration is being considered. Different species have different economic and social values. Identification of species should ensure that the most valuable species are readily identified, as well as the most common species.

All field staff should be well trained in species identification. In regions where certain species may have different common names, care should be taken that standard names are used. Care should also be taken to ensure that the same name is not used for different species in different regions.

Diameter

The size of a tree is best described with the diameter of the tree. In forestry, diameter should always be used for the description of the tree. In the past girth has been used, but this is now no longer recommended.

Diameter is best measured with a diameter tape, which is a tape marked with units that convert the girth to the diameter. It is important to make sure that a correctly calibrated tape is used. If an ordinary tape is used, the diameter will be overestimated by more than 300%.

A carefully defined point should be used for measuring the diameter of the tree. In many cases, especially plantation forestry, this will be at 1.3 m above the base of the tree, measured from where the tree meets the ground.

Figure 2 Correct measurement of diameter

The diameter of each tree should be measured in centimetres to one decimal point (e.g. "14.7") with a diameter tape at a point 1.3 m from the base of the tree, measured on the uphill side of the tree. This is defined as 'diameter breast height', or dbh.

It is sometimes necessary to move the measurement point up or down from 1.3 m to avoid unrepresentative measurements if there is a stem irregularity or significant stem buttress. It is better to make a true measurement than to attempt to make an averaged measurement, as averaged measurements are often calculated incorrectly.

Diameters should be recorded on the sample plot sheet to one decimal place, e.g. "11.3".

For some species, notably tropical rainforest species, buttressing will make a measurement at this point meaningless. Buttressing can also mean that diameter is better measured with a diameter stick.

In the case of severe buttressing, the diameter above buttress is the usual measurement collected. Field crew should be carefully instructed on how to define the point of measurement.

Figure 3 Example of tree with severe buttress

When a tape is used for the measurement, the tree should be cleared of all loose bark and vines, and the tape wrapped tightly around the tree, so that the smallest measurement is taken. The tape should be placed around the tree so that the numbers can be read directly.

Never permit field crews to take measurements with a tape held upside-down.

Height

After the diameter, height is the next most important variable that can be measured on the tree. The height that is being measured must be clearly defined. Height measurements that can be collected include total height, height of dominant leader, height to lowest green branch, height to crown break, and pruned height. The field crew must be in no doubt over what height is to be measured.

The team leader should be careful to ensure that only representative trees are measured. He should not measure short trees with large diameters, or tall trees with small diameters.

In mixed species stands a range of species should be included in the height tree sample.

Height can be measured directly for small trees, by holding a height pole beside the tree. The pole should be placed as close to the base of the tree as possible, on the uphill side of the tree. The height should be read from the tree by an observer standing at right angle to the tree.

Height can also be measured indirectly with a hypsometer, which is a tool for measuring the angle from the observer to a point. The observer must pick a suitable point, where the top and the bottom of the tree can be seen. In some cases the bottom of the tree may be obscured, and another point picked on the tree as a measurement datum.

The observer must measure the distance from the tree to the observation point, and then read the angle to the top of the tree, and the bottom of the tree, or to the datum point. The height of the tree can be calculated from these measurements, either with a calculator, or with a table of heights.

