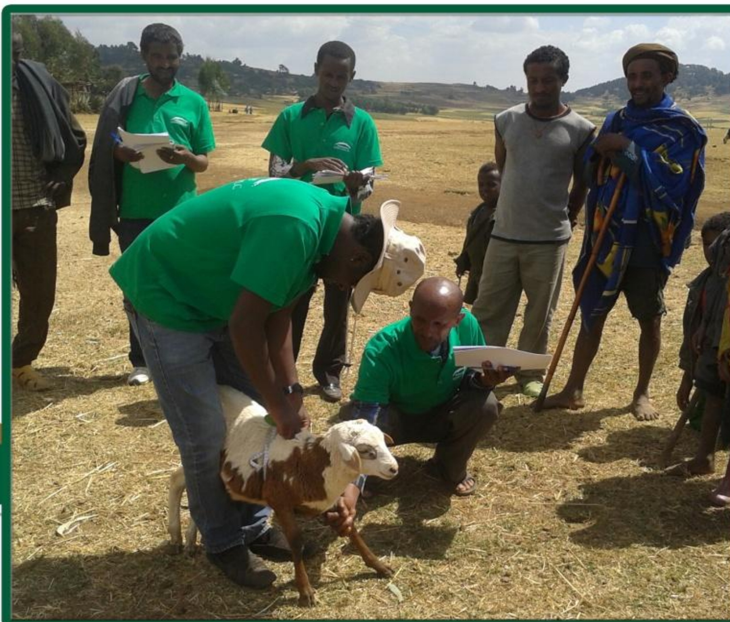

GHG Emission Assessment Guideline
Volume II: Aboveground Biomass
Field Guide for Baseline Survey

FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
MINISTRY OF AGRICULTURE

ADDIS ABABA
ETHIOPIA

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List of Acronyms

ABG	Above-Ground Biomass
AFOLU	Agriculture Forestry and Other Land Uses
BAU	Business As Unusual
BGB	Below-Ground Biomass
CDM	Clean Development Mechanism
CV	Coefficient of Variation
DBH	Diameter at Breast Height
DOM	Dead Organic Matter
FDRE	Federal Democratic Republic of Ethiopia
GBH	Girth at Breast Height
GHG	Green House Gas
GIS	Geographical Information System
IPCC	Intergovernmental Panel on Climate Change
ISDR	International Strategy for Disaster Reduction
LULUCF	Land Use, Land-Use Change and Forestry
MoWR	Ministry of Water Resources
NAPA	Climate change adaptation programme of action
OECD	Organization for Economic Co-operation and Development
UNFCCC	United Nations Framework Convention on Climate Change

CHAPTER ONE

1. Introduction

1.1. Background

Global awareness of environmental issues has increased on an unprecedented scale. Deforestation, land degradation, desertification, loss of biodiversity, global warming and climate change are some of the environmental issues linked directly to terrestrial ecosystems, both natural and human-managed. Forests, grasslands and croplands constitute over 63% of the global land area. Terrestrial ecosystems play a critical role in the global carbon cycle. Global rise in demand for food, fodder, fuel and round wood is increasing the pressure on land-use systems, and conservation and sustainable development of land-use systems are critical for meeting those demands sustainably and stabilizing CO_2 concentration in the atmosphere to mitigate global climate change (Ravindranath and Madelene, 2008).

The issue of global climate change problems has become a widespread and growing concern that has led to extensive international discussions and negotiations. Responses to this concern have focused on reducing emissions of greenhouse gases, especially carbon dioxide, and on measuring carbon absorbed by and stored in forests, soils, and oceans. One option for slowing the rise of greenhouse gas concentrations in the atmosphere, and thus possible climate change, is to increase the amount of carbon removed by and stored in forests (Ross, 2009).

Africa's particularly vulnerable to the effects of climate change because of multiple stresses and low adaptive capacities, arising from endemic poverty, weak institutions, and complex disasters and associated conflicts. Drought will continue to be a primary concern for many African populations. The frequency of weather- and climate-related disasters has increased since the 1970s, and the Sahel and Southern Africa have become drier during the twentieth century. Water supplies and agricultural production will become even more severely diminished. By 2020, in some African countries agricultural yields could be reduced by as much as 50%. By the 2080s, the area of arid and semiarid land in Africa will likely increase by 5-8% (ISDR, 2008).

Similarly, it is noted that Ethiopia is one of the countries more vulnerable to climate related hazards which include drought, floods, heavy rains, strong winds, frost, heat waves (high temperatures), etc. The impacts of hazards related to current weather variability and extremes has already prevailed in the country, and by 2050, the negative impacts of climate change, under an extreme scenario of higher temperatures and increased intensity and frequency of extreme events, could cost Ethiopia 10% or more of its GDP. The key hazards brought on by this potential extreme volatility are droughts, floods and soil erosion. The worst impacts are caused by droughts, with recent droughts negatively impacting GDP by between 1% and 4%.

In view of that the Government of Ethiopia is making efforts to address these adverse conditions and has designed coping mechanisms. In fact some of these efforts have brought about strategies that have induced changes in the attitude of the affected local communities. Some strategic measures include the development and implementation of national environmental initiatives, as well as policy/ program and project initiatives that directly and/or indirectly address climate change and adaptation mechanisms. These initiatives could be capitalized for mitigating the undesirable consequences of climate related hazards (MoW, 2007).

The priority initiatives that form the foundation of the green economy concept could help to curb the increase in the global emissions projected in the BAU scenario. While contributing to reaching economic and social development targets, we have the domestic potential to contribute to the global effort by abating around 250 Mt CO_2e in 2030 as compared to conventional development practices – this equals a decrease in GHG emissions of up to 64% compared to BAU in 2030.4 Given the projected population growth, emissions on a per capita basis would decrease from 1.8 t of CO2e to 1.1 – a decrease of around 35% – while multiplying GDP per capita from USD 380 to more than USD 1,800 (FDRE, 2011).

This initiative focuses on the sectors of responsibility covered by the Ministry of Agriculture (including crops, livestock and forestry). These sectors are the most vulnerable to the impacts of climate change, and play a major role in Ethiopia's economy, contributing 41% of GDP, 85% of employment and 75% of export commodity value. Hence, Ethiopia's Green economy strategy identified options for low-carbon growth in agricultural crop, livestock and forestry sectors. Of the four main pillars of the strategy, two are related to the sectors in the Climate resilient Strategy; (1) improving crop and livestock production practices for higher food security and farmer income while reducing emissions (agricultural and land use efficiency measures) and (2) protecting and re-establishing forests for their economic and ecosystem services, including as carbon stocks (increased GHG sequestration in forestry).

Land use sectors (agriculture, forest and grasslands) are critical to mitigating climate change by enhancing the stock of carbon in biomass and in soil or by reducing CO_2 emissions. Most land based developmental projects have the potential to deliver carbon benefits (carbon stock enhancement or CO_2 emission reduction) as a co-benefit of projects that have socio-economic development or improve management of natural resources as the main goal (Ravindrahnath and Indu ,undated).

According to IPCC (2006) the methods to estimate greenhouse gas emissions and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector can be divided into two broad categories: 1) methods that can be applied in a similar way for any of the types of land use (i.e., generic methods for forest land, cropland, grassland, wetland, settlement and other land); and 2) methods that only apply to a single land use or that are applied to aggregate data on a national-level, without specifying land use.

Estimating the carbon stock on an area can be achieved by taking a representative sample rather than measuring the carbon in all components over the whole area. A small, but carefully chosen sample can be used to represent the population. The sample reflects the characteristics of the population from which it is drawn. For carbon sampling, measurements should be accurate (close to reality for the entire population) and precise (short confidence intervals, implying low uncertainty) (Hairiah *et al.,* 2010).

Carbon estimation will necessitate appropriate guideline to undertake biomass inventory in various land uses. Carbon inventory is new techniques and it is difficult to get the practical guidance at variety of land uses nationally and even not widely available globally. Hence, the intention of this manual is basically focus to assist the beneficiaries to know the logical steps and process to conduct biomass inventory so as to estimate carbon stock in various land use system.

1.2 Objectives of the Guideline

The overall objective of this guideline is to provide basic background and key concepts of various elements in relation to biomass inventory. It enables users to understand and get familiarized on how biomass inventory is being undertaken at field level in varied lands uses. Carbon inventory is dynamic and continuous update is necessary to utilize it for future biomass inventory at wider scale.This guideline basically provides specific methods used for biomass baseline assessment which incorporates approaches, steps and techniques of biomass measurement, data requirement, materials and equipment needed in the course relevant data gathering.

1.3. Methodology

This guideline was prepared by a team of experts with wide experience in natural resource management. The methodology employed for this biomass carbon inventory is based on a review of existing literatures which are relevant to biomass inventory for the pilot of agricultural fast track project. Accordingly, various relevant documents such as hard copies, e-books and website electronic journals and reports were reviewed to grasp a broader understanding of the issues under scrutinised. The core approaches and steps of biomass inventory, development of appropriate model for carbon estimation, survey tools and measurement techniques were the focus in the review process.

CHAPTER TWO

2. Concepts and Definitions terms

2.1 The concept of Climate change

According to FAO (2008) Climate refers to the characteristic conditions of the earth's lower surface atmosphere at a specific location; weather refers to the day-to-day fluctuations in these conditions at the same location. The variables that are commonly used by meteorologists to measure daily weather phenomena are air temperature, precipitation (e.g., rain, sleet, snow and hail), atmospheric pressure and humidity, wind, and sunshine and cloud cover. When these weather phenomena are measured systematically at a specific location over several years, a record of observations is accumulated from which averages, ranges, maximums and minimums for each variable can be computed, along with the frequency and duration of more extreme events.

In line with this the official definition by the United Nations Framework Convention on Climate Change (UNFCCC) that climate change is the change that can be attributed "directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (ISDR,2008).

Ross (2009) noted that global climate change is a widespread and growing concern that has led to extensive international discussions and negotiations. Responses to this concern have focused on reducing emissions of greenhouse gases, especially carbon dioxide, and on measuring carbon absorbed by and stored in forests, soils, and oceans. One option for slowing the rise of greenhouse gas concentrations in the atmosphere, and thus possible climate change, is to increase the amount of carbon removed by and stored in forests.

