Measurement of Carbon Pools in Afforestation and Reforestation Project Activities under the Clean Development Mechanism

A Field Manual of Best Practice

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For further information please contact:
Climate Change Secretariat (UNFCCC)
Martin-Luther-King-Strasse 8
53175 Bonn, Germany
Telephone +49. 228. 815 10 00
Telefax +49. 228. 815 19 99
Email secretariat@unfccc.int
www.unfccc.int

This publication is available online at http://www.unfccc.int

Please report any errors in this publication to cdminfo@unfccc.int

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Contents

Abbreviations and acronyms

DBH	diameter at breast height (of a tree)
DOE	designated operational entity
DOM	dead organic matter
FAO	Food and Agricultural Organisation (of the United Nations)
GHG	greenhouse gas
GIS	geographical information system
GPS	global positioning system
IPCC	Intergovernmental Panel on Climate Change
QA	quality assurance
QC	quality control
SI	Sytème international (of units)
SOC	soil organic carbon
tCER	temporary certified emission reduction
tCO_2	tonne carbon dioxide
tCO_2e	tonne carbon dioxide equivalent
UNFCCC	United Nations Framework Convention on Climate Change

Units of measurement

ha	hectare
m	metre
t	tonne (metric)
tCO_2e	tonne carbon dioxide equivalent

Chapter 1 Introduction

Summary This chapter explains the purpose, the organization and the structure of the manual. It also describes the scope of the manual and points to other clean development mechanism (CDM) documents relating to afforestation and reforestation project activities which should be consulted along with this manual. The user is also guided on how this manual can be used effectively.

1.1 Purpose of the manual

This manual is intended to serve as a best practice guide for measurement of carbon pools in afforestation and reforestation (A/R) project activities under the clean development mechanism (CDM).

Approved A/R CDM methodologies provide for methodological requirements for estimation of carbon stocks and changes in carbon stocks in the carbon pools. Measurement-based estimation methods are mainly required in monitoring of project activities although measurement-based estimation methods can also be applied in the baseline.

A/R CDM methodologies require that "the commonly accepted principles and practices of forest inventory and forest management in the host country" should be followed while monitoring A/R CDM project activities. Where such principles and practices are not available, the "standard operating procedures (SOPs) and quality control/quality assurance (QA/QC) procedures for inventory operations, including field data collection and data management, shall be identified, recorded and applied".[1] The methodologies further provide that use or adaptation of SOPs available from published handbooks, or from *the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry 2003* could be one of the alternatives where nationally applied forest inventory practices are not available.

The present manual aims to assist project participants in meeting the requirements in respect of forest carbon inventory methods suitable for monitoring of A/R CDM project activities. Where the commonly accepted principles and practices of forest inventory and forest management in the host country are non-existent or are inaccessible to

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[1] AR-AM0014, paragraph 24; AR-ACM003, paragraph 23; AR-AMS003, paragraph 27; and AR-AMS007, paragraph 27. Also, see AR-TOOL-12, section 8.2 and AR-TOOL-14, section 12.2.

project participants, or where adequate capacity to access and implement internationally accepted methods is lacking, the present manual will help project participants in meeting the requirements relating to monitoring of A/R CDM project activities.

This manual should be used along with other relevant CDM documents, particularly the A/R CDM methodologies and methodological tools, the *CDM Project Standard* and the *CDM Validation and Verification Standard*. The manual should also be seen as a companion resource to the other CDM manual titled *Afforestation and Reforestation Projects under the Clean Development Mechanism: A Reference Manual*[2] which aims to assist project participants in development and registration of A/R CDM project activities.

The present manual is an instructional aid and not a regulatory document. It provides general guidance only and does not purport to give advice substituting for professional advice in the context of specific circumstances of individual project activities. It aims at presenting, in an accessible manner, the best practice guidance for measurement of carbon pools in A/R CDM project activities. It can also be used for capacity-building activities, such as training of technical personnel.

1.2 Scope of the manual

This manual describes best-practice procedures for conducting field measurement of only those carbon pools that could be required in the approved A/R CDM methodologies. The approved A/R CDM methodologies do not allow use of field measurement methods in respect of some carbon pools (e.g. soil organic carbon) and therefore this manual does not include methods of conducting such measurements..

The manual does not create new methodological requirements or imply new methodological approaches besides and beyond those contained in the approved A/R CDM methodologies. It only describes field procedures and best practices for implementation of the approaches allowed in the approved A/R CDM methodologies. If there are any discrepancies between the information contained in this manual and the regulatory documents, such as the A/R CDM methodologies and methodological tools, the latter shall prevail.

[2] UNFCCC (2013). *Afforestation and reforestation projects under the clean development mechanism: A reference manual*. Can be downloaded from http://unfccc.int/2625.

1.3 Structure of the manual

This manual consists of five chapters and five appendices. Following the present introductory chapter, Chapter 2 provides an overview of the carbon pools defined in afforestation and reforestation (A/R) project activities under the CDM and the methodological requirements relating to their measurement and accounting. Chapter 3 describes field procedures for measurement of land areas, including determination of project boundaries and strata boundaries. Chapter 4 provides a brief description of the sampling designs that are allowed in the A/R CDM methodologies and methodological tools and their implications for the measurement plan. Chapter 5 describes the field procedures for conducting measurements in sample plots. This is the most important chapter and constitutes a major part of the manual.

Appendices A to E provide further information aimed at assisting the readers in advancing their understanding of the contents of the manual. Worked out examples illustrating practical implementation of sampling designs and statistical calculations are provided in Appendix A. Study of these examples will be helpful to the readers interested in understanding and applying the procedures and practices in the context of a real-life projects. Appendix B provides details of the steps in implementation of plot measurement procedures. Appendix C contains a brief glossary of terms related to A/R CDM project activities. Appendix D provides a list of CDM regulatory documents that are of relevance in the context of monitoring and verification of A/R CDM project activities. Appendix E contains references for the readers who are interested in more detailed information the subject matter covered in each of the substantive chapters.

1.4 How to use this manual

This manual describes best practice field procedures for organizing and conducting measurements on carbon pools of A/R CDM project activities and programmes of activities.[3] The manual can be used as a reference, but the readers who are not familiar with the overall monitoring requirements and process for A/R CDM project activities will benefit most if they first read the manual from start to end, and then focus on specific areas of interest. The manual can also be used as resource material in training and capacity-building activities.

[3] Throughout this document, reference to project activities will be understood to include stand-alone project activities and component project activities under a programme of activities (PoA).

While using this manual for monitoring of actual projects, the reader should consult the applied A/R CDM methodologies and the requirements contained therein. Current versions of A/R can be found on the CDM website. A list of relevant CDM documents and other useful references is provided in the appendices.

Chapter 2 Carbon pools in afforestation and reforestation project activities under the clean development mechanism

Summary Afforestation and reforestation project activities under the clean development mechanism achieve carbon mitigation by increasing carbon stocks in the defined carbon pools. This chapter describes the carbon pools and the methods of accounting of carbon stocks and changes in carbon stocks in these carbon pools.

2.1 Carbon pools in A/R CDM projects

The afforestation and reforestation (A/R) clean development mechanism (CDM) project activities recognize five carbon pools: above-ground biomass, below-ground biomass, litter, dead wood and soil organic carbon.

The following are the definitions of the carbon pools[4]:

- **Aboveground biomass** All living biomass above the soil including stem, stump, branches, bark, seeds, and foliage.
- **Belowground biomass** All living biomass of live roots. Fine roots of less than (suggested) 2 mm diameter are sometimes excluded because these often cannot be distinguished empirically from soil organic matter or litter.
- **Dead wood** All non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country hosting the project.

[4] The agreed rules of A/R CDM project activities (the modalities and procedures for afforestation and reforestation clean development activities as contained in annex to decision 5/CMP.1) do not define carbon pools; these only list the carbon pools. The A/R CDM methodologies provide that where definitions terms are not defined within the methodologies, the definitions contained in the CDM glossary or those contained in the annex to IPCC-GPG-LULUCF 2003 should be used. The definitions of carbon pools presented in this section have been taken from the IPCC publication.

- **Litter** All non-living biomass with a diameter less than a minimum diameter chosen by the host country (for example 10 cm), lying dead or in various states of decomposition above the mineral or organic soil. This includes the litter, fumic and humic layers. Live fine roots (of less than the suggested diameter limit for belowground biomass) are included in litter where they cannot be distinguished from it empirically.
- **Soil organic carbon** Organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the host country and applied consistently through the time series. Live fine roots (of less than the suggested diameter limit for belowground biomass) are included with soil organic matter where they cannot be distinguished from it empirically.

Accounting of carbon pools
The aboveground biomass and belowground biomass carbon pools are always included in an A/R CDM project activity since these are major carbon pools affected by the project activity. The three other carbon pools may be optionally excluded from accounting if the effect of excluding these pools on the estimation of net anthropogenic greenhouse gas (GHG) removals achieved by the project activity is to make these estimates conservative.

2.2 Estimation of carbon stocks in carbon pools

Estimation of carbon stocks in carbon pools at a given point of time and the changes of carbon stocks in carbon pools over a period of time is carried out by applying the methods provided in approved A/R CDM methodologies. In general, the methodologies employ the following approaches for estimation:

(a) Estimation by applying default factors;
(b) Estimation by modelling;
(c) Estimation by measurement.

A brief description of the three approaches is provided in the sub-section below.

2.2.1 Estimation by applying default factors

Some carbon pools or components of carbon pools can be estimated on the basis of default factors. Often this estimation approach is applied when estimation based on measurement would not be cost-effective because the benefits of gains in precision resulting use of measurement-based estimation methods would not justify the corresponding increase in monitoring cost. An example is the below ground biomass. It is highly costly in terms of time and labour to measure this carbon pool by digging up all the roots of trees, isolating these from soil particles and fine roots and measuring the wet and dry weights of the root biomass. As a result, the carbon stocks in the belowground biomass are estimated as a default fraction of the aboveground biomass. The default ratio, called the root-to-shoot ration (or R/S ratio) is taken from IPCC database of factors. More precise value of this factor, applicable to the specific context of the project activity, can also be used if adequate justification can be provided for the same.

Other examples of use of the default factor approach used in A/R CDM methodologies and tools are as follows:

- Aboveground biomass in trees in the baseline (but not in the project monitoring) can be estimated as a fraction of the default value of the mean aboveground forest biomass in a country taken from the data tables of the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry 200,* although more precise values of the mean aboveground forest biomass in a country can be used if adequate justification can be provided for the same. This 'nominal tree biomass' is calibrated to the project site conditions by multiplying it by the actual tree crown cover in the project area at the time of estimation. The same approach can be applied to estimation of change in biomass in the baseline based on default forest growth rate (mean annual increment, or MAI) for the host country.
- Shrub biomass is estimated as a fixed fraction of the mean aboveground forest biomass in the region or the country where the project activity is located. This 'nominal shrub biomass' is calibrated to the project by multiplying it by the actual shrub crown cover in project area at the time of monitoring. The default value of the mean aboveground forest biomass in a country is taken from the data tables of the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry 2003*.
- The carbon stocks in the carbon pools of dead wood and litter can also be estimated as a fixed percentage of living tree biomass.
- The estimation of change in soil organic carbon is based on the default land-use change factors provided in the data tables of the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry 2003,* although more precise values can also be used if adequate justification can be provided for the same.

2.2.2 Estimation by modelling

Estimation by modelling is used only for ex ante estimation. Estimation of change in tree biomass in the baseline or in the project can be modelled from diameter increments obtained from past data applicable to the project site and species. Allometric equations, or a combination of volume equations and biomass expansion factors and wood density values, can be used for conversion of tree diameter increments into change in tree biomass.

2.2.3 Estimation by measurement

The carbon stock in aboveground tree biomass is the most important pool that is subjected to change in an A/R CDM project activity. This pool is always estimated by measurement.

Other pools which can be optionally estimated by measurement-based methods are dead wood and the litter. Often measurements are conducted in the same set of sample plots used for estimation of aboveground tree biomass, although the exact plot measurement methods for these carbon pools may be different from the methods used for tree biomass measurement.

2.3 Field measurement standards

The approved A/R CDM methodologies do not prescribe detailed methods for conducting field measurements of forest carbon pools, because these methods can vary from country to country. The methods and practices used by the national forest inventory organisations in the host country are recommended to be applied in monitoring of A/R CDM project activities. This is done for reasons of facilitating use of existing data, ensuring ease and consistency, and utilizing the existing capacity in the host country.

Where national forest inventory organisations do not exist in the host country, or the nationally accepted standard operating practices are not accessible to the project participants, the standard operating procedures of forest inventory from published handbooks, or from the IPCC GPG LULUCF 2003, can be used.