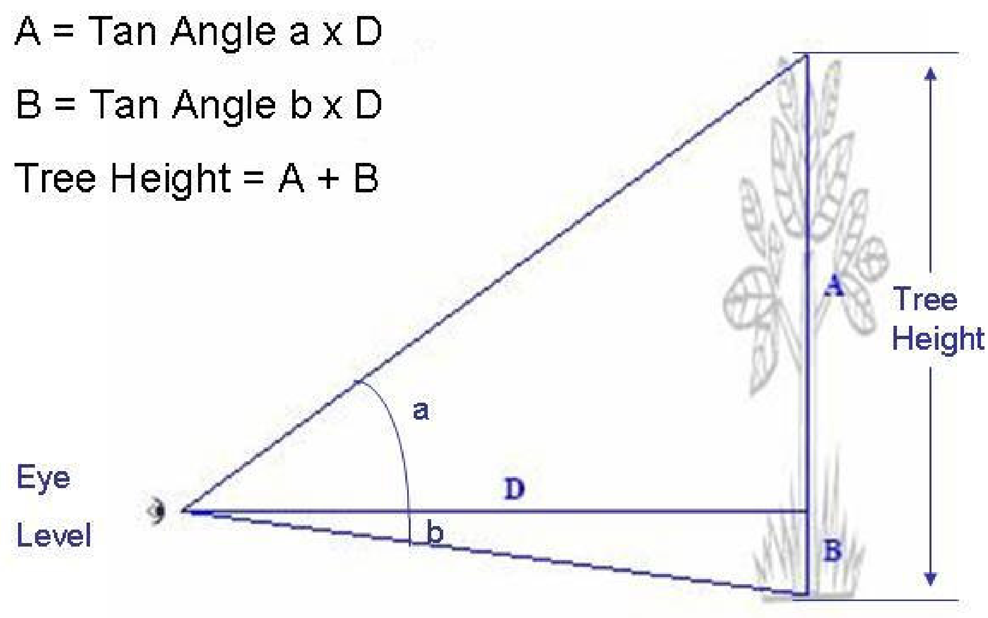

Figure 4 Trigonometry of tree height calculation

Some hypsometers come with a range finder. This is a graduated pole that the observer views through a prism, to find a point at a certain distance from the tree. If a range finder is used, the angles from the hypsometer can be converted directly into height readings.

Because a prism is used for finding the observation point, the range finder automatically corrects for any ground slope. This means that the nominal distance read from the range finder is not the exact distance.

> **Never use a range finder distance to calculate a height with a calculator or set of height tables**

Measuring heights with the Suunto PM-5

The Suunto PM-5 can be used to measure heights directly or indirectly. The PM-5 has two scales for reading heights directly, and an angle correction chart on the side.

Direct height measurement

To read a height directly, the observer should use a tape to locate a position exactly either 15 m, 20 m, 30 m, or 40 m from the tree measured horizontally. The distance should be more than the height of the tree.

The observer then sights the tree through the PM-5, so that the top of the tree can be seen to the left of the scale. The left scale shows the height for a 20 m distance. The right scale shows the height for a 15m distance. For 30m or 40 m distances the reading from the PM=5 must be doubled.

The observer should take a reading to the top of the tree, and then a reading to the bottom of the tree, and add the two readings together to get the total height of the tree.

NB. When taking the lower reading, be careful! If the reading is down, like in the example in Figure 4 above, the scale will be negative. The absolute value should be added to get the total. For example, if the scale shows -2.5, 2.5 m should be added to the upper reading.

If the lower reading is up, then the scale will read positive, BUT the value should be subtracted from the upper reading. So if the scale shows +2.5, then 2.5 m should be SUBTRACTED from the upper reading.

NB. If the lower reading is up, how was the distance measured? Best practice is not to measure heights from a position below the base of the tree.

Indirect height measurement

Many times it will not be possible to locate a position exactly 15 m, 20 m, 30 m, or 40 m from the tree where the observer can see the top and the bottom of the tree. In these cases the height must be calculated indirectly. The best way to do this is to take the measurements in the field, and calculate the height later back in the office.

The procedure to be followed is this.

1. Locate a position where the top of the tree can be seen, as well as part of lower 2 m of the tree.
2. Record the distance from the observer's eye to the lower part of the tree, which is called the datum.
3. Record the height to the datum
4. Read the left (20 m) scale of the PM-5 to the top of the tree.
5. Convert the reading to the angle to the top of the tree using the conversion on the side of the PM-5 and record this angle
6. Read the left (20 m) scale of the PM-5 to the datum, convert the reading to an angle, and record the angle. Remember that the angle is usually negative.

When a height is measured indirectly, the distance from the tree should be more than the height of the tree, so that the upper angle is less than 45 degrees.

Bark Thickness

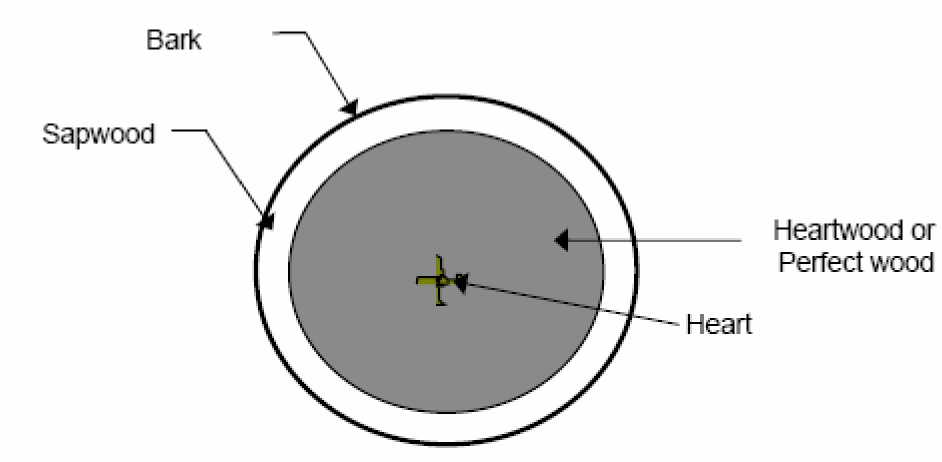

Figure 5 Cross section through a tree

Some species have bark that sheds, and others retain their bark. This means that some older trees can have an extremely thick bark, or a bark that varies in thickness. In most cases the valuable section of the tree is not the bark, and so measurements must be taken of the bark thickness.

