Manual for Measurement and Monitoring of Carbon Stocks in Forests and Other Land Uses in Ethiopia

DRAFT

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1. INTRODUCTION

Forests, both as sources and sinks of carbon, have the potential to form an important component in efforts to combat global climate change because of the link between climate change and accumulation of green house gases in the atmosphere from land use changes. Consequently, carbon forest projects have recently been flourishing, and carbon in forest ecosystems is becoming an increasingly important estimate from large scale forest inventories.

Access to carbon financing is at the core of several discussions and negotiations on climate change issues at least since the Kyoto protocol. For long Ethiopia has not been engaged in carbon trading perhaps due to lack of comprehensive, reliable and verified protocol for assessment and monitoring of forest carbon stocks and general lack of technical capability to deal with sophisticated requirements and highly bureaucratic procedure to access carbon finances. However, some forest carbon projects notably CDM and REDD are emerging often developed with the assistance of expatriates, and are opening avenues to access financial resources, which can be used catalyze sustainable forest management activities, and provide an economic incentive for government and for improvement of livelihoods of local communities.

Carbon accounting in a forest is one of the most crucial steps for successful implementation of forest carbon projects. Among others, successful forest carbon programs require reliable, accurate, and cost-effective methods for measurement and monitoring of forest carbon storage. The process needs to meet international standards while being cost-effective and easier handled by local capacities. The Ethiopian Climate Change Research and Networking (ECCR-net) has recognized the need for a standard manual for forest carbon stock estimation and monitoring combined with conventional forest inventory that meet the specificities of Ethiopian forests and its technical capability. Thus, developing standard guidelines and procedures for conducting credible field based surveys of forest carbon is the objective of ECCR-net and believes that it is urgently needed for Ethiopia. This user-friendly and simplified manual originated from

this understanding. In view of this, we develop this manual for guiding field and laboratory measurements for estimating carbon stocks in forests and other high carbon density land uses (e.g., agroforestry systems).

According to the IPPC forest ecosystems consist of the following broad carbon pools: the aboveground biomass carbon, which includes (1) carbon in the living biomass of trees and (2) in the understorey/herbaceous vegetation biomass, (3) carbon in belowground biomass (roots), (4) carbon in the dead mass of litter and (5) in woody debris, and (6) soil organic carbon. Forest management activities affect the exchange of CO_2 between these pools and the atmosphere, and hence sustainability of forest management practices should be adapted to enhance carbon sequestration while at the same time reducing green house gas emission. This calls for applying multiple objectives forest management planning approach; an approach that integrates values of forest carbon and other environmental services with values of various forest products (timber, fuelwood, NTFP, etc). The importance of, and the need for , multiple objectives forest management planning for the developing climate change resilient and economically viable forest resources in Ethiopia is recently articulated in a literature review document commissioned by UNDP (Yitebitu et al, 2010). This forest carbon assessment manual is a continuity of our literature reviewing work; which is intended to be a standard reference for designing forest (carbon) inventory and monitoring system in conjunction with sustainable forest management system.

In this manual, specific methods, field and laboratory procedures with the required equipment and tools for measuring and monitoring forest carbon are presented. Additionally, to accommodate the data requirements of multiple objectives forest management, the manual focuses not only on forest carbon assessment, it also provides guidelines for measuring forest growth stocks, regeneration and changes in forest ecosystem.

The guidelines and procedures presented in this manual have drawn information from standard forest inventory, soil science, ecology literature, besides the existing generic and specific forest (carbon) inventory manuals developed so far. The procedures are

designed for use by field assistants, researchers, academicians, high-level professionals or experts in forestry, soil science and climatology. expected users include the Designated National Authority (DNA) for climate change, forest enterprises, organizations engaged in developing and managing carbon projects, research and academic institutions. Although the manual is largely simplified and user friendly, at some stage such as using remote sensing and GIS techniques, involvement of experts or training for the non-experts on these areas will be needed. The guidelines and procedures described in this manual intended to provide cost effective, accurate and credible accounting of carbon storage in forest and related land uses; and to provide practical considerations for establishing permanent sample plots for quantitative monitoring of carbon and forest management data over time.

The manual is organized in three main sections, with annexes at the end:

- Chapter 1 is about planning phase of forest carbon inventory (Remote sending techniques until map production and inventory design)
- Chapter two deals with data collection phase (field and laboratory procedures)
- Chapter three is about data analysis and reporting phase (mathematical summary of estimates for the five pools and necessary statistical analysis and reporting).

Finally, field and laboratory measurements recording forms (Appendix 1), useful secondary data available for carbon estimation (growth models, yield tables, volume tables, and fieldwork support data) are presented at the end of the main document as Appendixes.

2. PLANNING PHASE FOR FOREST INVENTORY

2.1. Why Ethiopia needs a standard Forest and Carbon Inventory Protocol?

Ethiopia needs to have a standard forest (carbon) inventory protocol that needs to be adopted by a national forest or related authority (e.g., DNA) in order to:

- to produce consistent inventory data and summary statistics nationwide,
- to provide users with a common source for integrated Forest Inventory and Analysis (FIA) and
- to estimate changes in forest land area, timber volume and carbon stocks between successive FIAs.

2.2 Overview of phases required to finalize a forest (carbon) inventory

Forest (carbon) inventory consists of the whole process of forest carbon measurement from getting to know the project area, initial delineation of a project area and stratification, sampling design, taking measurements in the field and laboratory, analyzing the acquired data to reporting the results. three main phase are required to accomplish forest and forest carbon inventory.

Phase I: Preparatory Phase

In the first place, carefully study the purpose (objectives) of the assignment and select the right materials and methods needed to accomplish your tasks.

The objectives have to be SMART (Specific, Measurable, Achievable, Relevant and Time bound). Why SMART?

Specific objectives must be very clear and detailed enough so as to leave no room for ambiguity or misinterpretation.

Measurable Always use a verifiable verb and describe an action that can be seen and measured.

Achievable objectives should always be achievable.

Relevant objectives should be relevant to the performer – they should relate to the objectives that matter to that person.

Time bound objectives are more effective if they are to be achieved within a defined time frame.

Basically two main tasks have to be satisfied in the planning phase.

1. Review of the relevant literature to get to know the project area and identify gaps and overlaps of knowledge, and
2. Map production showing project area boundaries, stratification and clearly defined sampling design.

Phase II: Data collection

Once the inventory planning is done, data collection involves taking measurements on the required parameters in the field and in laboratory. Globally accepted procedures should be followed for accomplishing the task of data collection.

Phase III: Data analysis and reporting

Another major task to be accomplished after the data collection is completed is data analysis of various carbon pools measured in forests. Data analysis also involves final map production from spatial data.

The following diagram summarizes the major steps in forest (carbon) inventory:

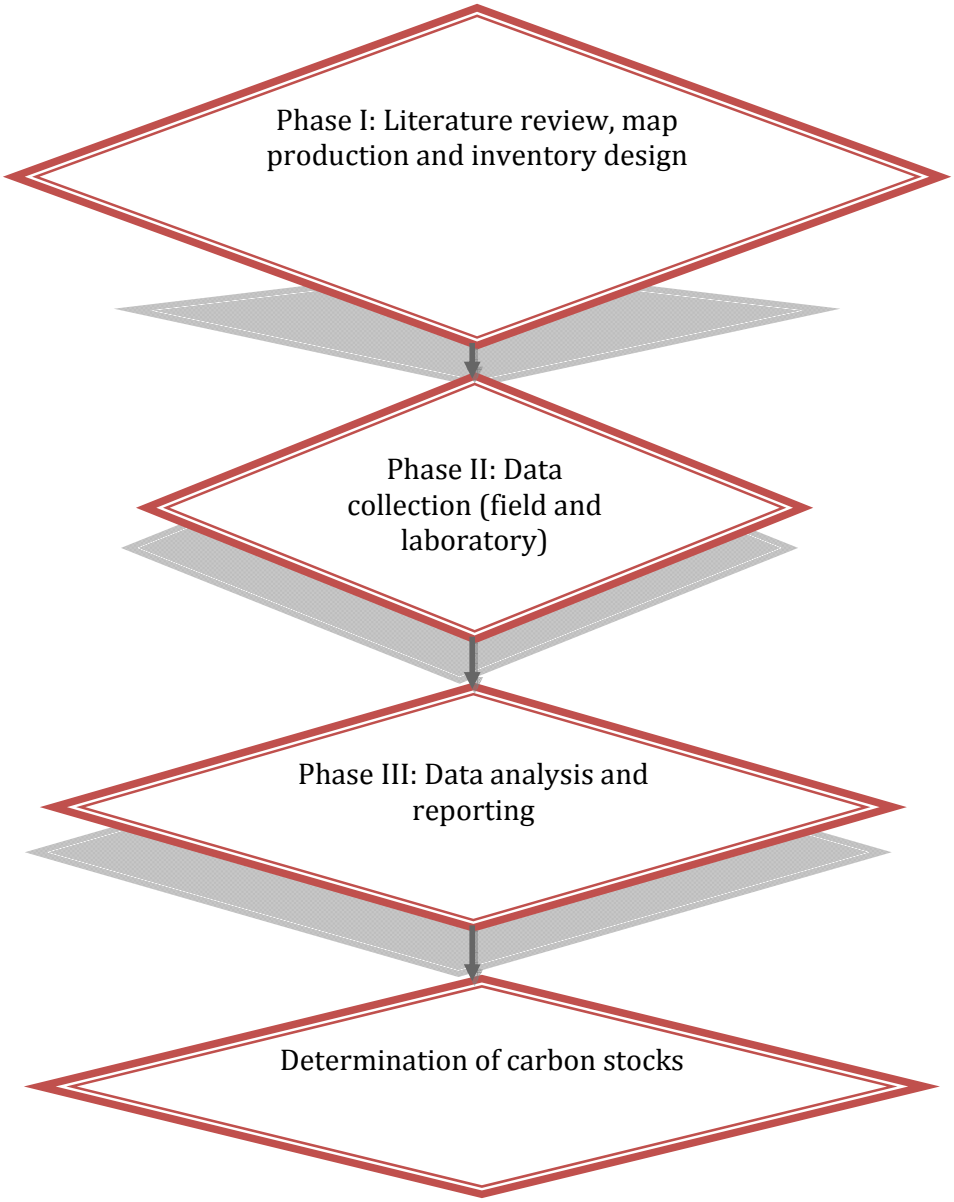


Figure 2-1 Phases in forest and carbon inventory
(Source: Jansen et al, 2003)

2.3 Equipment required for conducting forest (carbon) inventory

Table 2-1Equipment an tolls for forest and carbon inventory

No	Item	Purpose
Planning tools : Remote sensing and GIS tools		
1	Satellite imageries, RADAR images,	Spatial data for map production (boundary delineation and stratification
3	GIS software: ArcGIS, ILWIS, ERDAS, etc	Spatial data analysis
4	Computers and printers, digitizers	Processing and map production
5	Topographic map	
Equipment for field work_ permanent plot establishment		
5	GPS	Boundary survey, stratification, and locating plots
6	Base map	Plot navigation
7	Rope	Plot boundary delineation
8	Linear tape	For locating plot boundary and distance measurement
9	Chalk	For marking trees within the boundaries temporarily before permanent marking (tagging) and for ensuring that they are measured
10	Metal tags for tree	For permanent marking of trees
11	Metal tags for plot	For showing the direction of permanent plot from different vantage points
12	Enamel	For numbering metal tags
13	Brush	For numbering metal tags
14	Hammer	For fixing metal tags on tree
15	Cemented pillar/PVC pipe	For setting up the plot center
16	Spade	For digging and extracting soil
17	Nails	For placing the tags

NO	ITEM	PURPOSE
Equipment for fieldwork _ Leaf litter, herb/grass collection		
18	Frame (1m x 1m)	For delineating the sample collection area
19	Plastic bags	White plastic bags for collecting subsamples and big plastic bags to collect and weigh herb/grass and leaf litter
20	Cloth bags for twigs and woody parts	These materials from the litter or understorey vegetation should be collected in cloth bags as plastic bags may get torn
30	Knife and sickle	For cutting understorey vegetation
31	Scissors	For cutting understorey vegetation (woody)
32	Weighing scales	For weighing litter, herbs and grass; one allowing weights up to 10 kg , with a precision of 10 g for fresh samples and one with a 0.1 g precision for subsamples
Equipment for fieldwork _ Soil sample collection		
33	Metal scale or ruler	For measuring soil depth
34	Soil sample core	For collecting soil samples from various depths (also for root sampling, if needed)
35	Steel cylinders	For collecting samples from various depths for bulk density determination
36	Soil sample hammer	For bearing down on the soil core or steel cylinder while collecting sample
37	Munsell soil color chart	determining soil colour in field
38	Weighing scale	For weighing samples
Equipment for fieldwork _ Diameter and height measurement		
39	Linear tape	For measuring the distance between the tree and the measurer, and to establish plots
40	Diameter tape or caliper	To measure tree diameter at breast height
41	1.3 m long stick	To guide diameter at breast height measurement

Continued…

No	Item	Purpose
43	Spiegel Relaskop	To measure tree diameters at various points along the stem and height measurement
44	Clinometer/Hypsometer	For measuring ground slope and top and bottom angel to the tree

(Source: Sudeti et al (2010) and others

2.4 Details of planning phase

The planning phase should accomplish the tasks of understanding the task, literature review to check the existing knowledge and identify gaps about the task of forest inventory, delineating project area, stratification of the area, and choosing the inventory design.

2.4.1 Literature Review

Once the objectives are set, now it is easier to select reference materials for the task(s). Additionally any relevant studies conducted so far need to be reviewed. We don't need to do things that are already done: we don't need to waste resources. Therefore, literature review should be conducted not only to identify gaps but also to utilize information from works that are already done.

However, it must be noted that reviewing is not only one time activity. It should be updated every time until the study has been finalised, may be published. It should be also bear in mind that information from the Internet **is not always good!**. Peer-reviewed journal articles and officially declared documents are recommended.

At the end of the literature review at least we have some information about the study area, for example, type of forest (natural or plantation), broad land use type, the agro-ecological zone, and social-economic settings.

2.4.2. Delineating project boundary and stratification

Digital image classification

Depending on the scale of the work we need to collect reliable data in a cost effective way. In principle, there are two main categories of spatial data acquisition (Jansen et al, 2003):

i. ***Ground-based methods:*** such as making field observations, taking *in situ* measurements and performing land surveying. Using ground-based methods, you operate in the real world environment (Figure 2.2).

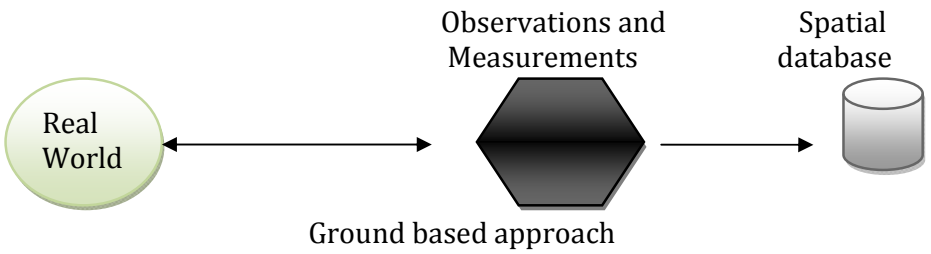


Figure 2-2 The principle of a ground-based method: measurements and observations are performed in real world

ii. ***Remote sensing methods:*** that are based on the use of image data acquired by a sensor such as aerial cameras, scanners or radar. Taking a remote sensing approach means that information is derived from the image data, which form a (limited) representation of the real world (Figure 2.3)

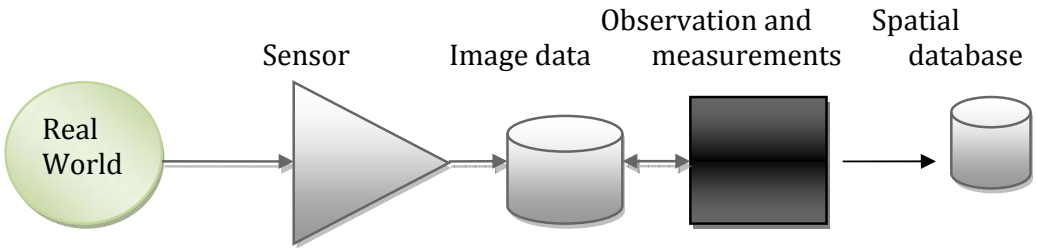


Figure 2-3 The principle of a remote sensing based method: measurements and analysis are

Remote sensing based approach

Remote sensing is a technique to obtain data on characteristics of the Earth's surface by a devise that is not in contact with the objects being measured. That means, unless our

knowledge limits us, we can get very important information about our project area using remote sensing without going to the field. In this manual principles of remote sensing will not be dealt as it is beyond its scope. It is assumed that either the users have basic knowledge on principles of remote sensing or they need to take training on basic remote sensing principles and practices.

ii. ***Combining the remote sensing and ground based methods:*** Remote sensing requires ground data. Although remote sensing data can be interpreted and processed without other information, the best results are obtained by linking remote sensing measurements to ground (or surface) measurements and observations (Figure 2-5)

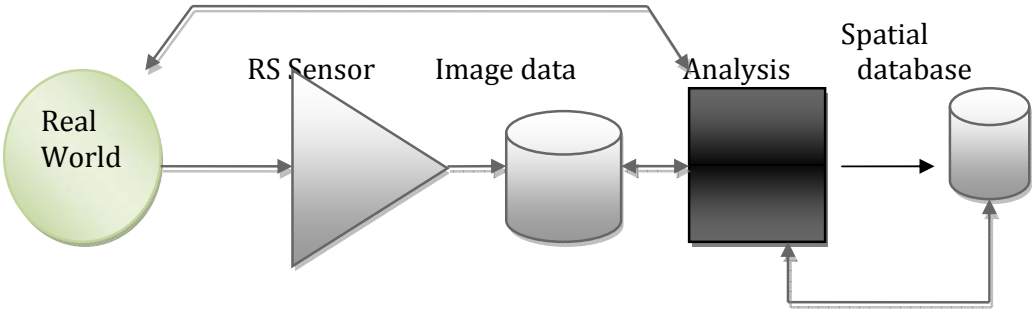


Figure 2-4 In most situations, remote sensing based data acquisition is complemented by ground-based measurements and observations

What kind of data exists in each stage?

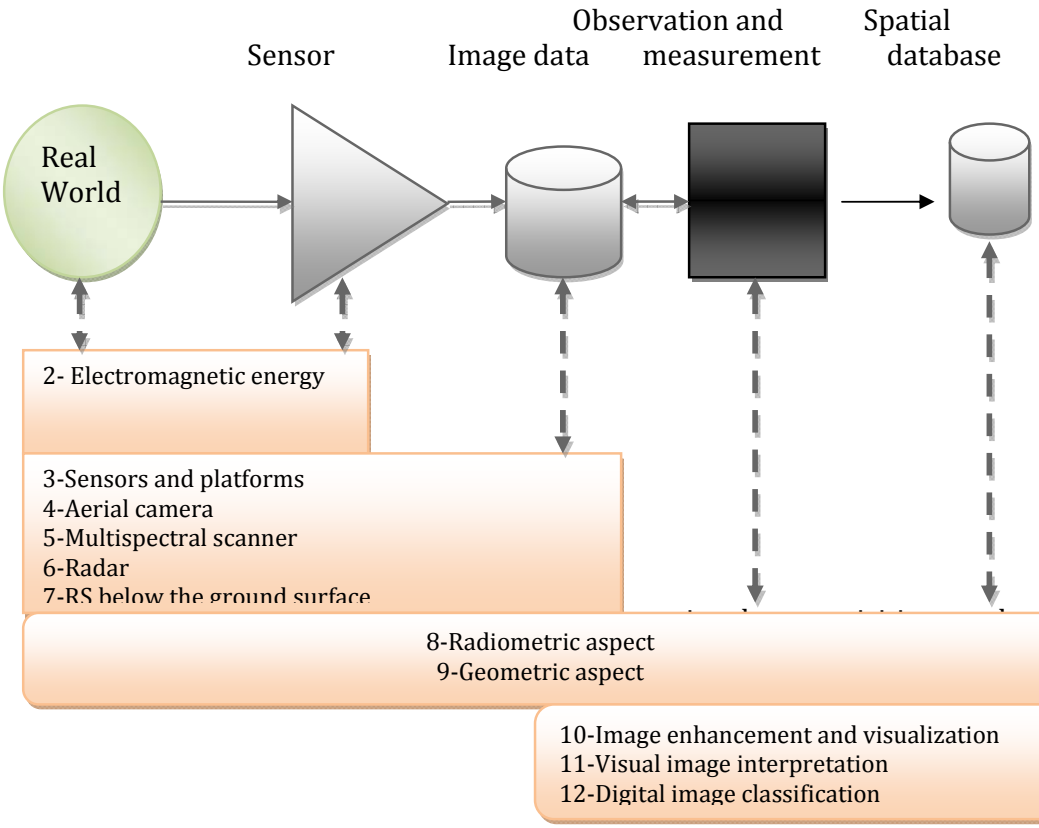


Figure 2-5 Remote sensing process

Source: ITC CourseBook

Satellite images are very important when large area assessment or forest inventory is needed. There are many types of image. The most applicable satellite images are: Land Sat ETM 7, ASTER, Ikonos, SPOT, and Radarsat.

Data selection criteria

1. Spatio-temporal characteristics
    a. Scale of the information-young plant, old growth, newly established forest may require different scale that the spatial resolution need to be considered
    b. Quality of images can be affected by shadow, cloud etc. the moment of image acquisition should be given due attention
    c. Seasonal cycles-leave fall, burning of vegetation etc affects the information we need to capture from the image
2. Availability of image data
    a. Investigating image availability (archive or request for new) and cost
3. Cost of image data
    a. Existing data from the archives are cheaper than data that have to be specifically ordered.
    b. The cost of vertical aerial photographs depend on the size of the area, the photo scale, the type of film and processing used and availability of aerial reconnaissance companies

(Source: ITC course book)

The resolution of a satellite sensor is an important aspect of the applicability of remote sensing images. The spatial resolution is the size of raster cells of the image. Before we order the image data we need to know the minimum area we would like to map.

Table 2-2 Applicability of remote sensing images

SENSOR & RESOLUTION	**MINIMUM MAPPING UNIT (CHANGE)**	**OBSERVED PHENOMENA**
Coarse (250-1000 m)	10~100 ha	Coarse land objects (large lakes, natural vs. agricultural areas, etc.)
Medium (10-60 m)	0.5~5 ha	Field level (farm parcels, forest boundaries, roads, etc.)
Fine (<5 m)	<0.1 ha	Structure of surface elements, such as trees or houses

Source: Ethiopian REDD R-PP document, 2010

For natural resources management in general and forestry in particular medium resolution imagery is suitable as the coarse resolution does not give enough details. If finance and skilled manpower is available large scale image data or fine resolution images are the best. The following table gives an overview of suitable medium to fine-resolution satellite imagery:

Table 2-3 Overview of suitable medium to fine-resolution satellite imagery for forest monitoring

SATELLITE	RESOLUTION	SENSOR TYPE	REVISIT TIME	COST
Landsat	30 m	Optical	16 days	free downloadable
SPOT	10-20 m	Optical	8 days	0.6 US$/km2
CBERS	20 m	Optical	26 days	Free for developing countries
IRS-LISS	20 m	Optical	24 daily	0.1 US$/km2
AwiFs	60 m	Optical	24 days	0.01 US$/km2
ASTER	15 m	Optical		0.02US$/km2
RapidEye	5 m	Optical	5.5 days (daily off-nadir	1US$/km2
DMC	32 m	Optical		0.15US$/km2
ERS-AMI	30 m	RADAR	Up to daily	0.05US$/km2
Palsar	5-30m	Optical Radar Radar	5.5 days (daily off-nadir) up to daily 35 days	1 US$/km2 0.15 S$/km2 0.05 S$/km2
IKONOS	0.82 meter x 3.2 meters	Optical	3 days	
Quickbird	0.65 m at nadir	Optical		

B. Image classification: Processing steps

In order to process image and analyse various data in the course of the study period high storage capacity computers and various software are important. Among software the following are important: ArcGIS, ILWIL, ERDAS.

A standard classification procedure has to be developed: the following processing steps form a generic standardized procedure (for further information see Appendix 5).

- Pre-processing (geo-referencing, radiometric correction, possible rescaling to uniform resolution)
- Image processing (includes filtering, stretch, colour composite, sampling and resample)
- Classification (supervised vs. unsupervised)
- Additional classification rules based upon extra information, like GIS layers e.g., parcels, roads, administrative units, making visualization more attractive and the map becomes more informative. Additional information can be included such as digital elevation model (DEM) and soil maps to improve the quality of the land cover classification.

Use of GPs for boundary delineation

If high-resolution satellite images are unavailable, GPS tracking is the most accurate and efficient alternative method for boundary delineation, even if the process is time consuming.