The measurement methods and practices described in this manual do not override the existing practices of the national forest inventory organisations in the host country. The procedures described in this manual can be used in lieu of, or in the absence of, the forest inventory practices of the national forest inventory organisations

It should be noted that forest inventories are often conducted with an objective that is broader than measurement of carbon stocks or forest biomass. The data collected under national forest inventory programmes or under commercial forestry inventories can be more comprehensive than the data required for the purpose of monitoring of the A/R CDM project activities. Therefore if commercial objectives or other objectives require that more accurate and more comprehensive data be collected[5], the necessity of conducting a separate inventory for the purpose of carbon stock monitoring may not arise at all. The estimates of carbon stocks can be derived from the relevant subset of the data collected within the more comprehensive forest inventory.

[5] Such data could include species-wise timber volume, expected volume increments, mortality rates and rates of recruitment or regeneration, or other data relevant to the specific objectives of forest management.

Chapter 3 Measurement of land areas

Summary Estimation of area of land subjected to an A/R CDM project activity is essential for estimation of total carbon stocks and changes in carbon stocks. The project area may be divided into strata and the same or different measurements may be conducted across the strata. Area of individual strata also needs to be known with required precision in order to derive a precise estimate of carbon stocks. Therefore measurement of land area using methods able to deliver cost-effective precision is important. This chapter suggests best practices for cost-effective methods for measurement of land areas.

3.1 Measurement of land areas

A/R CDM methodologies require conducting forest carbon inventory to determine the statistically estimated values of carbon stocks per hectare. These per hectare values are multiplied by the area inventoried in order to obtain the total carbon stocks. For this purpose, the boundaries of the areas to be inventoried would need to be determined.

If the project area, or the area to be inventoried, is already delineated on forest management maps, cadastral maps or other maps prepared during project development phase, there may be no need for conducting field survey to determine land areas at the time of inventorying. In practice, however, determination of boundaries and land areas may be required for delineation of strata or for exclusion of areas from inventory in which forest regeneration or plantation was not successful[6].

3.1.1 Surveying land areas

An accurate map may be produced by applying any accurate survey method. Some of the land survey methods that are commonly used are chain and compass survey, theodolite survey, total station survey, and survey based on satellite navigation systems.

[6] In cases where the strata boundaries can be drawn on the map on the basis of aerial photographs or other remotely sensed data, the areas of strata can be determined from maps. However, if strata are delineated on ground, by conducting field reconnaissance, then the boundaries of the strata would need to be transferred to the maps. In such cases, some form of surveying will be required.

In recent times, the availability, reliability, coverage and accuracy of satellite navigation systems, particularly the global positioning system (GPS), has become highly cost-effective. This method of surveying produces georeferenced data which can be easily migrated to a geographical information system (GIS) platform for mapping and subsequent analysis.

This manual provides best practice guidance only in respect of GPS-based surveying. For use of other methods of surveying, the reader is invited to refer to one of the sources listed in appendix E

3.2 Land survey by using GPS receivers

The Global Positioning System (GPS) is a satellite-based navigation system developed by the United States Department of Defence. It is widely used for civilian navigation and positioning, surveying and scientific applications worldwide.

When used by skilled professionals, the GPS provides surveying and mapping data of high accuracy. GPS-based data collection is much faster than conventional surveying, thus reducing the amount of equipment and labour required. Unlike conventional techniques, GPS surveying is not bound by constraints such as line-of-sight visibility between survey stations. The stations can be deployed at greater distances from each other and can be positioned accurately anywhere with a good view of the sky.

3.2.1 Basic concepts

As GPS-based surveying is relatively new and evolving, it would be useful for the readers to familiarize themselves with the basic concepts and the terminology used.

Global navigation satellite systems
A satellite navigation system is a system of satellites that provides autonomous geo-spatial positioning. A satellite navigation system with global coverage is called a global navigation satellite system (GNSS).[7]

Global positioning system
The term global positioning system (GPS) refers to the GNSS operated by the US Government. The satellite constellation that forms the basis of

[7] Apart from the GPS, other satellite navigation systems in operation are Russia's GLONASS, Europe's Galileo, China's Compass, and India's Regional Navigational Satellite System.

the GPS consists of 31 satellites and is known as NAVSTAR (for *nav*igation *s*atellite *t*iming *a*nd *r*anging).

GPS receiver
A GPS receiver is a device that can receive and interpret GPS satellite signals and thereby calculate its own geo-referenced position. A receiver can be stationary (e.g. a base GPS receiver) or mobile (e.g. handheld or vehicle mounted receiver). Mobile receiver is also called a rover when used in conjunction with a base GPS receiver.[8]

Autonomous positioning
The positioning that a GPS receiver can produce in real time from satellite data alone is called autonomous positioning. More precise positioning can be produced by combining the autonomously acquired data with data from another receiver (e.g. data from a receiver serving as a base GPS station). This mode of combining data from two GPS receivers is known as differential GPS (or DGPS) and can achieve far better accuracy than autonomous positioning.

Static and dynamic mode of surveying
An autonomously positioning receiver can be operated in two modes while surveying an open or a closed traverse:

- **Static traversing** In this mode, the receiver is made stationary for at least a few minutes at each data collection point on the traverse (traverse station) so that a more precise position of the point is recorded. This stop-and-go mode is also called the route mode.
- **Dynamic traversing** In this mode the receiver moves continuously along the traverse to be surveyed. The receiver records its instantaneous positions at fixed intervals of time and thus produces a smoothened profile of the traverse. While this method produces more accurately the shape of the traverse, the precision of area estimation would not necessarily be high. This mode is also called the track mode.

Sources of errors
Systematic and random errors are inherent in the coordinates calculated by a GPS receiver because of imperfections in satellite atomic clocks,

[8] Commercially available GPS receivers are often categorized as recreational grade, mapping grade, and survey grade receivers. However, with advancing technologies the boundaries between these categories, set in terms of precision and data handling capabilities, are getting somewhat blurred.

multi-path interference[9], receiver noise, and other sources. Additionally, sloping terrain, buildings, and other objects can obstruct satellite signals, limiting time periods and situations when accurate coordinates can be collected. However, by combining avoidance of high-error periods and avoidance of excessive obstruction of the view of open sky at the point of data collection, the data collected by GPS receivers can approach the accuracy of a few meters. Greater accuracy can be achieved by observing simple rules such as keeping the unit stationary while collecting measurements.

3.2.2 Step-wise method for GPS survey

GPS survey can be used for determining the coordinate positions of individual points, traversing closed areas and estimation of area as well as for laying out open traverse on the existing geo-referenced maps.

Although the exact steps might differ, depending upon to the make and type of GPS receiver used, the following illustrates a step-wise procedure for conducting GPS survey of a traverse:

Recording data

1. Pre-field work procedures
    a. Prepare data capture procedure with GPS and paper, as appropriate.
    b. Configure the GPS receiver, per manufacturer's instructions. Latitude and longitude values should be set to decimal degrees and map datum appropriately set (e.g. WGS84)
    c. If applicable, test the GPS receiver for its connectivity to PC or laptop to avoid any problems with data download later on.
    d. Check if extra batteries are needed.
2. Once you have located a target for data capture, make sure you have as clear a view of the sky as possible. When collecting data at a traverse station point, centre the unit over the point of interest precisely. Wait until the handheld device has locked into at least four satellites before recording the position.
3. Record the position of the station as a waypoint (refer to your unit's user guide)

[9] Multi-path interference error is the coordinate error caused by reflection of radio signals, resulting in multiple versions of a signal reaching a receiver at different times.

4. Fill out data capture form completely. Ensure that corresponding waypoint number is recorded on form.
5. Always check the accuracy level of GPS unit before taking a reading, and consider if it meets your requirements.
6. Depending on the memory capacity of your GPS receiver, periodically save track logs to the device.

Producing map and calculating area

Depending upon the capability of the receiver, the data collection can be done manually or stored in the device memory. The receiver device may also be capable of processing the collected data and producing the map and the estimated distances and areas, along with related uncertainties.

The data may also be transferred to a computer-based GIS application so that any further use of the data is seamlessly facilitated. This can be a significant convenience in the case where, for example, only a few parcels or strata need to be surveyed with a GPS receiver whereas the rest of the strata are already delineated on the documented maps and the data collected with the GPS receiver are required to be integrated with the existing maps.

In the simplest case, the GPS device will be capable of providing the latitudes and longitudes of the points of the surveyed traverse. These points can then be translated into local X-Y coordinates (i.e. northings and eastings) and the work of map preparation and area estimation can be carried out manually.

Chapter 4 Sampling design

Summary Inventorying of forest carbon stocks is carried out by using sampling-based estimation. The sampling design employed affects the cost-efficiency and precision of the estimations made thereunder. This chapter describes the sampling designs permitted under the approved A/R CDM methodologies and tools and application of these sapling designs in practice.

4.1 Sampling design

Estimation of carbon stocks in the carbon pools requires conducting forest inventory based on sampling. A sampling design defines the number and spatial distribution of sample elements drawn from the sample frame. The sample frame consists of the set of all elements of interest – often all the elements constituting the population to which the estimation relates. For the purpose of carbon stock inventory based on fixed area sample plots, the population and the sampling frame are identical to the set of all the possible plots of a fixed area that would cover the entire area being inventoried. For an inventory that is based on variable area plot sampling (point sampling), the population consists of all the possible points in the inventoried area and hence is infinite. In this case, a sampling frame is constructed by dividing the area into a grid of square cells of which the corner points (or centre points) constitute the sampling frame.

Forest inventories commonly employ two distinct approaches to sampling: fixed area plot sampling and variable area plot sampling.[10]

For the purposes of conducting biomass inventory of a forest area or forest plantation, fixed area plots are more appropriate, although a combination of fixed area sample plots and variable area sample plots can be efficient in certain conditions. For example, in the case of a two-phase sampling (also called double sampling) that uses the auxiliary variable of basal area along with the target variable of biomass per hectare, the variable area plot sampling can be used for observing values of basal area and the fixed area plot sampling can be used for

[10] Fixed area plots are also sometimes referred to as detached plots. The terms 'plot sampling' and 'point sampling' are sometimes used to contrast these two approaches to areal sampling in forest inventory. The non-areal approach employing individual trees as sampling units is rarely used.

observation of biomass values and thus both the approaches can be efficiently combined.

Sampling design can be categorized on the basis of different aspects of sampling. Sampling designs commonly used in forest inventory are all areal sampling and are summarized in Table X below.

Table 4.1. Types and categories of sampling designs in forest inventory

Criterion /aspect	*Sampling design/method*
Type of sampling unit	• Fixed area plot sampling • Variable area plot sampling
Number of variables observed	• Only target variable is observed • Auxiliary variable and the target variable are both observed
Method of sample selection	• Simple random sampling • Stratified random sampling • Systematic sampling • Multi-stage sampling

Commonly used sampling designs in forest inventory are *stratified random sampling* and *double sampling*. Choice of sampling design is made on the basis of the trade-off between precision of estimation and the cost of inventory.

4.2 Fixed area plot sampling

Fixed area plot sampling is the most common type of sampling used in forest inventory. Within this method, a commonly used sampling design is *stratified random sampling.*[11]

Under stratified random sampling using fixed area plots, the area to be inventoried is delineated into strata on the basis of the spatial pattern of distribution of carbon stocks.[12] The 'spatial pattern' of distribution is characterized by the two variables:

(a) The mean carbon stock density (or biomass density), usually expressed per hectare, as observed in sample plots, and

[11] This design defaults to simple random sampling when the number of strata is one.
[12] In this manual we will use the terms carbon stocks and biomass almost synonymously since the two are related by a fixed constant of proportionality, the carbon fraction of biomass. It is biomass that forms the direct object of estimation (target variable). If multiple carbon pools are being estimated in the same inventory based a common sample of plots, the dominant pool should form the basis of stratification (e.g. aboveground biomass)

(b) The variability of the biomass density values across the sample plots.

The variability of mean biomass per unit area can result from edaphoclimatic factors (climate and soil, aspect, slope), biological factors (species composition, age), management factors (stocking density, operations of thinning, harvest, and pruning) and disturbances (fires, pests). It is importance to recognize that these factors themselves are not necessarily the preferred basis of stratification, although any of these can be the dominant determinant of biomass variability and therefore the basis of stratification (e.g. the areas affected by a forest fire can be defined as one stratum, areas with low growth due to poor soils can be another stratum). A single-species even-age stand is likely to qualify as a single stratum, not because of the species but because of similar biomass resulting from this fact. Even so, stands of different species with similar mean biomass could belong to a single stratum (unless, of course, we are interested in species-wise biomass estimation for reasons other than estimation of carbon stocks).