Bark thickness can be measured on a standing tree with a bark gauge. Commercial bark gauges can be bought that have a scale calibrated on the gauge, and which have a handle suitable for use. The gauge is placed against the tree, and the sharp cutting edge is pushed until the wood is hit. The thickness of the bark is read from the gauge.

Commercial gauges may not be available, or may be too expensive. A bark gauge can be made from a chisel or screwdriver, by filling graduations into the side of the instrument.

When using a bark gauge, it is important that the gauge is pushed though the bark, but not into the timber. The field crew should practise the technique before collecting measurements.

Some species have bark that is too hard to penetrate with a bark gauge. These species may have their bark thickness measured by cutting the bark off with an axe. If the species is a particularly valuable one, the axe wound should be painted with a substance designed to prevent wood rot.

Some species have a deeply fissured bark. The bark thickness is collected to allow an estimate of under bark diameter, and so the bark thickness should be taken at points around the tree to give an average thickness.

Log Measurement

Log measurement is an important basic mensurational skill. There are considerable similarities between measuring logs and measuring trees, as the basic attributes are similar, but log measurement has a special set of problems, as the log may come from any section of the tree, and as such, will vary in shape.

Logs can be measured at various points, ranging from in the forest at the stump, to at a skid site, on a logging truck, or at the mill. The point selected for the assessment should be carefully considered. Measurement at the stump may be appropriate for high value species, while measurement at the skid site may allow more efficient use of resources.

Diameter

Diameter is the most important variable measured on a log. Log diameter may be measured at a number of points, depending on the value of the log, and the shape of the log. For high value straight logs, measurements can be taken at both ends and in the centre. Volume functions are available which can calculate the volume from such measurements.

Lower volume logs can be measured at one point, typically the mid-point. Alternatively, in high volume operations, the small end diameter may be selected as the measurement point. The decision where to measure the diameter is influenced by the measurement location. Midpoint diameters cannot be collected from logs in a stack or on a truck.

When the diameter is measured, allowance should be made for any log distortion. Cankers, abnormalities, and buttressing should not be included in the measurement, which should reflect a normal stem form. This applies to both log end measurement and midpoint measurement.

Length

The length of the log is an important variable for calculating the volume of the log. Length should be measured after the log has been cut to its final size.

The length measured is generally the shortest distance between the cleanly sawn ends of the log. If the log end is uneven, the log should be measured to the nearest normal section, with allowance being made for trimming the log. Total log length is used for volume calculations.