The procedures for marking current location and delineating the forest boundary using GPS are dependent on the type of GPs used and needs some training for people who do not have experience on GPS tracking. Each forest block (stratum) should be traced on to base maps first and then digitized on Arc View or ARC GIS software for data input. The data tracking from the GPS receiver is downloaded as a shape file (DNR Garmin software can be used). The areas of individual forest blocks are estimated after digitizing and editing the data downloaded.

At this stage, three basic information have been obtained:

1. We know about our study area. From our literature review we know the gaps that have to be filled and we are acquainted with our study area.
2. We have identified the type of tools to be used such as remote sensing materials, the type of software to use for various preliminary tasks in the office and data analysis, and
3. We have preliminary map of the study area at hand.

Are we ready to do fieldwork now? Do we know what kind of data to collect?
Not yet; we are one step behind: **sampling design.**

2.4.3 Sampling design

Since it is not practical to measure everything, we need to take a sample. We need to sample subset of land by taking relevant measurements of selected variables.

There is no one-inventory design universally for all inventories. The design to be used to meet the forest inventory objectives is determined by:

- the kind of sampling units
- the size and shape of the samples
- the manner of selection (random or systematic)
- the distribution of the sample
- procedure of measurements, and
- the analysis of the data

Forest inventory designers should consider the above elements to yield a desired degree of precision with minimum cost. Therefore, the design to use is the end product of a series of considerations including:

- kind of information required and its desired precision
- composition of the forest and its variability
- topography and accessibility to and within the forest
- availability of personnel and level of skill
- time and money available for the inventory
- availability of essential materials, e.g. photographs, maps, and imageries, and
- knowledge of the designer on statistics and sampling theory.

In general forest inventory designs can be grouped in to two types:

a. probability sampling (random sampling)
b. non-random sampling (systematic sampling)

Random sampling is further divided into simple and stratified random sampling. Experience shows that **stratified random sampling** is more appropriate and efficient when natural vegetation and plantation forests are inventoried.

A **stratified random sample** is one obtained by separating the population elements in to non- overlapping groups, called strata, and then selecting a simple random sample from each stratum. This procedure, in most instances, increases the quantity of information for a given cost.

Stratification is process of dividing the original population in to more homogeneous sub- populations for the purpose of reducing the variance. Each segregated sub-population is called a **stratum**.

Stratification of the project area into a number of relatively homogeneous units can reduce the number of plots needed. Potential stratification options include:

- Land use e.g. forest, plantation, grassland, cropland etc.,
- Vegetation species,
- Slope e.g. steep, flat,
- Aspect
- Drainage e.g. flooded, dry,
- Elevation, or
- Proximity to settlement.

The principal reasons for using stratified random sampling are:

i. Stratification may produce a smaller bound on the error of estimation than would be produced by a simple random sample of the same size. This result is particularly true if measurements within strata are homogeneous.
ii. The cost per observation in the survey may be reduced by stratification of the population elements into convenient groupings.

iii. Estimates of the population parameters may be desired for sub-groupings of the populations. These sub- groups should then be identifiable strata.

In order to employ stratified random sampling there is a need to consider how it is going to be done.

Steps for stratification and sample plot selection

The image data that encompasses the forest area must be classified using unsupervised classification. In this classification we need to limit the number of classes that we want to have up to 6 classes for project level inventory (See Appendix 5 for further clarification). In special cases such as national inventory the classes may consider at least broader land cover types.

Note that at this stage you cannot have land cover types in unsupervised classification. You can only have classes. In other words, we cannot determine whether an area is a water body or burnt area using unsupervised classification. We can only tell it is class "x". Once we define the classes with unsupervised classification procedure, we have a preliminary map of the study area with groups of relatively homogenous units. The groups can further be refined (higher accuracy and precision) later during reconnaissance survey (recall Figure 2-5) and then we label the classes as forest blocks (strata), lake or burnt area.

Permanent plot distribution and layout

There are two ways to distribute sample plots on a map:

1. Use of Software
2. Overlying grids on base map

Use of Software:

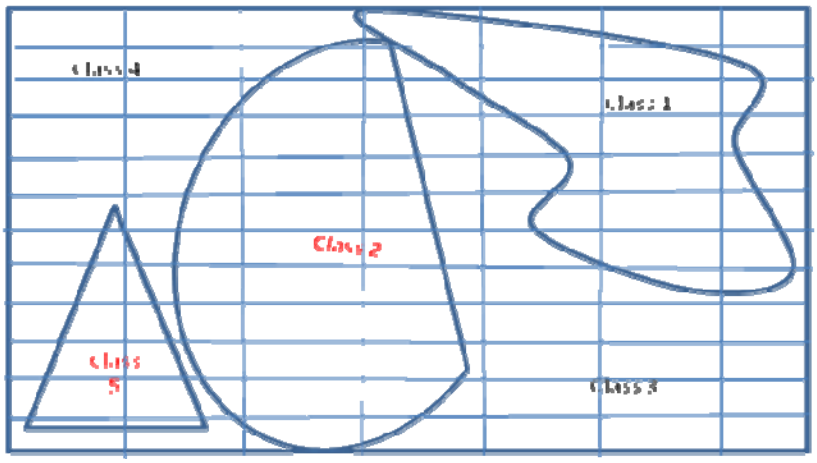
The number of permanent sample plots is dependent on the size and types of forest stratum. Plots used must be of the same size as those used in the pilot survey. A base map is used to produce locations of random sample plots. Plots are laid out or distributed randomly within each stratum using standard sampling methods or a GIS

software. Coordinates of each plot are also generated. The plots' coordinates are then loaded into the GPS; e.g., using DNR Garmin software. Cemented or wooden pillars marked with permanent paint are used to fix the center of each plot permanently. The marking in the center of the plots has proved to be very valuable in periodic monitoring as GPS alone could give a few meters of difference in locating the center of the permanent plot for subsequent measurements.

Overlying grids on base map:

This is how to do it:

1. Classify the image data that encompass the project area using unsupervised classification. In this classification we need to limit number of classes that we want to have (Appendix 5 for further clarification)-up to 6 classes.
2. Divide each stratum into grids of approxomately equal size. In the figure below assume there are 1000 grids of approxomately equal size. These grids are considered as our sampling units, which have equal chance of being selected as a sampling point.
3. Number each sampling unit in ascending orders. (You can also identify grids by labelling numbers or letters on the horizontal and vertical axes)
4. Distribute the required number of sample plots on each class (stratum) (see Section 2.4.4 for calculating optimal number of sample plots) using one of the following techniques.



- Draw lottery or
- Use calculator to generate random numbers or
- Use Microsoft Excel
- Use random number table

Example: suppose the sampling units (grids) in class 1 are 200. We want to sample 18 points from this class.

Until we get 18 points we continuously draw the lottery. Or we can get the sample points by writing the following formula in the excel formula bar: "=RANDBETWEEN(1,200)" to generate random numbers. We have to continue until the desired number of sample points is drawn. Sometimes one figure may come more than once and in this circumstance we need to ignore it.

Now we have all sample plots on the map. What we need is to locate the exact geographic coordinate and transfer the coordinate points to GPS. The stratification and defining sampling units is now completed.

2.4.4 Calculation of optimal sampling intensity and number of permanent sample plots

It is impossible to measure every tree within a forest. Statistical sampling theory explains how measuring only a fraction of the trees provides a measure of the biomass that is good enough to be used in carbon accounting. To quantify what 'good enough' means, it is important to distinguish between two concepts: accuracy and precision.

Accuracy refers to how close a measured quantity is to its actual value, whereas precision expresses how reproducible a measurement is. Ideally, measuring biomass is both accurate and precise. One can imagine, however, a measurement technique that yields very different values every time a measurement is taken, but which provides accurate measurements when large numbers of individual measurements are averaged. Such a technique would be accurate but not precise. In contrast, a technique that

continuously reproduces values within a narrow range but which are far from the actual values will be precise but not accurate. The measured values will be characterized by a systematic bias.

In classical sampling theory, the accuracy of a measurement system is established by setting a (often arbitrary) reference standard and repeatedly measuring this reference standard and calculating how far the measurements are to the set reference. The precision is usually quantified practically, using the width of the confidence interval around the mean, while the accuracy is quantified by the difference between the measured mean and the reference level.

For forest inventories, the reference measurement could be carried out by a team of truly experienced foresters, and the precision of a field crew can be tested by comparing the biomass values from the experienced foresters with that of the field crew. The precision of a forest inventory can be tested by performing multiple forest biomass inventories within the same forest stratum.

In other words, measurements that are 'good enough' are both accurate – meaning that measurements should be identical to measurements carried out by a team of truly experienced foresters – and precise – meaning that the width of the confidence interval around the mean should be sufficiently small. As a rule, one half of the width of the 95% confidence interval around the mean divided by the mean should be less than 10% within a stratum. If it is greater than that, more samples should be taken within that stratum, or the stratum should be split into two more homogeneous strata.

The following procedure is carried out to calculate the sampling intensity (number of permanent sample plots) required for inventory of aboveground forest biomass.

1. Identify the required precision level. A required precision with a value of 10% of the mean, calculated as the half-width of the 95% confidence interval, is frequently used.
2. Select the location of the 10-15 preliminary sampling plots per forest stratum – the selection can be either completely random, or can be a random selection from a preset

rectangular grid of sampling plots. Plots can be laid out or distributed randomly within each stratum using a standard sampling method. Plot size depends on density of trees (Table2-3). A plot size of 250 m^2 with 8.92 m radius is suitable for moderate to dense vegetation (MacDicken 1997).

3. Estimate carbon stock per tree, per plot, per ha, and mean carbon stock per ha for each of the preliminary sampling plots.

4. Calculate the standard deviation of carbon [ton C ha-1] for all the plots.

5. Calculate the number of plots required using the following statistical equation for multiple strata:

$$N = \frac{A}{A_p};\ N_i = \frac{A_i}{A_p} \quad \text{.....eq. 1}$$

where,

N = maximum possible number of sample plots in the project area [dimensionless];

A = total size of all strata, e.g. the total project area [ha];

A_p = sample plot size (constant for all strata) [ha];

N_i = maximum possible number of sample plots in stratum i [dimensionless];

i = index for stratum [dimensionless]; and

A_i = the size of each stratum i [ha].

With the above information, the total sample size (minimal number of sample plots to be established and measured) in all the strata can be estimated as:

$$n = \frac{(\sum_{i=1}^{L} N_i \times s_i)^2}{\frac{N^2 \times E^2}{t^2} + (\sum_{i=1}^{L} N_i \times s_i^2)} \quad \text{.....eq. 2}$$

where,

n = total number of sample plots (total number of sample plots required) in the project area [dimensionless];

i = project strata number from 1 until L [dimensionless];

L = total number of strata [dimensionless];

N_i = maximum possible number of sample plots in stratum i [dimensionless];

s_i = standard deviation for each stratum i [dimensionless];

N = maximum possible number of sample plots in the project area [dimensionless];

E = desired level of precision;

t = sample statistic from the t-distribution for the 95% confidence level: t is usually set at 2 since sample size is unknown [dimensionless]; and

s = standard deviation [dimensionless].

The following equation can be used to distribute the total number of sample plots over the different strata:

$$n_i = n \times \frac{Ni \times si}{(\sum_{i=1}^{L} N_i \times s_i)^2} \quad \text{.....eq. 3}$$

Where,

n_i = number of sample plots for stratum [dimensionless];

i = project strata number from 1 until L [dimensionless];

n = total number of sample plots (total number of sample plots required) in the project area [dimensionless];

N_i = maximum possible number of sample plots in stratum i [dimensionless];

S_i = standard deviation for each stratum i [dimensionless]; and

L = the total number of strata [dimensionless].

6. Visit the field to measure the biomass on the number of sample plots derived in step 5.

7. Calculate the true relative half-width of the confidence interval around the mean for each stratum and compare these to the required values of 10%. If the required precision of 10% is not attained, either split or merge the strata or update the number of samples required to get the required precision based on the standard deviation from all the sampling plots.

Repeat steps 5-7 until the required precision is attained.

Alternatively, the following formula can be used to generate the desired number of samples for a project that also provides statistically reliable result of a specified precision (Moor and McCabe, 2003, Loetsch-Haller, 1973 Vol.I & II).

$$n = \frac{CV^2 * t^2}{E^2} \quad \text{.....eq. 4}$$

Where:

n= number of sample points;

CV= coefficient of variation;

t=student's t (usually 1.96 approximately 2 in forestry) and

E=allowable error.

Table 2-4 Recommended allowable error (E)

Inventory type	Allowable error in percent	Level of probability
Reconnaissance	± 20	95 %
Management	± 10	95 %

Two approaches can be used to determine CV of particular interest variables: (1) looking up values from previous work of the same forest types and similar site conditions, (2) determine from pilot inventory by taking not less than 30 sample plots. in Ethiopia, you may use the CV for different land cover types calculated by Woody Biomass inventory and strategic planning project, WBISPP (2005) (See Appendix 6).

Once the total number of sample is determined it has to be distributed to each class proportionally to their sizes (Proportional Allocation Method, PAM).

Example: Assume a CV is 55, t is 2, and e is 10, n is then 121.

Class	Area (ha)	Number of samples detemined using PAM
1	21	18 = (21/143)*121
2	30	25
3	44	37
4	36	30
5	12	10
Total	143	121

For class 1, n1 = 18 following PAM.

How to select the 18 points out of n number of sampling units in class 1? Do randomization the same as the previous procedure.

For example, suppose the total number of sampling units (grids) in the class 1 is 200. Until we get 18 points we continuously draw the lottery labelled from 1 to 200. Or we can get the sample points by writing the following formula in the excel formula bar: "=RANDBETWEEN(1,200)". We have to continue until the desired number of sample points is drawn. Sometimes a number may appear more than once and in this circumstance we will ignore it.

Plot Size:

Most carbon inventory consider 100 m2 to 1000 m2 for sampling aboveground biomass (Dickenson, 1997). Similarly, from experiences in Ethiopia gathered in earlier inventories for natural forests 0.1 ha circular plots provide reliable results for trees above 5 cm DBH. For regeneration and sapling assessments, circular area of 0.01ha can be considered. In plantation forests 0.01 ha circular plots also provide the optimal sample size, unless the plantations are too old and the density of trees is very low. But depending on the variability of the population the plot size may be adjusted (increase or

decrease). MacDicken (1997) recommends the following plot sizes depending on tree density .

Table 2-5 Plot size according to tree density

PLOT SIZE M^2	PLOT RADIUS	TYPICAL AREA PER TREE	TREE DENSITY
100	5.64	0 to15	very dense vegetation, stands with large numbers of stems small in diameter, uniform distribution
250	8.92	15 to 40	Moderately dense woody vegetation
500	12.62	40 to 70	Moderately sparse vegetation
666.7	14.56	70 t0 100	Sparse vegetation
1000	17.84	More than 100	very sparse vegetation

Source: MacDicken (1997)

Plot shape:

Rectangular/squarer plots. The laying out of these plots involves the measurement of corner angles and diagonals. This is a slow process and quite subject to error. Smaller square plots can be laid out more quickly by laying out the two measured diagonals at right angles to each other.

Circular plots. Regarding shape, the favorable form of plot is the one which, with equal area, has the largest ratio of area to perimeter. A high ratio helps to minimize source of error due to border line ambiguities (determination of trees inside the plot is less problematic than square plots). Circular plot qualifies for this requirement. Additionally, circular plot is preferable because it is easy to implement in the field.

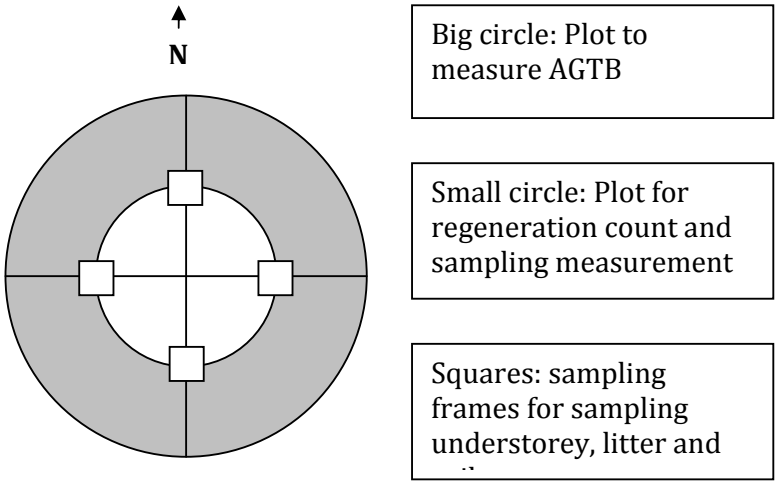


Figure 2-6 Sample plot shape and subplot arrangements

For defining the plot boundary, the radius of a circular plot in horizontal distance is determined by the radius which is derived from the formula:

$$r = \sqrt{\frac{A}{3.14}} \quad \text{.....eq. 5}$$

Where,

r is radius, A is plot area in m^2

Whenever the plot is not horizontal, the gradient must be measured using a clinometer and corresponding length should be added by making slope correction (Appendix 7).

2.4.5 Some more points on the planning

Which carbon pools to measure?

The following carbons pools will be measured in forest carbon estimation (IPCC, 2006).

1. Above-ground tree biomass (AGTB)
2. Understorey vegetation (UVB)
3. Leaf litter (Litter B),
4. Dead wood and fallen stumps (DW)
5. Below-ground biomass (BB)

6. Soil organic carbon (SOC)

How often and when should we make inventory?

For forest management and carbon projects verification and certification must occur periodically (every 5-7 years). It is therefore logical to re-measure forest resources at this time period. However, for slowly changing pools such as soil it will be necessary to measure less frequently. Additionally, the period may for assessment may change due to the interest of the carbon buyers.

Avoid too dry and too wet seasons for taking measurements, and the most ideal time is at the end of the rainy season and when it is easier to work in the field.

Before you leave your office:

Before going to the field to establish plots on a new site, a sufficient number of field teams should be formed (middle level forest technicians, local resource persons, and local community members, instruments and materials should be procured, responsibilities should be delegated, field work should be scheduled, appointments should be made with the user groups or forest owners, forms for recording field data should be photocopied, and maps should be printed.

For the carbon inventory, a crew of ***six people*** can be sufficient: 1 Team leader who controls the work records data, 1 Diameter man, 1 Height man, 1 person for collecting herbaceous vegetation, litter and soil samples, and 2-3 local assistants (brushing and local name identifier).

After arriving in the field:

Do not forget to visit all relevant offices particularly the local administration in your study area. Clearly explain to the authorities the purpose of your visit, where you wish to go and what you are going to do. If possible hold a meeting formally and present your objectives to the local stakeholders, and get permission to conduct the fieldwork.

Reconnaissance survey

Quick reconnaissance survey assists, among others:

- To have better understanding of the study area, such as checking accessibility, and meeting important authorities, and local communities,
- To adjust sampling procedures, if necessary, and
- To check on the type of land cover types and match with the classified area in the office.

What is remaining now? We need to develop data collection formats. Make sure you have all the necessary logistics, tools and materials for data collection. The next section will deal with data collection procedures.

How many days have you spent on the planning activity? Literature review, map preparation, boundary definition, preliminary stratification, and pilot survey for sample size determination?

How many days do you need to collect data?

3. DATA COLLECTION: FIELD AND LABORATORY PROCEDURES

Data collection involves taking measurements on the required parameters in the field and in laboratory. A series of procedures should be followed for accomplishing the task of data collection. In this section, tools required and detailed procedures for field and laboratory data collection relevant for estimating the carbon pools are presented. Other data that support sustainable forest management are also integrated in the procedures.

3.1 Aboveground tree biomass

3.1.1 Definition

Aboveground biomass comprises all woody stems, branches and leaves of living trees, creepers, climbers, and epiphytes as well as understorey plants and herbaceous growth. It accounts for the majority of the total accumulated biomass in a forest ecosystem. From these, ***aboveground tree biomass*** represents a large carbon pool as trees sequester and store large amounts of carbon in their above-ground parts (trunks, branches, leaves). The aboveground tree biomass is also sensitive to disturbance such as deforestation and degradation.

3.1.2 Aboveground tree biomass (AGTB) estimation approaches

The biomass of the whole or part (leaves, branches) individual trees in a stand can be obtained either by direct measurement (destructive methods) or through the use of biomass estimation functions (non-destructive methods). While measuring the sample tree variables such as BHD and height is easy and straightforward, measuring the sample tree biomass is difficult. Because of the large amount of work involved, direct measurement will be rare; usually it will be done in a research context or to obtain data to develop biomass estimation functions. Biomass equation can be developed for a single species or groups of species or life forms (trees or shrubs).

The non-destructive method does not require the trees to be felled. Although harvesting is the preferred way to develop biomass tables (destructive methods), it is not always possible due to conservation or regeneration considerations.

Sampling procedures (Use Form 1 and 2, Appendix 1)

1. Once the plot locations are determined in the inventory planning phase, navigate (with a GPS) to plot center coordinates provided from a database, or a map.
2. Establish plot center by setting a plot center post (preferably PVC pipe painted with fluorescent paint and marked with the plot number). Now, permanent measuring and monitoring plot is installed.
3. Check the slope of the plot in order to adjust the radius of the plot.
   If the slope is greater than 10%, use a clinometer or Abney hand level to determine slope. Correct for slope using the following formula:

   Ls = L / Cos S

   Where Ls is the corrected plot radius, S is the slope angle in degrees, Cos is the cosine decimal taken from the back of the clinometer or from a table, and L is the plot radius. Or use slope correction card (attached in Appendix 7).
4. Identify and mark in-trees with a bright, durable paint at 1.3 m. The team leader holds one end of a measuring tape at the plot center. One of the crew members together with the team leader measures the distance to the plot edge to determine in- and out-trees.
5. Measure diameter and height of marked trees clockwise starting from North. The diameter man and height man should take measurements on in-trees and read out the measurements to the team leader.

   The diameter measurements include (use Form 1):

   Db = basal diameter of a stem measured at 0.3 m above the ground surface;

   Dm = middle diameter of a stem measured by Spiegel Relaskop at half-way between Db and Dt;

   Dt = top diameter of a stem measured by Spiegel Relaskop at the base of the first major branch of the tree;

DBH = diameter at breast height, measured at 1.3 m above the ground surface.

Height measurements are Tot Ht = Total height; and MER Ht merchantable height.

Stump diameter (at 0.15 m above the surface).

6. When all of the trees (>5 cm DHB) in the plot have been measured, the team leader must check to see that all of the in-trees have been measured and painted.
7. Within a radius of 5.64 m, count the number of seedlings (small trees below 2.0 m) and samplings (trees bigger than seedlings and smaller than 5 cm DBH) and record their species. measure also the average height of saplings.
8. Finally, check and record disturbance level of the plot (Form 1). Note the number of stumps and measure the diameter in the plot.

Developing biomass tables - Destructive method

If local allometric equations are not available, research institutions should develop biomass tables of wider application through destructive method. Many recent biomass studies suggest that 30-100 trees are sufficient for a regional biomass table using stratified random sampling of the population. If sample trees are selected in equal or near-equal numbers for each size class (at 5 cm DBH class interval), 30 trees for an individual tree biomass table are adequate. If the tables are to be used only for a specific site, as few as 12 trees may be adequate.

The conventional destructive method is done by felling the sample trees and then weighing them. Direct weighing can only be done for small trees, but for larger trees, partitioning is necessary so that the partitions can fit into the weighing scale. Another destructive method proposed by Valentine et al. (1983) uses the principle of randomized branch sampling (RBS) and importance sampling, but not treated here because it is a laborious and mathematically complex approach.

Tools:

- Canvas sheets or plastic sheets (3), cross-cut saw/chainsaw, hand saw, shear and clipper, weighing scale (large), spring balance (5 kg), metric tape measure (50 m long), diameter tape and/or calliper, plastic bags.

Sampling procedures (Use Form 3):

1. Obtain the size class distribution of trees of the forest. If size class distribution is not available, establish at least 10 or a maximum of 20 sample plots outside the permanent sample plots in the forest and measure DBH of sample trees, and develop size class distribution of trees (e.g., at 5 cm diameter class interval)
2. Select and mark sample trees for each diameter class.
3. Prior to felling sample trees, measure DBH using a diameter tape or a calliper. Extra care should be taken to ensure that the tape runs around the trunk horizontally or the calliper is positioned at right angle to the axis of the tree.
4. Fell selected sample trees for further measurements (This is destructive sampling).
5. Measure the height of the tree with a measuring tape after felling the tree.
6. Segregate the felled tree into the following factions: (a) leaves, (b) twigs (diameter less than 3.2 cm), (c) small branches (diameter between 6.4 cm and 3.2 cm), (d) large branches (diameter greater than 6.4 cm) and (e) stem (Ketterings et al., 2001). The segregation is important because of the systematic difference in moisture content along the length of the tree.
7. Measure the stump height and diameter (at 0.15 m above the ground surface) to get an estimate of its volume and dry weight.
8. Determine the stem volume and weigh fresh weight of the stem. For trees with *DBH* > 15 cm, measure stem diameter every two meters length (Ketterings et al, 2001). This measurement is used for stem volume and dry weight estimation. Weigh the fresh weight of whole stem at once for trees with *DBH* < 15 cm.
9. Use volume equations to obtain the stem volume; if not available, use Samalian's volume equation.
10. Weigh the fresh weight of leaves, twigs, and branches.