The area of each stratum is estimated from the delineation of the stratum boundary on map of the inventoried area.[13] The preliminary estimated mean value of biomass per hectare and its variability in each stratum is used as the basis of estimation of number of sample plots to be installed in a stratum.[14]

The practical application of this sampling design is illustrated through a worked out example in appendix A (see example A.1).

4.2.1 Shape of sample plots

Fixed area sample plots can be circular, square, rectangular, or any other shape, including a composite shape composed of several simple geometric shapes (a cluster plot). It is best to select the plot shape that would meet the specific circumstances of the forest area being inventoried.

The following considerations should be kept in view while selecting the shape of sample plots.

[13] The approaches of double sampling for stratification and sampling by post-stratification do not require delineation of strata boundaries. However, these methods are not included in the approved A/R CDM methodologies and tools.

[14] The A/R CDM methodological tool "Calculation of the number of sample plots for measurements within A/R CDM project activities" provides the method of calculation of number of sample plots, although any other statistical tools or package can be used for this purpose.

Edge intensity

Trees located close to the plot boundary cost more measurement time as they need to be carefully checked for being inside or outside of the plot. Additional distance measurements would be required to determine if these trees inside or outside the plot. Since different geometric shapes have different perimeter-to-area ratios, this ratio, also called edge intensity, is a relevant consideration while selecting the shape of sample plots. A circular plot has the least edge intensity and is thus efficient on this count.

Ease of establishment in field

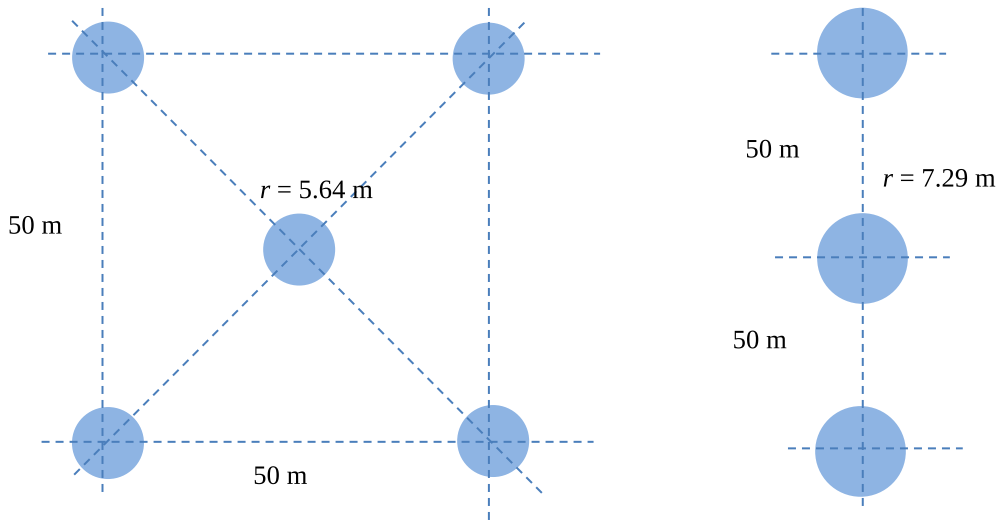
Establishment of a plot in field may require laying out distances and angles on ground to delineate the plot boundary unambiguously and precisely. Setting out angles can require more time since a small error in angle can lead to significant error in the area of the plot.

Circular plots are easy to establish since these only require the location of the plot centre and measuring distance equal to the radius of the circle. However, in stands with dense understory, or stands with high stocking, circular plots may be less time-efficient than square or rectangular plots.

Cluster plots

Cluster plots, sometimes called combined plots, attempt to spread out measurements over greater areal extent without increasing the actual area over which measurements are made. The objective is to capture more of local variability without increasing total area sampled. A cluster plot typically consists of a number of smaller circular or rectangular plots spread out to form a geometrical figure such as a triangle or a rectangle.

Figure 4.1 shows two examples of cluster plot configuration. Either of these cluster plot designs can be used in place of a compact circular or square plot of 500 sqm. In the configuration shown in Figure 4.1a, five smaller circular plots, each of 100 sqm, are laid out in a square lattice spread over a linear extent of 50 m in either direction. In the configuration shown in Figure 4.1b, three circular plots, each of 167 sqm, are laid out in linear lattice spread over a linear extent of 100 m. Of course, any other geometrical shape could have been used for the lattice defining the areal extent. The spatial autocorrelation of the target variable should be taken into consideration for determining the extent of areal spread of the lattice. For example, the distance between sub-plots would be different for observations of littler biomass per hectare and tree biomass per hectare, as litter biomass can show variability over much shorter distances than tree biomass.



(a) Square lattice **(b) Linear lattice**

Figure 4.1 Cluster plots

Cluster plots are usually employed in large area forest inventories (such as national forest inventories) or in inventories where target variables with intricate spatial variability, such as soil carbon, are to be estimated.

It should be noted that measurements at each cluster plot produce one independent observation of the target variable, even though multiple sub-plots are measured. The variability across the sub-plot values of the observed variable does not enter into calculations.[15]

Summary guidance for shape of sample plots

Table 4.2 summarizes the considerations and criteria that should be kept in view while selecting the shape of sample plot.

[15] Such variance would enter into calculations in a multi-stage sampling design where a sub-sample of the cluster elements would be drawn. The use of cluster plots should not be confused with cluster sampling, which is a different sampling design.

Table 4.2 Comparative advantages and disadvantages of different sample plot shapes

Shape	*Pros*	*Cons*
Circular plots	• Easy to establish (requires only one linear measurement, that of radius). • Has least edge per unit area and thus is least vulnerable to errors due to incorrect omission or inclusion of edge trees.	• In dense stands with low visibility more time may be needed in identifying trees hidden behind other trees
Square plots	• Once established, it is easier to identify and tally trees in the plot. • Can be efficient in high stocking density stands.	• Vulnerable to errors in plot area (an incorrect right angle at plot corners could significantly change the area of the plot). • Relatively difficult to establish (right angles must be precisely set in field).
Cluster plots	• Statistically efficient because it captures variance across a larger areal extent than that captured by a single geometrical shape of the same size. • Keeping tally of the trees falling inside a sub-plot is easier because fewer trees are contained in each sub-plot, and thus the error of double measurement or of omission of a tree from measurement is less likely.	• More time is required in demarcation of the boundaries of multiple shapes in field. • More edge is involved compared to a single compact shape, requiring greater effort time in conducting measurement per plot.

4.2.2 Size of sample plots

Size of sample plot impacts both the efficiency of statistical estimation and the practical considerations such as the cost and ease of measurement.

From statistical efficiency point of view, larger plots capture more within-plot variance and thus reduce the between-plot variance. On the other hand, larger plot size also means that fewer plots can be installed within the given cost. This reduces the sample size and could increase the standard error of estimation which varies inversely as the square root of the sample size.

If trees are of relatively homogenous size, the plots should be small because local variability is not high. If trees are of different size, as in a mixed uneven-aged plantation, or an old-growth natural forest, local variability (represented by the range of tree diameters) will be high and therefore larger plots size should be preferred.

Cost of measuring a plot can increase non-linearly with increasing number of trees included in the plot. Including too many trees would require more effort and time to be spent on keeping tally of the trees and avoiding errors of double counting or omission.

As a balance between the twin objectives of capturing enough local variability and ensuring ease of plot measurement, a plot size selection can be guided by the rule of thumb: select a plot size so that on an average a sample plot would include in it 10 to 15 trees in a homogeneous stand and 15 to 20 trees in a heterogeneous stand.

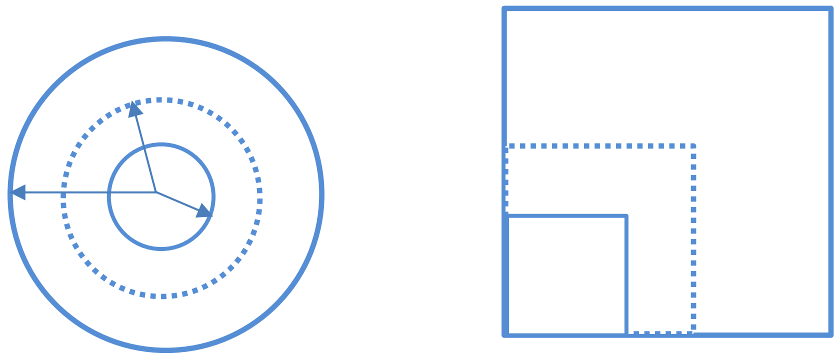
Typical plot sizes used in forest inventory are 200 sqm, 400 sqm, and 500 sqm, but any size could possibly be used.

When a more precise determination of the optimum plot size is desired (e.g. in a very important stratum), a pilot study can be conducted by selecting 15 to 20 randomly selected sample point locations with a uniform coverage of the stratum and establishing and measuring at each of these locations concentric sample plots of three different sizes. Precise observations of the time spent in measuring each plot size are recorded. Finally the variances of the measured values of the target variable are calculated separately for the three datasets. The plot size that leads to the least variance per unit cost is considered the optimum plot size.

4.2.3 Nested sample plots

In the case of fixed area plot sampling conducted in a mixed uneven-aged plantation, or an old growth natural forest, a sample typical plot will include a large number of small trees and a small number of large trees. This would lead to under-representation of the large tree diameter classes and can cause high variability across plot values. To remedy this situation, nested sub-plots are used in which trees belonging to different diameter classes are measured in plots of different sizes. Plots with larger radii are used for trees of large diameter classes and plots with smaller radii are used for trees of small diameter classes. This defines different plot sizes for different diameter classes such that from each diameter class more or less an equal numbers of trees are included in measurement.[16]

[16] Note that this also defines separate populations (sampling frames) for the different diameter classes and hence the target variables and associated uncertainties should be estimated separately. After estimation of the mean tree biomass values of the three diameter classes and their associated uncertainties, the total tree biomass and its uncertainty should be estimated by using appropriate formulae for propagation of uncertainty.



(a) Circular nested plots *(b) Square nested plots*

Figure 4.2 Nested plots

Figure 4.2a shows an example of a nested plot where trees in three diameter classes are to be measured in three different concentric circular plots. Figure 4.2b illustrates the same design for nested square plots.

Nested sample plots could also be efficient in an inventory that aims to estimate multiple target variables simultaneously. For example, in the case of the nested plots shown in Figure 4.2, the larger plots could be used for measurement of tree biomass, the mid-sized plots could be used for measurement of shrub biomass and the small plots could be used for measurement of litter biomass.

Nested plots are more expensive to measure than normal fixed area plots. The delineation of the inner plot boundaries will require more time. Trees with diameters close to the diameter class threshold values will require careful determination to decide whether or not to measure these in a particular plot size. Any error or confusion in counting in and out of the diameter class or plot boundary (which might not exist visibly marked) can lead to errors. This extra time can partially or wholly countervail the advantage of having to measure fewer trees of smaller diameter classes.

4.3 Variable area plot sampling

Variable area plot sampling, also called point sampling or angle count sampling, is a probability proportional to size (PPS) sampling method.[17]

[17] In forest inventory literature this type of sampling is known by various other names such as horizontal point sampling, variable radius plot sampling, plotless sampling, relascope sampling, and prism cruising.

In this sampling method, a sample point (point location) is selected in a forest stand and the neighbouring trees are observed against a critical angle defined by a device such as a dendrometer, a relascope, or a wedge prism. A sweep of 360° is taken by scanning all trees through the critical angle device and the trees that appear to be larger than the critical angle are counted. From the number of trees so counted, an estimate of basal area per hectare is made using the "calibration factor" of the critical angle device. This calibration factor is commonly called the basal factor (BAF) of the angle-defining device.

Point sampling is an efficient way of estimating the basal area and volume of forest stands. It is widely used because it is simple and economizes on field time.

Choice of basal area factor

Just a the optimal size of fixed area sample plots should be so decided that on an average 10 to 20 trees are included inside a sample plot, the critical angle, and hence the BAF, is so selected that on an average 10 to 15 trees would get tallied at a sample point. If the angle is too large, too few trees will be tallied, if it is too small, too many trees will be tallied and trees hidden behind other trees will make the process of measurement slow and time-consuming. Thus depending upon the stand density (stems per hectare) and distribution of tree diameter classes, the appropriate BAF should be selected.

Commonly used BAF values are 4 m^2/ha in high density stands and 1 m^2/ha in low density stands with good visibility. In dense tropical rain forest, however, BAF values of up to 9 m^2/ha may be appropriate.[18]

Efficiency

With a given number of trees to be measured, the point sampling method is more efficient for determining the basal area since the time involved in establishing plot boundaries is eliminated and the time involved in walking to individual trees and measuring their diameters is minimized (limited to the cases of borderline trees only). Only one skilled person is needed per team and easy and portable equipment is sufficient.