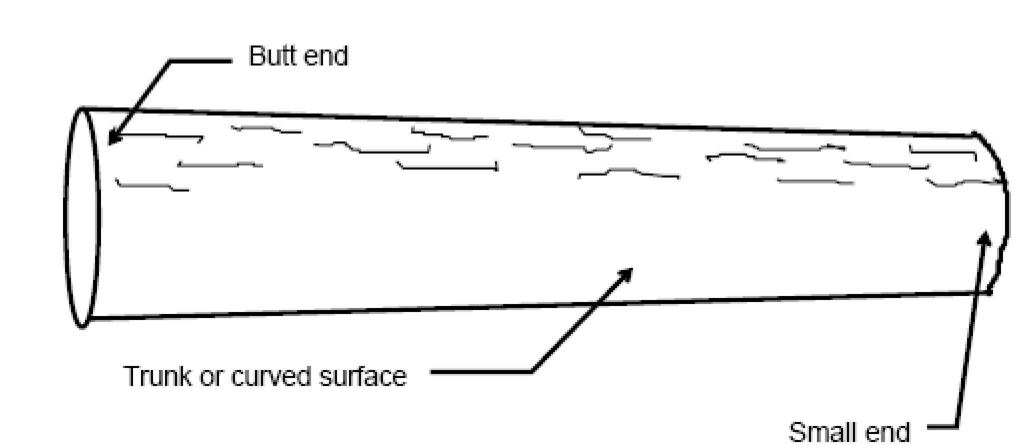

Figure 6 A simplified diagram of a log

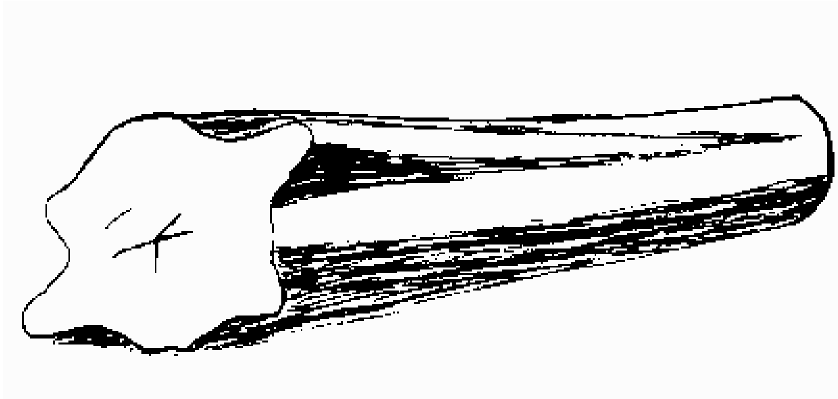

Figure 7 An example of a typical tropical log

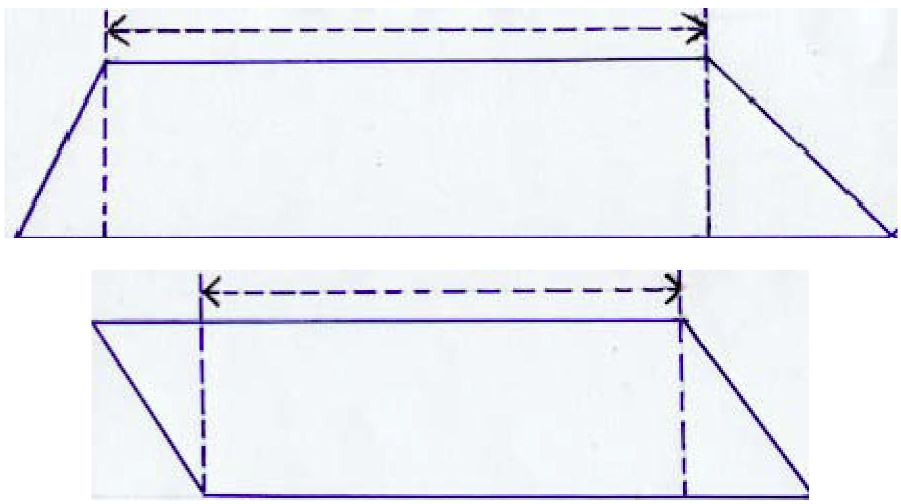

Figure 8 Examples of differing commercial lengths

Weight

An alternative to measuring individual logs is weight scaling. This will require the presence of some mechanism for weighing logs, usually a weighbridge scale. The principle is to weigh a loaded truck and subtract the weight of the truck, to get the weight of the logs. The weight of the logs can be converted to a volume, by the use of conversion factors.

Weight conversion factors should be prepared for each log type that is being assessed. There are many factors that need to be taken into account, such as the age, position in the tree, the amount of bark still on the logs, and the moisture content of the logs. For an accurate conversion, the truck should be carrying similar logs, of the same species, same moisture content, and same felling period.

> **If appropriate weight conversions are not used, the volumes calculated can be extremely inaccurate.**

Area Measurement

Measurements collected from trees need to be converted to area based information for management decisions. This requires the measurement of the area where the information is collected. The typical method is to establish a sample plot, measure the trees within the plot, and convert the tree measurements to area measurements using the known area of the sample plot.

Plot shape and size

There are a variety of plot shapes that can be used in forest mensuration. These include square, rectangular, diamond, and circular.

Laying out a sample plot involves deciding the size to use, calculating the dimensions, and location the plot in the forest.

The plot size is affected by forest conditions such as terrain and stocking, as well as the number of years the plot is likely to be observed. For plantation forestry, smaller plots can be used. One guideline is that the plot should contain at least 20 trees at the end of the plot's life.

Tropical forest requires larger plots, as the range of species can be considerable. The plot size should ensure that empty plots are infrequent.

Slope correction

When plots are being established, the area to be sampled is the flat projected area. This means that the actual dimensions of the plot on the forest floor need to be calculated considering slope corrections. For a square or rectangular plot, each side must have an individual slope correction. If the slope is even, a diamond plot can be established, with two corners across the slope, and two corners up and down the slope. If circular plots are established, the radius of the plot must be increased to ensure that a large enough area is sampled.

Use of a GPS (Geographic Positioning System)

GPS basics

A GPS is an instrument which uses data collected from satellites to calculate the position of the GPS on the earth. The GPS uses information from as many satellites as it can locate. The more satellites the GPS can locate, the more accurate the position estimate is.