11. Select wood subsamples arbitrarily from the stem: one each in the lower, middle and upper portion. Three wood subsamples are also collected from each of the large branches, small branches, and twigs factions (Ketterings et al., 2001). Three leaf subsamples, of about 100 grams each, are also collected for each tree sample.
12. Store the wood and leaf sub samples in a sealed plastic bag to retain moisture prior to measurement of fresh weight.
13. Weigh the fresh weights of the wood and leaf subsamples.
14. In the laboratory, oven dry the samples at 105° C until constant weight, and determine the wood dry density and dry weights (biomass) of the samples taken from the felled trees (stem, branch and leaves).
15. Once the mass of the trees are determined, develop biomass equations linking tree biomass data to DBH alone, or DBH and height.

3.2 Understorey vegetation and litter[1]

Herbaceous vegetation and litter also constitute a significant amount of carbon store in a forest ecosystem. The carbon content of herbaceous vegetation, litter and soil can be measured and analyzed at relatively low cost if the data is collected at the same time the tree inventory is conducted. This part describes sampling and analysis of biomass (carbon) in herbaceous vegetation and litter. Changes in litter pool can be important, particularly when forest soils are converted to land uses that oxidize organic matter (e.g., crops that require intensive cultivation). It is easy to measure the litter crop, but it requires consistent adherence to pre-defined standards.

Sampling procedures (Use Form 4):

1. Go to the northern direction (360°) of the circular plot and select a point at half of the radius of the (permanent) sample plot. This will be the first sampling location for herbaceous vegetation, litter, roots and soils (see below for roots and soil

[1] Data should be collected in the following order:

1. Herbaceous vegetation
2. Litter
3. Soil

sampling). The other three frames will fall at the same distance from the centre in East, South and West directions.

2. Place the square sampling frame (1m x 1m) on the ground at these points.
3. Cut all understorey vegetation within the frames (including trees below 5 cm DBH). Include in the sample only the vegetation that originates inside the sampling frame. Exclude vegetation over-hanging inside the frame if the plant originates outside the frame, but include vegetation over-hanging outside the frame if the plant originates inside the frame.
4. Separate the fresh harvested material taken from four frames into wood and leaf (grass), and weigh the wood and herbaceous material (leaf and grass) separately.
5. Take a small random sub-sample of wood and leaf (grass) of about 300 g each, and place them and in labelled (numbered) sample bags for moisture content determination.
6. Similarly, collect coarse litter from the same sample frames (a knife can be used to cut pieces that fall on the border of the frame), place in the sample-weighing bag, weigh, and record the fresh weight.
7. Mix the sample well and select a small random sub-sample (e.g., 300 g) of this litter and place in a numbered sample bag for moisture content determination.
8. Oven dry the samples at 105° C until constant weight, and determine the dry weight of the subsample.

3.3 Dead wood

Dead wood can be a significant pool of carbon in forest ecosystems, such as over-mature natural forests or after slash and burn activities. If the necromass portion of the carbon pool is not significant in the area due to frequent removal of dead wood for use as fuel by local communities, this pool should not be measured.

Sampling procedures (Use Form 5):

1. Within the main plot, measure the diameter and length of each piece of coarse dead wood (only wood greater than 10 cm in diameter and length >0.5 m) with callipers at the middle of the wood. If the log is hollow at the intersection point,

measure the diameter of the hollow. Do not use the hollow portion in the volume estimates.

2. Assign each piece of dead wood to one of three density classes –sound, intermediate or rotten. To determine what density class a piece of dead wood fits into, each piece should be struck with a saw or machete. If the blade does not sink into the piece –that is, if it bounces off –it is classified as sound. If it sinks partly into the piece and there has been some wood loss, it is classified as intermediate. If the blade sinks into the piece, there is more extensive wood loss and the piece is crumbly, it is classified as rotten.
3. Collect representative dead wood samples of the three density classes, representing the range of species present, to determine the density. This is done by measuring dry weight per green volume. Using a chainsaw or a hand saw, cut a complete disc from the selected piece of dead wood. The average diameter and thickness of the disc should be measured to estimate volume. The fresh weight of the disc does not have to be recorded. The disc should be oven-dried to a constant weight.
4. Change direction of the transects on successive measurements.

3.4 Below ground biomass carbon

3.4.1 Definition

Belowground biomass (BGB) is the biomass of living and dead roots (coarse and fine roots). Measuring the below ground biomass is not as easy as measuring the above ground biomass (AGB). BGB is estimated using 1) shoot to root ratios method and 2) sample measurement methods.

3.4.2 Estimating using shoot: root ratio method

For many carbon projects, the BGB is estimated using a conservative ratio for shoot: root biomass as the basis for claiming carbon credit. The lowest shoot:root ratio reported so far is 5:1 (i.e., BGB is 20% of AGB). To develop a conservative estimate without measuring roots, an inventory could calculate root biomass as less than 10 or 15% of the

ABG. For different forest ecosystems, regression models have been developed (n = 151; r^2 = 0.84) to estimate BGB density (tones/ha) from ABG biomass density (Cairns et al. 1997).

Boreal forests: BGB (tones/ha) = exp(-1.0587+0.8836xln AGB+0.1874……eq. 6

Temperate forests: BGB (tones/ha) = exp(-1.0587+0.8836xln AGB+0.2840……eq. 7

Tropical forests: BGB (tones/ha) = exp(-1.0587+0.8836xln AGB) ……eq. 8

The equation applicable for Ethiopia is the models developed for tropical forests. Multiplying AGB and BGB by 0.47 gives the amount of above- and below-ground carbon stock, respectively.

3.4.3 Estimates using sample measurement methods

There are several cases in which more accurate estimates of BGB are necessary. The advantage of measuring root biomass for carbon credit is that in most cases, actual root biomass will likely be substantially greater than the conservative estimates. The decision of whether or not to measurement should be based on the price of carbon compared to the cost of collecting the additional data to claim the credit. Once decision is made to measure the BGB and hence below ground biomass carbon stock, one should conduct field work by first determining i) sampling intensity ii) sampling depth and iii) sampling methods. Below ground biomass sampling should be collected within the same sampling frames from where the litter layer and herbaceous ground vegetation are collected. Within each permanent plot it is sufficient to take 4 core samples, which can be pooled as a single sample representing the sample plot.

<u>Determining sampling depth</u>

For most carbon projects all roots are sampled to a minimum depth of 30 cm soil layer. However, in a forest ecosystem ideally the sample should be collected down to the limits of rooting depth. Because rooting intensity varies with soil depth, describing soil profile to a depth of greater than 1 m per stratum is needed to set the lower limit of effective

rooting depth. Then you can decide to which depth you should sample based on root distribution.

Tools:

5 kg spring balance, plastic bags, water proof permanent parker, sharp edged steel corer (50-80 mm diameter), geologist hammer, spade, sharp knife, and water proof labels.

Procedures-Core sampling (Use Form 6)

1. Locate the centre of the sample frames where the litter and understory have been removed.
2. Mount 15 cm steel tube with a serrated cutting edge on a 1 m pipe with a plunger to remove the core.
3. Insert a scorer (5-8 cm diameter x 5 cm height) manually or mechanically into the mineral soil and drive a sharpened steel tube as many times as possible until you reach to the desired depth (high root concentration).
4. Make sure you have sampled from 4 replicated sample frames within the sample plot
5. Place the sample carefully in a pre-weighed polyethylene bag and label it.
6. Tie the bag tight and transport to the laboratory for drying, storage and further analyses.

Root extraction and biomass estimation

Once the samples reach in the laboratory, the roots should be separated from the soil and be ready for biomass estimation. The measured data at each step must be noted in Form 6.

Tools: Sensitive balance**,** oven, shaker machine, 1.1, and 0.3-0.5 mm mesh sieve and nylon cloth, forceps, rubber gummy, polyethylene bags, desiccators, and a muffle furnace,

Chemicals: 5% sodium hexametaphosphate,

Laboratory procedures:

1. Pre-soak the samples overnight in 5% sodium hexametaphosphate. This expedites the process of washing roots from clay soils [but this method is not suitable for root identification because the chemical discolours the root]. Alternatively, over soak the samples in a bucket with water and leave it on shaker machine to be agitated over night.
2. Gently wash a pre-soaked sample over combination of 1.1, and 0.3-0.5 mm mesh sieve or nylon cloth sieve. The first sieve will contain mostly roots, while the second mostly debris.
3. Remove the materials from the sieves and then mix in water; decant suspended materials, which are live roots with specific density of about 1.0 g/cm^3.
4. Sort out non-root residues, charcoals, debris, etc remaining on the sieve by picking up using forceps and place them in a shallow dish. Make sure you have all live roots on the nylon sieve. Living roots can be distinguished by their lighter colour, turgid appearance, and flexible rather than friable nature when manipulated. In case if living roots are not adequately distinguished from dead roots/debris, assess total root mass.
5. Tie the nylon cloth tightly with rubber gummy and label it with the sample code. These are washed root samples.
6. Hang on the samples on sunlight for drying
7. Transfer washed root samples (dead and live roots separately) into sealed and labelled polyethylene bags for a short time in refrigerator or preferably in deep freeze to protect from forming mould.
8. Oven-dry the root samples in pre-weighed porcelain for 24 hours at 70°C.
9. Place the samples in desiccators until they cool down.
10. Weigh the sample (W_0)

11. Put 1 g (W_1) of oven-dried samples in a crucible with a known weight (W_2), and combust for 5 hours in a muffle furnace at 550 °C, and then wait until the temperature drops to room temperature.

12. Keep it in desiccators until it cools down.

13. Weigh the residue or ash (W_3) as it is in the crucible.

Calculations:

14. Calculate ash weight (W_4) = W_3- W_2.

15. Express the results as ash-free oven dry weight (W_5) in g = W_1-W_4.

16. Estimate ash-free oven dry mass (M_0) per unit volume of soil core i.e.,

$$M_0\ (g/cm^3) = (W_0 \times W_5/W_1)/\text{core volume}\ (cm^3)$$

17. Estimate ash-free total root biomass (M_{t1}) in a core sample as the sum of ash-free oven dry mass of dead and living roots, i.e.

M_{t1} (g/cm^3) = Ash-free oven dry mass of live root + ash-free oven dry mass of dead root

18. Multiplying total ash-free oven-dry root mass stock by root sampling depth (Z) gives total root biomass per unit area of the sampling point, i.e.,

M_{t2} (g/cm^2) = M_{t1} x Z (cm)

19. Apply a correction factor of 1.25- 2.0 to the final data to correct estimation losses due to sampling and extracting processes (M_{t3}), i.e.

M_{t3} (g/cm2) = M_{t2} x 1.25, or M_{t3} (g/cm^2) = M_{t2} x 2.0……..eq. 9

20. Multiply the oven-dried mass of roots by a correction factor of 0.47 to obtain the carbon stock of below ground biomass per unit area of core sample, i.e.

C (g/cm^2) = M_{t3} x 0.47……..eq. 10

However, because the dead roots might have been passed through different stages of decomposition, substantial organic carbon loss is expected. Under such circumstances

applying conservative value of 0.47 may result over estimation of organic C stock in below ground biomass. Therefore, if high C loss due to decomposition is expected, below ground debris and dead roots should be analysed separately for their organic carbon content and added to the living root biomass.

3.5 Soil organic carbon

Soils are often large storage pools for carbon, which includes organic and inorganic carbon extending from the organic layer to the depth of the bed rock or parent material. For carbon trading, it is usually the top 30 cm soil depth and the organic layer are considered. Because soil carbon analyses are expensive, analyses can be done using composite samples.

Soil bulk density is determined by collecting undisturbed soil sample. There are several ways to collect undisturbed soil samples depending on soil conditions (stony or non-stony etc.) in the field. During the field work the soil layers or horizons must be well described for providing data for sustainable forest management. Soil sampling should be conducted in the same sampling frame from where the litter layer, and herbaceous plants are collected.

3.5.1 Sampling normal (non-stony) soils

Tools:

Steel cylinders with known volume, (100 or 300 cm^3), a spade or hoe, polyethylene bags labels, geologist hammer, Munsel Soil colour chart, and spring balance. A 0.1 N HCl can be used to check for presence of carbonates in the field.

Procedures (Use Form 7):

For bulk density sampling, a trench can be dug with a spade and a sample collected sideways. The following steps can serve as a guide for collecting soil samples.

1. Dig a trench with a spade or other similar equipment.
2. Orient yourself to the surface dug.
3. Wood or plastic planks can be used to smoothen the exposed surface.

4. Use a fine brush to remove any material from the exposed soil surface.
5. Insert a core at three subsequent depths (0-10, 10-20 and 20-30 cm).
6. Once the soil corer has been inserted into the soil to the desired depth, it is removed from the ground by pulling it outwards.
7. The top and bottom (or bottom only depending on the coring tool used) of the core should be trimmed to be even with the rims. When taking cores for measurements of bulk density, care should be taken to avoid any loss of soil from the cores; if any material is lost, re-sampling will be needed.
8. Label and place them in plastic bags.
9. Similarly, collect one composite sample mixing soils from all the three layers in order to determine concentrations of organic carbon and then weigh at a precision of 0.1 g. Around 100 g of composite sample is collected from one plot.
10. Place all material collected in the corers and composite samples into sample bags which are labelled appropriately.
11. Transport samples to the laboratory and oven dry (70^0 C) until constant weight to determine water content.
12. Prepare for carbon measurement by removing stones and plant residue > 2mm as well as by grinding
13. Let the samples be analyzed by professionals in the laboratory.

Sampling stony and rooty soils

i. Clod method

Procedure

1. Excavate an intact clod of soil about fist size.
2. Air-dry it and put it in labelled beaker, transport it to the lab

ii. Infill method

Procedures

1. Dig a hole 10 cm x 10 cm x 10 cm

2. Put the sample in the labelled polyethylene bag, tie tight for transporting to the lab

3. Fill the hole with dry course sand from a known volume of sand, and level it with the surrounding soil surface, record the volume of sand remaining and hence calculate the volume of sand used to fill the whole (V_0)

Alternatively, press ultra-thin plastic food wrap around the sides of the hole, and fill with a known volume of water, record the volume of water remaining and hence calculate the volume of water used to fill the hole (V_0)

3.5.2 Laboratory procedures:

Determining bulk density

Equipment: sensitive balance, beaker
Chemicals: melted paraffin wax (60°C), HCl, Water,

Procedures:

i. Non-stony soils

1. In the lab dry at 105°C for 24 hours,
2. Place in the desiccators until it cools down and weigh (W_{dry})
3. Calculate the bulk density (BD) of the sample (g/cm^3)

$$BD = W_{dry}/V \quad \text{.....eq. 11}$$

Where,
$V = h \times \pi \times r^2$; where h and r are height and radius of the steel cylinder
W_{dry} = ovendy weight of soil

ii. For Stony and Rooty soils (Clod and infill methods)

1. Dip the air-dried clod briefly in melted paraffin wax (60°C) to water proof it

2. Weigh the coated clod (W_{CP})
3. Calculate the weight of the paraffin coating ($W_p = W_{CP} - W_C$).
4. Suspend the clod from the balance arm and submerge it completely in a beaker of water. Record the weight (W_{CPW}). If it leaks air, discard it.
5. Break/ open the clod, take a subsample of the soil, weigh it (W_S),
6. Oven-dry the subsample for 24 hours at 105°C,
7. Keep it in the a desiccators until it cools
8. Weigh it (W_O).

Calculation

9. Correct W_C to its oven dry mass, W_{dry}:
10. W_{dry} = W_C x (weight of sub sample after drying (W_O) /weight of subsample before drying (W_S)

$$BD = W_{dry}/(((W_{CP} - W_{CPW})/\rho w) - Wp/\rho_p)) \quad \text{.....eq. 12}$$

Where
BD = Bulk density
Pw = density of water at temperature determination (1.0)
ρ_p = density of paraffin wax (approximately 0.9)

iii. ***Infill method***

1. In the lab dry at 105°C for 24 hours,
2. Place in a desiccators until it cools down and weigh (W_{dry})

Calculation

3. Calculate the bulk density (BD) of the sample on the bases of the volume of the sand or water that filled the whole, i.e., (g/cm^3) = W_{dry}/V_0

3.5.3 Soil organic carbon (SOC) analyses

Sample preparation

i. Soil material

Air dry the soils sampled from the field by spreading it out in a shallow tray in a well ventilated place protected from any contamination. Alternatively dry in a forced air oven dry at 60°C, when it is dusty it is dry enough

1. Crush the soil samples gently and separate grovels and roots
2. Sieve the soil through 2 mm sieve leaving gravel and roots on the sieve.
3. If necessary pick out the roots and gravel and save it. Retain the gravel for weighing if required. This should be done if it appears to be >5% of the original mass.
4. Retain a representative sample of approximately 100 g.

ii. Sample storage

Store both soil and plant samples in clearly labelled, air-tight, termite-proof containers in a well ventilated storage room until analyses is conducted.

iii. SOC analyses

The determination of organic carbon in soils, plant tissues, humus and other organic extracts is performed by using an acidic wet digestion, colorimetric, titration methods (Walkley 1947; Graham, 1948; Nelson and Sommers,1996; Combs and Nathan, 1998) and loss on ignition described by Golden 1987; Ben-Dor and Banin1989; Sommers,1996; Combs and Nathan, 1998). Recently, carbon has been determined by using isotope ratio mass spectrometry (IRMS). Analysis procedures presented in this manual are from a Handbook of Reference Methods for Soil analysis (Soil and Plant analysis Council, 1992) and Tropical Soil biology and Fertility Handbook (Anderson and Ingram, 1996).

<u>Colorimetric methods</u>

The method is suitable for all soils except with those where organic carbon is <0.2%

Reagents:

Barium chloride, 0.4%: dissolve in 4 g barium chloride in 1000 ml water

Potassium dichromate, 5%; dissolve 50 g in 1000 ml water

Sucrose

Sulphuric acid, concentrated (H_2SO_4, about 36 N)

Standards:

- Dry about 15 g sucrose at 105°C for 2 hours. Cool in a desiccators
- Dissolve 11.886 g dry sucrose in water and make up to 100 ml in a volumetric flask. This is a 50 mg /ml C solution
- Using a pipette transfer 0. 5. 10, 15, 20, 25 ml of the 50 mg/ml C stock solution into 100 ml volumetric flasks and make up the mark with water. Mix well. These are the working standards, and contain 0, 2.5, 5, 7.5, 10, 12.5, mg/ml C
- Pipette 2 ml of each working standards in to labelled 100 ml conical flasks, and dry a 105°C, or into labelled digestion tubes. These now contain 0, 5, 10, 20, 25 mg C.

Procedure with external heating:

1. Weigh about 1 ± 0.001 g soil (<0.15 mm) in to a labelled 100 ml conical flask (if the soil is suspected to have high organic matter, Ah, use about 0.5 ± 0.001 g). Record the weight of the soil, W.

   If the sample does not contain carbonate, continue to with procedure 2. If the sample contains carbonate, add 3 ml of 4-M H_2SO_4 and shake the uncapped tube slowly for one hour. Repeat this procedure two times with 1ml of 4-M H_2SO_4 to make sure that all carbonates have evolved. (together (3 ml x 1 hr) + (1 ml x 1 hr) + (1ml + 1 hr)). Alternatively rinse the sample by 1N HCL following the sample procedure.
2. Add 10 ml 5% potassium dichromate solution and allow it to completely wet the soil or dissolve the standards
3. Add 20 ml H_2SO_4 from a fast burette and gently swirl the mixer
4. Allow to cool, then add 50 ml 0.4% barium chloride, swirl to mix thoroughly, and allow to stand overnight, so as to leave a clear supernatant solution

5. Transfer an aliquot of the supernatant solution in to a colorimetric cuvette, and measure and record each standard and sample absorbance at 600 mm

Procedure without external heating:

1. Weigh about 1 ± 0.001 g soil (<0.15 mm) in to a labelled 100 ml conical flask (if the soil is suspected to have high organic matter, Ah, use about 0.5 ± 0.001 g). Record the weight of the soil, W.

   If the sample does not contain carbonate, continue to with procedure 2. If the sample contains carbonate, add 3 ml of 4-M H_2SO_4 and shake the uncapped tube slowly for one hour. Repeat this procedure two times with 1ml of 4-M H_2SO_4 to make sure that all carbonates have evolved. (together (3 ml x 1 hr) + (1 ml x 1 hr) + (1ml + 1 hr)). Alternatively rinse the sample by 1N HCL following the sample procedure.
2. Add 2 ml water
3. Add 10 ml 5% potassium dichromate solution and allow it to completely wet the soil or dissolve the standards
4. CAUTION: Slowly add 5 ml H_2SO_4 from a slow burette and gently swirl the mixer
5. Digest at 150°C for 30 min
6. Allow to cool, then add 50 ml 0.4% barium chloride, swirl to mix thoroughly, and allow to stand overnight, so as to leave a clear supernatant solution
7. Transfer an aliquot of the supernatant solution in to a colorimetric cuvette, and measure and record each standard and sample absorbance at 600 mm

Calculation

8. Plot a graph of absorbance against standard concentration. Determine solution concentrations for each unknown and the blanks. Subtract the mean blank value from the unknowns; this gives a value for corrected concentration, K. Where W = weight of soil:

For without external heating

% organic C = (K x 0.1)/(W x 0.74)……..eq. 13.

0.74 is mean oxidation factor for partial oxidation of organic C, when the sample is heated at 150°C for 30 min in a heat dilution of the acid in the dichromate solution, which has been found to oxidize about 74% of organic C.

For with external heating

% organic C = (K x 0.1)/W……eq. 14

Titration method

This method is suitable for determination of organic C in microbial biomass, mineral soils, litter layers, water soluble organic matter, and for soils with very low organic matter (> 0.5%).

Reagents:

Ferrous ammonium sulphate hexahydrate

Potassium dichromate, 0.0667 M: dissolve 19.622 g dry potassium dichromate in 800 ml water, and dilute to 1000 ml.

Acidified ferrous ammonium sulphate, 0.033 M: dissolve 12.940 g ferrous ammonium sulphate hexahydrate in 900 ml water, add 50 ml conc. Supheric acid, allow to cool and make up to 1000 ml with water; mix well.

Indicator solution: dissolve 1.485 g o-phenantholine monohydrate in 100 ml water.

Procedure:

1. Transferor 4.00 ml of sample extract in to a digested tube
2. Add 1. 00 ml 0.0667 M potassium dichromate
3. CAUTION: Add 5 ml concentrated sulphuric acid, mixing all the time.
4. Prepare 2 blank tubes (i.e., with reagents but without extracts)

5. Prepare 2 blank tubes and 1 blank in a preheated block at 150°C for 3 min, remove an allow to cool. Leave other blank unheated.

6. Quantitatively transfer the tube contents to labelled 100 ml conical flasks, and add 0.3 ml (3-4 drops; not by mouth) indicator solution

7. Using a magnetic stirrer to ensure good mixing, titrate all samples and blanks with acidified ferrous ammonium sulphate solution; the end point is a color change from green/violet to red. Record the titres for each sample (ml_{sample}), the heated blank (ml_{HB}).

8. Pipette the 1 ml 0.0667 M potassium dichromate into a conical flask

9. Add 0.3 ml (3-4 drops) indicator solution. (Do not use a mouth pipette)

10. Titrate with acidified ferrous ammonium sulphate solution, and record the millilitres used (T).

Calculations:

$M = 0.4/T$

$\text{Organic C (\%)} = ((A \times 0.003)/g) \times (E/S) \times 100$……..eq. 15

Where:

T = Standardization titre

M = molarity of ferrous ammonium sulphate (≈ 0.033 M)

$A = (ml_{HB} - ml_{sample}) \times ((ml_{UB} - ml_{HB})/ ml_{HB}) + (ml_{HB} - ml_{sample})$

G = dry soil mass (g)

E = extraction volume (ml) (= 50 for above procedure)

S = digest sample volume (ml) (= 4 for above procedure)

Loss on ignition method:

Procedure:

1. Weigh 5-10 g sieved soil
2. Dry at 105 °C for 4 hours

3. Weigh to the nearest 0.01 g (W_{105})
4. Ash the sample in a furnace
5. Place in a desiccators until it cools
6. Weigh to the nearest 0.01 g (W_{400})

Calculation:

$$\% \text{ OM} = \frac{(W_{105} - W_{400})}{W_{105}} \times 100$$

The methods is good for soils rich in organic matter.

Determining the organic carbon using IRMS

Background:

This method is suitable to determine the forest C sequestered in soils as a result of afforestation/ reforestation of degraded and former cultivated or pasture lands. It is widely applied for determining the sources of soil organic carbon. It is also suitable for determining changes in soil C stock in relation to forest development.