According to OECD (2006) Climate is closely intertwined with development. For one thing, climate is a resource in itself, and it affects the productivity of other critical resources, such as crops and livestock, forests, fisheries and water resources. Natural fluctuations in climate such as those related to the El Niño phenomenon cause widespread disruptions in society's ability to harness resources and even to survive. But human development choices also have a demonstrable impact on local and global climate patterns. Over-construction contributes to the formation of urban "heat islands"; deforestation and changes in land use can influence regional temperature and rainfall patterns; and increases in greenhouse gas concentrations as a result of industrial activity are responsible for global climate change.

The NAPA document (2007) stated that Ethiopia is one of the developing countries, which are more vulnerable to climate variability and change. Low level of socio-economic development, inadequate infrastructure, lack of institutional capacity and a higher dependency on natural resources base make the country more vulnerable to climatic factors including climate variability and extreme climate events. Climate related hazards in Ethiopia include drought, floods, heavy rains, strong winds, frost, heat waves (high temperatures), lightning, etc.

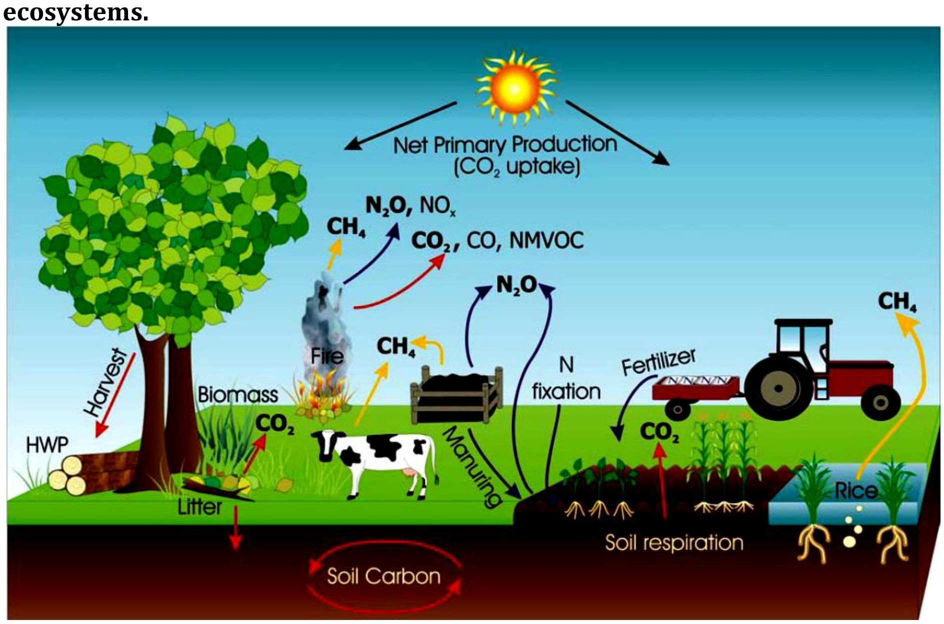
The major adverse impacts of climate variability in Ethiopia include:-.

- Food insecurity arising from occurrences of droughts and floods;
- Outbreak of diseases such as malaria, dengue fever, water borne diseases (such as cholera, dysentery) associated with floods and respiratory diseases associated with droughts;
- Land degradation due to heavy rainfall;
- Damage to communication, road and other infrastructure by floods;

2.2. Greenhouse Gases in AFOLU

IPPC (2006) has described the key greenhouse gases of concern in "AFOLU" (Agriculture, Forestry and Other Land Uses) are CO_2, N_2O and CH_4. CO_2 fluxes between the atmosphere and ecosystems are primarily controlled by uptake through plant photosynthesis and releases via respiration, decomposition and combustion of organic matter. N_2O is primarily emitted from ecosystems as a by-product of nitrification and denitrification, while CH_4 is emitted through methanogens is under anaerobic conditions in soils and manure storage, through enteric fermentation, and during incomplete combustion while burning organic matter. Other gases of interest (from combustion 1 and from soils) are NOx, NH3, NMVOC and CO, because they are precursors for the formation of greenhouse gases in the atmosphere. Formation of greenhouse gases from precursor gases is considered an indirect emission. Indirect emissions are also associated with leaching or run off of nitrogen compounds, particularly NO^{-}_{3} losses from soils, some of which can be subsequently converted to N_2O through denitrification.

Figure (2.1). The main greenhouse gas emission sources/removals and processes in managed ecosystems.



Source: (IPPC, 2006)

2.2.1. Emission and Removal Processes

Greenhouse gas fluxes in the AFOLU sector can be estimated in two ways: 1) as net changes in C stocks over time (used for most CO_2 fluxes) and 2) directly as gas flux rates to and from the atmosphere (used for estimating non-CO_2 emissions and some CO_2 emissions and removals). The use of C stock changes to estimate CO_2 emissions and removals, is based on the fact that changes in ecosystem C stocks are predominately (but not exclusively) through CO_2 exchange between the land surface and the atmosphere (i.e. other C transfer process such as leaching are assumed to be negligible). Hence, increases in total C stocks over time are equated with a net removal of CO_2 from the atmosphere and decreases in total C stocks (less transfers to other pools such as harvested wood products) are equated with net emission of CO_2. Non-CO_2 emissions are largely a product of microbiological processes (i.e., within soils, animal digestive tracts and manure) and combustion of organic materials. Below, emission and removal processes in the AFOLU sector are described for the major ecosystem stocks and processes, organized by ecosystem components, i.e., 1) biomass, 2) dead organic matter, 3) soils and livestock (Ibid)

2.3. Definition of some key terms

Watershed: According to Ravindrahnath and Indu (undated) A Watershed is the land that drains to a particular point along a stream. Each stream has its own watershed. Topography is the key element governing the total area of a watershed: The boundary of a watershed is defined by the highest elevations surrounding the stream. A watershed encompasses multiple and categories (such as cropland, grassland, forest, and catchment area) and water resources (irrigation tanks, streams, etc.). Watershed development is one of the major programs aimed at multiple economic and environmental objectives such as the development of agriculture, forest, and grassland, improvement of livelihoods, and reduction in vulnerability to climate change. Potential watershed project activities that contribute to enhancing carbon benefits include afforestation of catchment area, construction of farm ponds and check dams for water conservation and storage, soil conservation, grassland reclamation, desilting water bodies, and multiple cropping. Each of the land categories and watershed activities offers an opportunity to enhance carbon in biomass and soil. Further, soil and water conservation practices could enhance annual and perennial biomass production and litter turnover, contributing to increased biomass and soil carbon stocks.

Forest: According to (GOFC-GOLD, 2009) definitions of forest are myriad, however, common to most definitions are threshold parameters including minimum area, minimum height and minimum level of crown cover. In its forest resource assessment of 2005, the FAO uses a minimum cover of 10%, height of 5m and area of 0.5 ha stating also that forest use should be the predominant use. However, the FAO approach of single worldwide value excludes variability in ecological conditions and differing perception of forests. For the purpose of the Kyoto Protocol, the Marrakech Accords determined that parties should select a single value of crown area, tree height and area to define forests within their national boundaries. Selection must be from the following ranges, with the understanding that young stands that have not yet reached the necessary cover or height are included as forest:

- Minimum forest area 0.05 to 1ha
- Potential to reach a minimum height at maturity in situ of 2-5m
- Minimum tree crown cover (or equivalent stocking): 10 to 30%

Under this definition a forest can contain anything from 10 to 100% tree cover; it is only when cover falls below the minimum crown cover as designated by a given country that land is classified as non-forest.

Stratification By carbon Stocks: Stratification refers to the division of any heterogeneous landscape into distinct sub sections (or strata) based on some common grouping factor. In this case, the grouping factor is the stock of carbon in the vegetation. If multiple forest types are across a country, stratification is the first step in a well-designed sampling scheme for estimating carbon emission associated with deforestation and degradation over both large and small areas. Stratification is the critical step that will allow the association of a given area of deforestation and degradation with an appropriate vegetation carbon stock for calculation of emissions.

Afforestation is 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 the human-induced promotion of natural seed sources (Timothy *et al.,* 2005).

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

Agro-forestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agriculture crops and /or animals in some form of spatial arrangement or temporal sequence. Agro-forestry systems involve mixing or intercropping of rows of trees and annual crops, where there could be synergy between trees and crops and also diversification of biomass products and incomes.

Shelterbelts or windbreaks consisting of trees, shrubs, and grass strips of varying width are established in arid or desert areas to control soil erosion due to water and particularly due to wind. Trees rows are established at right angles to the prevailing wind direction.

Biomass: is defined as mass of live or dead organic matter. It includes the total mass of living organisms in a given area or volume; recently dead plant material is often included as dead biomass. The quantity of biomass is expressed as a dry weight or as the energy, carbon, or nitrogen content. Therefore, a global assessment of biomass and its dynamics are essential inputs to climate change forecasting models and mitigation and adaptation strategies.

Carbon sequestration: The removal of carbon from the atmosphere and long term storage in sinks, such as marine or terrestrial ecosystems.

Carbon stock: The mass of carbon contained in a carbon pool.

Biomass density: Changes in time of vegetation biomass per unit area and can be used as an essential climate variable, because they are a direct measure of sequestration or release of carbon between terrestrial ecosystems and the atmosphere. Therefore when using the term "biomass" we refer to the vegetation biomass density, that is mass per unit area of live or dead plant material.

Unit of measure is g/m2 or multiples.

Carbon: is the term used for the C stored in terrestrial ecosystems, as living or dead plant biomass (aboveground and belowground) and in the soil. C = (0.50)*biomass.This means about 50% of plant biomass consists of Carbon. To convert carbon in to CO_2, the tons of carbon are multiplied by the ratio of the molecular weight of carbon dioxide to the atomic weight of carbon (44/12).

Carbon sink: is a carbon pool from which more carbon flows in than out:

Carbon source: is a carbon pool from which more carbon flows out than flows in:

Net Emission Reduction: Indicates the expected amount of emissions reductions that will be generated by the project activities on a certain period of time. It's necessary to stress that, in many projects that are still in design phase, these numbers can be very preliminary and may change in the future.