[18] The choice of a BAF applies to the entire inventory, or in case of stratified sampling, to an entire stratum. In principle it is not allowed to choose a different factor at each sampling location, as doing so would implicitly define multiple populations.

4.4 Selection of sample plots

Sample selection implies drawing a sample from the sampling frame which is often the same as the population to be sampled. Selection of the sampling units (sample plots or sample point locations) from the sampling frame should meet the twin objectives of randomness (to enable unbiased estimation of uncertainty) and representativeness or coverage of the area (to enable a good approximation of the population mean).

A commonly used sample selection method in forest inventory is *systematic sample selection with a random start*. In this method, the first sampling unit is selected in a random manner, and thereafter the remaining sampling units are so selected that the stratum area is (nearly) uniformly covered by sample.

The practical application of this method of sample selection is explained through an illustrative example presented in appendix A (see example A.3).

4.5 Double sampling

Sometimes the inventory area, or one or more strata in the inventory area, shows variability of the target variable in such a random and entrenched manner that no homogenous areas are evident (e.g. in the case where patchy growth or regeneration results in, with a clumpy structure composed of tree stands interspersed with numerous small blanks). In such a situation, delineation of strata boundaries is either not feasible or would result in defining too many strata.[19] An appropriate strategy in such cases could be to use the design known as double sampling.[20]

In double sampling, an auxiliary variable that is linearly correlated with the target variable is observed in a large first-phase sample. In the second phase of sampling, a sub-sample is drawn from the first-phase sample, and in each sampling unit contained in the sub-sample, the target variable is measured. The mean and the variance of the target variable estimated from the second-phase sample are then updated by applying a

[19] A diminishing return sets in when the project area is divided into too many strata. A small stratum gets fewer sample plots allocated and the within-stratum variance will be larger.

[20] In literature this design is also called two-phase sampling. This term should not be confused with two-stage sampling which is another name for a two-stage cluster sampling.

regression-based adjustment which makes use of the information contained in the extensive first-phase sample.[21]

Measurement of the auxiliary variable should cost less than the measurement of the target variable; otherwise there would be no cost-efficiency. The stronger the correlation of the auxiliary variable with the target variable, the higher will be the statistical efficiency of the double sampling design.[22]

Practical application of double sampling is illustrated by an example in appendix A (see example A2).

[21] As a result of the adjustment, the mean may be revised either upwards or downwards but the variance will always be lower than the variance estimated from the smaller sample.

[22] For example, measurement of the basal area in a plot costs only a fraction of the cost of measuring plot biomass and has a strong correlation with plot biomass. In some cases, vegetation indices constructed from appropriate remotely sense data also have significant correlation with biomass. The plot values of these indices can be easily constructed in a very large sample, or even over the entire sampling frame of all the possible sample plots in the stratum.

Chapter 5 Conducting measurements in sample plots

Summary This chapter explains the process of conducting measurements of the target variables in a sample plot. Suggested protocols include the methods of navigating to sample plot locations, establishing sample plots and their boundaries and identifying trees and shrubs inside the plot and conducting the necessary measurements on these. This chapter is the heart of the inventory work since the outcome of the inventory will critically depend upon the quality of these measurements.

5.1 Establishment and measurement of fixed area sample plots in field

5.1.1 Locating sample plots centre

The location of sample plots might have been determined in local coordinates or in geocordinates of latitudes and longitudes as determined from maps. To transfer these locations on ground, it will be necessary to navigate to plot locations in field. Combined use of topographic maps and a GPS receiver could be an efficient way of navigating to the plot locations in field. It may also be useful to take the help of a local guide who can provide further information on how to access the plots more easily.

The following stepwise approach is suggested for this:

1. Decide the sequence in which the plots are to be established and measured. If multiple field crews are conducting the inventory simultaneously, each crew should decide this sequence among the plots under its responsibility. The sequence can be later modified as more detailed information about accessibility of individual plot locations becomes available.
2. Register the plot centre locations as GPS waypoints.
3. Use the GPS navigation function in combination with the topographic maps or local guide’s knowledge to arrive near the plot location as far as the vehicle will go.

4. Obtain the precise GPS coordinates of the point under open sky that is nearest to the estimated location of the sample plot centre. (The plot centre may or may not be under open sky).
5. Calculate the precise displacement of the plot centre location from this point in terms of northing and easting.
6. Use a tape to measure these distances and arrive at the plot centre location.
7. Drive a stake (iron pipe or GI metal tube) at the precise location of the plot centre.
8. If obstacles prevent driving a stake at the plot centre (e.g. because of presence of tree, rock, river, etc), the stake should be fixed as close as possible to the plot centre and the distance and bearing (in degrees) of the plot centre from the stake location should be measured and recorded.
9. In the vicinity of the plot centre identify at least three prominently visible fixed reference points (e.g. rock outcrop, a feature of a large tree, or a tag fixed on a witness tree). Measure distances and bearings of the plot centre from the fixed reference points and record these.
10. The geo-coordinates of the reference points are determined with the help of a GPS receiver and are recorded. Reference photos may also be taken.
11. In case of temporary plot the reference points would enable quick relocation of plot centre for re-checking of measurements for quality control.
12. In case of a permanent plot, due regard should be paid to the probability of the reference points being durable enough within the envisaged timeframe of future measurements..

It may be useful to take photographs of the plot location site as well as of key features along the route during the access to the plot, such as road/path junctions, settlements, that can help orient travel in the future to the sampling plot centre or in exiting from the site. A sketch representing the itinerary covered should be drawn on the topographic map and should be attached to the field data form, with indications of the reference points that will facilitate relocation of the plot. If required, the flagging coloured tape should be placed on trees along the access path. The tape be visible prominently enough to facilitate the return out of the plot location. In case of a permanent plot, a photo from the plot centre should be taken for each reference feature and recorded with suitable descriptions.

5.1.2 Plot boundary demarcation

Correct and precise demarcation of plot boundary is extremely important to avoid errors and bias in estimation.

The following aspects should be taken into consideration while conducting plot boundary demarcation in field:

Ground slope

Fixed area plot sampling is based on the assumption that all plots are laid out in the horizontal plane. If a sample plot is located on a slope, a slope correction should be applied to account for the fact that distances measured along a slope become smaller when they are projected on the horizontal plane. With circular plots, the slope can be corrected by enlarging the radius of the plot by a factor of $\sqrt{1/\cos(\beta)}$ where β is the maximum slope angle. With a rectangular plot, the sides perpendicular to the direction of the maximum slope should remain unaffected but the sides parallel to the direction of the maximum slope should be enlarged by a factor of $1/\cos(\beta)$.

Stratum edge

Forest stands often include voids, such as roads, lakes or power lines and the surveyor may be tempted to move the plot falling in these areas to a wooded spot. This is not correct as it can introduce bias in the estimates. Depending upon how stratum boundaries have been delineated blanks such as roads, water bodies, buildings, etc may or may not form part of the sampling frame. If these are included in the sampling frame and a sample plots falls in voids, the sample plot stays where it is and its biomass is recorded as zero. If void areas have been explicitly excluded from the sampling frame of the stratum (the map clearly indicates areas that do not form part of the stratum), then at the stage of sample selection it should be ensured the map locations of plots do not fall in these blank areas. However, since even the most detailed map is of such a scale that the exact determination of plot centre coordinates and its subsequent location in field will not match precisely. As a result it is possible that certain sample plots that appear to be close to the stratum boundary but clearly inside may upon navigation to these locations happen to lie astride the stratum boundary.

An edge correction is required in the situations where the plot is located so close to the edge of the stratum boundary that the distance to the stratum boundary is less than the radius *r* of the plot. In such as case, the area of the plot inside the stand would be smaller than the nominal plot area and thus, fewer trees would be measured which could lead to a biased observation.

A commonly applied method for edge correction is the "mirage method". In this method, a mirroring sample plot centre is located at the same distance x from the edge on the other side (outside the stratum or stand). Using the mirrored plot centre, the part of the sample plot falling outside the stratum boundary is reflected back inside the boundary. The trees in the reflected part are measured twice and the nominal area of the sample plot is used to convert the per plot values into per hectare values.

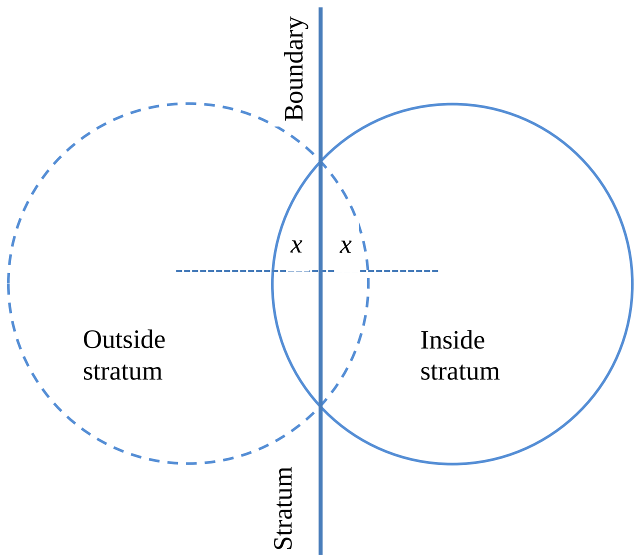


Figure 5.1 Mirage method

Stepwise procedures for plot boundary establishment in field

After the plot centre location has been determine in field, it will be necessary to determine the exact boundary (perimeter) of the sample plot and to determine and identify the trees that are determined to be inside the plot and will be subject to measurement. The following stepwise procedures should be followed for this.

Circular plots

1. Calculate the nominal plot radius (radius in the horizontal plane) from the nominal size of the plot:

$$r = \sqrt{\frac{a}{\pi}}$$

   where r is the radius in metre, a is the plot area in sqm, and π =3.14159.

2. Determine the ground slope and check if it exceeds 10%. This can be visually confirmed in most cases but where the slope is close to 10%, measurement should be taken to confirm this determination.

3. Determine the slope adjusted plot radius using the equation below.

$$r_{sa} = r\sqrt{\frac{1}{\cos\beta}}$$

where r_{sa} is the slope-adjusted radius, r is the nominal radius, and β is the slope of ground in nearest degrees.

4. From the plot centre, along 0° (the direction determined as north), run the measuring tape along the ground over a distance equal to the required slope-adjusted plot radius and mark the boundary with flagging tape on a pigtail stake.

5. In a clockwise direction repeat this measurement every 30 degrees. Use different coloured flagging tape to mark the cardinal bearings and divide the plot into quadrants (North East, South East, South West and North West).

6. To check whether a tree that appears to be on the borderline is inside or outside of the plot boundary, measure the distance from the plot centre to the tree. Compare this distance to the required slope-adjusted radius. Determine the precise location of the tree as its point of germination. The tree may be leaning out of the sample plot, but as long as its point of germination (the centroid of its base) is inside the plot the tree is determined as inside. Conversely, the tree may be leaning into the sample plot, but as long as its point of germination (the centroid of its base) is outside the plot the tree is determined as outside.

7. Temporarily tag the trees determined to be inside the plot. Number the trees using the quadrant prefixes followed by serial numbers (e.g. NE01, NE02 for trees in the North East Quadrant. Attach numbered tags on trees. Tags should be designed to last long enough until re-checking of plot measurements under quality control protocol has been done. Fixing of tags should not damage or endanger the trees.

Square plots

1. Calculate the length of the side of the plot:

$$s = \sqrt{a}$$

where s is the side of the square in metre and a is the plot area in sqm.

2. Determine if the ground slope exceeds 10%. This can be visually confirmed in most cases but where the slope is close to 10%, measurement should be taken to confirm this determination.

3. Determine the orientation of the plot as follows:

    a. On ground with more than 10 per cent slope, orient two of the parallel sides of the plot along the direction of maximum slope.

    b. On ground with less than 10 per cent slope, orient two of the parallel sides of the plot along a pre-determined cardinal direction (e.g. North). This pre-determined direction must be consistently followed in orienting all the sample plots where the ground slope is less than 10 per cent.

    c. Determine the slope adjusted length of the sides aligned along the direction of maximum slope using the equation

$$s_{sa} = s \frac{1}{\cos \beta}$$

where s_{sa} is the slope-adjusted side (the side parallel to the direction of the maximum slope), s is the nominal side, and β is the maximum slope of the ground expressed in nearest degrees.

4. Draw a line passing through plot centre and perpendicular to the direction of orientation determined in step above.

5. Scale off this line such that on each side of plot centre it extends equal to half the nominal length of the side of the square.