The carbon accounting is based on only a partial and discontinuous carbon budget for terrestrial vegetation (Jarkko Koskela et al 2000). Also, at the Kyoto Protocol full carbon accounting (changes in all carbon pools including soils and forest products and landscape units) which is more relevant for climate change problems is neglected, because it is considered technically difficult or impossible. More importantly, forests respond more favourably to an increasing atmospheric CO_2 concentration and mitigate the climate change better than grasslands.

In tropical and subtropical region C_3 and C_4 plants coexist at the same site and at the same time. In the tropical forests and savannah woodlands, most understorey grasses are C_4 plants, and there are no C_4 trees or C_4 woody plants. In such ecosystems the soil organic carbon in the 0-30 cm could be dominated by carbon pool mainly derived from C_4 grass vegetation. This may mask the net C sink potential of tropical forests; and total

soil organic C assessment may lead to underestimation of full carbon accounting of forests. Additionally, measurements of forest soil carbon stocks are not very accurate and are difficult to estimate forest carbon sinks from consecutive inventories, especially in forests dominated by large scale disturbances. To date existing scientific evidences show that forest soil carbon sink and role of forests in reducing CO_2 emission can be better estimated with minimum uncertainties using stable carbon isotopes .

Procedure:

1. Determine the age of the plantation
2. Collect the soil samples at 5 cm interval
3. Determine the organic soil carbon content (C_t) and expressed in g/kg soil;
4. Determine soil carbon isotope values ($\delta^{13}C_t$) expressed in -‰
5. Estimate soil organic carbon sequestered from the plantation forests using the formula:

C_f (g/kg soil) =(($\delta^{13}C_t$ - $\delta^{13}C_4$)/ ($\delta^{13}C_3$ - $\delta^{13}C_4$))x C_t……..eq. 16

Where:

C_t = total organic content measured

C_f (%) = C sequestered in soil from the newly established forests

$\delta^{13}C_t$ = the isotope values of total organic organic carbon

$\delta^{13}C_3$ = the carbon isotope values of C_3 plants which includes any woody plants (trees and shrubs); and their average values

$\delta^{13}C_4$ = the carbon isotope values of C_4 photosynthetic plants which includes tropical grasses and cereal crops (except wheat, barley, rice), and their average values in Ethiopia

Assuming a linear increase in soil organic carbon, estimate the rate of soil organic C increases using the formula

Estimate total forest carbon in soils using the formula:

Total C_f (Mg/ha) = C_f (g/kg soil) x Z x BD x 10……..eq. 17

Where:

C_f = defined as previously,

BD = bulk density.

Z = sampled soil layer thickness (0-30 cm)

(r): Rate of carbon sequestration (mg /year, ton/ha/yr) = C_f/age of plantation.

If the study site is located in arid, warm and humid climatic conditions, soil C isotope values can be obtained from literature.

Determining Soil Organic Matter

Once organic C is quantified, it is easy to determine soil organic matter. Soil organic matter is defined as all organic material in soils which has passed through a 2 mm sieve. It is measured by determining the organic carbon content of sieved soil. Depending on the composition and age, soil organic matter contains 40-60% of organic carbon. Soil organic carbon is often assumed to be 58% of organic matter.

Therefore soil organic matter (SOM) can be determined from organic carbon content (OC) using the formula:

$$SOM = 1.724 \text{ X } OC \quad \text{.....eq. 18}$$

(1.724 = 100/58)

4. DATA ANALYSIS AND REPORTING

Another major task to be accomplished after the data collection is completed is data analysis of various carbon pools measured in forests. Data analysis also involves map production from spatial data.

4.1 Produce final map

All relevant information to produce map of the study area including the type of land cover, stock and major species per unit area has to take place here. For the land cover classification there must be enough ground truth (during the survey period) in which at the later stages this data should be stored to computer then to the software in order to train the software. The number of sample should be enough and should represent the land cover in question.

Once the data is fed into the software then run the final classification to get the final land over/stock or the desired map type.

4.2 Carbon stock data analysis

Data analysis of the carbon pools is explained in this subsection.

4.2.1 Above-ground tree biomass (AGTB)

There are two major opitons for determining aboveground tree biomass: non-destructive methods (use of allometric equations, use biomass expansion factor, use of forest growth models) or destructive methods. The user can choose one of the options of non-destructivbe approaches depending on the availability of information. For example, if data on stem volume is available, the use of biomass expansion factor can be more appropriate. On the other hand, if the data available is only on DBH, DSH and/or height, then use of allometric equations will be appropriate. Among the options, the most expensive is destructive method, which should not be taken as an option, except in very few cases such as when developing allometric equations by research organizations.

A. Use of allometric equation: An allometric equation is a statistical relationship between key characteristic dimension(s) of trees that are fairly easy to measure, such as DBH or height, and other properties that are more difficult to assess, such as above-ground biomass. Allometric equations are established in a purely empirical way on the basis of exact measurements from a relatively large sample of typical trees. They permit an estimate of quantities that are difficult or costly to measure on the basis of a single (or at most a few) measurement.

The selection of the appropriate allometric equation is a crucial step in estimating aboveground tree biomass (AGTB). Allometric equations for biomass usually include information on trunk diameter at breast height *DBH* (in cm), and / or total tree height *H* (in m). The use of tree height as a predictive variable improves the quality of the allometric equation. Hence, the allometric equation enables AGTB to be easily estimated, provided that diameter (in some functions total height) of a tree are available. The unit of the AGB estimated from the allometric equation is the kilogram (kg).

After taking the sum of all the individual biomass (in kg) of a sampling plot and dividing it by the area of a sampling plot (e.g., 1000 m^2), the biomass stock density is attained in kg m^{-2}. This value can be converted to t ha^{-1} by multiplying it by 10. Since the project/forest areas are part of the tropical and sub-tropical region, the biomass stock density of a sampling plot will be converted to carbon stock densities after multiplication with the IPCC (2006) default carbon fraction of 0.47.

WBISPP developed biomass regression models for several tree species in 6 agro-ecological zones (Appendix 2-C). The measured attribute for trees was diameter at stump height (DSH, 0.30m above the ground surface). Biomass equations (stem, crown, foliage and total tree) for *Acacia tortilis* (Yitebitu Moges (1998, unpublished data) and for *Eucalyptus* species (Fanta *et al*, 2007) are also available.

If such equations are not available, one can use the general biomass equations developed by several authors (e.g., Brown, 1997). These models, however, are not recommended as they are the least precise approach for local conditions. On the other

hand, developing local biomass tables[2]/equations is not recommended in view of their limited application and the great deal of effort they require, as well as the duplication of effort they involve.

Use of biomass expansion factor: If the allometric equation does not include branches, twigs and foliage parts of the trees, then biomass expansion factors should be included to estimate the biomass constituted by these tree parts. For biomass tables from non-destructive samples, calculate stem volumes and convert them to biomass using specific wood density and expansion factors for canopy biomass. This requires a device such as a Spiegel Relaskop or laser measuring device for measuring diameters at least at three locations along the stem. However, for many species or forest types in Ethiopia biomass expansion factors (BEF) have not yet been developed. Thus, research institutions should consider developing BEFs.

If this approach is chosen, the following intermediate parameters have to be computed to arrive at carbon stock.

Basal area

The cross section area of the stem or stems of a plant or of all plants in a stand, generally expressed as square units per unit area. For tree stands, it is the cross section area of a tree stem in square meter commonly measured at breast height (1.3 m above ground) and inclusive of bark, usually computed by using DBH or tallied through the use of basal area factor angle gauge. The basal area factor is the number of units of basal area per hectare represented by each tree. In forestry, tree basal area is used to determine stocking.

The formula for basal area is:

$$BA = 0.785DBH^2 \quad \text{eq. 19}$$

[2] Tree biomass tables (biomass tables) show the average weight of individual trees for one or more dimensions, usually stem diameter alone (for local tables) or stem diameter along with height or length.

From basal area we can reach to volume of a tree by multiplying it by height and form factor. In plantation forest it is appropriate but this formula (v=g*h*f) is not applicable or most tropical forests. One of the reasons is linked to the form factor. The following equations are applied in such cases.

Volume

Volume can be calculated using the following three formulae:

Huber's Formula: $v = g_m L$ ……eq. 20

Smalian's formula: $v = \frac{g_l + g_s}{2} L$ ……eq. 21

Newton's formula: $v = \frac{(g_l + g_m + g_s)}{6} L$ ……eq. 22

Where v = volume of the log

g_m = cross-sectional area at log mid point

g_l = cross sectional area at large end of log

g_s = cross sectional area at small end of log

L = Log length

But to calculate the carbon stock of a tree the stem volume is not enough. There are branches, wood above the upper diameter, and leaves. Therefore, biomass expansion factor (BEF) and wood density are required in order arrive at the biomass of the tree.

Biomass Expansion Factor (BEF)

BEF is a multiplication factor that expands growing stock, or commercial round-wood harvest volume, or growing stock volume data, to account for non-merchantable biomass components such as branches, foliage, and non-commercial trees. Mathematically it is the ratio of the mass of the whole tree to the mass of stem.

Basic wood density (D) and biomass expansion factors (BEF) vary by forest type, age, growing conditions, stand density and climate Table 3A.1.10 of the IPCC provides default values of BEF by forest type and climatic zone for use with the minimum diameter ranges are indicated.

To calculate BEF of a stand we need to get biomass of stem volume, BV:

$$BV = VOB * WD \quad \text{.....eq. 23}$$

Where,

VOB is Volume over bark calculated as presented above.

WD is wood density and the information on this can be found in the literature (see Annex ...for WD of various tree species).

For a stand:

$BEF = \exp[3.213 - 0.505 * \ln(BV)]$ for BV less than 190t/ha ..... eq. 24

and

BEF =1.74 for BV ≥190t/ha

For an individual tree:

BEF = the mass of the whole tree/the mass of the stem.....eq. 25

Biomass:

In both cases (stand or individual tree), the above ground biomass equals the product of biomass of stem volume which is BV and Biomass Expansion Factor (BEF).

Carbon:

Now we have about to calculate the carbon stock per tree and defined as:

$$C = BV_i * BEF_i * 0.47 \quad \text{.....eq. 26}$$

Use of yield tables and other forest growth models:

Existing forest yield tables, volume tables or growth curves , especially for plantations provide information that is used for tree biomass estimation. Pukkala and Pohjonen (1989) developed yield tables and volume tables for *Eucalyptus globulus* in Ethiopian highlands and Pukalla and Pohjonen (1993) for *Cupressus lucitanica* (Appendix 4-B). Use of *Cupressus lucitanica* yield table developed by Pukalla and Pohjonen (1993) requires information on wood density, while *Eucalyptus globulus* yield table provides information on total biomass of the stand per ha. To use yield tables for carbon estimation, information on age and dominant height (Hdom) of the plantation under consideration (for carbon estimation) should be determined from field measurements. Volume tables require information on diameter (single entry tables) or both diameter and height (double entry tables). Once the volume is determined, it should be multiplied by wood density to arrive at a biomass estimate.

4.2.2 Leaf litter, herb and grass biomass

As shown in the data collection section, to determine the biomass of understorey vegetation and litter, samples are taken destructively in the field within a small area of 4 m^2. Fresh samples are weighed in the field with a 0.1 g precision; and a well-mixed sub-sample is then placed in a marked bag. The sub-sample is used to determine an oven-dry-to-fresh mass ratio that is used to convert the total fresh mass to oven-dry mass. A sub-sample is taken to the laboratory and oven dried until constant weight to determine water content.

For the forest floor (understorey wood vegetation, herbs, grass, and litter), the amount of biomass per unit area is given by:

$$HB = \frac{Wfield}{A} * \frac{Wsubsampl,dry}{Wsubsample,fresh} * \frac{1}{10000} \quad \text{.....eq. 27}$$

Where:

HB= Herbaceous biomass (biomass of leaf, herbs, and grass [t ha^{-1}]);

W_{field} = weight of the fresh field sample of leaf, herbs, and grass, destructively sampled within an area of size A [g];

A = size of the area in which leaf, herbs, and grass were collected [ha];

$W_{subsample}$, dry = weight of the oven-dry sub-sample of leaf litter, herbs, and grass taken to the laboratory to determine moisture content [g]; and

$W_{subsample}$, fresh = weight of the fresh sub-sample of leaf litter, herbs, and grass taken to the laboratory to determine moisture content [g].

The carbon content in HB, C(HB), is calculated by multiplying LHG with the IPCC (2006) default carbon fraction of 0.47.

Similar calculations are done for woody part of the understorey vegetation and for litter.

4.2.3 Dead wood

Volume: For **un-branched** cylindrical structures, an equation is based on cylinder

Biomass:

$$DWB\ (\text{single dead wood}) = \pi D^2 h \rho / 40 \quad \text{.....eq. 28}$$

Where:

DWB = dead wood biomass, expressed in kg,

h = length (m),

D = tree diameter (cm) and

ρ = specific gravity (oven dry density)(g cm-3) of wood.

For **branched dead wood**, use appropriate allometric equations, the same way as live trees.

After taking the sum of all the individual weights (in kg) of the dead wood in a sampling plot and dividing it by the area of a sampling plot (e.g.,. 1000 m^2), the biomass stock density is attained in kg m^{-2}. This value can be converted to t ha^{-1} by multiplying it by 10.

Carbon:

Carbon in dead wood is also computed by multiplying the biomass of the wood by 0.47.

4.2.4 Soil organic carbon (SOC)

The carbon stock density of soil organic carbon is calculated as (Pearson et. al 2007):

$$SOC = BD * d * \%C \quad \text{.....eq . 29}$$

Where,

SOC = soil organic carbon stock per unit area [t ha-1],

BD = soil bulk density [g cm-3],

d = the total depth at which the sample was taken [cm], and

%C = carbon concentration [%].

4.2.5 Total carbon stock density

The carbon stock density is calculated by summing the carbon stock densities of the individual carbon pools of a plot using the following formula.

To summarize carbon stock density of plot:

$C_{density} = C_{AGTB} + C_{BB} + C_{HB} + C_{WUVB} + C_{Lit} + C_{DW} + SOC$.....eq . 30

Where:

$C_{density}$ = carbon stock density for a land-use category or stratum [ton C ha^{-1}],

C_{AGTB} = carbon in above-ground tree biomass [ton C ha^{-1}],

C_{BB} = carbon in below-ground biomass [ton C ha^{-1}],

C_{HB} = carbon in leaf, herb & grass [ton C ha^{-1}],

C_{WUVB} = carbon in woody understorey vegetation [ton C ha^{-1}]

C_{Lit} = carbon in leaf, herb & grass [ton C ha^{-1}]

C_{DW} = carbon in dead wood [ton C ha^{-1}], and

SOC= soil organic carbon [ton C ha^{-1}]

For summarizing carbon stock per plot (in ton ha^{-1}), use the worksheet presented (Form 8) in Annex 1.

Calculation of data related to multiple objectives forest management such as regeneration, stock volume, etc are done in a similar way.

4.2.6 Statistical analysis

In reporting carbon stock data, a level of precision should be attached to the value obtained. this requires statistical analyses. the main pre-analyses required are presented below.

To summarize carbon stocks per stratum, we need statistical manipulations.

Mean: Mean carbon density per stratum

$$C_{Stratum} = \frac{\sum_{i=1}^{n} C_{density}}{n} \quad \text{.....eq. 31}$$

Where:

S_{tratum} = the mean carbon density per stratum

D_{ensity} = carbon density per plot

n = number of sample plots per stratum

Variance: The sample variance is defined as:

$$s^2 = \frac{\sum_{i=1}^{n} (C_{density} - \overline{C_{stratum}})^2}{n-1} \quad \text{.....eq. 32}$$

Standard deviation. The sample standard deviation is defined as the square root of the sample variance:

$$s = \sqrt{s^2}$$ ……..eq. 33

Standard error: The standard error is the standard deviation among sample means. It is therefore also called standard error of the mean, and is defined as:

$$s_x = \sqrt{\frac{s^2}{n}} = \frac{s}{\sqrt{n}}$$ ……..eq. 34

Coefficient of variation: This coefficient is the standard deviation, expressed as a percentage of the mean. It is defined as:

$$CV = \frac{s}{C_{stratum}} * 100$$ ……..eq. 35

Mean carbon density in a stratum should be multiplied by the area of the stratum to obtain the total carbon stock in a stratum.

Total carbon stock per stratum:

$$C_{strtot} = C_{stratum} \times A_i$$ ……..eq. 36

Where:

$C_{strtotal}$ = total carbon stock in a stratum

A_i = is the area of stratum i(ha)

Carbon stock in the project area is the sum of carbon stocks in all strata:

$$C_{total} = \sum_{i=1}^{n} C_{strtot}$$ ……..eq. 37

The total carbon stock is then converted to tons of CO_2 equivalent by multiplying it by 44/12, or 3.67 (Pearson et al. 2007).

4.3 Data reporting

The format and frequency of reports will depend in part on the inventory design, resources and the reporting requirements of the sponsoring agency. The way in which a project reports carbon credits will likely be determined by governmental regulations or intergovernmental agreements. Until such guidelines are in place, the following two types of reporting might be considered (MacDicken, 1997).

1. Report mean values for carbon stored along with confidence limits (at p=0.05). The formula for confidence interval calculations is:

$$CI = C_{total} \pm t \times SE \quad \text{.....eq. 38}$$

Where:

t = a two-sided t value for a probability level of 0.05.

C_{total} = total carbon stocks in the project area (tons)

*S*E **=** the standard error of the mean from the carbon inventory

2. Report the Reliable Minimum Estimate (RME) as a conservative measure of the minimum quantity expected to be present with its probability. The formula for this calculation is:

$$RME = C_{total} - t \times SE \quad \text{.....eq. 39}$$

Where:

t = a one-sided t value for a probability level of 0.05 (i.e., use p=0.10 in a two-tailed t table)

SE **=** the standard error of the mean from the carbon inventory (calculated from pooled variances of the different strata)

For most current uses, reporting mean values with confidence intervals is probably the most appropriate given the need for maximum incentives to potential investors in carbon offset projects (MacDicken, 1997).

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APPENDIX

Appendix 1: Data Collection Forms

Form 1: Tree data collection form

Cruiser_____ Date____/____/____

Project_____ Stratum number_____ Plot number _____

Elevation _____ Location N_____/E_____

Reference point_____ Distance to reference point (m)_____

Direction of reference point (Azimuth) (degree) _____

Plot disturbance level_____

Tree No (1)	Species code (2)	Diameter (cm)				Height (m)		Stem volume (m^3) (9)	WD (kg m^{-3}) (10)	BEF (11)	Tree Biomass (12) [9*10*11]	Carbon per tree (kg) (13) [12*0.47]
		Db (DSH) (3)	Dm (4)	Dt (5)	DBH (6)	Tot Ht (7)	MER Ht (8)					

Form 2: Regeneration and sapling data collection form

Collector_____ Date____/____/____

Project_____ Stratum number_____

Plot No	Species	Sapling Count	Height	Species	Seedling Count	Comments

Form 3: Biomass table/equation data collection form

Cruiser_____ Project_____ Date _____/_____/_____

Tree species/Forest type_____

Tree No	Stump diameter (cm)	DBH (cm)	Biomass component (stem, branch, leaf)	Volume segment No			Weight (kg)	Comments
				Diameter (cm)	Length (m)	bark thickness (cm)		

Form 4: Biomass of understorey vegetation-destructive sampling

Collector _____ Date_____/_____/_____

Project_____ Stratum number_____

Plot No	Subplot size	Total fresh weight (kg)		Subsample fresh weight (g)		Subsample dry weight (g)		Total dryweight (g)	
		Leaf/her	woo	Leaf/her	woo	Leaf/her	woo	g/fram	g/m

Form 4: Litter dry weight data collection form

Collector _____ Date_____/_____/_____

Project_____ Stratum number_____

Stratum No	Plot No	Total fresh weight (kg)	Subsample fresh weight (g)	Subsample dry weight (g)		Total C stock (ton ha-1)

Form 5: Deadwood data collection form

Collector _____ Date____/____/____

Project_____ Stratum number_____

Plot No	Dead wood (Log) No (1)	Length (cm) (2)	Diameter, D (cm) (3)	Estimated dry weight (kg) (4)	Stage of wood decomposition (5)	Biomass (6)	Carbon (7)=(6)*0.47

Form 6: Root biomass data collection form

Collector _____ Date____/____/____

Project_____ Stratum number_____

Plot Nr.	Sampling frame Nr.	Sample Code	Rooting depth interval (cm) Z	W_0	W_1	W_2	W_3	W_4	W_5	M_{t1}	M_{t2}	M_{t3}	C (g/cm^2)

Form 7: Soil carbon stock data collection form

Collector _____ Date_____/_____/_____

Project_____ Stratum number_____

Plot No	Soil depth (m)	Soil bulk density (kg dm-3)	C (%)	Total dry weight fine litter (kg m^{-2})

Form 8 Carbon stock summary worksheet

Team leader _____ Date____/____/____

Project_____ Stratum number_____

Plot No	C_{AGTB}[3]	C_{BB}	C_{HB}	C_{WUVB}	C_{Lit}	C_{DW}	SOC	$C_{density}$

[3] All pools are in ton ha^{-1}

Appendix 2: Allometric equations

Appendix 2-A: Local species specific allometric equations for estimating biomass from tree diameter (D > 5 cm) and height.

SITE/SPECIES	EQUATION	SOURCE	RANGE OF D	NUMBER OF TREES	R^2
Rift valley *Acacia tortilis*	ln AGB = -2.740 + 2.670 (ln D)	(Yitebitu, 1998)	5-40	30	0.95
E. globulus	Log (AGB) = -0.874 + 1.29 (log D^2)	Fantu et al., 2007			0.91
E. grandis	Log (AGB) = -0.136 + 2.73 (log D^2)	Fantu et al., 2007			0.99
E. saligna	Log (AGB) = -0.169 + 1.376 (log D^2	Fantu et al., 2007			0.77

AGB = aboveground tree biomass, kg/tree; D = DBH, cm; H = height, m; ρ = wood density, g cm^{-3})

Correction factor (CF) = 1.00 for *E. globulus*, 1.006 for *E. grandis*, and 1.020 for *E. saligna.*

Appendix 2-B: General allometric equations for estimating biomass from tree diameter (D > 5 cm) and height.