The GPS works out the position by calculating how long the signal from each satellite takes to reach the GPS unit. The satellite radio signals are not very strong, which means that the GSP needs to have a clear view of the sky. Things like roofs and tall buildings can stop the signal. In a car, the radio signal can easily go through glass, but not steel. This means that a GPS will get a more accurate reading when the unit is sitting on the dashboard than when it is inside the car.

This means that GPSs have problems working under forest canopy. The GPS will provide a more accurate position out in the open. Unfortunately we usually have to work under the trees. However, modern GPS units can often give a fairly accurate position under tree canopy when they have been outside the canopy at the previous time.

GPS configuration

A GPS has a number of settings which can be used to make sure that the information the GPS provides is suitable. These include:

- Scale. The GPS should be set to the measurement scale used locally. For St Lucia this is the metric scale.
- Time. Some GPSs can be set to a different time than that of the location of use. This is usually only of use for aviation and marine uses. For St Lucia the GPS should be set for UT -4, with no daylight savings.
- Map Datum. GPS units use a map datum to correct for differences in the shape of the earth. For St Lucia the GPS should be set to North American Datum 1927, or NAD27.
- Compass True or Magnetic. The GPS can be set to show the True bearing or Magnetic bearing. For most uses the True bearing should be selected.
- Coordinate system. The GPS unit can show the location in different coordinate systems. For the St Lucia inventory the UTM coordinate system will be used.

GPS use

For forest inventory the GPS is mainly used for navigation and for recording positions. A GPS can show the direction that the unit is travelling when it is not staying still. This can help when moving along a compass bearing. However a compass is more reliable in many cases.

The GPS can show the speed of travel, and can show the direction o a certain point. This can be used in inventory to move to a random point. Random points are sometimes used in inventory, although not usually in natural forest inventory.

The main use of the GPS in forest inventory is to record the location of a sample plot. The GPS operator should be positioned in the centre of the sample plot, and a waypoint recorded. A waypoint is a position stored in the GPS.

Exercises

1. Give an example of a species in which the bark is the most valuable part of the tree.

2. A 50 metre by 100 metre sample plot was established in an area of forest in which logging of trees over 60 cm in diameter is permitted. The measurements shown in Table 1below were collected.

   i. What is the total stocking of the plot?

   ii. What is the stocking of the species SMAC?

   iii. What is the stocking of harvestable stems?

3. What is the estimated volume of a 5 metre log with a midpoint diameter of 60 cm?

4. A 100 metre by 50 metre sample plot is to be established in an area of forest with an even 15 degree slope. The plot will be established with the 100 metre side running directly up the slope.

   i. What slope distance should be used for the 100 metre side?

   ii. What slope distance should be used for the 50 metre side?

SPECIES	DBH	SPECIES	DBH	SPECIES	DBH
SMAC	44.8	LAGL	9.5	DEDE	5.8
GOMM	55.2	SMAC	69.4	BACH	5.7
GOMM	7.8	MERI	36.5	ANGE	7.4
SMAC	98.6	SMAC	10.5	BOBL	8.4
BTAN	9.9	DELM	100.6	DELM	11.5
BRIV	10.3	DELM	85.6	DELM	10.5
SMAC	98.2	POMM	8.4	POMM	9.9
BTAN	14.6	MERI	84.4	MERI	29.2
LAUR	75.2	SMAC	5.8	SMAC	10.9
SMAC	12.5	LAGL	6.8	LAGL	28.7
SMAC	4.7	BOPA	72.1	DELM	34.5
LAUR	89.7	SMAC	142.3	DELM	4.7
LAGL	8.8	BALA	89.7	POMM	7.6
SMAC	7.8	BOPA	23.4	MERI	7.8

Table 1 Sample plot measurements for exercise

Slope (degrees)	Plot Size (ha.)							
	0.010	0.025	0.040	0.050	0.060	0.075	0.080	0.100
0	7.1	11.2	14.1	15.8	17.3	19.4	20.0	22.4
5	7.1	11.2	14.2	15.8	17.4	19.4	20.0	22.4
10	7.1	11.3	14.3	15.9	17.5	19.5	20.2	22.5
15	7.2	11.4	14.4	16.1	17.6	19.7	20.3	22.8
20	7.3	11.5	14.6	16.3	17.9	20.0	20.6	23.1
25	7.4	11.7	14.9	16.6	18.2	20.3	21.0	23.5
30	7.6	12.0	15.2	17.0	18.6	20.8	21.5	24.0
35	7.8	12.4	15.6	17.5	19.1	21.4	22.1	24.7
40	8.1	12.8	16.2	18.1	19.8	22.1	22.9	25.5