6. Draw two lines passing through the end points of the above line and in the direction of maximum slope.

7. Scale off these lines so that each extends on either side half the distance of adjusted length of the side.

8. Having fixed the four corners as the intersections of the extended lines, measure the diagonals of the plot and check for correctness of the plot boundary by comparing this with a computed length of the diagonals.

9. If the computed and measured lengths of the diagonals differ by more than 5%, re-check the angles and distances and re-

determine the positions of the four corner points until the measured values of the diagonals are in agreement with the calculated values.

10. To check borderline trees, if possible, stretch coloured tape along each of the four sides of the square (one after another, not necessarily at the same time) and determine whether trees near border are inside or outside of the plot.
11. Temporarily tag the trees determined to be inside the plot. Number the trees using the quadrant prefixes followed by serial numbers (e.g. NE01, NE02 for trees in the North East Quadrant. Attach numbered tags on trees. Tags should be designed to last long enough until re-checking of plot measurements under quality control protocol has been done. Fixing of tags should not damage or endanger the trees.

Cluster plots

A cluster plot should be laid down following a procedure similar to the above procedures. It will require much more time to precisely locate the centres and establish the boundaries (perimeters) of the sub-plots constituting the cluster plot. The orientation of the cluster lattice should be pre-defined and should not be arbitrarily decided at the time of establishment of plots. That is, in the in case of a cluster plot design shown fig X, if the rectangle is to run North-South, it should be consistently done so at all plots. Note that only the radii of the subplots need to be adjusted for ground slope and not the lattice distances as these distances do not enter into the calculations of the target variable and do not contribute the bias or the variance of the target variable.

For further guidance in specific situations commonly encountered in field, the reader may refer to appendix B.

5.1.3 Measurements in sample plots

Once plot boundary has been established and the trees inside the plot boundary have been determined and tagged, measurements would need to be conducted on the trees and other components of carbon pools. This sub-section describes the methods to be followed in conducting measurements inside sample plots.

Measurement of trees

All trees that have been determined to be inside of the sample plot are to be measured.

Basic information about trees

The following basic information about the trees subjected to measurements should be recorded so as to facilitate any subsequent quality control work and other issues related to monitoring and verification:

1. Tree species (local name and Latin name)
2. Tree status: Live standing: leaning in/out of the plot; live fallen (fallen in/out of the plot)
3. Stem status: whether forked above/below measurement level; number of stems (cross reference to other stems measured as separate trees/stems)

Measurement of tree dimensions

Tree diameter

Tree diameters can be defined in different ways. It is important to consider how the diameter measurements obtained from the inventory will be used. The measurements should be consistent with that use should be made. For example, measuring the diameter at breast height (*dbh* or d) will not be useful if the model or the equations in which the diameter to be used as input variable requires collar diameter (d_{rc}), or diameter at a height equal to one-tenth of tree height ($d_{0.10}$).

Diameter at breast height

Diameter at breast is the most commonly used tree diameter in forestry inventory. It is defined as the over-bark tree stem diameter measured at a pre-determined height above the ground level. The pre-determined height, called the breast height, can be fixed as 1.30 m, 1.37 m or 1.40 m. This height should be selected carefully. If the project's host country has national forest inventory standards that define the breast height, this one should be used. If a breast height is not defined in the host country, either 1.30 m or 1.40 m may be selected as the breast height but once selected it should remain fixed throughout the future verifications of the project activity.

The following is the stepwise procedure for measurement of DBH of a tree stem:

1. Determine the highest point of mineral soil or humus layer on the uphill side at the base of the tree.

2. From this point on the ground, locate the point 1.30 m up the stem (or 1.30 m along the stem axis where the stem is leaning or curved).
3. Measure the stem diameter at this point to the nearest 0.1 cm using a diameter tape or diameter callipers.
4. If using diameter callipers, the following precautions should be kept in mind:
    a. The graduated beam of the callipers must be perfectly straight and the graduations should be clearly visible.
    b. The movable and the fixed arms should run exactly parallel to each other and perpendicular to the graduated beam and the three should stay in a plane.
    c. The point of measurement should be correctly positioned. A wooden T-bar of height equal to the selected breast height can be used for ensuring this consistently.
    d. Presence of snow or thick ground vegetation at the foot of the tree can lead to incorrect determination of the point of measurement.
    e. Too much pressure should not be exerted during measuring as it can lead to operator-bias because of squeezing of the bark. Too less pressure can also lead to bias as bark surface irregularities can make the recorded diameter larger than it actually is.
    f. The callipers should be calibrated regularly. They should be capable of measuring diameter to the precision of to 0.10 cm.
    g. The stem diameter should be measured in two mutually perpendicular directions and if the difference of these two measurements is more than 0.10 cm, the geometric mean of the two diameters should be recorded as the measured diameter.
5. If using diameter tape, the following precautions should be taken kept in mind:
    a. Systematic errors can occur when the measuring position is consistently located above or below 1.30 m, or when the tape is slanted around the tree and sags on one side.
    b. Excessive pressure or tension in the tape can induce an operator bias.
    c. The occurrence of loose or bulging bark can generate an error unless these bark irregularities are removed prior to measurement.

6. If at the point of measurement of diameter a stem irregularity such as a fork, branch, bump or abnormal swelling is encountered, measure the diameter at equal distances above and below the irregularity. Record the average of these diameter measurements as the DBH.

For further guidance in specific situations commonly encountered in field, the reader may refer to appendix B.

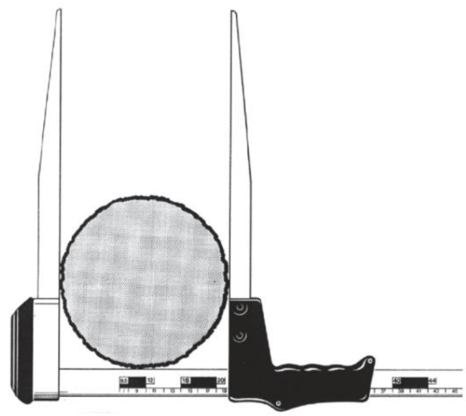


Figure 5.2 Use of diameter callipers

Tree height

Tree height is to be measured when the allometric equations or volume equations used for estimation of tree biomass require tree height as an input variable. Tree height may be defined variously (e.g. total height, bole height, merchantable height, height to a pre-determined top diameter) and only that tree height should be measured for which the model or the equation to be used was developed.

The method of tree height measurement depends upon the instrument used. Commonly used instrument for this purpose is a hypsometer. Different types (and marks) of hypsometers are available but all hypsometers measure tree height in terms of angles subtended at a known distance.

The following step-wise method describes measurement of tree height, irrespective of the exact instrument used:

1. Stand at a known distance from the tree (use a tape to measure off this distance) and by sighting to the top of the tree and the base of the tree record the two vertical angles.
2. Calculate the height of the tree by using the equation:

   $$h = b(\tan\beta - \tan\alpha)$$

   where h is the tree height, b is the base distance from the the point exactly under the instrument to the base of the tree, β is the vertical angle to the base of the tree, and α is the vertical angle to the top of the tree (or the top of the bole if bole height is being measured).

3. The following precautions and sources of errors should be kept in mind and adjustments made where necessary:
   a. For total height it is necessary to sight to the top of the tree crown, rather than to the highest visible point on the outside of the crown. For bole height it is necessary to estimate correctly and consistently the point where the bole ends.
   b. Keep the base distance longer than the estimated height of the tree so as to achieve an angle of less than 45º.
   c. If the base of the tree cannot be sighted because of undergrowth, ask an assistant to hold a staff of known height close to the tree trunk and sight to the top of this staff. Add the height of the staff to the tree height calculated from equation X.
   d. If a tree is leaning more than 10 degrees, it should be observed from such a point that the tree appears to lean to the left or the right of the observer and not towards or away from the observer. The tree height calculated from the equation X should be corrected for the lean by using the following equation:

      $$h_{al} = \sqrt{h^2 + c^2}$$

      where h_{al} is the tree height adjusted for lean, h is the tree height as calculated from equation X, and c is the distance between the point of vertical projection of the tree top on the ground and the base of the tree.

For further guidance in specific situations commonly encountered in field, the reader may refer to appendix B.

Crown cover

Crown cover is the proportion of ground covered by the vertical projection of the crowns of live trees.[23]

Tree crown cover would normally be of interest in the estimation of tree biomass in the baseline (i.e. the pre-project tree biomass). Since baseline tree crown cover is expected to be rather low, it will be in most cases only a few individual trees in a plot whose crown spread (diameter) will need to be measured. Assuming a circular or oval shape, the tree crown area projected on the horizontal plane can be calculated for each tree and the individual crown areas of all the trees in the sample plot added together and divided by the plot area provides an estimated value of the crown cover at the centre of the plot.

The following methods can be used for measuring crown diameter and crown area of individual trees:

Aerial measurement

Aerial photographs made at scales of 1:15,000 or larger can be used to determine crown cover estimates, usually done by ocular interpretation. Standardized screens representing crown density classes can be used as an aid. Low density stands make for an easy ocular estimation, but as the stand density increases the ocular estimates become more difficult to obtain.

Ground measurement

On-site measurement of tree crown cover can be conducted by measuring the crown spread of the individual trees. Crown spread measurements are used to calculate the crown areas projected on the ground. The area of the crown as projected on the ground is calculated by assuming the crown shape to be circular. Summing the crown areas for all trees in a fixed plot area and dividing the sum by the plot area provides an estimated value of the crown cover at the centre of the plot.

Any of the following two different methods for measurement of the spread of the crown of a tree can be followed:

[23] Crown closure and crown cover are two different measures of the forest canopy. Crown cover (also called canopy cover) represents the aggregate of all vertically projected tree crowns onto the ground surface, while crown closure (also called canopy closure) represents the amount of the sky obscured by the crowns from a certain point on the ground.

Cross-method

In this method, the points on the ground immediately below the branch tips on two diametrically opposite extremities of the crown are determined and marked. The spread along the line joining these two points on the ground is measured as the crown spread in one direction. This process in repeated in the direction perpendicular to the first spread. The average of the two spreads is taken as the spread of the crown.

On sloping ground (usually more than 10 per cent) the distance measured between the two points can be reduced to the true horizontal distance by multiplying it by $\cos\beta$ where β is the maximum slope of the ground.

Spoke Method

Under this method, four or more measurements are taken from the ground projection of the outer extremities of the crown to the edge of the trunk. The individual spoke lengths are averaged and the average is doubled to obtain the crown spread.

On sloping ground (usually more than 10 per cent) the measured spoke distances can be reduced to the true horizontal distance by multiplying these by $\cos\beta$ where β is the slope of the ground along a spoke.

Measurement of shrub attributes

If shrubs are included in monitoring, the same plots can be used for inventorying shrubs. The approved A/R CDM methodologies require measurement of only one parameter for estimation of shrub biomass: the mean shrub crown cover.

The methods described above for measurement of tree crown cover can also be employed for measurement of shrub crown cover.

Alternatively, the angle count method can be used for estimation of shrub crown cover. This method would be based on the assumption that shrub crowns have circular shape. Since shrub crowns can have typically larger diameters than tree stems, an angle count instrument with small BAF will be more suitable for estimation of shrub crown cover. The tally provided by field observation can be directly converted to shrub crown cover by multiplying it by the BAF value.

Measurement of dead wood

Measurement of deadwood involves three distinct components: dead trees that are intact, dead trees that have lost branches and hence become stumps, and dead trees and their parts that are lying on or along ground.

Standing dead wood

Standing dead trees are measured in the same way as the living trees. The same models (allometric equations, or volume equations in combination with biomass expansion factors) are used for conversion of tree measurements (e.g. *dbh*) into tree biomass.

Lying deadwood

Lying deadwood is measured by using the line transect method.

The following stepwise method is followed for this:

1. Define on ground two mutually perpendicular transect lines passing through the centre of the sample plot, each line being 50 m long. Transect lines can be defined by stretching a string or tape.
2. Start at one end of the transect line and traverse along it until a piece of dead wood (with diameter greater than 10 cm) crosses the line.
3. At the point where the piece intersects the transect line, measure the diameters of the piece in two mutually perpendicular directions. The geometric average of these diameters is as the measured diameter of the piece.
4. Determine decay class into which the piece of wood falls, using the pre-defined decay class criteria (e.g. the machete test).
5. Input the measured data is into the relevant equation of the A/R methodological tool “Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities” to estimate the carbon stock in lying dead wood in the plot.

Measurement of littler

Litter measurements are conducted by subsampling in the same sample plots in which tree measurements are conducted. Su-sampling is done by using a wire frame (usually 1 m square) which defines the perimeter of sub-plots for litter measurement.