LIFE ZONE (RAINFALL MM YR^{-1})	EQUATION	SOURCE	RANGE OF D	NUMBER OF TREES	R^2
Dry (< 1500)	AGB = 0.139 $D^{2.32}$	(Brown, 1997)	5-40	28	0.89
Moist(1500-4000)	AGB = 0.118 $D^{2.53}$	(Brown, 1997)	5-148	170	0.90
	AGB = 0.049 ρ D^2 H	(Brown *et al.*, 1995)			
	AGB = 0.11 r D^{2+c}	with c (default 0.62) based on (Ketterings *et al.*, 2001)			
	H = a D^c				
Wet (> 4000)	AGB = 0.037 $D^{1.89}$ H	(Brown, 1997)	4-112	160	0.90

AGB = aboveground tree biomass, kg/tree; D = DBH, cm; H = height, m; ρ = wood density, g cm^{-3})

Appendix 2-C:

Appendix 2-C: Regression formulas for estimating oven dry mass with DSH

*	SPECIES	*OF SPL	MAX DSH (CM)	REGRESSION MODEL OVENDRY MASS(KG)*	R^2
DRY KOLLA					
*	ACACIA DOLICHOCEPAHALA	17	29	(0.9304X DSH)+(0.0571x (DSHexp2.6))	0.95
	ACACIA DREPANALOBIUM	24	16	(0.0819x DSH)+(0.3601x (DSHexp1.9))	0.84
*	ACACIA ETBAICA	39	37	(-.1024x DSH)+(0.1502x (DSHexp2.3))	0.88
*	ACACIA MELIFERA	49	27	(0.0627x DSH)+(0.3091x (DSHexp1.9))	0.91
*	ACACIA NILOTICA	17	27	(2.3624x DSH)+(0.0035x(DSHexp3.4))	0.96
*	ACACIA ROBUSTA	16	36	(0.0573X DSH)+(0.0643x(DSHexp3.6))	0.96
*	ACACIA SEYAL	40	34	(0.1124x DSH)+(0.1238x(DSHexp2.4))	0.95
*	ACACIA TORTILIS	40	30	(1.1725x DSH)+(0.0106x(DSHexp3.0))	0.97
	ACACIA ZANZIBARICA	59	35	(0.4021x DSH)+(0.5212x(DSHexp1.8))	0.76
*	ACACIA Sp	311	38	(0.0755x DSH)+(0.1548x(DSHexp2.3))	0.87
*	BALANITES GLABRATA	6	33	(0.1980x DSH)+(0.2496x(DSHexp2.0))	0.98
*	BALANITES Sp	8	33	(0.2086x DSH)+(0.0243x(DSHexp2.7))	0.98
*	BARBEYA OLEOIDES	47	37	(0.2370x DSH)+(0.2727x(DSHexp2.1))	0.92
*	BOSWELLIA Sp	7	19	(0.0534x DSH)+(0.0013x(DSHexp3.8))	0.98
	CASSIA SINGUEANA	6	8	(0.3845x DSH)+(0.0870x(DSHexp2.9))	0.82
*	COMMIPHORA AFRICANA	33	27	(0.0800x DSH)+(0.0939x(DSHexp2.3))	0.84
*	COMMIPHORA TENUIS	16	28	(0.0046x DSH)+(0.0604x(DSHexp2.4))	0.87
*	COMMIPHORA Sp	53	28	(0.1476x DSH)+(0.0930x(DSHexp2.3))	0.88
*	DELONIX ELATA	20	34	(0.9054x DSH)+(0.0805x(DSHexp2.5))	0.89
*	GREWIA BICOLOR	17	12	(0.2483x DSH)+(0.2214x(DSHexp2.1))	0.84
*	GREWIA MOLLIS	7	30	(0.1963x DSH)+(0.3438x(DSHexp1.8))	0.88
	GREWIA Sp	17	12	(0.0355x DSH)+(0.2978x(DSHexp2.1))	0.86
*	LANNEA SCHIMPERI	58	42	(0.1750x DSH)+(0.0444x(DSHexp2.5))	0.95
*	LANNEA Sp	59	42	(0.3587x DSH)+(0.0989x(DSHexp2.3))	0.95
	MAERUA CRASSIFOLIA	6	47	(0.4960x DSH)+(0.7262x(DSHexp1.8))	0.90
	MAERUA Sp	8	47	(0.7217x DSH)+(0.1601x(DSHexp2.2))	0.97
	MAYTENUS SENEGALENSIS	22	31	(0.2685x DSH)+(0.0492x(DSHexp2.3)	0.88
	MAYTENUS Sp	22	31	(0.2685x DSH)+(0.0492x(DSHexp2.3))	0.88
*	PAPPEA CAPENSIS	17	43	(0.2445xDSH)+(0.2451x(DSHexp2.6))+(0.1022x(DSHexp2.8	0.92
*	STERCULIA SETIGERA	19	38	(0.1638x DSH)+(0.0216x(DSHexp2.4))	0.89
*	TERMINALIA BROWNII	42	28	(0.4040x DSH)+(0.0766x(DSHexp2.4))	0.96
*	TERMINALIA MOLLIS	10	24	(0.4253x DSH)+(0.0056x(DSHexp3.4))	0.98
*	TERMINAKLIA Sp	53	28	(0.4380x DSH)+(0.1587x(DSHexp2.2))	0.82
*	All species	654	47	(0.4861x DSH)+(0.1659x(DSHexp2.2))	0.78

*	SPECIES	*OF SPL	MAX DSH (CM)	REGRESSION MODEL OVENDRY MASS(KG)*	R^2
MOIST KOLLA					
*	ACACIA ABYSSINICA	29	54	(1.0497x DSH)+(0.0300x(DSHexp2.8))	0.90
*	ACACIA BREVISPICA	24	15	(0.2265x DSH)+(0.0769x(DSHexp2.4))	0.88
*	ACACIA BUSSEI	48	36	(0.1006x DSH)+(0.2207x(DSHexp2.2))	0.89
*	ACACIA DOLICHOCEPHALA	27	29	(0.9304x DSH)+(0.057x(DSHexp2.6))	0.95
	ACACIA MACROTHYRSA	11	42	(0.3771x DSH)+(0.0212x(DSHexp2.8))	0.99
*	ACACIA NILOTICA	17	35	(0.3624x DSH)+(0.0035x(DSHexp3.4))	0.96
	ACACIA POLYACANYHA	18	35	(0.0191x DSH)+(0.7448x(DSHexp1.8))	0.96
	ACACIA REFICIENS	12	9	(0.0573x DSH)+(0.0643x(DSHexp2.9))	0.97
	ACACIA SIEBERIANA	19	17	(0.0417x DSH)+(0.0485x(DSHexp2.6))	0.98
*	ACACIA SENEGAL	53	34	(0.2819x DSH)+(0.0696x(DSHexp2.5))	0.93
*	ACACIA SEYAL	12	36	(0.1124x DSH)+(0.1238x(DSHexp2.4))	0.95
*	ACACIA TORTILIS	13	50	(1.1725x DSH)+(0.0106x(DSHexp3.0))	0.97
*	ACACIA Sp	312	55	(0.1357x DSH)+(0.0275x(DSHexp2.8))	0.88
*	ACOKANTHERA SCHIMPERI	16	24	(0.2383x DSH)+(0.2211 x(DSHexp1.9))	0.98
*	BALANITES AEGYPTIACA	31	53	(0.0982x DSH)+(0.0643x(DSHexp2.4))	0. 95
*	BALANITES Sp	62	48	(0.3619x DSH)+(0.1182x(DSHexp2.2))	0.91
*	BARBEYA OLEOIDES	28	43	(0.1980x DSH)+(0.2496x(DSHexp2.0))	0.97
*	BERCHEMIA DISCOLOR	15	31	(0.8007x DSH)+(0.6036x(DSHexp1.8))	0.93
*	BOSWELLIA HILDEBRANDTII	21	23	(0.0424x DSH)+(0.1717x(DSHexp1.9))	0.81
*	BOSWELLIA Sp	30	23	(0.1628x DSH)+(0.0882x(DSHexp2.1))	0.81
	CARISSA EDULIS	13	7	(0.0345x DSH)+(0.0377x(DSHexp3.3))	0.91
*	CANTHIUM EURYOIDES	12	25	(0.0312x DSH)+(0.0554x(DSHexp2.6))	0.98
*	CANTHIUM Sp	12	25	(0.2019x DSH)+(0.0388x(DSHexp2.7))	0.97
	CALPURNIA SUBDECANDRA	9	23	(0.5385 x DSH)+(0.5341x(DSHexp1.6))	0.98
	CASSIA SINGUEANA	13	9	(0.3845x DSH)+(0.0870x(DSHexp2.9))	0.82
*	COMBRETUM COLLINUM	47	36	(0.2130x DSH)+(0.0055x(DSHexp3.2))	0.91
*	COMBRETUM MOLLE	38	49	(0.0922x DSH)+(0.1540x(DSHexp2.2))	0.86
*	COMBRETUM Sp	108	49	(0.5095x DSH)+(0.0725x(DSHexp2.4))	0.87
	COMMIPHORA BRUCEAE	16	18	(0.0581x DSH)+(0.0703x(DSHexp2.3))	0.87
*	COMMIPHORA ERYTHRAEA	47	44	(0.3004x DSH)+(0.0781x(DSHexp2.4))	0.93
*	COMMIPHORA OGADENSIS	17	14	(0.0365x SH)+(0.0232x(DSHexp3.3))+(0.0106X(DSHexp3.5))	0.96
*	COMMIPHORA TENUIS	33	28	(0.0046x DSH)+(0.0604x(DSHexp2.4))	0.87
	COMMIPHORA Sp	137	48	(0.3259x DSH)+(0.1504x(DSHexp2.1))	0.73
	CROTON ODIXCHOGAMUS	19	19	(0.2938x DSH)+(0.0562x(DSHexp2.6))	0.98
*	CROTON MACROSTACHYUS	30	37	(0.2972x DSH)+(0.1588x(DSHexp2.2))	0.88

*	SPECIES	*OF SPL	MAX DSH	REGRESSION MODEL OVENDRY MASS(KG)*	R^2
	(CM)				
MOIST KOLLA					
*	CROTON Sp	48	37	(0.1075x DSH)+(0.3332x(DSHexp1.8))	0.89
*	DELONIX ELATA	6	44	(0.9054x DSH)+(0.0805x(DSHexp2.5))	0.89
*	DICHROSTACHYS CINEREA	49	33	(0.4012x DSH)+(0.0251x(DSHexp2.7))	0.96
	DODONAEA ANGUSTIFOLIA	11	13	(0.1505x DSH)+(0.0122x(DSHexp2.0))	0.99
	EHRETIA CYMOSA	11	17	(0.0197x DSH)+(0.2344x(DSHexp1.8))	0.58
*	ENTADA ABYSSINICA	21	47	(0.7586x DSH)+(0.3910x(DSHexp1.9))	0.99
	EUCLEA SCHIMPERI	23	14	(0.0397x DSH)+(0.2144x(DSHexp1.9))	0.94
*	FAUREA SALIGNA	16	23	(0.1381x DSH)+(0.0535x(DSHexp2.4))	0.87
	FLACOURTIA INDICA	8	13	(0.0891x DSH)+(0.1115x(DSHexp2.4))	0.97
*	GALINIERA SAXIFRAGA	15	23	(0.0388x DSH)+(0.0557x(DSHexp3.1))+(0.0140X(DSH exp3.5	0.97
*	GARDENIA TERNIFOLIA	27	22	(0.0016x DSH)+(0.2316x(DSHexp1.9))	0.91
*	GREWIA BICOLOR	21	36	(0.2483x DSH)+(0.2214x(DSHexp2.1))	0.84
	GREWIA FERRUGINEA	29	17	(0.5983x DSH)+(0.0017x(DSHexp3.7))	0.96
*	GREWIA MOLLIS	11	22	(0.1963x DSH)+(0.3438x(DSHexp1.8))	0.88
*	GREWIA Sp	61	36	(0.6224x DSH)+(0.0485x(DSHexp2.5))	0.81
*	ILEX MITIS	24	16	(0.0576x DSH)+(0.1243x(DSHexp2.3))	0.93
*	KIRKIA BURGERI	32	54	(0.0045x DSH)+(0.5661x(DSHexp1.8	0.84
*	LANNEA STUHLMANNII	12	33	(0.0913x DSH)+(0.0745x(DSHexp2.2))	0.99
*	LANNEA TRIPHYLLA	54	40	(0.1675x DSH)+(0.0173x(DSHexp2.7))	0.89
*	LANNEA Sp	65	40	(0.3055x DSH)+(0.0119x(DSHexp2.8))	0.89
	MAERUA ANGOLENSIS	13	33	(0.4312x DSH)+(0.1848x(DSHexp2.0))	0.79
*	MAERUA CRASSIFOLIA	40	45	(0.1229x DSH)+(0.2550x(DSHexp2.0))	0.95
*	MAERUA Sp	53	45	(0.2551x DSH)+(0.1673x(DSHexp2.1))	0.92
	MAYTENUS ADDAT	17	14	(0.1317x DSH)+(0.1075x(DSHexp2.4))	0.93
	MATENUS Sp	17	14	(0.1317x DSH)+(0.1075x(DSHexp2.4))	0.93
	MYSTROXYLON AETHIOPICUM	9	18	(0.1472x DSH)+(0.0029x(DSHexp3.3))	0.94
*	OCOTEA VIRIDIS	50	47	(0.02358x DSH)+(0.0786x(DSHexp2.0))	0.85
	OLEA CAPENSIS	25	17	(0.0117x DSH)+(0.4742x(DSHexp2.6))+ (01859x(DSHexp2.9))	0.96
*	OLEA Sp	27	20	(0.3534x DSH)+(0.5094x(DSHexp1.8))	0.98
*	OZOROA INSIGNISIN	25	37	(0.0015x DSH)+(0.0690x(DSHexp3.1))+(0.0316xDSHe xp3.3))	0.94
*	OZOROA Sp	25	37	(0.1684x DSH)+(0.0662x(DSHexp3.2))+(0.0309xDSHe xp3.4))	0.82
*	PAPPEA CAPENSIS	5	48	(0.2445x DSH)+(0.2451x(DSHexp2.6))+(0.1022xDSHe xp2.8))	0.92
*	PILIDIOSTIGMA THONNINGII	25	27	(0.1423x DSH)+(0.0127x(DSHexp2.9))	0.95
	PISTACIA LENTISCUS	13	11	(0.0318x DSH)+(0.2136x(DSHexp1.8))	0.97
*	RHUS NATALENSIS	20	13	(0.0281x DSH)+(0.1505x(DSHexp2.3))	0.96

*	SPECIES	*OF SPL	MAX DSH	REGRESSION MODEL OVENDRY MASS(KG)*	R^2
			(CM)		
MOIST KOLLA					
*	RHUS VULGARIS	21	14	(0.0038x DSH)+(0.6092x(DSHexp1.5))	0.84
*	RHUS Sp	42	17	(0.0884x DSH)+(0.0331x(DSHexp2.8))	0.86
*	SCLEROCARYA BIRREA	15	25	(0.4000x DSH)+(0.5142x(DSHexp1.6))	0.94
	STEGANOTAENIA ARALIACEA	12	18	(0.0173x DSH)+(0.0261x(DSHexp2.6))	0.94
	STEREOSPERMUM KUNTHIANUM	12	18	(0.3513x DSH)+(0.0032x(DSHexp3.1))	0.95
*	TAMRINDUS INDICA	23	36	(0.5031x DSH)+(0.2536x(DSHexp2.1))	0.88
	TECLEA NOBILIS	18	18	(0.0648x DSH)+(0.1561x(DSHexp2.2))	0.98
*	TERMINALIA BROWNII	4	43	(0.4040x DSH)+(0.0766x(DSHexp2.4))	0.96
*	TERMINALIA LAXIFLORA	28	30	(0.0110x DSH)+(0.0771x(DSHexp2.4))	0.82
*	TERMINALIA MOLLIS	26	38	(0.3682x DSH)+(0.0944x(DSHexp2.3))	0.97
*	TERMINALIA PRUNIOIDES	48	42	(0.0240x DSH)+(0.2974x(DSHexp2.2))	0.94
*	TERMINALIA SCHIMPERIANA	18	33	(0.1603x DSH)+(0.0320x(DSHexp2.6))	0.93
*	TERMINALIA SPINOSA	38	29	(0.2934x DSH)+(0.1109x(DSHexp2.4))	0.89
*	TERMINALIA Sp	162	43	(0.0927x DSH)+(0.1052x(DSHexp2.4))	0.82
*	XIMENIA AMERICANA	22	17	(0.1324x DSH)+(0.2158x(DSHexp1.6))	0.97
*	XIMENIA CAFFRA	22	14	(0.7883x DSH)+(0.0111x(DSHexp2.9))	0.91
	XIMENIA Sp	44	17	(0.0604x DSH)+(0.6719x(DSHexp1.3))	0.71
*	ZANTHOXYLUM CHALYBEUM	14	28	(0.0101x DSH)+(0.0115x(DSHexp3.1))	0.83
*	ZIZIPHUS MAURITANIA	38	24	(0.1067x DSH)+(0.0131x(DSHexp3.0))	0.94

	ZIZIPHUS MUCRONATA	12	24	(0.0443x DSH)+(0.0021x(DSHexp3.5))	0.71
*	ZIZIPHUS Sp	50	24	(0.6950x DSH)+(0.0022x(DSHexp3.5))	0.85
*	All species	2040	55	(0.4277x DSH)+(0.0088x(DSHexp3.0))	0.75

*	SPECIES	*OF SPI	MAX DSH	REGRESSION MODEL OVENDRY MASS(KG)*	R^2
		(CM)			
WET KOLLA					
	ACACIA DREPANOLOBIUM	14	9	(0.1280x DSH)+(0.0037x(DSHexp3.8))	0.98
	ACACIA LAHAI	20	19	(0.0565x DSH)+(0.0912x(DSHexp2.3))	0.73
	ACACIA POLYACANTHA	10	15	(0.0577x DSH)+(0.1573x(DSHexp2.3))	0.98
*	ACACIA POLYACANTHA	65	20	(0.1914x DSH)+(0.0091x(DSHexp3.3))	0.81
*	ALBIZIA Sp	14	29	(0.3006x DSH)+(0.0621x(DSHexp2.1))	0.99
*	BALANITES Sp	19	50	(0.0349x DSH)+(0.0003x(DSHexp3.9))	0.91
	BRIDELIA MICRANTHA	11	16	(0.0007x DSH)+(0.0648x(DSHexp2.5))	0.85
*	CANTHIUM EURYOIDES	5	21	(0.0312x DSH)+(0.0554x(DSHexp2.6))	0.98
*	CANTHIUM GIORDANII	19	48	(0.3845x DSH)+(0.0870x(DSHexp2.4))	0.86
*	CANTHIUM Sp	24	48	(0.6194x DSH)+(0.0859x(DSHexp2.4))	0.87
*	COMBRETUM ADENOGONIUM	27	29	(0.1135x DSH)+(0.1140x(DSHexp2.3))	0.94
*	COMBRETUM MOLLE	13	29	(0.0922x DSH)+(0.1540x(DSHexp2.2))	0.87
	COMBRETUM Sp	48	29	(0.0564x DSH)+(0.0419x(DSHexp2.6))	0.95
*	COMMIPHORA BRUCEAE	25	33	(0.1408x DSH)+(0.0481x(DSHexp2.4))	072
	COMMIPHORA OGADENSIS	25	48	(0.0365x DSH)+(0.0232x(DSHexp3.3))+(0.0106xDSHexp3.5))	0.96
*	COMMIPHORA Sp	30	33	(0.3140x DSH)+(0.0168x(DSHexp2.7))	0.74
*	CORDIA OVALIS	18	12	(0.0175x DSH)+(0.2220x(DSHexp2.2))	0.98
	GARDENIA TERNIFOLIA	10	16	(0.2263x DSH)+(0.0863x(DSHexp2.3))	0.77
	LANNEA FRUTICOSA	10	18	(0.0410x DSH)+(0.0078x(DSHexp2.9))	0.98
*	LANNEA Sp	11	36	(0.0486x DSH)+(0.0101x(DSHexp28))	0.99
	MAERUA ANGOLENSIS	6	29	(0.4312x DSH)+(0.1848x(DSHexp2.0))	0.79
	MAERUA Sp	7	33	(0.3990x DSH)+(0.2387x(DSHexp1.9))	0.95
	MAESA LANCEOLATA	6	14	(0.0229x DSH)+(0.0525x(DSHexp2.3))	0.98
	MYSTROXYLON AETHIOPICUM	32	18	(0.1472x DSH)+(0.0029x(DSHexp3.3))	0.94
*	OZOROA INSIGNIS	10	12	(0.0015x DSH)+(0.0690x(DSHexp3.1))+(0.0316xDSHexp3.3))	0.94
	OZOROA PULCHERRIMA	23	21	(0.0670x DSH)+(0.0413x(DSHexp2.4))	0.78
*	OZOROA Sp	33	20	(0.0419x DSH)+(0.0418x(DSHexp2.4))	0.80
*	PILIDIOSTIGMA THONNINGII	17	17	(0.1423x DSH)+(0.0127x(DSHexp2.9))	0.90
	PISTACIA LENTISCUS	9	7	(0.0184x DSH)+(0.1301x(DSHexp2.1))	0.81
	PREMNA SCHIMPERI	9	15	(0.1423x DSH)+(0.0065x(DSHexp3.2))	0.99
*	SCLEROCARYA BIRREA	6	4	(0.4000x DSH)+(0.5142x(DSHexp1.6))	0.94
*	STRYCHNOS INNOCUA	23	35	(0.3515x DSH)+(0.0643x(DSHexp2.3))	0.95
*	STRYCHNIOS Sp	23	35	(0.3515x DSH)+(0.0643x(DSHexp2.3))	0.95
*	TAMARINDUS INDICA	10	40	(0.5031x DSH)+(0.2536x(DSHexp2.1))	0.89
	TERMINALIA MOLLIS	11	15	(0.1527x DSH)+(0.1614x(DSHexp2.1))	0.72

*	SPECIES	*OF SPI	MAX DSH	REGRESSION MODEL OVENDRY MASS(KG)*	R^2
WET KOLLA					
*	TECLEA Sp	19	38	(0.5853x DSH)+(0.0036x(DSHexp3.4))	0.96
	VERAU	9	15	(0.7364x DSH)+(0.0065x(DSHexp2.9))	0.99
*	VERAU Sp	9	15	(0.0972x DSH)+(0.1521x(DSHexp1.9))	0.98
	ZIZIPHUS SPINA-CHRISTI	9	12	(0.0340x DSH)+(0.0431x(DSHexp2.6))	0.97
	ZIZIPHUS Sp	9	12	(0.0340x DSH)+(0.0431x(DSHexp2.6))	0.97
*	All species	557	50	(0.3989x DSH)+(0.0126x(DSHexp2.9))	0.82
DRY WEYNA DEGA					
	All Species	8	17	(0.2313x DSH)+(0.1073x(DSHexp2.0))	0.98
	ACACIA Sp	19	18	(0.0291x DSH)+(0.2897x(DSHexp1.9))	0.87
	BALANITES Sp	6	35	(0.2118x DSH)+(0.0112x(DSHexp2.9))	0.93
*	COMBRETUM MOLLE	6	30	(0.0922x DSH)+(0.1540x(DSHexp2.2))	0.86
	COMBRETUM Sp	6	30	(0.1111x DSH)+(0.0557x(DSHexp2.5))	0.99
	MAESA LANCEOLATA	3	19	(0.1751x DSH)+(0.2044x(DSHexp2.0))	0.93
	MAYTENUS SENEGALENSIS	25	17	(0.0587x DSH)+(0.0509x(DSHexp2.4))	0.93
*	MAYTENUS Sp	133	34	(0.2451x DSH)+(0.0271x(DSHexp2.6))	0.93
	OLEA CAPENSIS SUB.HOCHSTETTERI	9	13	(0.0358x DSH)+(0.0389x(DSHexp2.4))	0.98
	OLEA Sp	11	13	(0.0238x DSH)+(0.0143x(DSHexp2.8))	0.95
	RHUS NATALENSIS	8	18	(0.0281x DSH)+(0.1505x(DSHexp23))	0.97
*	RHUS Sp	10	17	(0.3989x DSH)+(0.0126x(DSHexp2.9))	0.97
*	All species	118	39	(0.3989x DSH)+(0.0126x(DSHexp2.9))	0.93
MOIST WEYNA DEGA					
	ACACIA POLYACANTHA	14	50	(0.3251x DSH)+(0.3517x(DSHexp1.9))	0.98
*	ACACIA SIEBERIANA	10	25	(0.4250 DSH)+(0.0528x(DSHexp2.5))	0.98
*	ACACIA SEYAL	19	48	(0.9103x DSH)+(0.6782x(DSHexp1.7))	0.90
*	ACACIA Sp	64	54	(0.6308x DSH)+(0.4535x(DSHexp1.8))	0.94
*	ACOKANTHERA SCHIMPERI	25	29	(0.1788x DSH)+(0.0319x(DSHexp2.6))	0.96
*	ALBIZIA GUMMIFERA	42	46	(0.0517x DSH)+(0.0236x(DSHexp2.8))	0.99
	ALBIZIA SCHIMPERIANA	16	33	(0.2910x DSH)+(0.0124x(DSHexp2.9))	0.99