Table 2 Slope correction table for diamond plots

Strip width (m)	4	6	6	8	8	10	10	10
Slope (degrees)	**Plot Size (ha.)**							
	0.010	0.020	0.030	0.040	0.050	0.050	0.075	0.100
0	25.0	33.3	50.0	50.0	62.5	50.0	75.0	100.0
5	25.1	33.5	50.2	50.2	62.7	50.2	75.3	100.4
10	25.4	33.8	50.8	50.8	63.5	50.8	76.2	101.5
15	25.9	34.5	51.8	51.8	64.7	51.8	77.6	103.5
20	26.6	35.5	53.2	53.2	66.5	53.2	79.8	106.4
25	27.6	36.8	55.2	55.2	69.0	55.2	82.8	110.3
30	28.9	38.5	57.7	57.7	72.2	57.7	86.6	115.5
35	30.5	40.7	61.0	61.0	76.3	61.0	91.6	122.1
40	32.6	43.5	65.3	65.3	81.6	65.3	97.9	130.5

Table 3 Slope correction table for strip plots

Tropical Rainforest Inventory

Introduction

There are many reasons for conducting a forest inventory. At the heart is the desire to know more about the forest, for environmental reasons and commercial reasons.

Too often an inventory is begun from a sense of lack of knowledge, and a feeling that an inventory will fill all the gaps in a manager's knowledge of the forest. It will not.

Inventory can be conducted with a range of aims, including the following.

- To quantify what is there
- To quantify where is it
- To plan forest use
- To monitor change
- To monitor diversity
- To monitor harvesting

The key consideration at the start of the inventory is to ensure that the objectives of the inventory are clearly identified.

Objectives

The objectives of the inventory should establish what is to be assessed. This could include the following.

- Standing volume
- Standing value
- Harvestable volume
- Species distribution
- Floristic diversity
- Changes from past assessments

The number of elements that must be assessed will increase the cost of the inventory. There is a common mistaken belief that including many different elements can increase the value of an inventory. This can lead to an inventory becoming logistically complicated, with a subsequent increase in cost. The additional elements may influence the inventory unduly, to the extent that the principle aims are underachieved.

The required accuracy of the inventory will need to be determined. This should be realistically assessed, as the level of accuracy has a significant influence on the cost of the inventory.

What to measure

One of the first decisions is what to measure in the inventory. What is to be measured depends on the objectives of the inventory. There are a large number of variables that could include the following.

- Diameter
- Height
- Volume
- Biomass
- Crown structure
- Floristic composition
- Fauna
- Bio diversity
- Water

A key factor to be considered at this stage is the analysis of the results. One principle that must be adhered to is that the analysis must be predetermined. Every measurement collected must have a predetermined method of analysis.

Too often inventories will include measurements collected because someone thought that the information could be of value, and might as well be collected while the inventory team is there, with the analysis details to be worked out later.

Such information is never used, and adds greatly to the cost and difficulty of the inventory.

Integration

Other data sources should be considered. These could include the following

- Remote sensing data
- GIS
- Earlier inventories
- Growth models
- Planning systems

Such data should be used for planning the inventory. A previous inventory may provide information for stratification. Growth model plots may allow sampling with partial replacement to be used.

Stratification

One of the best methods of refining an inventory design is the use of stratification. Stratification may be required as part of the inventory design, as often estimates may be required for different regions.

Stratification allows some of the variation within a forest to be removed to variation between strata. The greater the difference between strata, the greater the reduction in variation, and the more efficient the inventory. Stratification reduces the number of samples required, which reduces the overall cost of the inventory.

Stratification should be based on information that is available before the inventory commences. This could include the following

- Land use
- Forest use type
- Forest type
- Geographic boundaries
- Socio-political boundaries

Field plots

The typical method of conducting a forest inventory is through the measurement of a field plot. Field plots provide a means of finding out what is in the forest, in a form which can be combined with other data, and which can be used for management planning.

Plot measurements should be collected by trained field crews who are capable of taking measurements that can be verified in a repeatable fashion.

Plot types

There are a considerable number of plot types. These include inventory plots and growth plots. Inventory plots are designed to find what is in the forest at a point in time, and are temporary. Growth plots are designed to measure what is in a forest, and at what rate the forest is growing over time, and are permanent.

Inventory plots and growth plots need different standards of measurement. As a growth plot will be remeasured, it is important that individual trees can be compared for growth over time. This requires a greater measurement precision. Temporary plots can be measured with tree callipers, as the resultant measurements provide an unbiased estimate of diameter, but this is not suitable for growth plots.

Inventory plot layout

There are many different plot designs. The design will depend on the objectives of the inventory. The basic designs are round plots, square or diamond plots, and rectangular plots. The strip plot is a form of rectangular plot often used in tropical rainforest inventory.