The following stepwise method is followed for this:

1. Place the sampling frame in four randomly selected places within the sample plot so that the plot is well covered by the four locations.
2. Collect all the litter within the perimeter defined by each position of the sample frame. Mix the four litter samples into one composite sample.
3. Weigh the composite sample and record its fresh weight.
4. Take a sub-sample from the composite sample and record its fresh weight.
5. Dry the sub-sample at 70 degrees for forty-eight hours and record its dry weight.
6. Input the measured data is into the relevant equation of the A/R methodological tool “Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities” to estimate the carbon stock in litter in the plot.

5.2 Establishment and measurement of variable area sample plots in field

5.2.1 Plot establishment

In variable area plot sampling, only plot centre location needs to be established in field, since plot boundary is not fixed.

For establishing plot centre location in field, the method explained in section 5.1.2 above should be used.

5.2.2 Conducting tree measurements in variable area plot sample plots

The common tree parameter measured in variable area sampling is the tree basal area. To measure the tree basal are at a plot centre location, the following stepwise method is followed:

1. Stand at the plot centre location and set up the angle count instrument at this point.
2. If the instrument used is a wedge prism, or a relascope, the instrument must be located vertically above the plot centre. If the instrument used is a dendrometer the person taking observation must so stand that his eye is located vertically above the plot centre.

3. Establish a reference direction from where to start a sweep (typically the North). A flag can be fixed on a distant tree in this direction so as to make this direction clearly visible and to avoid overshooting the sweep beyond 360 degrees.
4. Scan all the trees by sweeping the instrument in clockwise direction. Record each tree that appears to be larger than the critical angle as the sweep progresses.
5. Multiply the number of trees tallied by the BAF of the critical angle or the instrument to obtain the measured value of tree basal area at the sample point.

For further guidance in specific situations commonly encountered in field, the reader may refer to appendix B.

5.2.3 Variable area plot sampling on sloped terrain

As in sampling with fixed area plots, all area measures in variable area plot sampling are assumed to be in the horizontal plane. When applying this method in sloped terrain, the slope should be taken into account. This is done either by using an instrument that does the slope correction automatically, or by introducing the correction factor into the calculations if the slope is not automatically corrected. Normally slope correction is applied at slopes of 10 per cent and more. The correction factor, as in the case of fixed area plot sampling, is $1/\cos\beta$. That is, the observed value is expanded by this factor at each of the sample points where the ground slope is 10 per cent or more.

Appendix A Worked-out examples

This appendix includes illustrative examples that demonstrate application of the methods described in the manual.

A.1 Application of stratified random sampling

In a hypothetical case of a project undergoing monitoring and verification, the area shown in Figure A1 constitutes the project area. We delineate the project area into the following parcels on the basis of satellite imagery[24]:

1. Area with insignificant (zero) biomass (e.g. due to high mortality of planted trees);
2. Area with relatively low biomass;
3. Area with medium biomass and uniform growth;
4. Area with medium biomass but patchy growth;
5. Area with relatively high biomass.

Satellite image is confirmed to conform to the field reality by conducting a rapid reconnaissance in field.

We make preliminary estimation of the mean values of biomass density of the strata (in t d.m./ha) and its variability in each stratum as estimated coefficient of variation (CV).[25]

We delineate the above areas on the basis of visual study of the remote sensing data (satellite image) of the project area[26]. We then insert the values, along with the estimated areas of the strata and the targeted precision of our inventory, into equation (1) of the tool "Calculation of the number of sample plots for measurements within A/R CDM project activities" and calculate the total number of sample plots. Our calculations are presented in Table A1.

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[24] We could have also used Google Earth image for this purpose.

[25] This might seem counterintuitive at first sight since the very purpose of the exercise is to find these values. However, one proceeds from rough knowledge to precise knowledge and not from complete uncertainty to precise values. The basis of the preliminary estimations can be varied – such as species, age, past data from similar areas, data from previous inventories, or expert judgement.

[26] We note that if we did not have access to satellite data for our project area, we could have carried out a rapid cruise to measure the variable "basal area per hectare" at a predetermined number of sample points. The cost of doing this would be lower because we could use the point sampling method for this. We could then stratify the area on the basis of basal area instead of biomass per hectare.

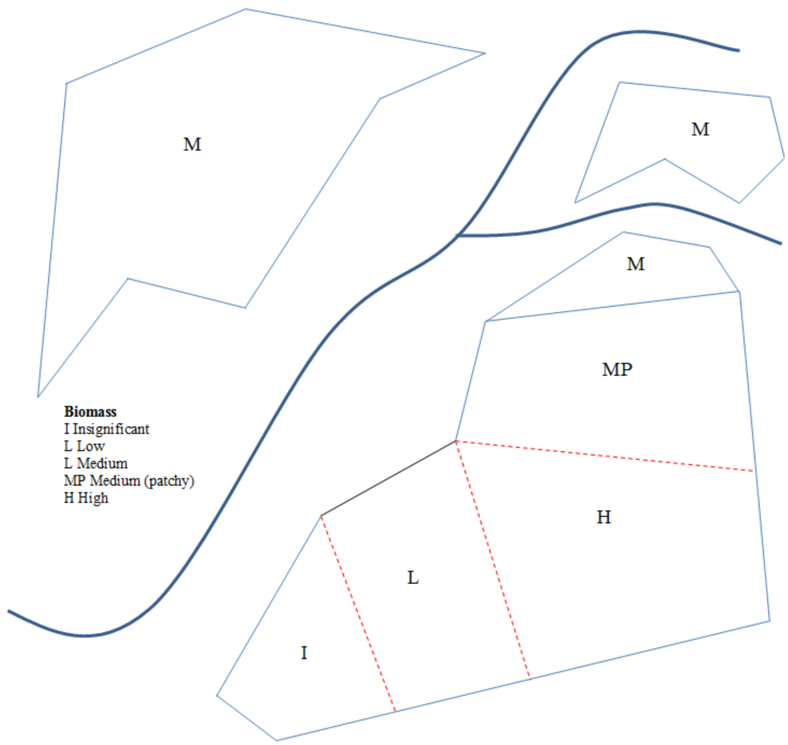

Figure A1 Map of stratification

Our calculation results in total number of sample plots to be 120. We then increase the calculated number of plots by 10% to be on the safer side since once inventory has been carried out and the required precision in the estimate is not reached, it can be very costly to go back to field and install additional plots. We thus increase the total number of sample plots from 120 to 133. We allocate these 133 sample plots to the different strata using equation (4) of the tool. Since stratum *M* comprises of three discrete areas, the 50 plots allocated to this stratum are distributed among these discrete areas (parcels) in proportion of their sizes, thus the three parcels receiving 35, 8 and 7 plots respectively.

Table A1 Calculation of number of sample plots their allocation to strata using stratified random sampling

Calculation of number of sample plots and their allocation to strata

	Plot size =	1/20 ha	N =	22000		E =	3.14	t_{VAL} =	1.645		
	=	500 sqm									

Stratum number	*Stratum Name*	*Stratum area (A_i) ha*	*Stratum weight (w_i)*	*Guestimated values of*		*Standard deviation (s_i)*	w_i*s_i	$w_i*s_i^2$	n_i *(fractional)*	n_i *(integer)*
				Mean biomass (t d.m.)	*Coefficient of variation*					
1	L	195	0.1773	11.00	0.80	8.80	1.560	13.728	9.84	10
2	M	435	0.3955	30.00	0.60	18.00	7.118	128.127	44.91	45
3	MP	210	0.1909	30.00	0.90	27.00	5.155	139.173	32.52	33
4	H	260	0.2364	50.00	0.60	30.00	7.091	212.727	44.73	45
	Total/avg	1100	1	31.36	0.73	20.95	20.924	493.755	132.00	133

		Parcel	Area	Weight	Number of plots
n =	120	M1	300	0.689655172	31
	132	M2	75	0.172413793	8
		M3	60	0.137931034	6
			435	1	45

We note that since plots can be only installed in whole numbers, where we obtain fractional values of number of plots, we round these upwards to the whole number.

The results of our calculation are summarized in Table A1.

A.2 Application of double sampling

At the time of inventorying of carbon stocks in the hypothetical example of project described in example A.1, we find in that the stratum *MP* (area 210 ha) shows highly patchy growth and thus clumped distribution of biomass. It is not evident to delineate biomass strata with uniform mean values or with uniform variability at any spatial scale.

We therefore decide to adopt the design of double sampling for this stratum. We know that "basal area per hectare" and "tree biomass per hectare" are linearly correlated variables. We therefore decide to measure the auxiliary variable of "basal area per hectare" in a first-phase sample of 100 sample plots. We do this by using point sampling method. Measurement of basal area by using point sampling costs only a fraction of the cost of measurement of biomass in sample plots.[27]

In the second-phase, we draw a random sample of 15 sample plots from the first-phase sample and we measure the tree diameters in these plots and estimate the per hectare tree biomass in each of these plots. We then perform linear regression between the measured biomass values against the measured basal area values of the same plots. Using equations (18) and (19) of the A/R CDM methodological tool "Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities", we adjust the observed mean of tree biomass and its variance as estimated from second-phase sample. The results of our calculations are laid out in Table A2.1 and Table A2.2.

Table A2.1 Regression of auxiliary variable against the target variable

Coeff of correlation:					
r =	0.869497				
Slope:	*Intercept:*				
7.561964	-20.1991				
Thus:					
y =	*-20.199*	+	*7.56196*	*	*x*
$\bar{y}_{ds}$	141.1732				

[27] By 'measurement of the tree biomass in a sample plot' we mean measurement of the DBH and/or tree height of the trees in the sample plot and conversion of these measures values into per hectare tree biomass in the plot.

Table A2.2 Adjusted and unadjusted means and their uncertainties

	y Aboveground biomass ($t\ d.m.\ ha^{-1}$)	*x* Basal area ($m^2\ ha^{-1}$)
	117.60	17.60
	168.00	21.60
	94.00	18.60
	180.00	27.80
	104.00	16.80
	110.00	21.40
	158.80	23.00
	178.00	25.60
	167.20	25.10
	98.00	15.20
	148.40	23.10
	140.60	22.30
	106.00	16.10
	137.80	19.40
	185.00	23.30
mean	139.56	21.13
var	1053.778286	13.9320952
var (mean)	70.25188571	0.92880635
adj (var (mean))	25.10650805	
adj SEM (mean)	5.010639485	
adj (U_{90} (mean))	8.825290111	
adj (%U_{90} (mean))	0.06323653	
unadj (%U_{90} (mean))	0.105780074	

We note that if had not taken the auxiliary variable measurements in the first phase sample, our uncertainty in the estimated biomass would have been 10.58%. With the information contained in the first-phase sample, we are able to reduce this uncertainty to 6.32%. In this process, the mean value of biomass per hectare in the stratum has also been adjusted from 139.56 to 141.17, but we are aware that this adjustment could have been either upwards or downwards.[28]

[28] We note that the Tool requires us to control uncertainty at project level and not at stratum level. However, if we use very imprecise estimates for major strata, we risk exceeding the maximum allowed uncertainty. If a stratum is relatively minor, such as of 50 ha, we could have risked a large variance and uncertainty in its estimated mean.

A.3 Application of systematic sample selection with random start

In our hypothetical project described in example A1, we illustrate determination of sample plot locations using the method systematic sample selection with a random start in parcel *M1* of stratum *M* which is to receive 31 sample plots. The same method could be applied to the other strata.

We overlay a transparent grid of square cells such that each cell represents one plot. This grid illustrates all the possible sample plots in parcel *M1* (Fig A2). The full grid of 107 columns and 101 rows covers the entire map of the parcel but also has cells that do not fall into the parcel. All the cells falling within the boundary of the parcel constitute our sampling frame (and also the population to be sampled).

To select the first (random start) sample plot, we use the Excel function RANDBETWEEN(1,107) to generate a random column number, and again RANDBETWEEN(1,101) to generate a random row number. The resulting cell with coordinates (60,64) falls outside the parcel, so we ignore this and generate another set of random numbers which gives use the coordinates (87, 56) which also falls outside the parcel. We repeat this again and we get the cell with the coordinates (27, 53) and this cell falls inside the parcel. This is the first (random start) sample plot[29].

We now determine the X-axis and Y-axis interval between two plots considering that we want the 31 sample plots to be evenly spread over the parcel. We calculate the value SQRT(6000/31) in Excel because with our plot size of one-twentieth of a hectare the parcel area will accommodate a total of 6000 plots. The square root is needed because we need two intervals, one along the X-axis and the other along the Y-axis. This gives us an interval of 13. Using this interval, we select every 13^{th} plot along X axis and likewise every 13^{th} plot along Y axes until we reach the parcel boundary. We find that we can accommodate only 28 plots in this manner and therefore we downsize the interval to 12 and then re-select the plot locations. This gives us 34 plots which we accept since it gives us a safer number of sample plots[30].