*	SPECIES	*OF SPI	MAX DSH	REGRESSION MODEL OVENDRY MASS(KG)*	R^2
MOIST WEYNA DEGA					
*	ALBIZIA Sp	65	46	(0.2290x DSH)+(0.0160x(DSHexp2.9))	0.99
	BALANITES AEGYPTIACA	14	54	(0.4743x DSH)+(0.0693x(DSHexp2.3))	0.98
*	BALANITES Sp	16	54	(0.5418x DSH)+(0.1070x(DSHexp2.1))	0.96
*	BERSAMA ABYSSINICA	39	17	(0.1189x DSH)+(0.0011x(DSHexp4.0))	0.98
	CALPURNIA SUBDECANDRA	12	14	(0.9511x DSH)+(0.0295x(DSHexp2.4))	0.98
*	CROTON MACROSTACHYUS	22	47	(0.3679x DSH)+(0.0459x(DSHexp2.5))	0.99
*	CROTON Sp	22	47	(0.1330x DSH)+(0.0682x(DSHexp2.4))	0.99
	CUSSONIA HOLSTII	12	18	(0.3861x DSH)+(0.2063x(DSHexp1.6))	0.97
	DIPHASIA DAINELLII	12	18	(0.0285x DSH)+(0.1386x(DSHexp2.0))	0.97
	DOMBEYA TORRIDA	15	13	(0.8630x DSH)+(0.0744x(DSHexp1.2))	0.93
	EHRETIA CYMOSA	13	40	(0.8808x DSH)+(0.0348x(DSHexp2.5))	0.98
*	EUCLEA SCHIMPERI	19	26	(0.0935x DSH)+(0.0140x(DSHexp3.6)+(0.0035xDSHexp3.4.0))	0.96
	GREWIA VILLOSA	6	7	(0.1346x DSH)+(0.0149x(DSHexp1.5))	0.88
	GREWIA Sp	7	14	(0.1532x DSH)+(0.2018x(DSHexp1.9))	0.98
	HYPERICUM REVOLUTUM	6	8	(0.0164x DSH)+(0.1514x(DSHexp1.9))	0.96
*	ILEX MITIS	7	17	(0.0576x DSH)+(0.1243x(DSHexp2.3))	0.93
	MAERUA CALOPHYLLA	32	17	(0.1373x DSH)+(0.5803x(DSHexp1.3))	0.96
	MARRUA Sp	33	17	(0.1849x DSH)+(0.5569x(DSHexp1.3))	0.96
	MAESA LANCEOLATA	26	18	(0.1751x DSH)+(0.2044x(DSHexp2.0))	0.93
*	MILLETTIA FERRUGINEA	15	26	(0.3494x DSH)+(0.3687x(DSHexp2.0)+(0.0780xDSHexp3.2.4))	0.96
	MIMUSOPS KUMMEL	15	26	(0.6143x DSH)+(0.0014x(DSHexp3.3))	0.98
	NUXIA CONGESTA	30	31	(0.6804x DSH)+(0.0020x(DSHexp4.0)+(0.0005xDSHexp3.4.4))	0.98
	OLEA AFRICANA	16	23	(0.6806x DSH)+(0.0422x(DSHexp2.7))	0.91
	OLEA Sp	15	23	(0.1517x DSH)+(0.1518x(DSHexp2.3))	0.91
	OPILIA CAMPESTRIS	15	25	(0.3061x DSH)+(0.3635x(DSHexp1.4))	0.96
	OZOROA INSIGNIS	13	52	(0.1362x DSH)+(0.1759x(DSHexp2.0))	0.98
	OZOROA Sp	13	52	(0.1362x DSH)+(0.1759x(DSHexp2.0))	0.98
	PITTOSPORUM VIRIDIFLORUM	21	17	(0.0051x DSH)+(0.6359x(DSHexp1.2))	0.99
	POLYSCIAS FULVA	9	14	(0.0475x DSH)+(0.4485x(DSHexp2.3)+(0.2394xDSHexp3.2.5))	0.97
	PROTEA GAGUEDI	9	13	(0.8716x DSH)+(0.0108x(DSHexp2.5))	0.99
	RHUS NATALENSIS	10	17	(0.0281x DSH)+(0.1505x(DSHexp2.3))	0.97
	RHUS Sp	10	17	(0.0281x DSH)+(0.1505x(DSHexp2.3))	0.97
	SCLEROCARYA BIRREA	3	18	(0.4000x DSH)+(0.5142x(DSHexp1.6))	0.94
	SCHREBERA ALATA	14	26	(0.0111x DSH)+(0.1014x(DSHexp1.3))	0.94
	TECLEA NOBILIS	19	46	(0.2619x DSH)+(0.3880x(DSHexp2.3)+(0.0667xDSHexp2.7.5))	0.99

*	SPECIES	*OF SPI	MAX DSH	REGRESSION MODEL OVENDRY MASS(KG)*	R^2
MOIST WEYNA DEGA					
*	TECLEA SIMPLICIFOLIA	18	30	(0.2896x DSH)+(0.6451x(DSHexp1.1))	0.96
*	TECLEA Sp	36	30	(0.3331x DSH)+(0.1921x(DSHexp2.6+(0.0318xDSHexp2.3.1))	0.68
	VERAM	14	8	(0.0299x DSH)+(0.0206x(DSHexp3.0))	0.98
*	VERAU	16	16	(0.1429x DSH)+(0.1498x(DSHexp2.0))	0.99
*	VERAU Sp	30	16	(0.0046x DSH)+(0.1946x(DSHexp2.9+(0.1377xDSHexp2.3.0))	0.98
	ZIZIPHUS MUCRONATA	30	18	(0.2359x DSH)+(0.1457x(DSHexp2.2))	0.99
	ZIZIPHUS Sp	30	18	(0.2359x DSH)+(0.1457x(DSHexp2.2))	0.99
*	All species	798	54	(0.3658x DSH)+(0.1144x(DSHexp2.2))	0.86
WET WEYNA DEGA					
	ALBIZIA GUMMIFERA	12	18	(0.1200x DSH)+(0.0701x(DSHexp2.3))	0.97
	ALBIZIA Sp	12	18	(0.1200x DSH)+(0.0701x(DSHexp2.3))	0.97
*	ERYTHRINA BRUCEI	17	30	(0.1228x DSH)+(0.0330x(DSHexp2.4))	0.96
	All species	68	31	(0.0633x DSH)+(0.0104x(DSHexp29	0.84

Appendix 3: Wood density of common tree species in Ethiopia (at 12% moisture content)

SCIENTIFIC NAME	VERNACULAR NAME	WOOD DENSITY (KG M^{-3})
Hardwoods		
Acrocarpus fraxinifolius	-	610
Albizia grandibracteata	Alele (O)	600
Albizia gummifera	Sissa (Am)	580
Albizia shimperiana	Sessa (Am)	530
Allophylus abyssinicus	Lekeme (Am)	580
Aningeria adolfifriederici	Kerero (Am/O)	560
Antiaris toxicaria	Tengi (Sh)	470
Apodytes dimidiata	Cheleleka (O)	710
Blighia unijugata	Tucho (O)	700
Bosqueia phoberos	Gabu (O)	560
Celtis kraussiana	Kaut (Am)	760
Chlorophora excelsa	Dego (An)	570
Croton macrostachyus	Bisanna (Am)	560
Diospyros abyssinica	Loko (O)	790
Ekebergia rueppennalia	Sombo (O)	580
Eucalyptus globulus	Nechi-bahrzaff (Am)	780
Eucalyptus grandis	Grandis-bahirzaff (Am)	560
Eucalyptus saligna	Saligna-bahrzaff (Am)	680
Fagaropsis angolensis	Dero (O)	700
Hagenia abyssinica	Kosso (Am)	560
Manilikara butugi	Butugi (E)	870
Mimusops kummel	Kolati (O)	880
Morus mesozygia	Shamgareza (Am)	690
Ocotes kenyensis	Soecho (Si)	560
Olea Hochsttetri	Gagama (O)	990
Olea welwitschii	Baha (O/S)	820
Polyscias ferruginea	Zinjero-wonder (Am)	440
Prunus africana	Tiuku-enchet (Am)	850
Sysygium guineense	Dokma (Am)	740
Warburgia ugandensis	Befti (O)	770
Softwoods		
Cupresssus lucitanica	Yeferenji-tidh	430
Pinus patula	Patula pine (E)	450
Pinus radiata	Radiata pine (E)	450
Podocarpus falcatus	Zgba (Am)	520

Appendix 4: Yield and volume tables

Appendix 4-A: Yield table for *Eucalyptus globules (Pukkala and Pohjonen, 1989)*

Seedling stand												
Site class 1												
									DRY MASSES			
Age	**Hdom**	**DgM**	**HgM**	**N**	**G**	**V**	**MAI**	**CAI**	**Stem**	**Branch**	**Leaf**	**Total**
1	0.6	0	0	1431	0	0	0	0	0	0	0	0
2	2.4	2.8	2.8	1413	2	0.5	0.2	0.5	0.3	0.1	0.4	0.7
3	5.0	5.3	4.3	1385	1.5	4.2	1.4	3.7	2.3	0.3	0.8	3.4
4	8.4	7.6	6.9	1351	3.7	14.9	3.7	10.7	8.2	0.8	1.6	10.6
5	12.1	10	10.1	1313	6.9	36.9	7.4	22	20.4	1.6	2.6	24.6
6	15.9	12.4	13.5	1273	10.8	72.2	12	35.3	39.7	2.9	3.8	46.4
7	19.7	14.8	16.9	1235	15.2	120.1	17.2	47.9	66.1	4.4	5.1	75.5
8	23.2	16.9	20.3	1198	19.7	178.4	22.3	58.3	98.1	6	6.3	110.4
9	26.5	18.9	23.5	1164	24.1	243.8	27.1	65.4	134	7.8	7.5	149.2
10	29.6	20.8	26.5	1133	28.3	313	31.3	69.3	172	9.6	8.5	190.1
11	32.3	22.4	29.2	1105	32.2	383.4	34.9	70.3	210.5	11.3	9.5	231.3
12	34.7	23.8	31.6	1080	35.8	452.5	37.7	69.2	248.5	12.9	10.3	271.6
13	36.9	25.1	33.8	1058	39.1	519.1	39.9	66.6	284.9	14.4	11	310.4
14	38.8	26.3	35.8	1038	42	582.1	41.6	63	319.5	15.7	11.7	346.9
15	40.5	27.3	37.6	1020	44.6	641	42.7	58.9	351.7	17	12.3	381
16	42.0	28.2	39.1	1005	47	695.7	43.5	54.6	381.6	18.1	12.8	412.5
17	43.3	29	40.5	991	49.1	746	43.9	50.3	409.2	19.1	13.2	441.5
18	44.5	29.7	41.8	979	51	792.2	44	46.2	434.5	20	13.6	468.1
19	45.5	30.3	42.9	968	52.6	834.4	43.9	42.3	457.6	20.9	13.9	492.4
20	46.5	30.9	43.9	958	54.1	873.1	43.7	38.6	478.8	21.6	14.2	514.6
21	47.3	31.4	44.8	950	55.5	908.3	43.3	35.3	498.1	22.3	14.5	534.8
22	48.1	31.9	45.6	942	56.7	940.5	42.8	32.2	515.7	22.9	14.7	553.3
23	48.8	32.3	46.3	935	57.8	970	42.2	29.4	531.8	23.4	14.9	570.1
24	49.4	32.7	47	928	58.8	996.8	41.5	26.9	546.5	23.9	15.1	585.5
25	49.9	33	47.6	923	59.7	1021.4	40.9	24.6	559.9	24.4	15.2	599.6
26	50.4	33.3	48.1	917	60.5	1044	40.2	22.5	572.3	24.8	15.4	612.4
27	50.9	33.6	48.6	913	61.2	1064.6	39.4	20.7	583.6	25.1	15.5	624.2
28	51.3	33.8	49.1	908	61.9	1083.6	38.7	19	594	25.5	15.6	635
29	51.7	34.1	49.5	905	62.5	1101.1	38	17.5	603.5	25.8	15.8	645
30	52.0	34.3	49.9	901	63	1117.1	37.2	16.1	612.3	26.1	15.9	654.2

Hdom = dominant height (m), DgM = basal area median diameter(cm), HgM = basal area median height (m), N = number of stems per hectare, G = stand basal area(m^2/ha), V= stand volume (m^3/ha), MAI = Mean annual increment (m^3/ha), CAI= current annual increment (m^3/ha), Dry masses (ton/ha).

Yield table for *Eucalyptus globulus*												
Seedling stand												
Site class	**2**											
									DRY MASSES			
Age	**Hdom**	**DgM**	**HgM**	**N**	**G**	**V**	**MAI**	**CAI**	**Stem**	**Branch**	**Leaf**	**Total**
1	0.5	0.0	0	1432	0	0	0	0	0	0	0	0
2	2.0	0	0	1417	0	0	0	0	0	0	0	0
3	4.2	4.6	3.7	1394	1	2.5	0.8	2.5	1.4	0.2	0.6	2.2
4	7.0	6.7	5.8	1365	2.7	9.4	2.4	6.9	5.2	0.5	1.2	7
5	10.1	8.7	8.3	1333	5.1	23.5	4.7	14.1	13	1.1	2	16.2
6	13.3	10.7	11.1	1301	8	46.3	7.7	22.8	25.5	2	3	30.5
7	16.4	12.7	13.9	1268	11.4	77.6	11.1	31.2	42.7	3	4	49.7
8	19.4	14.6	16.7	1238	14.8	115.8	14.5	38.2	63.7	4.2	5	72.9
9	22.1	16.3	19.3	1209	18.2	158.8	17.6	43.1	87.4	5.5	5.9	98.8
10	24.6	17.8	21.7	1183	21.5	204.6	20.5	45.8	112.5	6.8	6.8	126.1
11	26.9	19.2	23.9	1160	24.6	251.4	22.9	46.7	138.1	8	7.6	153.7
12	28.9	20.4	25.8	1139	27.4	297.5	24.8	46.1	163.5	9.2	8.3	180.9
13	30.7	21.4	27.6	1121	30	342.1	26.3	44.6	187.9	10.3	8.9	207.1
14	32.3	22.4	29.2	1104	32.3	384.4	27.5	42.3	211.1	11.3	9.5	231.8
15	33.7	23.2	30.6	1090	34.4	424	28.3	39.7	232.8	12.2	10	255
16	35.0	24	31.9	1077	36.2	460.9	28.8	36.9	253	13.1	10.4	276.5
17	36.1	24.7	33.1	1065	37.9	495	29.1	34.1	271.7	13.8	10.8	296.3
18	37.1	25.2	34.1	1055	39.4	526.3	29.2	31.3	288.9	14.5	11.1	314.5
19	38.0	25.8	35	1046	40.8	555	29.2	28.7	304.6	15.2	11.4	331.2
20	38.7	26.2	35.8	1038	42	581.4	29.1	26.3	319	15.7	11.7	346.4
21	39.4	26.7	36.5	1031	43.1	605.4	28.8	24.1	332.2	16.2	11.9	360.4
22	40.1	27	37.2	1024	44.1	627.4	28.5	22	344.3	16.7	12.1	373.1
23	40.6	27.4	37.8	1018	44.9	647.6	28.2	20.1	355.3	17.1	12.3	384.7
24	41.2	27.7	38.3	1013	45.7	666	27.7	18.4	365.4	17.5	12.5	395.4
25	41.6	28	38.8	1008	46.5	682.9	27.3	16.9	374.6	17.9	12.6	405.1
26	42.0	28.2	39.2	1004	47.1	698.4	26.9	15.5	383.1	18.2	12.8	414.1
27	42.4	28.4	39.6	1000	47.7	712.6	26.4	14.2	390.9	18.5	12.9	422.3
28	42.8	28.7	40	997	48.3	725.6	25.9	13.1	398.1	18.7	13	429.8
29	43.1	28.8	40.3	993	48.8	737.7	25.4	12	404.6	19	13.1	436.7
30	43.4	29	40.6	990	49.2	748.7	25	11.1	410.7	19.2	13.2	443.1

Yield table for *Eucalyptus globulus*												
Seedling stand												
Site class	**3**											
									DRY MASSES			
Age	**Hdom**	**DgM**	**HgM**	**N**	**G**	**V**	**MAI**	**CAI**	**Stem**	**Branch**	**Leaf**	**Total**
1	0.4	0.0	0	1433	0	0	0	0	0	0	0	0
2	1.6	0	0	1421	0	0	0	0	0	0	0	0
3	3.4	3.8	3.1	1402	0.6	1.3	0.4	1.3	0.7	0.1	0.5	1.3
4	5.6	5.8	4.7	1380	1.8	5.4	1.4	4.1	3	0.3	0.9	4.2
5	8.1	7.4	6.7	1354	3.4	13.5	2.7	2.7	7.4	0.7	1.5	9.7
6	10.6	9	8.8	1328	5.5	26.8	4.5	13.3	14.8	1.3	2.2	18.2
7	13.1	10.6	11	1302	7.9	45.1	6.4	18.4	24.9	1.9	2.9	29.7
8	15.5	12.2	13.1	1278	10.4	67.7	8.5	22.6	37.3	2.7	3.7	43.7
9	17.7	13.5	15.1	1255	12.8	93.3	10.4	25.6	51.4	3.5	4.4	59.3
10	19.7	14.8	17	1234	15.2	120.7	12.1	27.4	66.4	4.4	5.1	75.9
11	21.5	15.9	18.7	1216	17.5	148.7	13.5	28	81.8	5.2	5.7	92.7
12	23.1	16.9	20.2	1199	19.5	176.5	14.7	27.8	97.1	6	6.3	109.3
13	24.6	17.8	21.6	1184	21.4	203.5	15.7	26.9	111.9	6.7	6.8	125.4
14	25.8	18.5	22.8	1171	23.1	229.1	16.4	25.6	125.9	7.4	7.2	140.6
15	27.0	19.2	23.9	1159	24.7	253.2	16.9	24.1	139.2	8	7.6	154.8
16	28.0	19.8	24.9	1149	26.1	275.7	17.2	22.5	151.5	8.6	8	168.1
17	28.9	20.3	25.8	1140	27.3	296.5	17.4	20.8	162.9	9.1	8.3	180.3
18	29.7	20.8	26.6	1132	28.4	315.6	17.5	19.2	173.4	9.6	8.5	191.6
19	30.4	21.2	27.3	1124	29.5	333.3	17.5	17.6	183.1	10.1	8.8	201.9
20	31.0	21.6	27.9	1118	30.4	349.4	17.5	16.2	191.9	10.5	9	211.4
21	31.6	22	28.5	1112	31.2	364.2	17.3	14.8	200	10.8	9.2	220.1
22	32.1	22.3	29	1107	31.9	377.8	17.2	13.5	207.5	11.1	9.4	228
23	32.5	22.5	29.4	1102	32.6	390.2	17	12.4	214.3	11.4	9.5	235.2
24	32.9	22.8	29.8	1098	33.2	401.5	16.7	11.4	220.5	11.7	9.7	241.9
25	33.3	23	30.2	1094	33.7	412	16.5	10.4	226.2	11.9	9.8	248
26	33.6	23.2	30.6	1091	34.2	421.5	16.2	9.6	231.5	12.2	9.9	253.6
27	33.9	23.4	30.9	1088	34.7	430.3	15.9	8.8	236.3	12.4	10	258.7
28	34.2	23.5	31.1	1085	35.1	438.4	15.7	8.1	240.7	12.6	10.1	263.4
29	34.5	23.7	31.4	1082	35.5	445.9	15.4	7.5	244.8	12.7	10.2	267.4
30	34.7	23.8	31.6	1080	35.8	452.7	15.1	6.9	248.6	12.9	10.3	271.8

Yield table for *Eucalyptus globulus*												
seedling stand												
Site class 4												
									DRY MASSES			
Age	**Hdom**	**DgM**	**Hgm**	**N**	**G**	**V**	**MAI**	**CAI**	**Stem**	**Branch**	**Leaf**	**Total**
1	0.3	0	0	1434	0	0	0	0	0	0	0	0
2	1.2	0	0	1425	0	0	0	0	0	0	0	0
3	2.5	2.9	2.7	1411	0.3	0.6	0.2	0.6	0.3	0.1	0.4	0.8
4	4.2	4.6	3.6	1394	1	2.5	0.6	1.9	1.4	0.2	0.6	2.2
5	6	6.1	5.1	1375	2.1	6.6	1.3	4.1	3.6	0.4	1	5
6	8	7.3	6.6	1355	3.4	13.1	2.2	6.5	7.2	0.7	1.5	9.4
7	9.8	8.5	8.1	1336	4.9	22.2	3.2	9.1	12.2	1.1	2	15.3
8	11.6	9.7	9.7	1317	6.5	33.5	4.2	11.3	18.5	1.5	2.5	22.5
9	13.3	10.7	11.1	1300	8.1	46.5	5.2	13	25.6	2	3	30.6
10	14.8	11.7	12.5	1285	9.6	60.4	6	13.9	33.3	2.5	3.5	39.2
11	16.1	12.6	13.7	1271	11.1	74.7	6.8	14.3	41.2	2.9	3.9	48
12	17.3	13.3	14.8	1258	12.4	89	7.4	14.3	49	3.4	4.3	56.7
13	18.4	14	15.8	1247	13.7	102.8	7.9	13.9	56.6	3.8	4.7	65.1
14	19.4	14.6	16.7	1237	14.8	116.1	8.3	13.2	63.9	4.2	5	73.1
15	20.2	15.1	17.5	1229	15.9	128.6	8.6	12.5	70.7	4.6	5.3	80.6
16	21	15.6	18.2	1221	16.8	140.2	8.8	11.7	77.1	4.9	5.5	87.6
17	21.7	16	18.8	1214	17.6	151	8.9	10.8	83.1	5.3	5.8	94.1
18	22.2	16.3	19.4	1208	18.4	161	8.9	10	88.6	5.5	6	100.1
19	22.8	16.7	19.9	1203	19.1	170.2	9	9.2	93.6	5.8	6.1	105.6
20	23.2	17	20.3	1198	19.7	178.6	8.9	8.4	98.2	6	6.3	110.6
21	23.7	17.2	20.7	1193	20.2	186.4	8.9	7.7	102.5	6.3	6.5	115.2
22	24	17.4	21.1	1189	20.7	193.5	8.8	7.1	106.4	6.5	6.6	119.4
23	24.4	17.6	21.4	1186	21.2	200	8.7	6.5	109.9	6.6	6.7	123.3
24	24.7	17.8	21.7	1183	21.6	205.9	8.6	6	113.2	6.8	6.8	126.8
25	25	18	22	1180	22	211.4	8.5	5.5	116.2	6.9	6.9	130.1
26	25.2	18.2	22.2	1177	22.3	216.4	8.3	5	119	7.1	7	133.1
27	25.5	18.3	22.5	1175	22.6	221.1	8.2	4.6	121.5	7.2	7.1	135.8
28	25.7	18.4	22.7	1173	22.9	225.3	8	4.3	123.9	7.3	7.1	138.3
29	25.9	18.5	22.8	1171	23.1	229.3	7.9	3.9	126	7.4	7.2	140.6
30	26	18.6	23	1169	23.4	232.9	7.8	3.6	128	7.5	7.3	142.8

Yield table for *Eucalyptus globulus*												
Coppice stand												
Site class 1												
									DRY MASSES			
Age	**Hdom**	**DgM**	**Hgm**	**N**	**G**	**V**	**MAI**	**CAI**	**Stem**	**Branch**	**Leaf**	**Total**
1	4.2	2.5	4	41094	5.4	15.8	15.8	15.8	8.8	4.8	15.3	28.9
2	8.1	5.1	7.3	15528	12.1	52.6	26.3	36.7	29.1	6.4	13.6	49.1
3	11.7	6.8	9.9	8985	15.8	85.9	28.6	33.3	47.4	7.8	13.3	68.5
4	15.1	8.6	12.5	6188	19.8	128.1	32	42.2	70.6	9.4	13.7	93.7
5	18.2	10.4	15.1	46.86	23.7	176.5	35.3	48.4	97.3	11	14.1	122
6	21.1	12.1	17.7	3768	27.4	228.5	38.1	52	125.8	12.4	14.5	153
7	23.8	13.8	20.2	3157	30.8	282.4	40.3	53.9	155.4	13.8	14.8	184
8	26.2	15.4	22.5	2725	33.9	337.1	42.1	54.7	185.4	15.1	15.1	216
9	28.5	16.9	24.7	2406	36.8	391.7	43.5	54.7	215.4	16.2	15.3	247
10	30.7	18.3	26.8	2163	39.4	445.7	44.6	54	245	17.3	15.5	278
11	32.6	19.7	28.8	1971	41.9	498.6	45.3	52.9	274	18.3	15.7	308
12	34.5	20.9	30.7	1818	44.1	549.9	45.8	51.4	302.1	19.2	15.9	337
13	36.1	22.1	32.4	1693	46.2	599.6	46.1	49.6	329.3	20.1	16	365
14	37.7	23.2	34.1	1590	48.2	647.3	46.2	47.7	355.4	20.9	16.1	392
15	39.2	24.2	35.6	1503	49.9	693	46.2	45.7	380.5	21.6	16.2	418
16	40.5	25.2	37	1429	51.6	736.6	46	43.6	404.3	22.3	16.3	443
17	41.8	26.1	38.3	1366	53.1	778.1	45.8	41.5	427	22.9	16.4	466
18	42.9	26.9	39.6	1312	54.5	817.5	45.4	39.4	448.6	23.5	16.5	489
19	44	27.6	40.7	1265	55.8	854.7	45	37.3	469	24	16.6	510
20	45	28.4	41.8	1224	57	890	44.5	35.2	488.2	24.5	16.7	529
21	45.9	29	42.8	1187	58.1	923.2	44	33.2	506.4	25	16.7	548
22	46.8	29.7	43.8	1155	59.1	954.4	43.4	31.3	523.5	25.4	16.8	566
23	47.6	30.2	44.6	1127	60.1	983.8	42.8	29.4	539.5	25.8	16.8	582
24	48.3	30.8	45.5	1101	61	1011.4	42.1	27.6	554.6	26.1	16.9	598
25	49	31.3	46.2	1097	61.8	1037.3	41.5	25.9	568.8	26.5	16.9	612
26	49.6	31.7	46.9	1059	62.5	1061.5	40.8	24.3	582	26.8	17	626
27	50.2	32.2	47.6	1040	63.2	1084.2	40.2	22.7	594.4	27.1	17	639
28	50.7	32.6	48.2	1024	63.9	1105.5	39.5	21.2	606.1	27.3	17	650
29	51.2	32.9	48.7	1009	64.5	1125.3	38.8	19.8	616.9	27.6	17	662
30	51.7	33.3	49.3	996	65	1143.9	38.1	18.5	627	27.8	17	672