The design of the field plot should consider the plot size as well as the shape. The size of the plot is affected by the density of the population being assessed. The plot size should generally be large enough to ensure that an average of 10 individuals is in a plot. The inventory will be biased if too many empty plots are encountered.

An inventory may use a range of plot sizes, such as a series of concentric circles. An inner small plot may be used to capture data for smaller seedlings, with an intermediate plot size capturing information on medium size trees, and a larger radius capturing information on crown trees.

The choice of what plot should be used depends on many factors, not least the skill required to establish the plot, and the type of plot the staff involved are used to working with.

Attribute sampling

In many ecological surveys the estimate to be made may be the presence or absence of a species, or the proportion of individuals falling into a category. This is different from the estimation of the population total. In particular, the total population of a rare or infrequently observed species is difficult to estimate accurately using conventional sampling techniques. Under conventional estimation techniques, a high proportion of empty plots leads to a biased estimation of the population total.

A more suitable method of obtaining estimates for rare or infrequent species is to estimate the proportion of areas containing the species.

Such estimation is termed attribute sampling, or proportion sampling.

As in conventional forest sampling, the population is divided into sampling units. Instead of the variable of interest being the number or size of the individuals within the sampling unit, the variable observed is the presence or absence of the species of interest. If one or more individuals are present, the observation is recorded as a 1, and if no members of the species are present, the observation is recorded as 0.

The estimate of the proportion of the sampling units containing the species is

$p=a/n,$

where p is the sample proportion, a is the sum of sampling units containing one or more individuals, and n is the total sample size.

This estimate is an unbiased estimate of the population proportion.

The standard deviation of the estimate of p is estimated from

$$S_{\tilde{p}} = \sqrt{\frac{\tilde{p}(1-\tilde{p})(1-\frac{n}{N})}{(n-1)}}$$

where N is the total number of possible sampling units. In most cases, N is sufficiently large that the variance reduces to

$$s_{\tilde{p}} = \sqrt{\frac{\tilde{p}(1-\tilde{p})}{(n-1)}}$$

Field plot measurement

Every field plot should have the desired details recorded accurately, either on a plot sheet, or with a portable data recorder.

The plot sheet should include space for the plot location, which could include one or more of the following.

- Map sheet number
- State/division/region
- Forest district

The plot size should be recorded, and the forest type, both as according to any stratification in use, and as is found at the site. Other location information could include:

- land use category
- land form
- altitude
- slope
- aspect
- soil type

For all trees the information collected will typically include

- species
- diameter
- bark thickness
- height
- crown class
- defects

It is important to note that all information to be collected must be realistic. The field crew should be capable of recognising the major species in the area, and should be trained in diameter and height assessment. Diameters should be measure at predetermined points, such as above buttress, and all field crews should be recording the same measurements.

If plots are to be remeasured in future, trees should be identified with a suitable method, such as paint, or tags. Reference nails can be used to indicate the point of diameter measurement.

The standard measurement methods should be clearly laid out in a field manual, along with any codes that are to be used.

Random sampling design

Conventional statistical analysis requires that the population of interest, the forest, be divided into sampling units, each of which is equally likely to be sampled. This condition is usually meet by random sampling.

Simple random sampling requires the plots to be located wherever the random selection determines. Simple random sampling is generally not efficient, and often impractical. The analysis is comparatively simple.

Stratified random sampling can reduce the number of plots, but is again often impractical.

Systematic sampling design

Systematic sampling violates the basic assumption that each sampling unit is equally likely to be selected. In systematic sampling a line is selected, and plots placed at regular intervals. This means that after the line has been selected, many sampling units are predetermined.

The theoretical objections to systematic sampling can be reduced by randomising the location of plots along the sampling lines. This allows the logistic advantages of stratified sampling to be captured, and minimises the departure from theoretical optimality.

Calculations

After the data has been collected, the inventory analysis will need to use standard calculation methods. These should be prepared before the inventory has commenced. If this is not possible, the analysis methods should be tested on the first data to be collected, and the field methods refined if necessary.

Tree volumes may need to be prepared, and the equation form should be considered before data collection.

The summary information from the inventory must be prepared to answer the questions the inventory was designed for. Any utilisation figures must reflect current utilisation standards, including merchantability criteria, and suitability of species.

Computer systems for processing field data

The processing of the field data should be considered at the start of the inventory. Computers should be used to ensure that the processing is carried out accurately, and quickly.

Any computer systems should be flexible enough to meet any changing needs. Complex systems should be avoided, as the training required may mean that the system may not be able to be maintained at all times.

The equipment should be appropriate to the circumstances, and should be given necessary protection. This may require an air conditioned room.