Leakage: Some projects will be successful in sequestering more carbon within the project area, but the project activities may change activities or behaviors elsewhere. These changes may lead to reduced sequestration or increased emissions outside the project boundary, negating some of the benefits of the project. This is called leakage.

2.3.1 Carbon pool definitions and non-CO_2 gases

According to IPPC (2006) within each land-use category, C stock changes and emission/removal estimations can involve the five carbon pools that are defined in Table 1.1. For some land-use categories and estimation methods, C stock changes may be based on the three aggregate carbon pools (i.e., biomass, DOM and soils). National circumstances may require modifications of the pool definitions introduced here. Where modified definitions are used, it is good practiceto report and document them clearly, to ensure that modified definitions are used consistently over time, and to demonstrate that pools are neither omitted nor double counted. The non-CO_2 gases of primary concern for the AFOLU sector are methane (CH_4) and nitrous oxide (N_2O).Emissions of other nitrogenous gases including NOx and NH_3, which can serve as a source of subsequent N_2O emissions (and hence referred to as indirect emission sources), are also considered.

The definitions of each carbon pools have been further elaborated by Ravindranath and Madelene (2008). Hence, they are stated as:

Above-ground biomass (AGB) Above-ground biomass is expressed as tonnes of biomass or carbon per hectare. Above-ground biomass is the most important and visible carbon pool, and the dominant carbon pool in forests and plantations, although not in grasslands and croplands. Above-ground biomass is given the highest importance in carbon inventory and in most mitigation projects and is the most important pool for afforestation and reforestation CDM projects under the Kyoto Protocol as well as any inventory or mitigation project related to forest lands, agroforestry and shelterbelts in croplands. The above-ground biomass is often the only carbon pool measured or estimated in round wood production projects. The methods and models for measuring and projecting above-ground biomass are also the most developed compared to other carbon pools. In non-forest land-use systems such as cropland and grassland, biomass predominantly consists of non-woody perennial and annual vegetation, which makes up a much smaller part of the total carbon stock in the ecosystem than that in forest lands. The non-woody biomass is part of the annual carbon cycle and is subjected to turnover every year or every few years and hence net biomass carbon stock may remain more or less constant, although stocks may diminish over time because of land degradation.

Below-ground biomass (BGB) Below-ground or live root biomass is expressed as tonnes of biomass or carbon per hectare. Roots play an important role in the carbon cycle as they transfer considerable amounts of carbon to the ground, where it may be stored for a relatively long period of time. Although roots can extend to great depths, the greatest proportion of the total root mass is confined to the top 30 cm of the soil surface. Carbon loss and accumulation in the ground is intense in the top layer of the soil profile, which indicates that this should be the focus in sampling (Ponce-Hernandez *et al.* 2004, cited in Ravindranath and Madelene, 2008). In many land-use systems such as grasslands and croplands, however, this pool may not be important. Further, below-ground biomass in grassland and cropland under annual crops is part of the annual carbon cycle, and need not be measured. Below-ground biomass is the least researched or measured carbon pool because of the difficulty in measuring or modelling of the stock or growth rates: estimating it requires uprooting of trees and grass and disturbs top soil, which is destructive in normal circumstances, and most often, the quantity is estimated as a proportion of above-ground biomass.

Dead wood includes 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 the diameter specified by the country).

Litter The layer of organic debris, dead plant material fallen or removed and plant parts not attached to plants are considered litter. Build-up of litter is a natural process in which woody and non-woody parts of trees and shrubs dry up and fall to the ground (floor of the forest or of a plantation); the process is also part of the overall process of turnover of forest biomass. Litter is not a major carbon pool because it usually accounts for only 6–8% of plant biomass (Whittaker and Likens 1973; Bazilevich 1974 cited in Ravindranath and Madelene, 2008) and sometimes even less (Table 2.1).

Soil carbon Soil organic matter is defined as organic carbon in mineral soils to a specified depth. The generic term for all organic compounds in the soil is particles that are not living roots or animals. As dead organic matter is fragmented and decomposed, it is transformed into soil organic matter. It includes a wide variety of materials that differ greatly in their residence time in soil: some of them are easily decomposed by microbial organisms and return the carbon to the atmosphere but some of the soil organic carbon is converted into recalcitrant compounds (e.g. organic–mineral complexes) that decompose slowly and may remain in soil for decades or centuries or even longer. Fires often result in the production of small amounts of so-called black carbon, a nearly inert carbon fraction with turnover times that may span several thousand years (IPCC 2006). Within a given land-use system, such as cropland and grassland, management practices can have a significant impact on storage of soil carbon. Management practices and other forms of disturbances can alter the net balance between carbon input and carbon losses from the soil. Input to soil carbon stock can come from higher plant production. When native grassland or forest land is converted into cropland, 20–40% of original soil carbon stock can be lost (Mann 1985; Davidson and Ackerman 1993; Ogle et al. 2005cited in Ravindranath and Madelene, 2008). Although both organic and inorganic forms of carbon are found in soil, land use and management typically has a larger impact on organic carbon stocks, and this handbook accordingly focuses only on organic form of carbon.

Table 2.1 Distribution (%) of carbon among different pools in forests and other wooded lands (Figures in parentheses are percentages of the row totals)

	Carbon in				
Region/sub region	Living biomass	Deadwood	Litter	Soil	Total
East and South Africa	63.5	7.5	2.1	-	73.1
North Africa	26.0	3.3	2.1	33.5	64.9
West and Central Africa	155.0	9.8	2.1	56.0	222.9
Total Africa	95.8 (59.5)	7.6 (4.6)	2.1 (1.6)	55.3 (34.3)	160.8 (100.0)
E. Asia	37.0	5.0	–	–	41.9
South and South-east Asia	77.0	9.0	2.7	68.4	157.1
West and Central Asia	39.0	3.6	11.4	41.0	95.8
E. Asia	37.0	5.0	–	–	41.9
Total Asia	57.0	6.9	2.9	66.1	132
Total Europe	43.9 (24.8)	14.0 (7.9)	6.1 (3.4)	112.9 (63.9)	176.9 (100.0)
Caribbean	99.7	8.8	2.2	70.5	181.2
Central America	119.4	14.4	2.1	43.3	179.2
North America	57.8	8.8	15.4	35.8	117.8
Total North and Central America	60.1	9.0	14.8	36.6	120.6
Total Oceania	55.0	7.4	9.5	101.2	173.1
Total South America	110.0	9.2	4.2	71.1	194.6
World average	71.5	9.7	6.3	73.5	161.0

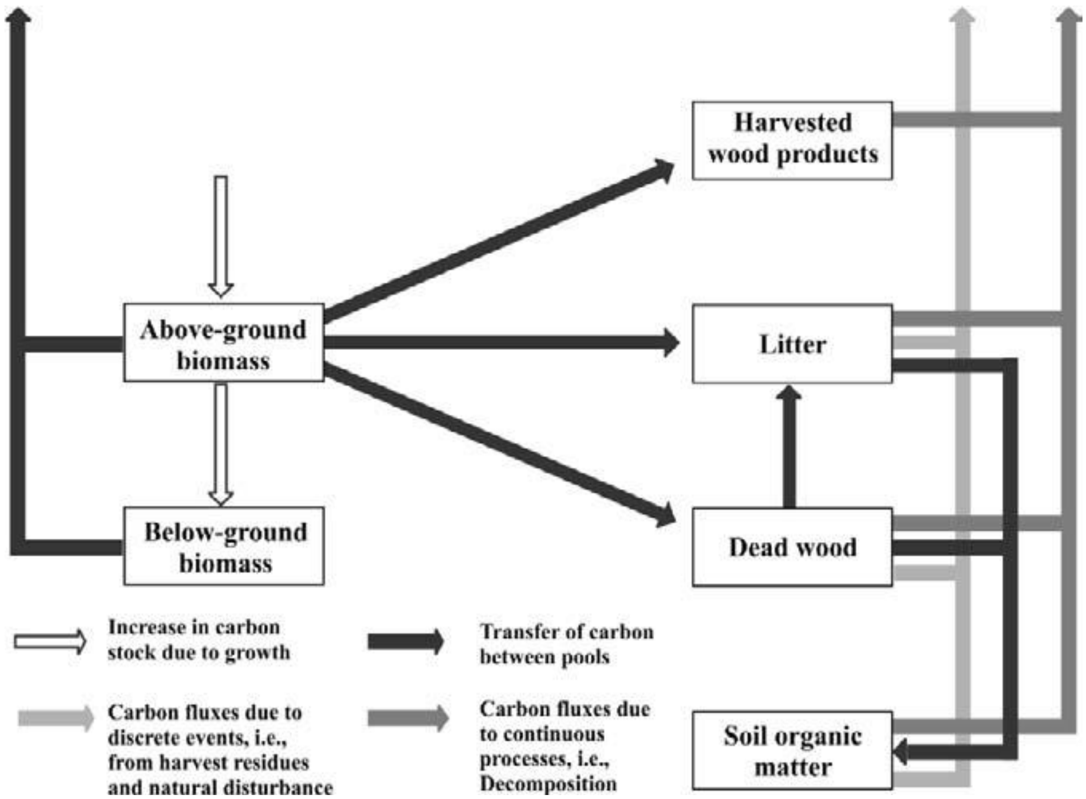
Source :(FAO, 2006, cited in Ravindranath and Madelene, 2008)

2.3.2 Flux of Carbon Pools

CO_2 fixed by plants during photosynthesis is transferred across pools such as litter, deadwood and soil carbon. Carbon cycle in a land-use system includes changes in carbon stocks due to both continuous processes (growth and decay) and discrete episodic events such as disturbances (fire, harvest, and land-use change and pest attack).

A generalized flow chart of flux of carbon pools is given in Fig.2.2 All fluxes can be accounted for by estimating the stocks of all the carbon pools at two points in time. The annual carbon stock change for a given land-use system or land-use change or management practice is estimated as the sum of changes in all the pools, expressed as tonnes of carbon per hectare per year (tC/ha/year).

Fig 2.2: Generalized flow of carbon between pools



Source: (IPCC 2006, cited in Ravindranath and Madelene, 2008).