Yield table for *Eucalyptus globulus*												
Coppice stand												
Site class	**2**											
									DRY MASSES			
Age	**Hdom**	**DgM**	**Hgm**	**N**	**G**	**V**	**MAI**	**CAI**	**Stem**	**Branch**	**Leaf**	**Total**
1	3.5	2	3.5	50000	3.9	10.4	10.4	10.4	5.8	4.3	15.4	25
2	6.8	4.1	6.1	20352	9.9	38.1	19.1	27.7	21.1	5.8	13.8	40
3	9.8	5.9	8.5	11776	13.8	67.2	22.4	29.1	37.1	7	13.3	57
4	12.6	7.2	10.5	8110	16.8	95.3	23.8	28.1	52.6	8.1	13.4	74
5	15.2	8.6	12.6	6142	19.9	129.1	25.8	33.8	71.2	9.4	13.7	94
6	17.6	10	14.6	4938	22.9	166	27.7	36.8	91.5	10.6	14.1	116
7	19.8	11.3	16.5	4137	25.8	204.4	29.2	38.4	112.6	11.8	14.3	138
8	21.9	12.6	18.4	3571	28.4	243.5	30.4	39.1	134.1	12.8	14.6	161
9	23.8	13.8	20.2	3153	30.8	282.7	31.4	39.2	155.6	13.8	14.8	184
10	25.5	15	21.9	2834	33	321.4	32.1	38.7	176.9	14.7	15	206
11	27.2	16	23.4	2584	35.1	359.4	32.7	37.9	197.7	15.6	15.2	228
12	28.7	17	24.9	2383	37	396.2	33	36.9	217.9	16.3	15.3	249
13	30.1	18	26.3	2219	38.8	431.9	33.2	35.6	237.4	17.1	15.5	270
14	31.4	18.9	27.6	2084	40.4	466.2	33.3	34.3	256.2	17.7	15.6	289
15	32.6	19.7	28.8	1970	41.9	499	33.3	32.8	274.2	18.3	15.7	308
16	33.8	20.4	30	1874	43.3	530.4	33.1	31.3	291.4	18.9	15.8	326
17	34.8	21.2	31	1791	44.6	560.2	33	29.8	307.7	19.4	15.9	343
18	35.8	21.8	32	1720	45.8	588.5	32.7	28.3	323.2	19.9	16	359
19	36.7	22.5	33	1658	46.9	615.2	32.4	26.8	337.9	20.4	16	374
20	37.5	23	33.8	1604	47.9	640.5	32	25.3	351.7	20.8	16.1	388
21	38.3	23.6	34.6	1556	48.8	664.4	31.6	23.9	364.8	21.2	16.2	402
22	39	24.1	35.4	1514	49.7	686.9	31.2	22.5	377.1	21.5	16.2	414
23	39.6	24.5	36.1	1477	50.5	708	30.8	21.1	388.6	21.8	16.3	426
24	40.2	25	36.7	1444	51.2	727.8	30.3	19.8	399.5	22.2	16.3	438
25	40.8	25.4	37.3	1414	51.9	746.4	29.9	18.6	409.7	22.4	16.4	448
26	41.3	25.7	37.9	1387	52.6	763.8	29.4	17.4	419.2	22.7	16.4	458
27	41.8	26.1	38.4	1363	53.2	780.2	28.9	16.3	428.1	22.9	16.4	467
28	42.3	26.4	38.9	1342	53.7	795.4	28.4	15.3	436.5	23.2	16.5	476
29	42.7	26.7	39.3	1322	54.2	809.7	27.9	14.3	444.3	23.4	16.5	484
30	43.1	27	39.8	1305	54.7	823	27.4	13.3	451.6	23.6	16.5	491

Yield table for *Eucalyptus globulus*												
Coppice stand												
Site class	**3**											
									DRY MASSES			
Age	**Hdom**	**DgM**	**Hgm**	**N**	**G**	**V**	**MAI**	**CAI**	**Stem**	**Branch**	**Leaf**	**Total**
1	2.8	0	0	50000	0	0	0	0	0	0	0	0
2	5.4	3.2	5	28340	7.6	25.4	12.7	25.4	14.1	5.2	14.3	33.6
3	7.8	4.9	7	16399	11.6	49.3	16.4	23.8	27.3	6.3	13.6	47.1
4	10.1	6	8.7	11293	14.1	65.5	17.4	20.2	38.4	7.1	13.3	58.8
5	12.1	7	10.2	8553	16.2	90.2	18	20.7	49.8	7.9	13.4	71.1
6	14.1	8	11.7	6877	18.5	113.8	19	23.6	62.8	8.9	13.6	85.3
7	15.8	9	13.1	5761	20.7	138.9	19.8	25.1	76.6	9.7	13.8	100.2
8	17.5	10	14.5	4973	22.8	164.6	20.6	25.7	90.8	10.6	14	115.4
9	19	10.9	15.8	4391	24.8	190.5	21.2	25.9	105	11.4	14.2	130.6
10	20.4	11.7	17.1	3947	26.6	216.2	21.6	25.7	119	12.1	14.4	145.6
11	21.7	12.5	18.3	3598	28.2	241.4	21.9	25.2	133	12.8	14.6	160.3
12	23	13.3	19.4	3319	29.8	265.9	22.2	24.5	146	13.4	14.7	174.5
13	24.1	14	20.5	3091	31.2	289.6	22.3	23.7	159	14	14.9	188.2
14	25.1	14.7	21.5	2902	32.5	312.5	22.3	22.8	172	14.5	15	201.4
15	26.1	15.3	22.4	2743	33.8	334.3	22.3	21.9	184	15	15.1	214
16	27	15.9	23.3	2609	34.9	355.2	22.2	20.9	195	15.5	15.2	226
17	27.8	16.5	24.1	2494	35.9	375.1	22.1	19.9	206	15.9	15.3	237.4
18	28.6	17	24.8	2395	36.9	394	21.9	18.9	217	16.3	15.3	248.3
19	29.3	17.5	25.5	2309	37.8	411.8	21.7	17.9	226	16.7	15.4	258.5
20	30	17.9	26.2	2233	38.6	428.7	21.4	16.9	236	17	15.5	268.1
21	30.6	18.3	26.8	2167	39.4	444.6	21.2	15.9	244	17.3	15.5	277.2
22	31.2	18.7	27.4	2108	40.1	459.6	20.9	15	253	17.6	15.6	285.8
23	31.7	19	27.9	2057	40.8	473.7	20.6	14.1	260	17.9	15.6	293.8
24	32.2	19.4	28.4	2010	41.4	486.9	20.3	13.2	268	18.1	15.7	301.4
25	32.7	19.7	28.8	1969	41.9	499.3	20.1	12.4	274	18.3	15.7	308.4
26	33.1	20	29.3	1932	42.4	511	19.7	11.6	281	18.6	15.7	315
27	33.5	20.2	29.7	1899	42.9	521.8	19.3	10.9	287	18.7	15.8	321.2
28	33.8	20.5	30	1869	43.4	532	19	10.2	292	18.9	15.8	327
29	34.2	20.7	30.4	1842	43.8	541.5	18.7	9.5	298	19.1	15.8	332.4
30	34.5	20.9	30.7	1817	44.2	550.4	18.3	8.9	302	19.3	15.9	337.5

Yield table for *Eucalyptus globulus*												
Coppice stand												
Site class	**4**											
									DRY MASSES			
Age	**Hdom**	**DgM**	**HgM**	**N**	**G**	**V**	**MAI**	**CAI**	**Stem**	**Branch**	**Leaf**	**Total**
1	2.1	0	0	50000	0	0	0	0	0	0	0	0
2	4.1	2.4	3.9	43430	5.1	14.7	7.3	14.7	8.1	4.8	15.5	28.4
3	5.9	3.6	5.4	25131	8.4	29.5	9.8	14.8	16.4	5.4	14.1	35.8
4	7.5	4.7	6.8	17306	11.2	46.2	11.6	16.7	25.6	6.1	13.7	45.4
5	9.1	5.6	8	13107	13.3	62	12.4	15.8	34.3	6.8	13.5	54.5
6	10.5	6.2	9	10538	14.5	73.8	12.3	11.8	40.8	7.3	13.3	61.3
7	11.9	6.9	10	8829	16	87.4	12.5	13.6	48.2	7.8	13.3	69.4
8	13.1	7.5	10.9	7621	17.4	101.8	12.7	14.4	56.2	8.4	13.5	78.1
9	14.3	8.1	11.8	6729	18.8	116.6	13	14.8	64.3	9	13.6	86.9
10	15.3	8.7	12.7	6048	20.1	131.4	13.1	14.8	72.5	9.5	13.8	95.7
11	16.3	9.3	13.5	5514	21.3	146.1	13.3	14.7	80.5	10	13.9	104.4
12	17.2	9.8	14.3	5086	22.5	160.4	13.4	14.3	88.4	10.5	14	112.9
13	18.1	10.3	15	4736	23.6	174.3	13.4	13.9	96.1	10.9	14.1	121.1
14	18.9	10.8	15.7	4447	24.6	187.7	13.4	13.4	103.4	11.3	14.2	129
15	19.6	11.2	16.4	4204	25.5	200.6	13.4	12.9	110.5	11.7	14.3	136.5
16	20.3	11.6	17	3998	26.3	212.9	13.3	12.3	117.3	12	14.4	143.7
17	20.9	12	17.5	3822	27.1	224.6	13.2	11.7	123.7	12.3	14.5	150.5
18	21.5	12.4	18	3670	27.9	235.8	13.1	11.1	129.8	12.6	14.6	157
19	22	12.7	18.5	3538	28.6	246.3	13	10.6	135.6	12.9	14.6	163.2
20	22.5	13	19	3422	29.2	256.3	12.8	10	141.1	13.2	14.7	168.9
21	23	13.3	19.4	3321	29.8	265.7	12.7	9.4	146.3	13.4	14.7	174.4
22	23.4	13.6	19.8	3231	30.3	274.6	12.5	8.9	151.1	13.6	14.8	179.5
23	23.8	13.8	20.2	3152	30.8	282.9	12.3	8.3	155.7	13.8	14.8	184.4
24	24.1	14.1	20.5	3081	31.3	290.7	12.1	7.8	160	14	14.9	188.9
25	24.5	14.3	20.9	3017	31.7	298.1	11.9	7.3	164.1	14.2	14.9	193.1
26	24.8	14.5	21.1	2961	32.1	305	11.7	6.9	167.8	14.3	14.9	197.1
27	25.1	14.7	21.4	2910	32.5	311.4	11.5	6.4	171.4	14.5	15	200.8
28	25.4	14.8	21.7	2864	32.8	317.5	11.3	6	174.7	14.6	15	204.3
29	25.6	15	21.9	2822	33.1	323.1	11.1	5.6	177.8	14.8	15	207.6
30	25.9	15.2	22.1	2784	33.4	328.4	10.9	5.3	180.7	14.9	15.1	210.6

Appendix 4-B: Yieldtables for *Cupressus lusitanica* (Pukkala and Pohjonen, 1993)

SITE CLASS1											
Age	Hdom	DgM	HgM	N	G	V	Log	Pulp	CAI	Min	Max
1	.9	.0	.0	3000	.0	0	0	0	.0	0	0
2	2.4	1.4	2.0	3000	.3	0	0	0	.3	0	2
3	4.2	3.6	3.7	2394	1.7	3	0	0	2.7	1	5
4	6.1	6.4	5.5	2033	4.8	12	0	0	8.8	1	9
5	7.9	9.3	7.2	1795	9.1	28	0	14	16.6	2	13
6	9.6	12.0	8.8	1624	13.8	52	0	38	23.4	3	16
7	11.2	14.2	10.2	1494	18.3	80	0	66	27.7	4	19
8	12.6	16.1	11.5	1391	22.3	109	14	83	29.4	5	22
9	13.8	17.7	12.7	1308	25.6	138	34	93	29.0	7	23
10	15.0	18.9	13.8	1238	28.3	165	64	92	27.4	8	25
11	16.0	20.0	14.7	1179	30.5	191	81	101	25.1	9	26
12	16.9	20.8	15.6	1128	32.2	213	97	108	22.5	10	28
13	17.7	21.5	16.3	1083	32.5	233	116	109	19.8	11	29
14	18.5	22.1	17.0	1044	34.5	250	137	107	17.4	12	30
15	19.1	22.6	17.6	1009	35.2	265	155	103	15.1	13	30
16	19.7	23.0	18.2	977	35.7	278	165	106	13.0	13	31
17	20.2	23.4	18.7	948	36.1	290	182	100	11.3	14	32
18	20.7	23.7	19.1	922	36.4	299	195	98	9.7	15	32
19	21.2	24.0	19.5	898	36.6	308	200	101	8.3	15	33
20	21.6	24.2	19.9	876	36.7	315	209	100	7.1	16	33
21	21.9	24.4	20.2	856	36.7	321	223	92	6.1	16	34
22	22.3	24.6	20.5	837	36.7	326	231	89	5.2	17	34
23	22.6	24.8	20.8	819	36.7	331	239	85	4.5	17	34
24	22.9	24.9	21.1	803	36.6	334	244	85	3.9	18	35
25	23.1	25.1	21.3	787	36.5	338	252	80	3.3	18	35
26	23.4	25.2	21.5	773	36.4	341	254	81	2.8	18	36
27	23.6	25.4	21.7	759	36.3	343	261	77	2.4	19	36
28	23.8	25.5	21.9	746	36.2	345	263	78	2.1	19	36
29	24	25.6	22.1	734	36.1	347	269	73	1.8	19	37
30	24.2	25.7	22.2	723	35.9	348	276	68	1.6	20	37
31	24.3	25.8	22.4	712	35.8	350	276	69	1.3	20	37
32	24.5	25.9	22.5	701	35.7	351	285	62	1.2	20	37
33	24.6	26.0	22.7	691	35.5	352	285	62	1.0	20	38
34	24.8	26.1	22.8	681	35.4	353	285	64	.9	21	38
35	24.9	26.2	22.9	672	35.3	354	285	64	.7	21	38
36	25.0	26.3	23.0	664	35.2	354	287	63	.6	21	39
37	25.1	26.3	23.1	655	35.1	355	289	62	.5	21	39
38	25.2	26.4	23.2	647	34.9	355	289	63	.4	21	39
39	25.3	26.5	23.3	639	34.8	355	289	63	.4	21	39
40	25.4	26.6	23.4	632	34.7	356	292	60	.3	22	40

SITE CLASS 2											
Age	Hdom	DgM	HgM	N	G	V	Log	Pulp	CAI	Min	Max
1	.7	.0	.0	3000	.0	0	0	0	.0	0	0
2	1.9	1.0	1.5	3000	.1	0	0	0	.1	0	1
3	3.3	2.3	2.8	2453	.7	1	0	0	.9	0	4
4	4.7	4.4	4.2	2084	2.2	4	0	0	3.3	1	7
5	6.1	6.7	5.5	1839	4.6	11	0	0	7.0	1	10
6	7.5	8.9	6.8	1662	7.6	22	0	10	11.1	2	13
7	8.8	11.1	8.0	1528	10.8	37	0	24	14.6	3	16
8	10.0	13.0	9.1	1422	13.9	54	0	42	17.1	3	18
9	11.1	14.6	10.1	1336	16.9	73	0	61	18.5	4	20
10	12.1	16.1	11.1	1263	19.6	91	10	71	18.9	5	22
11	13.0	17.3	12.0	1202	21.9	110	25.0	75	18.6	6	24.0
12	13.8	18.4	12.7	1149	23.8	128	36	83	17.8	7	25
13	14.6	19.3	13.5	1103	25.5	144	48	89	16.7	7	27
14	15.3	20.1	14.1	1062	26.9	160	67	85	15.4	8	28
15	16.0	20.8	14.7	1026	28.1	174	79	87	14.1	9	29
16	16.5	21.4	15.3	993	29.0	187	92	88	12.8	9	30
17	17.1	21.9	15.8	964	29.8	198	110	82	11.6	10	30
18	17.6	22.3	16.2	937	30.4	209	111	91	10.4	10	31
19	18.0	22.8	16.7	912	31.0	218	125	87	9.3	11	32
20	18.4	23.1	17.1	889	31.4	226	131	90	8.3	12	32
21	18.8	23.5	17.4	868	31.7	234	146	82	7.4	12	33
22	19.2	23.8	17.7	849	32.0	240	152	83	6.6	12	34
23	19.5	24.0	18.1	831	32.2	246	160	81	5.9	13	34
24	19.8	24.3	18.3	814	32.3	252	161	86	5.3	13	35
25	20.1	24.5	18.6	798	32.4	256	165	85	4.7	14	35
26	20.4	24.7	18.8	783	32.5	260	172	83	4.2	14	35
27	20.6	24.9	19.1	769	32.6	264	176	83	3.7	14	36
28	20.8	25.1	19.3	756	32.6	267	180	82	3.3	15	36
29	21.0	25.3	19.5	743	32.6	270	188	78	2.9	15	37
30	21.2	25.4	19.7	731	32.6	273	188	80	2.6	15	37
31	21.4	25.6	19.8	720	32.5	275	192	78	2.3	15	37
32	21.6	25.7	20.0	709	32.5	277	193	79	2.0	16	38
33	21.8	25.8	20.2	699	32.4	279	200	74	1.8	16	38
34	21.9	26.0	20.3	689	32.4	281	202	74	1.6	16	38
35	22.1	26.1	20.5	680	32.3	282	203	75	1.4	16	39
36	22.2	26.2	20.6	671	32.2	283	208	71	1.2	16	39
37	22.3	26.3	20.7	662	32.1	284	207	73	1.0	17	39
38	22.5	26.4	20.8	654	32.0	285	218	62	.9	17	39
39	22.6	26.5	20.9	646	31.9	286	218	63	.8	17	40
40	22.7	26.6	21.0	639	31.9	286	217	65	.6	17	40

SITE CLASS 3											
Age	Hdom	DgM	HgM	N	G	V	Log	pulp	CAI	Min	Max
1	.2	.0	.0	3000	.0	0	0	0	.0	0	0
2	.7	.0	.0	3000	.0	0	0	0	.0	0	0
3	1.5	.0	.0	2641	.0	0	0	0	.0	0	0
4	2.4	1.4	2.0	2220	.2	0	0	0	0.2	0	2
5	3.4	2.7	2.9	1942	.7	1	0	0	.8	0	4
6	4.5	4.3	4.0	1744	1.7	3	0	0	2.1	1	7
7	5.6	6.2	5.0	1594	3.3	7	0	0	4.1	1	10
8	6.7	8.1	6.1	1475	5.2	14	0	3	6.5	2	12
9	7.8	9.9	7.1	1381	7.5	23	0	13	8.9	2	15
10	8.8	11.7	8.0	1302	9.9	34	0	24	11.1	3	17
11	9.8	13.3	8.9	1235	12.3	47	0	36	12.7	3	19
12	10.7	14.7	9.8	1177	14.6	60	1	50	13.8	4	21
13	11.5	16.0	10.6	1128	16.8	75	7	59	14.3	5	23
14	12.3	17.2	11.4	1084	18.7	89	18	62	14.4	5	25
15	13.1	18.2	12.1	1045	20.5	103	28	66	14.1	6	26
16	13.8	19.1	12.7	1010	22	117	38	70	13.5	6	27
17	14.4	19.8	13.3	979	23.3	130	48	74	12.8	7	28
18	15.0	20.5	13.9	951	24.4	142	64	70	12.0	8	29
19	15.5	21.1	14.4	925	25.4	153	78	68	11.1	8	30
20	16.0	21.7	14.8	901	26.3	163	82	75	10.2	9	31
21	16.5	22.1	15.3	879	27.0	172	93	73	9.4	9	32
22	16.9	22.6	15.7	859	27.6	181	99	76	8.5	10	33
23	17.3	23	16.0	840	28.1	189	113	70	7.8	10	33
24	17.7	23.3	16.4	823	28.5	196	115	75	7.0	11	34
25	18.0	23.6	16.7	806	28.8	202	120	76	6.4	11	34
26	18.3	23.9	17.0	791	29.1	208	128	74	5.7	11	35
27	18.6	24.2	17.3	776	29.4	213	130	78	5.2	12	35
28	18.9	24.4	17.5	763	29.5	218	138	75	4.6	12	36
29	19.1	24.6	17.7	750	29.7	222	148	69	4.2	12	36
30	19.4	24.9	18.0	738	29.8	225	149	71	3.7	13	37
31	19.6	25.0	18.2	726	29.9	229	150	74	3.4	13	37
32	19.8	25.2	18.4	715	30.0	232	157	70	3.0	13	37
33	20.0	25.4	18.5	708	30.0	235	161	69	2.7	13	38
34	20.1	25.6	18.7	695	30.0	237	161	71	2.4	14	38
35	20.3	25.7	18.9	685	30.1	239	162	72	2.1	14	38
36	20.5	25.9	19.0	676	30.1	241	163	73	1.9	14	39
37	20.6	26.0	19.1	667	30.0	243	166	72	1.7	14	39
38	20.8	26.1	19.3	659	30.0	244	172	67	1.5	14	39
39	20.9	26.3	19.4	651	30.0	245	173	68	1.3	14	40
40	21.0	26.4	19.5	643	29.9	247	176	66	1.2	15	40

SITE CLASS 4											
Age	Hdom	DgM	HgM	N	G	V	Log	pulp	CAI	Min	Max
1	.1	.0	.0	3000	.0	0	0	0	.0	0	0
2	.3	.0	.0	3000	.0	0	0	0	.0	0	0
3	.7	.0	.0	2825	.0	0	0	0	.0	0	0
4	1.3	.0	.0	2357	.0	0	0	0	0	0	0
5	1.9	1.1	1.6	2051	.1	0	0	0	.1	0	2
6	2.7	1.8	2.2	1832	.3	0	0	0	.2	0	3
7	3.5	2.9	3.0	1667	0.7	1	0	0	0.7	0	5
8	4.3	4.3	3.9	1538	1.4	3	0	0	1.5	1	7
9	5.2	5.8	4.7	1433	2.5	5	0	0	2.7	1	9
10	6.1	7.4	5.5	1347	3.8	9	0	1	4.1	1	12
11	7.0	9.0	6.4	1274	5.4	15	0	5	5.6	2	14
12	7.8	10.5	7.2	1212	7.2	22	0	13	7.1	2	16
13	8.7	12.0	8.0	1158	9.0	30	0	21	8.3	3	18
14	9.5	13.4	8.7	1111	10.9	40	0	31	9.4	3	20
15	10.2	14.6	9.4	1069	12.7	50	0	41	10.1	4	22
16	10.9	15.8	10.1	1032	14.3	60	5	46	10.5	4	24
17	11.6	16.8	10.7	999	15.9	71	9	53	10.6	5	25
18	12.2	17.7	11.3	969	17.3	81	20	53	10.5	5	26
19	12.8	18.5	11.8	941	18.6	92	28	55	10.3	6	27
20	13.4	19.3	12.4	916	19.8	102	38	57	9.9	6	29
21	13.9	19.9	12.8	893	20.8	111	47	57	9.4	6	29
22	14.4	20.5	13.3	872	21.7	120	50	64	8.9	7	30
23	14.8	21.1	13.7	853	22.5	128	58	64	8.3	7	31
24	15.2	21.6	14.1	834	23.2	136	66	63	7.7	8	32
25	15.6	22.0	14.4	817	23.9	143	77	60	7.2	8	33
26	15.9	22.4	14.8	801	24.4	150	83	61	6.6	8	33
27	16.3	22.8	15.1	786	24.8	156	86	64	6.1	9	34
28	16.6	23.1	15.4	772	25.2	161	94	62	5.6	9	34
29	16.9	23.4	15.6	759	25.6	166	97	64	5.1	9	35
30	17.1	23.7	15.9	746	25.9	171	101	64	4.7	10	35
31	17.4	24.0	16.1	734	26.1	175	107	64	4.2	10	36
32	17.6	24.2	16.3	723	26.3	179	113	61	3.9	10	36
33	17.8	24.5	16.6	712	26.5	183	117	61	3.5	11	37
34	18.0	24.7	16.7	702	26.7	186	118	63	3.2	11	37
35	18.2	24.9	16.9	692	26.8	189	119	65	2.9	11	38
36	18.4	25.1	17.1	683	26.9	191	125	62	2.6	11	38
37	18.5	25.2	17.2	674	27.0	194	129	60	2.4	11	38
38	18.7	25.4	17.4	666	27.1	196	129	62	2.1	12	39
39	18.8	25.6	17.5	657	27.1	198	130	64	1.9	12	39
40	19.0	25.7	17.7	650	27.1	200	131	64	1.7	12	39

HEIGHT, M																								
0	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Diameter, cm																								
6	12	14	15	17	18	19	21	22	23	25	26	27	28	30	31	32	33							
7	16	18	20	22	24	26	28	29	31	33	34	36	38	40	41	43	44	44						
8	21	23	26	28	31	33	35	38	40	42	44	46	49	51	53	55	57	59	61					
9	26	29	32	35	38	41	44	47	50	52	55	58	61	63	66	69	71	74	76	79				
10	32	36	39	43	47	50	54	57	61	64	67	71	74	77	80	84	87	90	93	96	99			
11	38	43	47	51	56	60	64	68	72	76	80	84	88	92	96	10	10	10	11	11	11	12		
12	45	50	55	61	66	71	75	80	85	90	95	99	10	10	11	11	12	12	13	13	14	14	14	
13	52	58	64	70	76	82	88	93	99	10	11	11	12	12	13	13	14	14	15	15	16	16	17	
14	60	67	74	81	88	94	10	10	11	12	12	13	13	14	15	15	16	16	17	18	18	19	19	
15	68	76	84	92	10	10	11	12	12	13	14	15	15	16	17	17	18	19	19	20	21	21	22	
16	77	86	95	10	11	12	12	13	14	15	16	17	17	18	19	20	20	21	22	23	23	24	25	
17	86	96	10	11	12	13	14	15	16	17	18	19	20	20	21	22	23	24	25	26	26	27	28	
18	96	10	11	12	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	28	29	30	31	
19	10	11	13	14	15	16	17	19	20	21	22	23	24	25	26	27	28	29	31	32	33	34	35	
20	11	13	14	15	17	18	19	20	22	23	24	25	27	28	29	30	31	32	34	35	36	37	38	
21		14	15	17	18	20	21	22	24	25	27	28	29	31	32	33	34	36	37	38	39	41	42	
22			17	18	20	22	23	25	26	28	29	30	32	33	35	36	38	39	40	42	43	44	46	
23				20	22	23	25	27	28	30	32	33	35	36	38	39	41	42	44	45	47	48	50	
24					24	25	27	29	31	32	34	36	38	39	41	43	44	46	48	49	51	52	54	
25						27	29	31	33	35	37	39	41	42	44	46	48	50	51	53	55	57	58	
26							32	34	36	38	40	42	44	46	48	50	51	53	55	57	59	61	63	
27								36	38	41	43	45	47	49	51	53	55	57	59	61	63	65	67	
28									41	44	46	48	50	53	55	57	59	61	64	66	68	70	72	
29										46	49	51	54	56	59	61	63	66	68	70	73	75	77	
30											52	55	57	60	62	65	67	70	72	75	77	80	82	
31												58	61	64	66	69	72	74	77	80	82	85	87	
32													65	68	71	73	76	79	82	85	87	90	93	
33														72	75	78	81	84	87	90	92	95	98	
34															79	82	85	89	92	95	98	10	10	
35																87	90	96	97	10	10	10	11	

CONTINUED	HEIGHT,						
Diameter, cm		31	32	33	34	35	36
6							
7							
8							
9							
10							
11							
12							
13	177						
14	204	210					
15	232	238	245				
16	262	269	276	28			
17	293	301	310	31	326		
18	326	335	345	35	363	372	
19	361	371	381	39	401	411	421
20	397	409	420	43	442	453	463
21	436	448	440	47	484	496	508
22	475	488	502	51	528	541	554
23	516	531	545	56	574	588	602
24	559	575	591	60	621	637	652
25	604	621	637	65	671	687	704
26	650	668	686	70	722	740	758
27	697	717	736	75	775	794	813
28	746	767	788	80	830	850	870
29	797	820	842	86	886	908	930
30	849	873	897	92	944	967	990
31	903	929	954	97	100	102	105
32	959	985	101	10	106	109	111
33	1015	104	107	11	112	115	118
34	1074	110	113	11	119	122	125
35	1134	116	119	12	126	129	132

Appendix 5: Image Processing

Appendix 5-A: Image Processing

Classify

The Classify operation performs a multi-spectral image classification according to training pixels in a sample set.