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[29] We are aware that this somewhat elaborate process of selection of the starting cell can be substituted by subjectively picking up a random cell inside the map. The only difference would be that while the process we followed can be replicated, it will not be possible for a third party verifier to verify our subjective choice of the starting cell.

[30] We understand that the sample size is not a requirement in itself; it is a means of assuring that we meet the requirement relating to uncertainty. The A/R CDM standards prescribe the requirements in terms of the maximum allowable uncertainty. As long as we can demonstrate that the uncertainty of our estimation does not exceed the

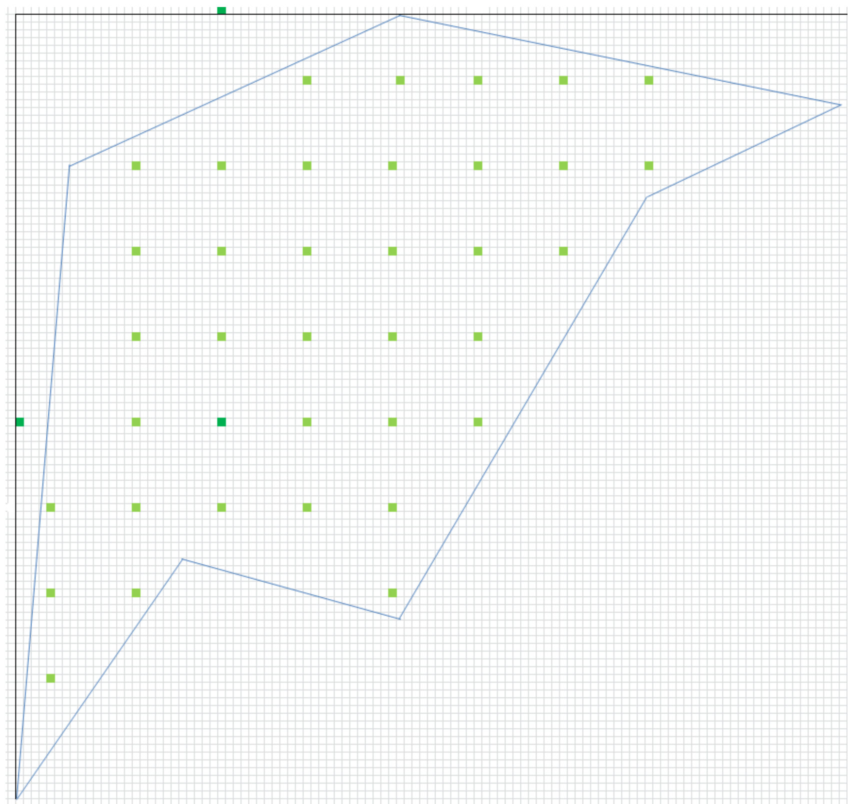

Figure A2 Systematic sample selection using a grid of cells

If we knew the georeferenced coordinates (e.g. the latitude and longitude) of one of these plots, we could have calculated the coordinates of all the sample plot centres and by feeding these coordinates into a GPS receiver we would be able to locate the plot centres in field.

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maximum allowable uncertainty, the number of sample plots can exceed or fall short of the number calculated from the tool. This is also the reason why the tool is an optional tool. We do not attach excessive important to the exact number of sample plots we install in a stratum or in total; instead we can increase or decrease the number of sample plots by a marginal amount.

Appendix B Implementation of plot measurement procedures

B.1 Determining trees that are inside the sample plot

Correct decision on whether a tree close to the plot boundary is inside or outside is of great significance. Each tree wrongly determined in or out will lead to bias that will propagate magnified at the stratum level.

It is the germination point (the imaginary point at the centroid of the base area of the tree stem) that determines whether the tree is inside or outside of plot boundary, irrespective of the lean of the tree. Figure B1 illustrates the three situations. Since the germination point is not accessible in practice to measurement, it is best practice to measure the distances from the plot centre to the nearer (inner) edge and the farther (outer) edge of the tree base and then calculate the average of the two distances. If this average distance is greater than the slope-adjusted plot radius, the trees is determined as out. If the average of distance is less than the slope-adjusted plot radius, the tree is determined as in. If the average distance is equal to the slope-adjusted plot radius, the tree may be considered either in or out but a record should be made of this fact and the next time a similar situation is encountered the alternative determination should be made. This alternation of determinations should be followed until all the plots in the stratum have been measured.

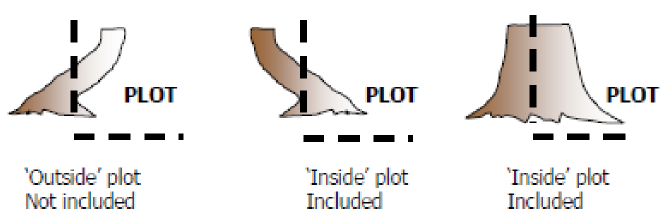

Figure B1 Determining the borderline trees

B.2 Numbering the trees determined inside a sample plot

The confusion leading to measurement of a tree two times or of omission of a tree from measurement can lead to serious errors in plot measurement. This is particularly important concern when the number of trees in a plot is large and visibility of stems is poor.

It is a best practice to adopt a standard scheme of identifying and numbering the trees determined to be inside the sample plot. One method is as illustrated in Figure B2.1 where the trees are numbered in four numbered series corresponding to the four plot quadrants. Within a quadrant, numbering sequence follows the azimuth angle, and within the same azimuth angle the sequence follows from centre outwards. Using this scheme (or any other systematic scheme that is well understood by the crew members) will avoid errors of omission or double measurement of trees.

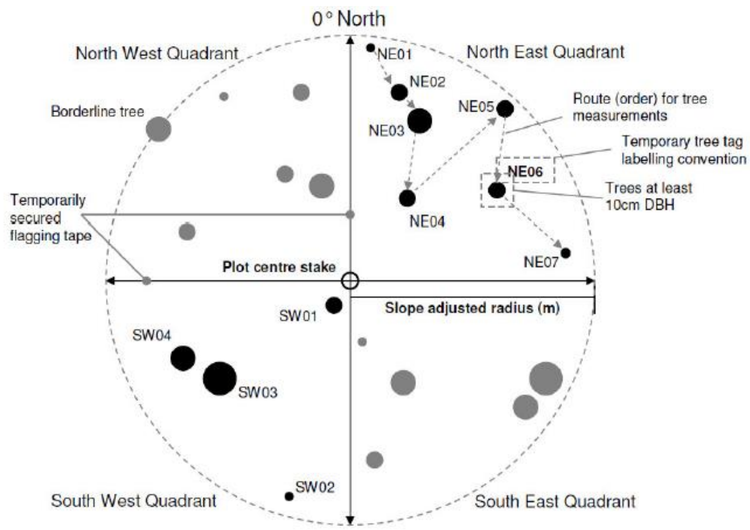

Figure B2 Identification and numbering of trees in a sample plot

The trees should thereafter be tagged with temporary tags. This will also help in avoiding double counting or omission of trees and will also assist in conducting quality control check when a small fraction of sample plots are subjected to verification by the quality control team. The tags do not have to be permanent but these should be sturdy enough to last until the end of the time of verification.

B.3 Measurement of diameter at breast height

The *dbh* is the most common of all tree measurements. Correct and precise measurement of the *dbh* is of utmost importance. Commonly encountered field situations that require a determination in this respect are depicted in Figure B2.3. In general, the following principles are used as standard practice in measurement of the *dbh*:

(a) When trees are on slopes or uneven ground, the point of measurement is located at a height equal to the breast height on the uphill side of the tree.

(b) When a tree is leaning, breast height is measured parallel to the lean on the high side of the tree. The diameter is measured perpendicular to the longitudinal axis of the stem.

(c) When a tree has a limb, bulge or some other abnormality at breast height, the two diameters above and below the abnormality should be measured and the average of the two diameters should be recorded as the measured *dbh*.

(d) When a tree consists of two or more stems forking below breast height, each stem is measured separately. If the fork occurs above breast height, it is measured as one tree. If the fork occurs at breast height, the diameter below the enlargement caused by the fork is measured.

(e) If a tree has buttress that extends higher than 100 cm, the diameter at 30 cm above the top of the buttress is measured.

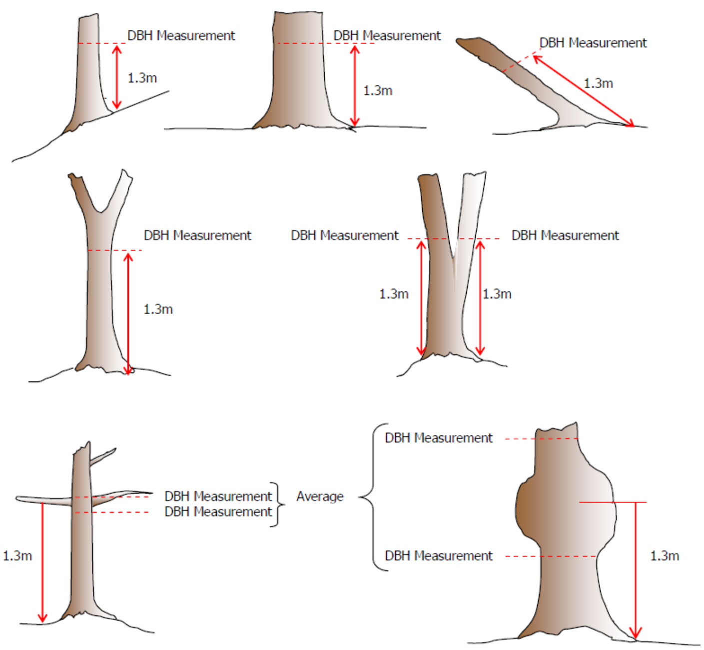

Figure B3. Measurement of diameter at breast height of trees in different situations

B.3 Measurement of tree height

Tree height measurement does not have to be conducted with the same precision as tree diameter. The basic principles of tree height measurement are based on the simple rules of trigonometry. The basic situation of tree height measurement is illustrated in Figure B4, wherein using the values of the angles and distances indicated in the figure, the tree height is calculated as:

$h = b\ (\tan \alpha_1 - \tan \alpha_2)$,
while recording angle α_2 as negative when it is below horizon.

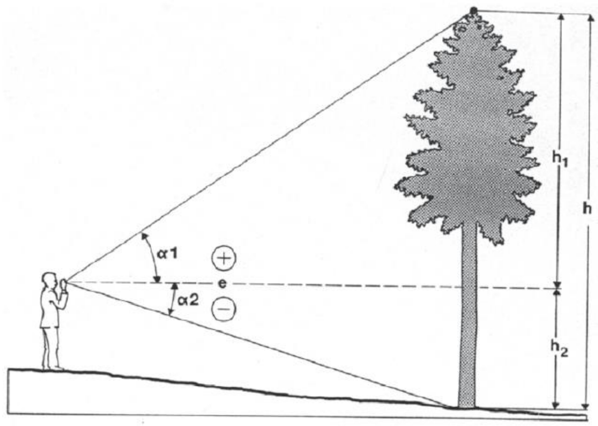

Figure B4 Tree height measurement when observer is at a higher elevation

On the other hand when the observer is at a lower elevation than the tree base, a positive angle will be observer in both the cases (Figure B5).

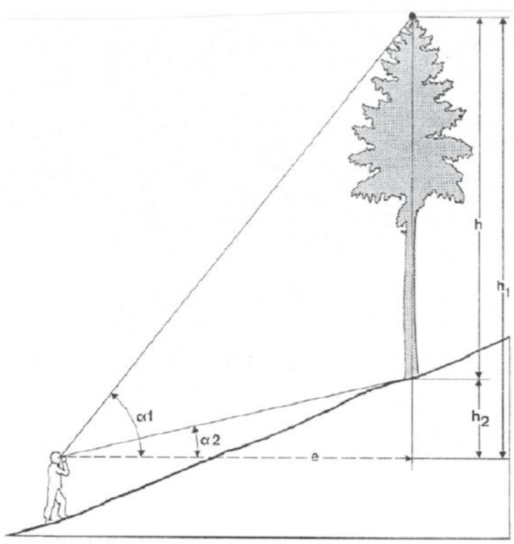

Figure B5 Tree height measurement when observer is at a lower elevation

When a tree is leaning in a plane perpendicular to the line of sight of the observer, the corrected height is equal to the quadratic sum of the observed height and the length of the projection of the leaning tree on the ground (Figure B.5)

B.5 Measuring tree basal area with angle count method

Point sampling requires only determining whether a tree seen through observer through a critical angle is in or out (that is, tallied or not tallied). The critical angle can be cast by using a web prism, a dendrometer or a relascope. If using a relascope, the accompanying user manual should be consulted for exact rules of use.