2.4 Why Carbon Inventory

IPCC 2006 as cited in Ravindranath and Madelene (2008) stated that carbon inventory involves estimation of stocks and fluxes of carbon from different land-use systems in a given area over a given period and under a given management system. Further, carbon inventory is often referred to as the process of making such estimations. Carbon in land area consists of biomass and the soil carbon pools. The biomass pool includes living above-ground and below-ground biomass, litter and deadwood. The two broad methods for carbon inventory are carbon 'Gain–Loss' and 'Stock–Difference'.

Carbon inventory is expressed as tonnes of CO_2 emission or removal per hectare or at a project or national level over 1 year. It can also be expressed as changes in carbon stocks in tonnes of carbon per hectare or at a project or national level over a period of time. Net carbon emission indicates loss of CO_2 from biomass and soil to the atmosphere through decomposition or combustion. Net carbon removal or sequestration indicates net CO_2 uptake and storage in biomass and soil.

Carbon inventory methods and guidelines are required for estimation of emissions or removal of CO_2 from biomass and soil or changes in carbon stocks from a given land-use system at a project or national level, resulting from human interventions such as land-use change, extraction of biomass, burning of biomass, soil disturbance leading to oxidation of soil organic matter, afforestation, reforestation, forest conservation and other management activities. Carbon inventory is required for activities related to climate change in land-use sectors as well as other forest conservation and development projects such as round wood production and forest conservation not directly aimed at climate change mitigation.

2.4.1 Carbon Pools and Measurement Frequency for Carbon Inventory

As it was explained by Ravindranath and Madelene (2008) global carbon cycle involves exchange of CO_2 between the atmosphere and the biosphere, apart from oceans. Plants fix CO_2 from the atmosphere during photosynthesis to produce organic matter, which is stored in above- and below-ground parts. Bulk of the biomass in above- and below-ground plant parts is eventually transferred to the dead organic matter pool or it is oxidized or burnt. Dead organic matter, which consists of deadwood (standing as well as fallen) and litter, is either decomposed or oxidized, or stored for longer periods above or below the ground as detritus. CO_2 fixed by plants ends up in soil as organic matter or in finer forms as humus through the process of decomposition. Thus, CO_2 removed from the atmosphere is stored as dead and living biomass or soil carbon in the biosphere.

A carbon inventory, for carbon mitigation as well as forest conservation and land development programmes and for greenhouse gas inventory programmes and projects, requires estimation of stocks of carbon pools in biomass and in soil for a given period. There are five carbon pools, and measurement, monitoring and projection of changes in stocks of carbon in all the five carbon pools may be desirable. However, the cost of monitoring all the carbon pools is likely to be high. Further, stocks of some of the carbon pools may not change or change only marginally during the period selected for monitoring or projection. Therefore, the most cost-effective way of carbon inventory is to identify and monitor the key carbon pools that are likely to be impacted by the project activities or as a result of human intervention involving land-use change, conservation practices, planting trees or grasses, improved management practices, harvesting rates, cultural operations and so on (Ibid).

Table 2.2.Frequency of monitoring of carbon pools in carbon mitigation and other land-based projects

Project category	Project type	Monitoring frequency of carbon pools (years)				
		Aboveground biomass	Belowground biomass	Litter	Deadwood	Soil
Carbon mitigation	Avoided deforestation	Annual	_	3-5	3-5	Annual initially
	Afforestation and Reforestation	Annual	_	3-5	3-5	3-5
	Bioenergy plantations	Annual	5	3-5	_	3-5
	Forest management	2-3	_	3-5	3-5	5
	Grassland management	2-3	_	_	_	3
	Community forestry	Annual	_	3-5	_	5
Other land-based	Agro-forestry	Annual	_	_	_	5
	Shelterbelts	Annual	_	_	_	5
	Watershed	Annual	_	_	_	2-3
	Land reclamation	2-3	_	_	_	2-3
	Grassland development	2-3	_	_	_	2-3

Source :(Ravindranath and Madelene , 2008)

2.5 Carbon Inventory for Climate Change Mitigation Projects or Programmes

Land-use sectors have been recognized as critical to addressing climate change concerns. Mitigation of climate change through land-based activities has been a contentious issue in global negotiations under the UNFCCC and the Kyoto Protocol because of several methodological issues related to measurement, monitoring, reporting and verification of carbon benefits (Ravindranath and Sathaye 2002, cited in Ravindranath and Madelene2008). Carbon inventory for mitigation projects requires methods for estimating carbon stocks and changes due to project activities for selected periods at the project concept formulation, proposal development, project implementation and monitoring stages. Methods are required for the baseline (without project) and mitigation scenarios. Mitigating climate change through land-use sectors involves reducing CO_2 emissions or enhancing carbon sinks in biomass, soil and wood products. Reducing deforestation, sustainable forest management, afforestation, reforestation, agroforestry, urban forestry, shelter belts, grassland management and substitution of fossil fuels with bioenergy are examples of mitigation opportunities in land-use sectors.

CHAPTER THREE

3. Methodological Issues in Land-Based Carbon Inventory Projects

All land-based projects require carbon inventory for land use, land-use change and forestry (LULUCF) projects for climate change mitigation is contentious because of both methodological issues and uncertainty in the data required to estimate gains in carbon stocks. LULUCF projects include carbon mitigation activities in three categories, namely forestry, cropland and grassland. The complexity of methods for estimation and projection of carbon stock changes leads to several methodological issues, which are important to consider at different phases of a project cycle but in this guideline more focused on baseline which is relevant with our project (Ravindranath and Madelene, 2008).

The following methodological issues are:

- Baseline
- Additionally or instrumentality
- Permanence
- Leakage
- Project boundary
- Scale of projects

3.1 Baseline

All land-based carbon mitigation projects require estimation of net carbon stock gains resulting from the implementation of project activities. It is important to recognize that even in the absence of a proposed project, carbon stock will change because of natural factors or human intervention. This fact requires estimation of carbon stock changes that would have occurred in the absence of the proposed project, a situation or scenario referred to as the "baseline". A baseline needs to be developed for all projects against which project results can be compared and additional benefits estimated. According to the UNFCCC "the baseline for project activity is the scenario that reasonably represents anthropogenic emissions by sources and removal by sinks that would occur in the absence of the proposed the reference or business-as-usual scenario. Estimating and projecting baseline carbon stocks is a difficult task since all potential future scenarios in the absence of the project must be evaluated. Establishing the baseline scenario therefore requires knowledge of the history of the given area, local socio-economic situation, and
ongoing and wider economic trends (national, regional or even global) that may affect future land use and carbon stocks. Carbon stocks on the land when the project starts, often referred to as the base year, can serve as the baseline if it can be demonstrated that changes to business-as-usual activities. The baseline is established by projecting these past trends, current situation and future plans. Consequently, a baseline scenario is necessarily based on a range of assumptions.

3.1.1 Fundamental Steps in Establishing a Baseline

Baselines can be characterized by making a projection of business-as-usual changes in land use and carbon stocks in the area where the project is proposed. The approach is to elaborate a scenario of possible future changes in land use and associated changes in carbon stocks under the "without-project" scenario. Usually this is done by considering past trends and the current situation and, based on this, making a projection. Two approaches to get the past trends for a project are:

- ❖ Compilation of historical data and
- ❖ Participatory rural appraisal based on local community knowledge.

There are four fundamental steps in establishing a baseline as follows:

1. Define the project area, the boundary and stratify the area into homogenous strata.
2. Establish past trends in land-use systems.
3. Estimate carbon stocks in all the land-use strata for the base year and for at least one more point in time prior to the base year.
4. Project the future land-use scenario and carbon stocks.

For further information summary of implications of various methodological issues for carbon mitigation and other land-based conservation and development projects is given below in Table 3.1.

Table 3.1 Implications of different methodological issues for carbon mitigation and land-based conservation and development projects

Issue	Carbon Mitigation Projects	Land-based Projects
Baseline	- Very critical for estimating net carbon benefits - Approved methodologies to be used - Requires periodic monitoring of relevant carbon pools if carbon stocks are dynamic	- Not very critical for assessing round wood production or soil fertility - Estimates of carbon stocks at the beginning of the projects adequate
Additionally	- Estimation of additional carbon stock gains over the baseline carbon stock changes is necessary - Approved methodologies to be used - Periodic monitoring of carbon pools in project and baseline scenario necessary - Multiple carbon pools are relevant	- Carbon stock estimates at a given period such as at the end of rotation or project - Standard textbook methods adequate - Need to monitor only one or two carbon pools
Leakage	- Estimation of leakage of carbon benefits outside the area subjected to direct project activities necessary for estimating net carbon benefits - Approved methodologies to be used	- Leakage relevant to forest conservation projects, if protection in one area leads to forest conversion in another area
Permanen ce	-Estimation of reversal or loss of carbon benefits required - Carbon Stock-Difference method estimates any loss due to reversal of carbon	- Not an issue for most land-based projects

Project boundary	- Includes areas directly subjected to project activities as well as areas not directly subjected to project activities but where carbon stocks will be impacted	-Not an issue for most land-based projects, except forest conservation projects
Scale	-Has implications for carbon inventory methods and cost of monitoring	-Has implications for carbon inventory methods

Source: (Ravindranath and Madelene, 2008)

3.2 Generic Methods for Inventory of Carbon Pools

Ravindranath and Madelene (2008) noted that a carbon inventory involves estimation of changes in the stocks of the carbon pools over 1 year or between two points in time. Carbon inventory requires measurement and monitoring of all the selected carbon pools relevant to a land-based project or national greenhouse gas inventory for land-use categories. The features of different carbon pools showed the need for different methods for inventory of different pools. Because multiple methods are available even for a single carbon pool, an appropriate method should be selected.

The choice of an appropriate method depends on several factors:

- Land-use category or land-use system, including vegetation cover
- Size of the land-use category and project area
- Accuracy of the estimate needed
- Resources available and cost-effectiveness of the method
- Project cycle; project development phase or project monitoring phase
- Technical capacity, institutional and infrastructure available for inventory

Approaches to Estimating Carbon Stock Changes

Carbon stock change is the sum of changes in stocks of all the carbon pools in a given area over a period of time, which could be averaged to annual stock changes. A generic equation for estimating the changes in carbon stock for a given land-use category or project is given below: Annual carbon stock change for a land-use category is the sum of changes in all carbon pools:

$$\Delta C_{LUi} = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SC}$$

Where:
ΔC_{LUi} is carbon stock change for a land use category, AB above ground biomass, BB below − ground biomass, BW = dead wood, LI = litter and SC = soil carbon

The equation requires the stock change to be estimated for each of the pools. The changes in the carbon pool could be estimated using the two approaches based on IPCC guidelines (Ibid).