The following classification methods can be used:

- Box classifier,
- Minimum distance,
- Minimum Mahalanobis distance,
- Maximum Likelihood,
- Maximum Likelihood including Prior Probabilities.

Cluster

- Clustering, or unsupervised classification, is a rather quick process in which image data is grouped into spectral clusters based on the statistical properties of all pixel values. It is an automated classification approach with a maximum of 4 input bands.
- Optionally, an attribute table can be created for the output map. The table will contain statistical information on the output clusters: the average, predominant and minimum and maximum value of each cluster as found in the input bands.
- Clustering, or unsupervised classification, is a rather quick process in which image data is grouped into spectral clusters based on the statistical properties of all pixel values. It is an automated classification approach with a maximum of 4 input bands.
- Optionally, an attribute table can be created for the output map. The table will contain statistical information on the output clusters: the average, predominant and minimum and maximum value of each cluster as found in the input bands.
- Dialog box options:

NUMBER OF INPUT MAPS:	**SELECT THE NUMBER OF INPUT BANDS TO BE USED IN THE CLUSTER ANALYSIS (1, 2, 3, OR 4). FOR THE SELECTED NUMBER OF INPUT BANDS, A NUMBER OF INPUT MAP LIST BOXES APPEAR.**
Input maps:	Select the input raster maps. Open each list box and select the desired input map, or drag raster maps directly from the Catalog into the list boxes. All input maps should use domain Image.
Number of clusters:	Type a value for the number of clusters that should be created. You can create between 2 and 60 clusters. But for forest inventory in Ethiopian condition 5 or 6 may be sufficient.
Output raster map:	Type a name for the output raster map that will contain the desired number of clusters after the unsupervised classification.

Description:	Optionally, type a description for the output map. The description will appear in the status bar of the Main window when moving the mouse pointer over the map in a Catalog, and in the title bar of a map window when the output map is displayed. If no description is supplied, the output map will use its own definition as description.
Output table:	Select this check box if you wish to obtain an attribute table which will contain for each output cluster the average, predominant and minimum and maximum value of each input band. Subsequently, type a name for the output table.

- When you click the **Show** button, the dependent output map will be defined, calculated and shown. When you click the **Define** button, the dependent output map will only be defined; if necessary the map will be calculated later, for instance when the map is opened to be displayed.
- Optionally, an output attribute table can be defined.
- The output cluster names (Cluster 1, Cluster 2, etc.) which are used in the output map as well as in the optional attribute table are stored by the output map (internal class domain).

Color composite

- A color composite is a combination of three raster bands. One band is displayed in shades of red, one in shades of green and one in shades of blue. Putting three bands together in one color composite map can give a better visual impression of the reality on the ground, than by displaying one band at a time. Examples of color composites are false color (or IR) images and 'natural color' images.
- The Color Composite operation on the Operations, Image Processing menu creates a *permanent* color composite raster map.
- To *interactively* display a map list as a color composite (16 or 24-bit), choose Show MapList as Color Composite from the Operations, Visualization menu. Interactive color composites can be stored by saving the map window as a map view.

Filter

- Filtering is a raster operation in which each pixel value in a raster map is replaced with a new value.
- The new value is obtained by applying a certain function to each input pixel and its direct neighbours. These neighbours are usually the 8 adjacent pixels (in a 3 x 3 filter) or the 24 surrounding pixels (in a 5 x 5 filter). When you create or define your own filters, any odd sized matrix is allowed (5 x 1, 11 x 23, 25 x 25).
- Filtering is for instance used to sharpen a satellite image, to detect line features, etc.

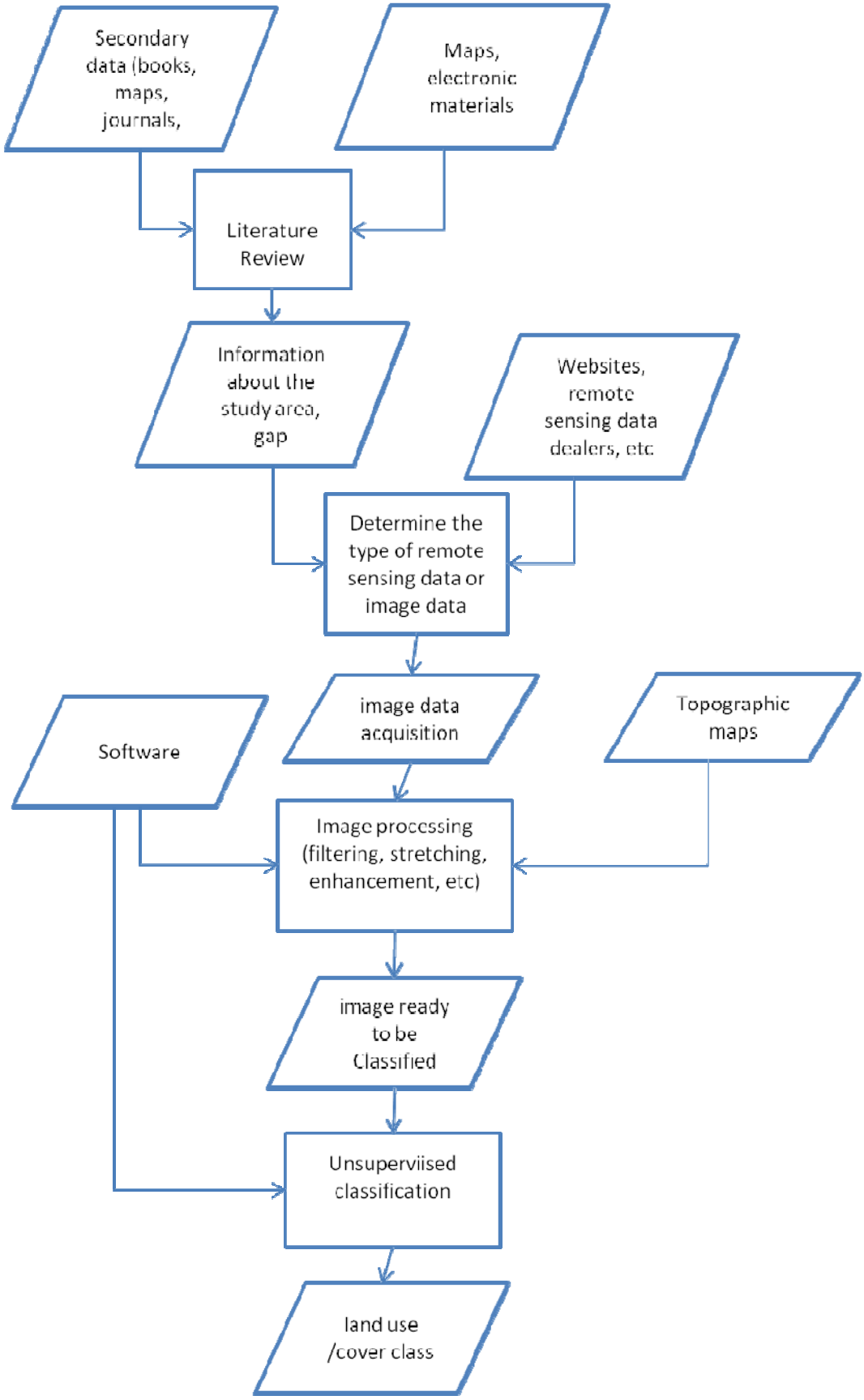
Slicing

- The Slicing operation classifies ranges of values of an input raster map into classes of an output map. A group domain should be created beforehand; it lists the upper value boundaries of the groups and the output class names.
- To perform an interactive slicing, you can create a representation value for the input map and change value boundaries and colors of the representation value.

Stretch

- The Stretch operation re-distributes values of an input map over a wider or narrower range of values in an output map. Stretching can for instance be used to enhance the contrast in your map when it is displayed. Two stretch methods are available: linear stretching and histogram equalization.

Appendix 5-B Flow chart showing steps in land use land cover or forest stratification map



Appendix 6: Coefficient of variation of various land covers in Ethiopia (WBISPP,2000)

CARTOGRAPHIC LAND COVER SYSTEM	CROWN COVER (%)	STOCK (ADT/HA)	Δ	CV(%)
Forest				
Open	20-50	40	55	138
Dense	50-80	82	70	85
Closed	>80	120	75	62
Montane Mixed				
Open	20-50	40	55	138
Dense	50-80	75	65	87
Closed	>80	100	60	60
Montane Coniferous				
Open	20-50	65	70	108
Dense	50-80	105	70	67
Closed	>80	140	65	46
Dry Juniperus "Woodland"				
Open	20-50	45	55	122
Dense	50-80	67	60	90
Closed	>80	101	65	64
Lowland Semi-evergreen				
Open	20-50	45	55	122
Dense	50-80	73	65	89
Closed	>80	106	65	61
Riparian				
Open	20-50	30	35	117
Dense	50-80	70	65	93
Closed	>80	90	60	67
Bamboo				
Highland Bamboo				
Open	20-50	55	45	90
Dense	50-80	70	60	86
Closed	>80	90	60	67
Lowland Bamboo				
Open	20-50	55	50	91
Dense	50-80	75	55	73
Closed	>80	90	60	67
Plantation Forest				
Open	20-50	70	65	93
Dense	50-80	101	65	64
Closed	>80	151	65	43
Wetland				
Open water	N/A	N/A	N/A	N/A
Perennial swamp/marsh		4.4	7.5	170
Seasonal swamp/marsh		3	6	200
Bare land				
Exposed surface		0.1	0.5	50
Exposed rock		0.1	0.5	50
Salt flats		0.1	0.5	50
Urban		1	4.6	460

Stock = average stock for the given land cover stratum
δ = standard deviation
CV = coefficient of variation, expressed in %
adT.ha = air-dry Metric Tons of woody biomass per hectare, standardized at 12% Moisture content

Appendix 7: Student's t distribution

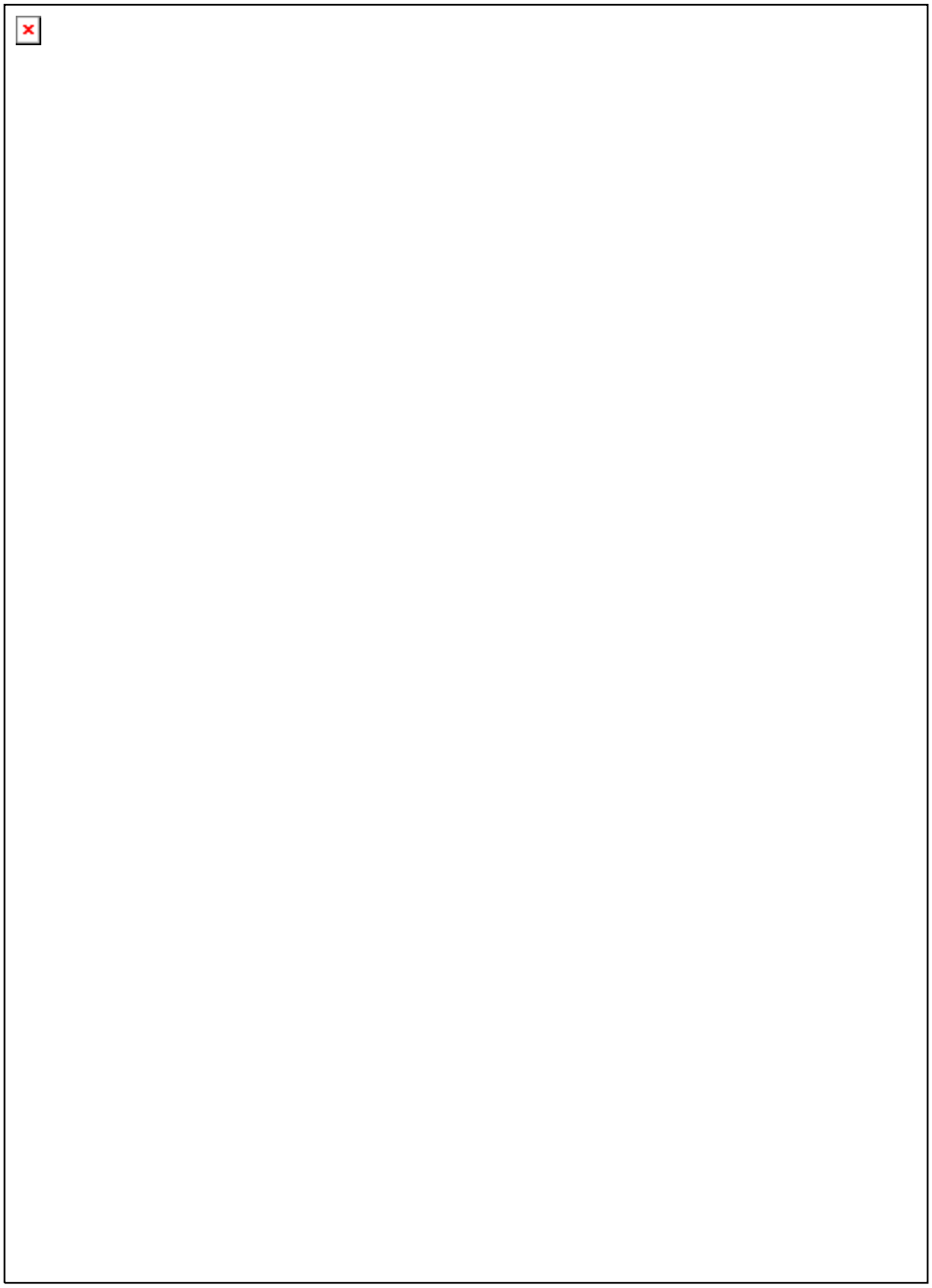
DF	0.1	0.05	0.01	0.001
1	6.314	12.706	63.657	636.619
2	2.92	4.303	9.925	31.598
3	2.353	3.182	5.841	12.941
4	2.132	2.776	4.604	8.61
5	2.015	2.571	4.032	6.859
6	1.943	2.447	3.707	5.959
7	1.895	2.365	3.499	5.405
8	1.86	2.306	3.355	5.041
9	1.833	2.262	3.25	4.781
10	1.812	2.228	3.169	4.587
11	1.796	2.201	3.106	4.437
12	1.782	2.179	3.055	4.318
13	1.771	2.16	3.012	4.221
14	1.761	2.145	2.977	4.14
15	1.753	2.131	2.947	4.073
16	1.746	2.12	2.921	4.015
17	1.74	2.11	2.898	3.965
18	1.734	2.101	2.878	3.922
19	1.729	2.093	2.861	3.883
20	1.725	2.086	2.845	3.85
21	1.721	2.08	2.831	3.819
22	1.717	2.074	2.819	3.792
23	1.714	2.069	2.807	3.767
24	1.711	2.064	2.797	3.745
25	1.708	2.06	2.787	3.725
26	1.706	2.056	2.779	3.707
27	1.703	2.052	2.771	3.69
28	1.701	2.048	2.763	3.674
29	1.699	2.045	2.756	3.659
30	1.697	2.042	2.75	3.646
31	1.696	2,040	2.745	3.635
32	1.694	2.037	2.74	3.624
33	1.693	2.035	2.734	3.613
34	1.691	2.032	2.729	3.602
35	1.69	2.03	2.724	3.591
36	1.689	2.028	2.72	3.583
37	1.688	2.026	2.716	3.575
38	1.686	2.025	2.025	3.567
39	1.685	2.023	2.023	3.559

40	1.684	2.021	2.704	3.551
41	1.683	2.02	2.701	3.545
42	1.682	2.018	2.698	3.539
43	1.682	2.017	2.696	3.532
44	1.681	2.015	2.693	3.526
45	1.68	2.014	2.69	3.52
46	1.679	2.013	2.688	3.515
47	1.678	2.012	2.685	3.51
48	1.678	2.01	2.683	3.506
49	1.677	2.009	2.68	3.501
50	1.676	2.008	2.678	3.496
51	1.675	2.007	2.676	3.492
52	1.675	2.006	2.674	3.488
53	1.674	2.006	2.673	3.484
54	1.674	2.005	2.671	3.48
55	1.673	2.004	2.669	3.476
56	1.673	2.003	2.667	3.473
57	1.672	2.002	2.665	3.47
58	1.672	2.002	2.664	3.466
59	1.671	2.001	2.662	3.463
60	1.671	2	2.66	3.46
61	1.671	1.999	2.659	3.458
62	1.67	1.999	2.658	3.455
63	1.67	1.998	2.656	3.453
64	1.669	1.998	2.655	3.45
65	1.669	1.997	2.654	3.448
66	1.669	1.996	2.653	3.445
67	1.668	1.996	2.652	3.443
68	1.668	1.995	2.65	3.44
69	1.667	1.995	2.649	3.438
70	1.667	1.994	2.648	3.435
71	1.667	1.994	2.647	3.433
72	1.667	1.993	2.646	3.431
73	1.666	1.993	2.645	3.429
74	1.666	1.992	2.644	3.427
75	1.666	1.992	2.643	3.426
76	1.666	1.991	2.642	3.424
77	1.666	1.991	2.641	3.422
78	1.665	1.99	2.64	3.42
79	1.665	1.99	2.639	3.418
80	1.665	1.989	2.638	3.416
81	1.665	1.989	2.637	3.415
82	1.664	1.988	2.637	3.413

83	1.664	1.988	2.636	3.412
84	1.664	1.988	2.636	3.41
85	1.664	1.988	2.634	3.409
86	1.663	1.987	2.634	3.408
87	1.663	1.987	2.633	3.406
88	1.663	1.987	2.632	3.405
89	1.662	1.986	2.632	3.403
90	1.662	1.986	2.631	3.402
91	1.662	1.986	2.63	3.401
92	1.662	1.985	2.63	3.4
93	1.662	1.985	2.629	3.398
94	1.662	1.984	2.629	3.397
95	1.662	1.984	2.628	3.396
96	1.661	1.984	2.627	3.395
97	1.661	1.983	2.627	3.394
98	1.661	1.983	2.626	3.392
99	1.661	1.982	2.626	3.391
100	1.661	1.982	2.635	3.39
101	1.661	1.982	2.625	3.389
102	1.661	1.982	2.624	3.388
103	1.661	1.982	2.624	3.387
104	1.66	1.982	2.623	3.387
105	1.66	1.982	2.623	3.386
106	1.66	1.981	2.623	3.385
107	1.66	1.981	2.622	3.384
108	1.66	1.981	2.622	3.383
109	1.66	1.981	2.621	3.382
110	1.659	1.981	2.621	3.382
111	1.659	1.981	2.621	3.381
112	1.659	1.981	2.62	3.38
113	1.659	1.981	2.62	3.379
114	1.659	1.981	2.619	3.378
115	1.659	1.981	2.619	3.377
116	1.659	1.98	2.619	3.376
117	1.658	1.98	2.618	3.376
118	1.658	1.98	2.618	3.375
119	1.658	1.98	2.617	3.374
120	1.658	1.98	2.617	3.373
>120	1.645	1.9	2.576	3.291

Appendix 8: Tips on diameter and height measurements.

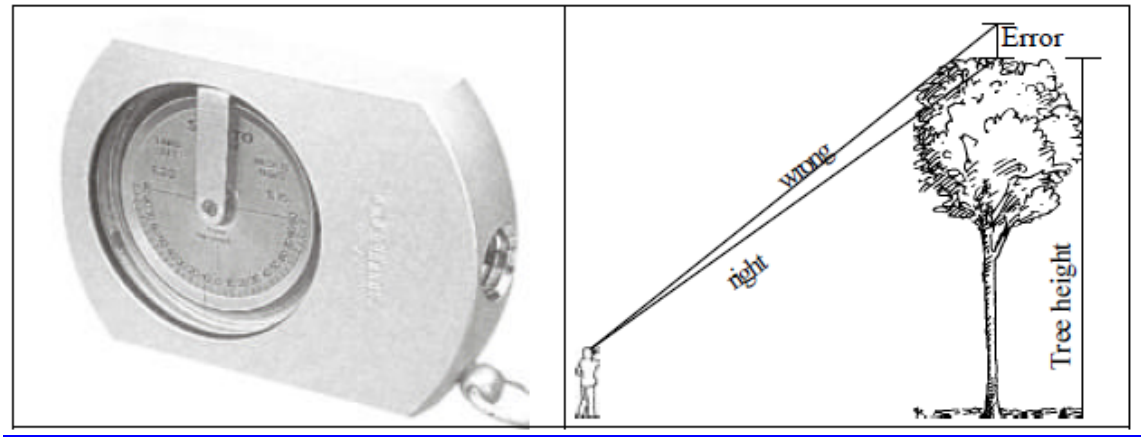
Appendix 8-A: How to deal with DBH measurement on difficult sites or on trees of unusual shape.



Source: Verplanke and Zahabu (2009)

Appendix 8-B: Correct diameter measurement to avoid introducing bias

Appendix 8-C: Correct height measurement to avoid introducing bias



Appendix 9 Slope correction chart

SLOPE			
(degrees)			
1m		**5.64m**	**8.92m**
0	1.00	5.64	8.92
2	1.00	5.64	8.93
4	1.00	5.65	8.94
6	1.01	5.67	8.97
8	1.01	5.70	9.01
10	1.02	5.73	9.06
12	1.02	5.77	9.12
14	1.03	5.81	9.19
16	1.04	5.87	9.28
18	1.05	5.93	9.38
20	1.06	6.00	9.49
22	1.08	6.08	9.62
24	1.09	6.17	9.76
26	1.11	6.28	9.93
28	1.13	6.39	10.10
30	1.15	6.51	10.30
32	1.18	6.65	10.52
34	1.21	6.80	10.76
36	1.24	6.97	11.03
38	1.27	7.16	11.32
40	1.31	7.36	11.65
42	1.35	7.59	12.01
44	1.39	7.84	12.40
46	1.44	8.12	12.85
48	1.50	8.43	13.34
50	1.56	8.78	13.88