All systems should be well documented, so that the users can keep the system running without the assistance of costly specialists.

When computer systems are under consideration, remember that computers are now a disposable item, and the cheapest system that will do the current job should be selected. Money can be wasted by attempting to buy a system which is intended to be used for another purpose at the end if the inventory. This can lead to a system which is too powerful for current uses, and which is too slow for future uses.

Integration

An inventory is a snap shot in time. For effective forest management, the inventory must be integrated over time with alternative sources of data. These may include

- Remote sensing
- Aerial photography
- GIS
- New technologies

Information from other agencies and other inventories may be of value.

The inventory design should ensure that the results of the inventory can be used with growth models in a planning system.

Remote sensing

Remote sensing is the use of information from a range of sources for forest analysis. These sources include Landsat and SPOT satellite imagery, as well as a variety of radar imaging techniques.

Remote sensing is a powerful source of information, but demands a high degree of technical skill. A combination of ground truthing and remote information is needed.

It must be remembered that forest managers use areas of land, not pixels. Remote sensing cannot be used in isolation.

Geographical information systems

Geographic information systems have developed considerably in the past few years. However there is a tendency to regard the GIS as the solution to all problems, which it is not.

A GIS system is highly demanding, and requires a considerable degree of technical training, as well as powerful computer hardware and software. The training requirements mean that implementing a GIS is likely to require a considerable training budget, which is often overlooked.

Setting up a GIS system is complex and time consuming. Such systems can provide a considerable amount of data for forest managers, but typically take over two years to implement.

Complete systems integration

The ultimate desire of forest managers is a completely integrated forest management and planning system. This is not a practical aim, although it often appears so.

The different components of such a system are continually changing, and as such the maintenance of the system can come to take up more time than if separate systems were used. The complexity of the system can rise to the extent that very few system users understand more than a part of the system. At this point, the benefits of integration have been lost.

The most desirable system is one that permits related systems to exchange data with ease, yet allows individual systems to be operated by different users, without unnecessary complexity.

People

One of the key considerations in any inventory is the people involved. For an inventory to be successful, a wide range of skills and training is required. The inventory design must be made with the assistance of someone who has a high degree of training and experience. As the effectiveness of the inventory depends on the design, the design should not be left to chance. Here is one of the places that a consultant can provide best return for the cost. A short term consultant can be used to either assist in the preparation, or fine tuning of the inventory.

The field staff is best picked from people with experience of the local conditions. The staff selection should always be made bearing in mind that a combination of local experience and inventory experience will provide a strong team.

Staff training should ensure that all members of the team are skilled in the major points of the inventory. Some specialist training may be needed, for example, in the use of point sampling or relaskopes. Training should not be rushed, and should be followed by spot checks, and plots audits, where a plot is remeasured to ensure the measurements are being taken correctly.

Summary

The inventory must be driven by the forest managers needs, not their wants. Technicians who understand their own technology, but not the needs of users should not unduly affect the inventory.

Specialists and consultants should be used to ensure that the inventory is carried out efficiently, but the forest manager should ensure that the specialists don’t change the inventory to reflect their past experience.

The inventory manager should never lose sight of the overall objectives that were defined at the start of the inventory. The manager should stop from time to time, and consider whether these objectives are being met.

Exercises

1. A forest manager has been asked to provide an estimate of how much timber is in a 20 hectare block of eucalypts which was planted on a flat area of land after logging in the mid 1960's. What method of sampling should he consider, and what measurements should be taken?

2. A provincial governor has asked his forestry division how long it will be before the natural forests in his province run out of wood, at the current rate of harvest. What objectives should the forestry division set for the inventory required to answer the governor's request?

3. An inventory is to be conducted on an island that is dominated by a ridge running from north to south. The west side of the island is known as the wet side, and the east side of the island has a popular tourist resort. What is one of the first considerations the designer of the inventory should consider? Why?

4. A common system for conducting forest inventories in tropical rainforest is the strip plot, where a continuous strip of forest is measured, at a predefined width. What are the advantages and disadvantages of this system?

5. An ecologist wishes to determine the proportion of a 15,000 hectare forest in her area that contains a particular shrub. Local environmentalists have stated that the shrub is rare, defined as present in less than 5% of the forest, and must be protected, by closure of the forest to logging. The ecologist has designed an inventory, where 182 randomly selected sites were visited, and the presence or absence of the shrub noted. The shrub was found at 8 of the sites. Does this inventory support the environmentalist's case?

Field Exercise notes

Exercise 1. DBH measurement

Exercise 2. Direct height measurement

Exercise 3. Use of GPS

Exercise 4. Plot layout

Exercise 5. Indirect height measurement