1. Carbon “Gain–Loss”
2. Carbon “Stock-Change” or “Stock-Difference

3.2.2 Carbon "Gain–Loss" Method

The carbon "Gain–Loss" methods involves estimation of gains in carbon stock of the pools due to growth and transfer of carbon from one pool to another pool, e.g. transfer of carbon from the live-biomass carbon pool to the dead organic matter pool due to harvest or disturbance. The method also involves deducting losses in carbon stocks due to harvest, decay, burning and transfer from one pool to another as described in the following equation. Annual carbon stock change in a given pool as a function of gains and losses ("Gain–Loss" method) is given by:

$$\Delta C = \Delta C_G - \Delta C_L$$

Where:

ΔC is the annual carbon stock change in the pool, ΔC_G is the annual gain of carbon, and ΔC_L is the annual loss of carbon

The "Gain–Loss" method requires estimation of gain in the stock of each relevant carbon pool during the year or over a period under consideration in a given area. Similarly, losses in the stock of each pool need to be separately estimated and aggregated for a given area over a given period. The difference between carbon gain and loss will give an estimate of net carbon emission or removals.

3.2.3 Carbon "Stock-Difference" Method

The "Stock-Difference" method includes all processes that bring about changes in a given pool. The carbon stocks are estimated for each pool at two points in time, namely t1 and t2. The duration between the two points could be 1 year or several years, say 5, 7 or 10 years. As discussed above the frequency of measurement of most of the carbon pools is once in several years 5 years, for example, for soil carbon. Thus , the estimated stocks at t2 need to be deducted from the estimated stock at t1 and the difference divided by the number of years between the two periods (t2 – t1). The "Stock-Difference" must be estimated separately for each carbon pool. Carbon stock change in a given pool as an annual average difference between estimates at two points in time (Stock-Difference method) is given by:

$$C = \frac{(C_{t2} - C_{t1})}{(t_2 - t_1)}$$

Where:

ΔC is is the annual carbon stock change in the pool, C_{t1} *is the carbon stock at time* t_1, *and*

the carbon stock in the same pool at time $t_{2.}$

Changes in carbon stock using this method are estimated for a given land-use category or project area as follows:

- Estimate the stock of a pool at time t1 and repeat the measurement to estimate the stock at time t2.
- Estimate the change in the stock of selected carbon pool by deducting the stock at time t1 from that at t2.
- To obtain the annual change in stock, divide the difference in stocks by the duration (t2 - t1) in years.
- If the estimates are made for sample plots, extrapolate to per hectare basis.

- ❖ To obtain the total for the project area, extrapolate the per hectare estimate to the total project or land-use category area.

The periodicity or frequency of measurement varies from pool to pool. Therefore, add the annual changes in each pool to obtain the total change in carbon stocks for the total project area over the selected period. It is important to ensure that the area under project activities between the two periods is identical; if it has changed, it is important to account for the change by calculating the changed area and multiplying it by the per hectare values.

3.2.4 Comparison of "Gain–Loss" and "Stock-Difference" Approaches

Of the two approaches, the "Stock-Difference" approach may be more suitable for estimating carbon stock differences for carbon mitigation as well as land conservation and development projects because of the following reasons:

- ❖ "Gain–Loss" approach requires estimation of rates of growth and losses of carbon pools, which can be obtained through "Stock-Difference" approach.
- ❖ It is difficult to estimate the losses due to extraction, fire, decay, burning and other causes in the project area.
- ❖ "Gain–Loss" approach requires apportioning the annual transfer of biomass into litter, deadwood and soil carbon pools, which requires significant additional effort.
- ❖ In the "Stock-Difference" approach, it is easier to account for changes in the stocks of all the relevant pools to obtain the per-hectare change although the frequency of measurement is different for different pools.

IPCC (2006) as stated by Ravindranath and Madelene (2008) concludes that the "Gain–Loss" method is the default method, to be used when limited measured data are available. Further, the "Stock-Difference" method is suggested for greater accuracy. Accordingly, this guideline focuses on the "Stock-Difference" method.

3.3 Methodological Options for Estimating Carbon Pools

The project developer or manger and greenhouse gas inventory compiler will have to decide on the method to be adopted for carbon inventory of different pools at different phases. This section provides a generic description of various methods and their applicability to inventory of different pools for land-based projects and national greenhouse gas inventory. A list of methods for different carbon pools and their applicability is given in Table 3.2.

Table 3.2 Methodological options for estimating carbon pools

Carbon Pool	Methods	Suitability for Carbon Inventory of Land-use Systems
Aboveground biomass	-Harvest method	- Not suitable, not often permitted, leads to disturbance of forest and even carbon emissions, expensive
	-Carbon flux measurements	- Not suitable, expensive, requires skilled staff
	-Satellite/remote sensing	- May not be suitable for multiple land-use systems and project activities - Not suitable for small projects - Practical methods still evolving
	-Modeling	-Suitable for projections - Requires basic input parameters to be obtained using other methods
	-Plot less method	-Suitable, but less suitable for periodic monitoring and dense vegetation
	-Plot method	- Most suitable, cost-effective, commonly adopted and familiar
Belowground biomass	-Root extraction and weight measurement	-Expensive and not suitable - Requires uprooting of trees or grass and disturbs the soil
	-Root to shoot ratio or conversion factor	-Most commonly adopted - Requires above-ground biomass estimate
	-Biomass equations	-Requires input data on tree parameters, girth, height
Litter and deadwood	-Litter trap	-Not always suitable in village or forest conditions, large effort needed
	-Stock measurement	-Feasible, commonly adopted

Source: ((Ravindranath and Madelene ,2008)

CHAPTER FOUR

4. Methods for Estimating Above-Ground Biomass

Above-ground biomass includes all biomass in living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds and foliage. Above-ground biomass is the most visible of all the carbon pools, and changes in it are an important indicator of change or of the impact of an intervention on benefits related to both carbon mitigation and other matters. Above-ground biomass is a key pool for most land-based projects. The different methods available for estimation and monitoring of above-ground biomass pool are described. Among all the methods described above the “plot method” is described in detail in this chapter. The rationale for selecting the “plot method” as the most suitable method includes the following factors:

- Applicability to baseline as well as project scenario measurements
- Applicability at project development and project monitoring phases
- Applicability to national greenhouse gas inventory estimation
- Suitability for all project types and projects of different tree sizes (mature and young) and density (dense and spare) of tree vegetation
- Simple and cost-effective
- Suitability for long-term monitoring

The “plot method” is extensively used in forest inventory programmes and by project managers and evaluators for estimating and monitoring carbon stock changes. Researchers in forestry, ecology and agriculture routinely adopt this method not only for estimating the changes in biomass stock, but also for monitoring biodiversity and production of commercial timber, fuel wood and grass. The “plot method” is further used for estimating biomass changes in cropland as well as grassland projects. The “plot method” is described in reports, manuals and books Special Report of Intergovernmental Panel on Climate Change on Land Use Land-Use Change and Forestry (Watson et al. 2000), Winrock Carbon Monitoring Guideline (MacDicken 1997), FAO (Brown 1997), Revised IPCC 1996 Guidelines (IPCC 1996), IPCC Good Practice Guidance (IPCC 2003), USEPA and LBNL (Vine and Sathaye 1999), CIFOR Methods (Hairiah et al. 2001), GHG Inventory Guidelines 2006 (IPCC 2006) and Forest Inventory (Kangas and Maltamo 2006, Cited in Ravindranath and Madelene, 2008)

This section presents a detailed description of methods, procedures, and steps for measurement, estimation and monitoring of above-ground biomass stocks and changes in those stocks.

Fig 4.1 Steps in measurement and estimation of above-ground biomass stock

Step 1. Select a land use category or project activity

Step 2. Define the project boundary and map of the Land use category or project area

Step 3. Stratify the project area or land use category

Step 4. Select the plot method

Step 5. Select carbon pools and frequency of measurement

Step 6. Identify the indicator parameter

Step 7. Select sampling method and sampling size

Step 8. Prepare for field work and data recording

Step 9. Decide on sampling design

Step 10. Locate and lay sample plots

Step 11. Measure the indicator parameter in the field and conduct laboratory analysis

Step 12. Record and compile data

Step 13. Analyze data and estimate uncertainty

The methods and steps are applicable to national greenhouse gas inventory for land-use categories such as forest land, cropland and grassland projects related to carbon mitigation.

4.1. Selection of Land-Use Category, Project Activity or Vegetation Type

Every project will have a set of activities aimed at achieving the project goals. A project may have a single activity such as planting eucalyptus species with a single set of management practices. Some projects may have multiple activities, where a part of the project area is under monoculture plantation and the rest could be natural regeneration of degraded forest land. These activities will have different above-ground biomass accumulation rates. Further, the density, rotation period and silvicultural practices application may vary. These different activities and management systems will have implications for carbon inventory and decisions on plot sizes, frequency of monitoring and parameters for measurement. The selection could be along the following lines:

- Land-use category (forest land, grassland and cropland), subcategory (based on soil or topography), vegetation type (evergreen and deciduous forests)

- ❖ Project activity (afforestation, avoided deforestation, integrated watershed management and grassland reclamation) and management system (density of plantation, rotation period, fertilizer application or irrigation)

4.2. Project Boundary definition and Mapping of the Land-Use Category

It is important to define the project boundary and prepare a map of the project area, demarcating the areas under different activities and management systems for carbon inventory. The project boundary may incorporate all the land-use categories, project activities and management systems. The project boundary and the extent of area under each of the land-use systems and activities should be spatially represented on a map. The following procedure could be adopted for defining the boundary and mapping.