In the case of instruments such as wedge prism or a dendrometer (an angle device), Figures B6, B7 and B8 illustrate their proper use.

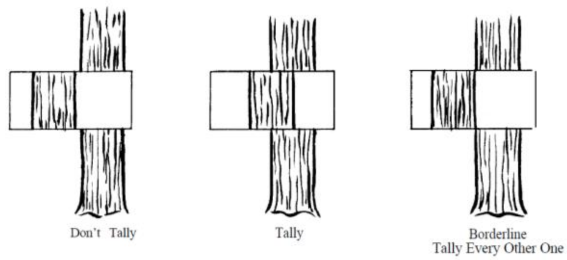

Figure B6 Observing a tree stem through wedge prism

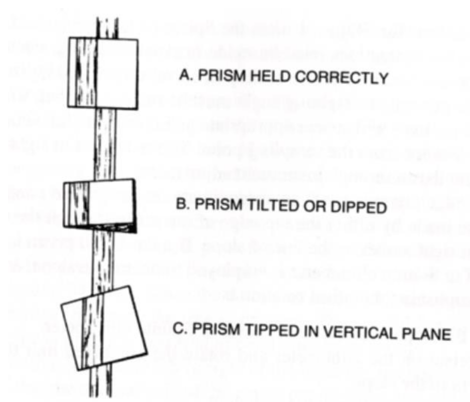

Figure 7 Correct and incorrect methods of holding wedge prism

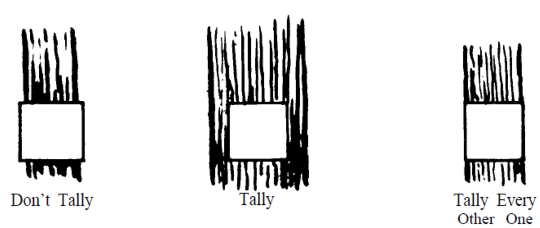

Figure B7 Observing a tree stem through a dendrometer (angle gauge)

Appendix C Glossary of terms

This appendix contains definition of CDM terms relating to afforestation and reforestation project activities. The user may like to refer to the Glossary of CDM terms for a full set of CDM terms and definitions.

Actual net GHG removals by sinks
The sum of the verifiable changes in carbon stocks in the carbon pools within a project boundary that are attributable to an A/R or SSC A/R CDM project activity or PoA (A/R), as applicable, minus any increase in anthropogenic GHG emissions by sources (measured in carbon dioxide equivalents) within the project boundary that is caused by the implementation of the A/R or SSC A/R CDM project activity or PoA (A/R), as applicable.

Afforestation
The direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or human-induced promotion of natural seed sources.

A/R CDM project activity
An afforestation or reforestation measure, operation or action that aims to achieve net anthropogenic GHG removals by sinks, whether as a whole project or as a part of a project.

Baseline net GHG removals by sinks
The sum of the changes in carbon stocks in the carbon pools within the project boundary that would have occurred in the absence of the A/R or SSC A/R CDM project activity or PoA (A/R).

Carbon pools
Above-ground biomass, below-ground biomass, litter, dead wood and soil organic carbon.

CER (certified emission reduction)
A unit issued for emission reductions from CDM project activities or PoAs (non-A/R) in accordance with the CDM rules and requirements, which is equal to one metric tonne of carbon dioxide equivalent, calculated using global warming potentials defined by decision 2/CP.3 or as subsequently revised in accordance with Article 5 of the Kyoto Protocol. See also the definition for “lCER” and “tCER”.

Convention

The United Nations Framework Convention on Climate Change (UNFCCC).

CPA (component project activity)
A single measure, or a set of interrelated measures under a PoA, to reduce GHG emissions by sources or result in net anthropogenic GHG removals by sinks, applied within a designated area defined in the baseline methodology(ies).

DNA (designated national authority)
The body granted responsibility by a Party, among other things and where applicable, to issue a letter of approval with respect to CDM project activities or PoAs on behalf of that Party, in accordance with the CDM rules and requirements.

DOE (designated operational entity)
An entity designated by the CMP, based on a recommendation by the Board, as qualified to validate proposed CDM project activities and PoAs, as well as verify and certify reductions in anthropogenic emissions by sources of GHG and net anthropogenic GHG removals by sinks.

Eligibility of land
The determination of which land meets the conditions required to be included in an A/R or SSC A/R CDM project activity or PoA (A/R), in accordance with the CDM rules and requirements.

Forest
"Forest" is a minimum area of land of 0.05–1.0 hectare with tree crown cover (or equivalent stocking level) of more than 10–30 per cent with trees with the potential to reach a minimum height of 2–5 metres at maturity in situ. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10–30 per cent or tree height of 2–5 metres are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest.

GHG (greenhouse gas)
A greenhouse gas listed in Annex A to the Kyoto Protocol, unless otherwise specified in a particular methodology.

Host Party

A Party involved not included in Annex I to the UNFCCC on whose territory a CDM project activity or PoA, as applicable, is physically located.

Issuance
The instruction by the Board to the CDM Registry Administrator to issue a specified quantity of CERs, lCERs, or tCERs for a project activity or PoA, as applicable, into the pending account of the Board in the CDM registry, for subsequent distribution to accounts of project participants in accordance with the CDM rules and requirements.

lCER (long-term certified emission reduction)
A unit issued pursuant to Article 12 of the Kyoto Protocol for net anthropogenic GHG removals by sinks from an A/R or SSC A/R CDM project activity or PoA (A/R), which expires at the end of the crediting period of the A/R or SSC A/R CDM project activity or PoA (A/R) for which it was issued. It is equal to one metric tonne of carbon dioxide equivalent. See also the definitions of "CER" and "tCER".

Leakage
The increase in GHG emissions by sources or decrease in carbon stock in carbon pools which occurs outside the boundary of an A/R or SSC A/R CDM project activity or PoA (A/R), as applicable, which is measurable and attributable to the A/R or SSC A/R CDM project activity or PoA (A/R), as applicable.

Monitoring
Collecting and archiving all relevant data necessary for estimating or measuring the net anthropogenic GHG removals by sinks.

Monitoring plan
The plan which sets out the methodology to be used by project participants or CMEs for the monitoring of, and by DOEs for verification of the amount of reductions of anthropogenic emissions by sources or removals by sinks of GHGs achieved by the CDM project activity or PoA, as applicable.

Monitoring report
A report prepared by a project participant which sets out the GHG emission reductions or net GHG removals of an implemented registered CDM project activity or PoA for a particular monitoring period.

Net anthropogenic GHG removals by sinks
In the context of A/R or SSC A/R CDM project activities or PoAs (A/R), the actual net GHG removals by sinks minus the baseline net GHG removals by sinks minus leakage.

PDD (project design document)
The document prepared by the project participant of a CDM project activity which sets out in detail, in accordance with the CDM rules and requirements, the CDM project activity which is to be undertaken. The form of PDD, and guidelines on preparing the PDD, are publicly available on the UNFCCC CDM website.

PoA (programme of activities)
A voluntary coordinated action by a private or public entity which coordinates and implements any policy/measure or stated goal (i.e. incentive schemes and voluntary programmes), which leads to anthropogenic GHG emission reductions or net anthropogenic GHG removals by sinks that are additional to any that would occur in the absence of the PoA, via an unlimited number of CPAs.

Project boundary
Boundary that geographically delineates the A/R or SSC A/R CDM project activity or CPA (A/R) under the control of the project participant as determined in accordance with the CDM rules and requirements.

Project participant
A Party involved that intends to participate, or a private and/or public entity authorized by the DNA of a Party involved to participate in a CDM project activity or PoA, as applicable.

Reforestation
The direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but has been converted to non-forested land.

Registration
The formal acceptance by the Board of a CDM project activity or PoA validated by a DOE as a CDM project activity or PoA, as applicable. Registration is the prerequisite for the verification, certification and issuance of CERs, lCERs or tCERs, as applicable, related to that CDM project activity or PoA.

Small-scale A/R CDM project activity
An afforestation or reforestation measure, operation or action:
(a) Where the average projected net anthropogenic GHG removals by sinks for each verification period do not exceed eight kilotonnes of carbon dioxide equivalent per year; and
(b) Which is developed or implemented by low income communities and individuals as determined by the host Party.

tCER (temporary certified emission reduction)
A unit issued pursuant to Article 12 of the Kyoto Protocol for an A/R CDM project activity or SSC A/R CDM project activity, which expires at the end of the commitment period following the one during which it was issued. It is equal to one metric tonne of carbon dioxide equivalent.

Validation
The process of independent evaluation of a CDM project activity or PoA by a DOE against the requirements of the CDM rules and requirements, on the basis of the PDD or PoA-DD and CPA-DDs.

Verification
The periodic independent evaluation and ex post determination by a DOE of the net anthropogenic GHG removals by sinks achieved by the A/R or SSC A/R CDM project activity or PoA.

Appendix D List of regulatory documents

This appendix contains the list of the regulatory documents applicable to A/R CDM project activities. Regulatory documents can be classified into hierarchical categories as listed below. The documents have been assigned numbers for facilitating citing of their reference in the body of the manual.

C.1 CMP decisions

The reader interested in the high level source documents on the CDM should consult the documents listed under this section.

C.1.1 The Kyoto Protocol

C.1.2 Decision 3/CMP.1 - Modalities and procedures for a clean development mechanism as defined in Article 12 of the Kyoto Protocol

C.1.3 Decision 5/CMP.1 - Modalities and procedures for afforestation and reforestation project activities under the clean development mechanism in the first commitment period of the Kyoto Protocol

C.1.4 Decision 6/CMP.1 - Simplified modalities and procedures for small-scale afforestation and reforestation project activities under the clean development mechanism in the first commitment period of the Kyoto Protocol and measures to facilitate their implementation

C.2 CDM Standards

The reader interested in development of A/R CDM project activities should consult documents listed under this section and the sections that follow.

C.2.1 Clean development mechanism project standard

C.2.2 Clean development mechanism validation & verification standard

C.2.3 Clean development mechanism project cycle procedure

C.3 A/R CDM methodologies

C.3.1 Afforestation and reforestation of degraded mangrove habitats

C.3.2 Afforestation and reforestation of lands except wetlands

C.4 Small-scale A/R CDM methodologies

C.4.1 Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on wetlands

C.4.2 Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands

C.5 A/R CDM methodological tools

C.5.1 Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM project activities

C.5.2 Demonstrating eligibility of land for A/R CDM project activities.

C.5.3 Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities

C.5.4 Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities

C.5.5 Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM project activities

C.5.6 Demonstrating appropriateness of allometric equations for estimation of aboveground tree biomass in A/R CDM project activities

C.5.7 Demonstrating appropriateness of volume equations for estimation of aboveground tree biomass in A/R CDM project activities

C.5.8 Estimation of non-CO2 GHG emissions resulting from burning of biomass attributable to an A/R CDM project activity

C.5.9 Estimation of the increase in GHG emissions attributable to displacement of pre-project agricultural activities in A/R CDM project activity

C.5.10 Calculation of the number of sample plots for measurements within A/R CDM project activities

C.6 A/R CDM methodological guidelines

C.6.1 Establishment of standardized baselines for afforestation and reforestation project activities under the CDM

C.6.2 Guidelines for completing the proposed new afforestation and reforestation baseline and monitoring methodology form

C.6.3 Guidelines for completing the project design document form for afforestation and reforestation CDM project activities

C.6.4 Guidelines on accounting of specified types of changes in A/R CDM project activities from the description in registered project design documents

C.7 A/R CDM forms

C.7.1 F-CDM-AR-PDD - Project Design Document form for Afforestation and Reforestation CDM project activities

C.7.2 F-CDM-SSC-AR-PDD - Project design document form for small-scale afforestation and reforestation CDM project activities

C.7.3 F-CDM-AR-PoA-DD - Programme design document form for afforestation and reforestation CDM programmes of activities

C.7.4 F-CDM-SSC-AR-PoA-DD - Programme design document form for small-scale afforestation and reforestation CDM programmes of activities

C.7.5 F-CDM-AR-CPA-DD - Component project activity design document form for afforestation and reforestation component project activities

C.7.6 F-CDM-SSC-AR-CPA-DD - Component project activity design document form for small-scale afforestation and reforestation component project activities

C.7.7 CDM-AR-NM-FORM - Proposed new afforestation and reforestation baseline and monitoring methodology form

Appendix E References

This appendix provides references which the interested reader can consult for more detailed information relating to forest inventory and other issues covered in this manual.