(1) **Select the land-use category and project activities:** A project may include multiple land-use categories, project activities and management systems. All the land-use categories, project activities and management systems should be selected separately for carbon inventory, for example:

- ❖ Land-use categories such as forest land, grassland and cropland
- ❖ Multiple activities such as promotion of natural regeneration on degraded forest land, monoculture plantation on grasslands and agro-forestry in cropland
- ❖ Plantation activity may include short-rotation as well as long-rotation species
- ❖ Plantation activity may have high and low density plots and could be with or without fertilizer application

(2) **Estimation of area under the project or project activity:** Data on area under different activities are required for sampling as well as for estimating the above-ground biomass stock and changes. Project area estimation is required at the following phases of a project:

- ❖ Project development phase obtain the area under each land-use category and project activity proposed in the project document.
- ❖ Project monitoring phase obtain the actual area under each of the activities from the project authorities.

The area actually brought under the project activity may differ from the area proposed at the project development phase. If the project activity is implemented in phases, obtain the data annually.

(3) **Map preparation:** Data on the total project area and area under different activities, sub activities and management systems should be obtained and spatially marked on a geo-referenced map with a grid. Map preparation involves the following key steps:

- ❖ Historical land records collect any historical land-use records over the last 10–20 years to understand the trends in land-use change and to project the future land-use pattern under the baseline scenario.
- ❖ Maps collect all the maps available for the project location: soil, vegetation, land tenure and land use.
    - If maps from satellite imagery and aerial photography are available, it would be very useful to collect them.

- Using different maps, select the most important map showing the features relevant to the project, for example, land use or soils.

- ❖ Overlay different maps with various features on a geo-referenced map with many identifiable landmarks on the ground and mark the existing land-use systems such as cropland, grassland, water bodies or settlements.
- ❖ Boundary mark the boundary of different project activities and management systems on the geo-referenced grid map with relevant features such as soil quality and land use.
- ❖ GPS readings mark the GPS readings of the polygons (plots of different shapes) under different activities and of different parcels of land.
- ❖ GIS maps if GIS facility is available, which is becoming increasingly common, different maps with various land features as well as the project activities could be overlaid along with positions needed for boundary and areas. These spatially oriented maps on a GIS platform would help the project managers and monitoring teams to
    - Understand the land-use changes
    - Map the area brought under different activities over the years
    - Track the area brought under different management activities such as area harvested periodically or treated differently
    - Locate and sample the plots and revisit the "permanent plots" periodically
    - Mark areas for estimating leakage
    - Store existing data
    - Easily record changes throughout the project period
- ❖ Updating of maps it is necessary to periodically update the maps, depending on any new information on changes in land use, such as implementation of project activities or area subjected to harvest.
- ❖ Maps from remote sensing data on land-use changes, particularly the historical ones, can be obtained from interpreting satellite images over the area. Periodic updates of remote sensing maps will help in assessing
    - Changes in boundaries of different land-use systems
    - Changes in crown cover
    - Rate of implementation of project activities
    - Biomass stocks and changes

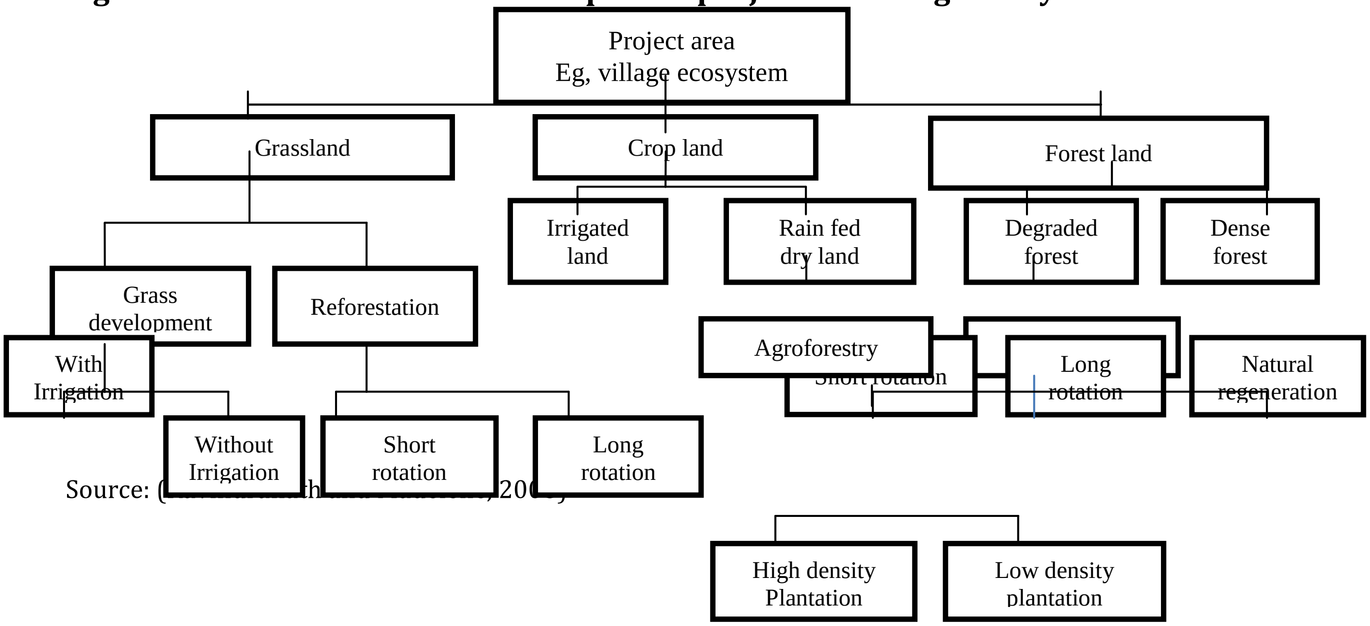
4.3. Stratification of the Project Area or Land-Use Category

Stratification is disaggregation of land area into homogeneous subunits. Land area of any project will consist of strata with varying physical and biological features, subjected to different management practices, and carbon stocks may vary because of these and other features. Stratification helps in obtaining a better representation of the land or project activities while sampling reflects the diversity of conditions that contribute to carbon stocks and minimizes costs. Stratification reduces sampling error and sampling effort by aggregating those spatial components that are homogeneous. Stratification of land area is required for the baseline as well as the project scenario (Fig. 4.2), which may be the same or different. Multistage stratification may be required, for example, to highlight broad land-use categories, features of the land, the main project activity and management systems within a project activity. The strata for sampling and monitoring refer to the last stage of disaggregated homogeneous land area or project activity such as:

- ❖ High-density short-rotation plantation on degraded forest land and
- ❖ Grassland development with irrigation.

In this guideline, a stratum refers to the last stage homogeneous unit of multistage strata for a given land-use category or project activity.

Fig 4.2 Stratification for a multicomponent project in a village ecosystem



Source: ([illegible], 200[illegible])

4.3.1 Stratification for Baseline Scenario

The baseline scenario requires estimates of carbon stock at the beginning of the project, before project activities are implemented. Further, carbon stock changes in the control plots need to be monitored to estimate the changes under the adjustable or moving baseline scenario, where carbon stocks are expected to change over the years. The land area considered for the project for the baseline scenario may consist of diverse land conditions in terms of

- ❖ Pre-project land-use category degraded forest land, grassland, cropland
- ❖ Soil quality soil erosion status and topography
- ❖ Extent of dependence or use of the land resource grazing, fuel-wood collection, proximity to the settlements
- ❖ Tenure/ownership state-owned, farmland, community land
- ❖ Current management system regulated grazing or open access system, irrigated, rainfed or fallow cropland

4.3.2 Stratification for Project Scenario

Carbon inventory during the project scenario requires estimation of stocks and changes in stocks annually or any other selected frequency of monitoring aboveground biomass. Carbon stocks may have to be estimated separately for the total area under each activity (e.g. short-rotation plantation or natural regeneration) and for the total project area consisting of multiple activities (e.g. area under short rotation and that under natural regeneration and so on). Therefore, each of the activities implemented needs to be sampled. Stratification in the project scenario may depend on the following factors:

- ❖ Preliminary status of the land status of land at the beginning of the project, that is the baseline scenario:
    - Pre-project land-use system, soil quality, extent of dependence on the land resource, tenurial status and current management system
- ❖ Project activity short- or long-rotation plantation, natural regeneration, agro-forestry and grassland management
- ❖ Species monoculture, multispecies plantation and natural regeneration
- ❖ Management system density of plantation, irrigation and fertilizer application

Stratification during the project scenario could be identical to that adopted for the baseline scenario or different from it to reflect the impacts of project activities implemented on the baseline strata.

(a) Disaggregation of baseline strata if a baseline stratum, for example, a land-use system, is subjected to multiple project activities in the project scenario, disaggregation of that stratum may be necessary. For example, if part of the grassland stratum of baseline is under short-rotation species and the rest under natural regeneration activity, disaggregation of the baseline stratum may be required to represent the two project activities that have different implications for carbon inventory.

(b) Aggregation of baseline strata if multiple baseline strata are covered with a single project activity and if the soil or other parameters characterizing the strata are identical, the multiple strata could be aggregated. For example, if grassland and degraded forest land strata of the baseline scenario with identical initial characteristics (e.g. vegetation, soil quality or slope) are planted with a monoculture short-rotation plantation with similar density and management system, the two strata could be aggregated.

4.3.3 Stratification under Land-Use Change

The project scenario may involve land-use change from the baseline or the land use may remain unchanged, with land remaining in the same category as that in the baseline, but with improved managed system, which will have implications for carbon inventory and methods to be adopted for carbon stock estimation.

- ❖ Land remaining in the same category the project scenario will involve no change in the land-use compared to the baseline; however, the project activity may improve land management or prevent the expected change in land use.

- Avoided deforestation where forest land of the baseline scenario would remain as forest land in the project scenario.
- Improved grassland management the land use and the land cover may remain the same in the project scenario as in the baseline, but with improved management system.

❖ Land converted to another category the project scenario will involve change in land use or land cover in the project scenario as a result of project activities.

- Afforestation grassland converted to short-rotation forest plantations in the project scenario.
- Agro-forestry cropland converted to agro-forestry.

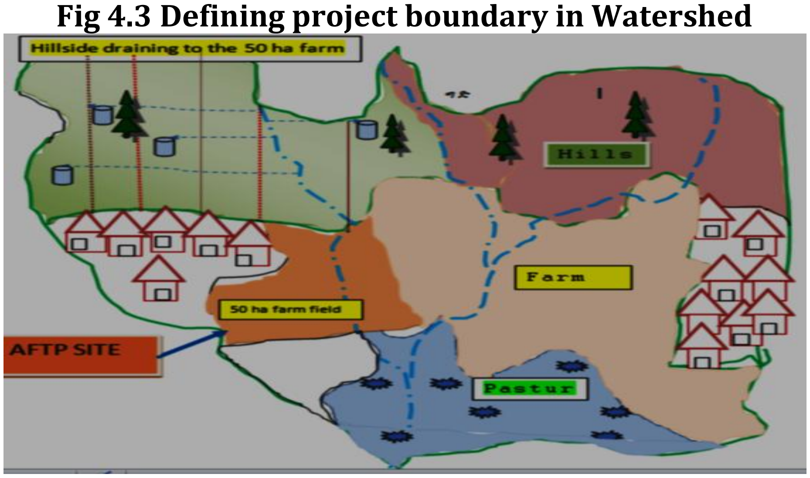
4.3.4 Approach to and Steps in Stratification

A stratification procedure for the baseline as well as the project scenario, which requires identical steps is presented in this section:

1. Define the project boundary
2. Obtain maps of the project area and overlay the different maps representing, for example, land-use systems, soil and topography under the baseline scenario.
3. Overlay the project activities on land-use systems in the baseline scenario, such as degraded forest land or grassland.
4. Identify the key differentiating features for stratification of land-use systems in the baseline scenario that are likely to impact carbon stocks:

- Current land-use such as open access grazing, controlled grazing, fuel-wood extraction and rainfed cropping.
- Soil quality good, moderate and low
- Topography levelled, sloping, hilly terrain

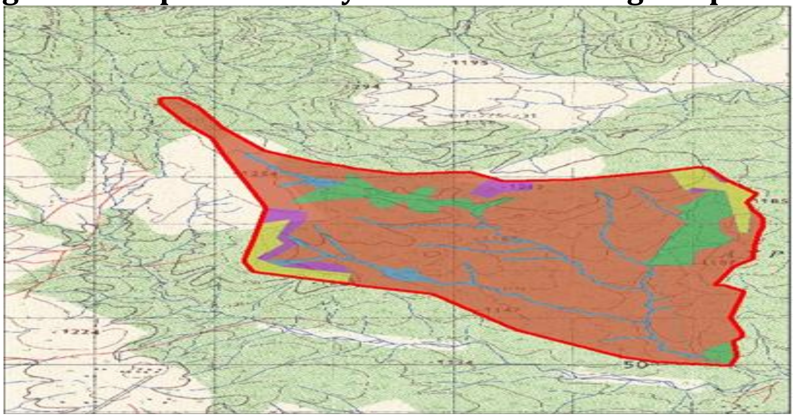
Fig 4.3 Defining project boundary in Watershed



5. Collect all the information available from secondary sources as well as from participatory rural appraisal.
6. Stratify the area under the baseline scenario:
    - Delineate areas under different project activities.
    - Overlaying the delineated areas with key features of land-use systems that are critical for estimating baseline carbon stocks.

- Mark the strata to be brought under different project activities spatially on the project map.

Fig 4.4 Example Boundary Delineation through Topo-map



7. Stratify the area under the project scenario:
    - Locate the project activities on the baseline scenario strata spatially.
    - Mark spatially the different strata representing different project activities, land-use systems and other features; however, each stratum is homogeneous within itself.

4.3.5 Application of Remote Sensing and GIS for Stratification

A variety of remote sensing data are available, which can be used for defining project area or land-use category. The data products can be in the form aerial photography or satellite imagery. This means that different data sets may cover different time series, a point significant for developing a baseline for above-ground carbon. More information on remote sensing and its use in carbon inventory. Several important criteria govern the selection of remote sensing data and data products for defining the project area or land-use category (IPCC 2006 cited in Ravindranath and Madelene, 2008)

- ❖ Adequate categorization of land use the data should help in distinguishing between different types of land use; for example, grassland and forest land are seldom a problem to monitor, but natural forest and degraded forest can be difficult, depending on the remote sensing product.
- ❖ Appropriate spatial resolution the data should be available at an appropriate resolution, since the spatial resolution determines how well the data can be classified into different levels of land-use classes. For most project-based assessments, a fine resolution (25 m or lower) is needed to categorize different land uses.
- ❖ Appropriate temporal resolution because land use may change with time, the data should offer adequate temporal resolution as well for estimating land-use conversions. To be able to assess the process of change, data need to be analysed across a given time span. Depending on geographical location and vegetation, it is also important to take seasonality of vegetation into account. Usually, peak vegetation periods are the ones most easily used.
- ❖ Ground-truthing to validate the data from remote sensing, they need to be compared against data obtained by other means. Interpretation of remote sensing data is cross-checked with empirical data on vegetation in the land-use systems to be assessed. For

above-ground biomass, actual biomass inventory data are very useful but management plans, land-use maps or data from participatory rural appraisal can also be used.

Geographical information system (GIS) can be used not only for interpreting actual remote sensing data but also for synthesizing the data collected over the project area. Further, it is a perfect system for storing and adding data over time. Several user-friendly programs are available to be used on regular PCs.

Fig 4.5 Example Boundary Delineation through Google-earth

4.4. Selection of a Method for Estimation of Above-Ground Biomass: the "Plot Method"

Several methods are presented for estimating above-ground biomass and the "plot method" is the one most commonly used. The method, versatile, cost-effective and applicable to baseline as well as project scenario, is described in detail here. The "plot method" is used in preparing a forest inventory and estimating biomass in grassland, crop productivity and timber and fuelwood production. "Plot method" is also among the methodologies approved by the Clean Development Mechanism for afforestation and reforestation projects. The method involves selecting plots of an appropriate size and number, laying them randomly in the selected strata, measuring the indicator parameters (e.g. tree DBH, height or grass production), using different approaches such as allometric functions to calculate the biomass and extrapolating the value to per hectare and for the total project area. These sample plots could also be used for assessment of biodiversity, land degradation and soil fertility improvements.

4.5. Selection of Appropriate Frequency of Measurement for the Above Ground Biomass Pool

The frequency of measurement and monitoring of above-ground biomass pool depends on the land-use system, soil quality, species and management systems. The frequency is different for the baseline and for the project scenario and also depends on the biomass stock and its rate of growth. Frequency of monitoring has implications for carbon inventory due to the effort and cost involved:

- ❖ Baseline scenario the frequency will depend on the rate of above-ground biomass growth, which is likely to be low for most baseline scenario situations. Thus, the above-ground biomass could be monitored once in 3–5 years. The frequency of monitoring for avoided deforestation projects, with high biomass stock under baseline scenario, could also be 3–5 years.
- ❖ Project scenario the frequency will be determined by the type of project activity and the rate of growth of above-ground biomass. Fast growing species, such as those grown intensively for bio-energy plantations, may require frequent monitoring. It is important to decide on the frequency of monitoring above-ground biomass stocks so that resources can be planned for and allocated accordingly.

4.6. Identification of the Parameters to be measured for Estimating the Above-Ground Biomass Pool

The goal of measurement and monitoring is to estimate the stocks of above-ground biomass or its rate of growth on per hectare basis as well as for the total project area. This requires identification and selection of a key set of indicator parameters. The parameters to be selected depend on the method adopted; those required for the “plot method” are presented here. The most commonly used parameters are as follows:

(1) Name of the species the first parameter to be recorded is the plant form, namely tree, shrub, herb or liana, followed by the name of the species. Among trees, species differ in shape, size, rate of growth and wood density. It is also important to estimate the density of trees (number per unit area) of each species in the sample plots and per hectare. Names of species are important even for non-tree plant forms such as shrubs, herbs and grass. Biomass for tree species is estimated as volume or weight per tree, which can be extrapolated to per hectare based on the density and distribution of each species. While recording the species name and number, it is desirable to record other features such as:

- Regeneration naturally regenerated or planted
- Status of tree crown percent damaged or full crown
- Status of the tree living, dead and standing, or dead and fallen

(2) Diameter or girth at breast height for trees size, usually measured in terms of diameter or girth at breast height (DBH or GBH), is one of the most important parameters and represents the volume or weight of a tree, which can be converted to biomass per unit area (tonnes/hectare or tonnes/hectare/year). The diameter and height can be used for estimating the volume by simple equations; DBH values can also be used in allometric functions to estimate volume or biomass per tree or per hectare. Usually, DBH is easy to measure in the field and, by appropriate marking; the measurements can be repeated over time. The breast height in DBH is normally taken to be 130 cm or 1.3 m above the ground.
(3) Height of trees next to DBH, height is the most important indicator of the volume or weight of a tree and used in many allometric functions along with DBH (see appendix 5). Measuring the height of tall trees, especially those with overlapping canopies, requires instruments and may introduce errors.
(4) Indicator parameters for non-tree species height and DBH are not measured for non-tree species such as herbs and grasses; biomass is estimated in terms of weight per unit area by actually harvesting and weighing all the herbs and grasses in the sample plots.

Table 4.1 The parameters to be monitored for estimating above-ground biomass

Carbon pool	Parameters to be Recorded
Above-ground biomass of trees and shrubs	-Name of the species -DBH (cm) -Height (m) -Origin: regenerated or planted -Extent of crown: full crown or percent crown damaged -Status: dead or living
Above-ground biomass of herb or ground-layer vegetation	-Name of the species -Density (number/plot) -Fresh weight of herb layer biomass (g/m2) -Dry weight of herb layer biomass (g/m2)

Source: (Ravindranath and Madelene ,2008)

4.7. Selection of Sampling Method and Sample Size

Sampling includes deciding on the number, size and shape of the plots, a step often ignored by project developers and managers because of the perceived complexity of the methods. Two approaches can be considered for measurement and estimation of carbon in land-use systems, namely complete enumeration and sampling. Complete enumeration, measurement and monitoring of all trees and non-tree plants in different land-use systems is time-consuming, very expensive and not even necessary to get a reliable estimate of biomass. A carbon inventory based on appropriate sampling can yield reliable estimates at a limited cost and human effort. Thus, the main goal of sampling is to get a reliable estimate with minimal cost. Sampling methods include simple random sampling, stratified random sampling and systematic sampling. This section presents the principles of sampling, the accuracy and precision needed the methods for choosing sample size and shape of the plots and practical steps to be followed. Sampling is crucial to measuring and monitoring carbon stock changes. Several books (Johnson et al. 2000; Shiver and

Borders 1996; De Vries 1986; Wenger 1984) and Guide books (MacDicken 1997; Pearson et al. 2005b; FAO 2005; http://cdm.unfccc.int) are available to assist sampling, including IPCC Good Practice Guidance (IPCC 2003, cited in Ravindranath and Madelene ,2008).

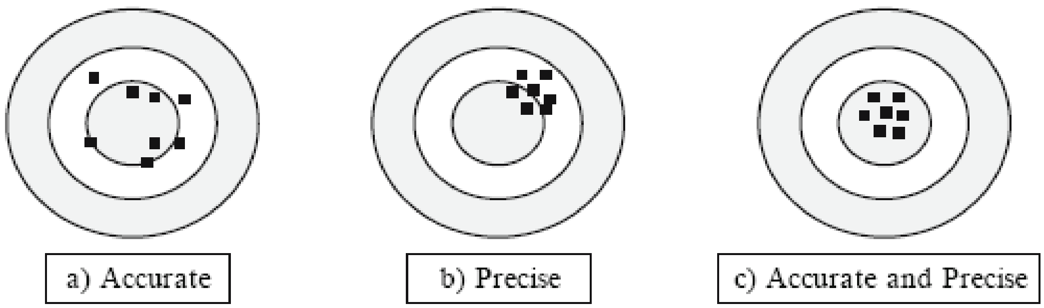
4.7.1 Sampling Principles

Sampling enables conclusions to be drawn about an entire population by observing only a portion of it. Sampling theory provides the means for scaling up information from the sample plots to the whole project area or even to a regional and national level (IPCC 2003, cited in Ravindranath and Madelene, 2008).

Thus, measurements of indicators of carbon stocks made on a small set of sample plots can be extrapolated to per hectare, for the strata and the whole project area or the land-use category. Field sampling is needed for all methods of carbon inventory plot method, harvest method and even remote sensing techniques that require ground based data from sample sites for interpretation and verification. Standard sampling theory relies on random selection of a sample from the population so that each unit of the population has an equal probability of being included in the sample.

Accuracy and precision: Sampling involves two common statistical concepts, namely accuracy and precision (IPCC 2003; Pearson et al. 2005b). Accuracy is a measure of how close the sample measurements are to actual values. Inaccurate or biased measurements will move the average away from the actual value. Precision is a measure of how well a value is defined. In the case of carbon inventory, precision shows how closely the results from different sampling points or plots are grouped.

Fig 4.6 Accuracy and precision



(a) Points are close to the center and therefore accurate but widely spaced and thus not precise.
(b) Points are closely grouped and therefore precise, but far from the centre and thus not accurate.
(c) Points are close to the center as well as tightly grouped, and thus both accurate and precise.

Accuracy and precision reflect how well the measurements estimate the true value of tree variables such as diameter, height and area covered by a stand of trees. An unbiased estimate will depend on repeated measurements being similar (precise) and averaging close to the true value (accuracy). A carbon inventory requires measurements that are both accurate, or close to the population values, and precise or closely grouped. Sampling involves selecting plots that are appropriate in size, number and location, which contributes to accuracy and precision. The level of precision required for carbon inventory has direct implications for inventory costs. The level of precision should be determined at the beginning of a project, and could vary from ± 5% to ± 20% of the mean. The lower the precision, the lower the confidence that the change in carbon stocks over time is real and due to project activity. The chosen level of precision will determine sample sizes for each project activity (Pearson et al. 2005b cited in Ravindranath and Madelene, 2008). Confidence interval the representativeness of the estimate, or precision, is indicated by the confidence interval. Normally a 95% confidence interval is used, which implies that 95 times out of 100, the estimated value lies within the limits of twice the standard deviation.

4.7.2 Sampling Design

Sampling design aims at locating the sample plots in each of the selected stratum. The soil, topography, water availability and status of vegetation vary spatially within a land-use category, area proposed for the project activities or even in the area brought under a given project activity. Trees, biomass stock and growth rate are not distributed uniformly in a given project area or even for a given project activity, and the location of sampling plots could determine the biomass stock or growth rate estimates. The project staff may be biased in locating sample plots in spots with good tree or grass growth to obtain higher biomass stock values. Sampling techniques ensure unbiased selection of sites for laying out sample plots in the field. The main purpose of adopting a sampling design is to avoid bias in locating the sampling plots in land-use systems in both baseline scenario and project scenario. Different sampling designs for laying out sample plots for vegetation studies are as follows.

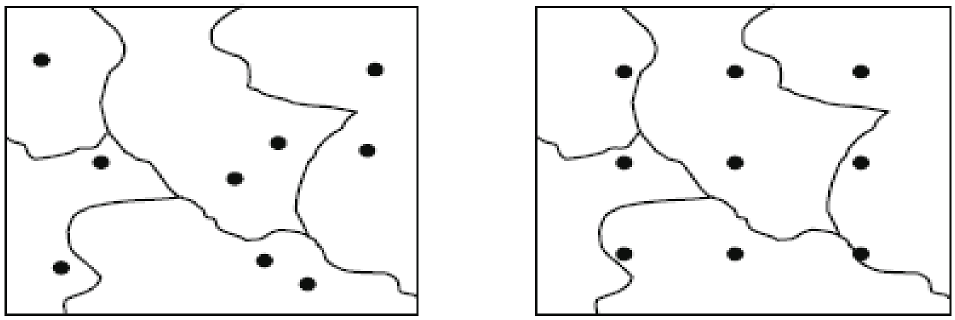
Selective sampling: Selective, subjective or purposive sampling design is used for vegetation studies to assess the biomass carbon stock at some selected locations or as part of some projects. Although the time and effort required for locating and laying out sample plots selectively are minimal (Kangas and Maltamo 2006, cited in Ravindranath and Madelene ,2008).The biomass estimate may not be reliable, reflecting a ground value that is not representative of the site. The error is likely to be high. Purposive sampling could be adopted, for example, to estimate the above-ground biomass of a project activity by laying plots close to and away from a village settlement to assess the impact of grazing or fuel wood extraction.

Simple random sampling: To apply the simple random sampling technique, convert the project area into a large number of equal-sized grids. In this method, the sample plots are laid out randomly to avoid bias in locating the plots. Random sampling ensures that each point or grid in the inventory area has an equal chance of being included in the sample. Further, the position of one plot has no influence on the position of other plots. Randomization makes it possible to obtain unbiased estimates of variability as well as the mean per unit area. However, randomized sampling layouts are not very convenient for field staff in locating the plots during periodical monitoring (Myers and Shelton 1980, cited in Ravindranath and Madelene, 2008). Simple random sampling method is not often adopted out of consideration to the heterogeneity of the population or the project area because it is based on the premise that the population is homogenous, however, the method could be adopted when no prior information is available about the project area. All the area under project activity is therefore considered as one unit and the heterogeneity of soil, topography or other features is not considered.

Systematic sampling: In systematic random sampling, the sample plots are placed at fixed intervals throughout the project area for a given activity. As the term implies, sample plots are not randomly distributed over the inventory area but arranged in a systematic pattern (Fig 4.7). An important feature of systematic sampling and layout is that the position of the first plot, which is chosen at random, determines the positions of all the subsequent plots. According to (Myers and Shelton 1980, cited in Ravindranath and Madelene, 2008) states that, the main advantage is that this approach is simple and can be adopted even in the absence of the maps. The regular spacing and systematic layout does tend to give convenient patterns for travel and fieldwork. The disadvantages include:

- ❖ The regular spacing of sample units might coincide with some cyclic fluctuation in the vegetation being sampled;
- ❖ Dependence on the location of the first sampling unit; and
- ❖ The difficulty in estimating the variability of the population from systematic samples.

Fig 4.7 Layout for simple random sampling (left) and for systematic sampling (right)

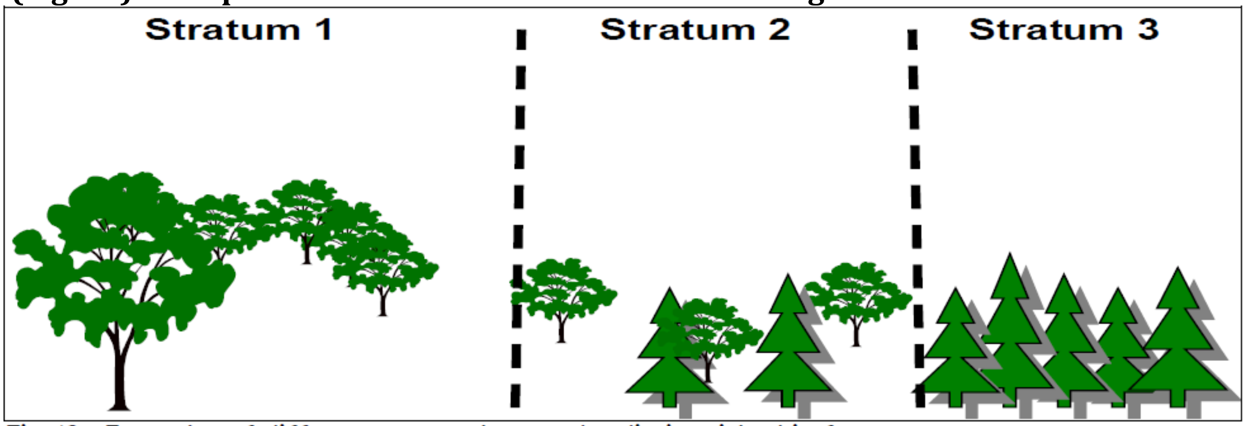


a. Random sampling b. Systematic sampling

Stratified random sampling: Stratification leads to efficient sampling and reduction of standard error. Each stratum can be considered as a subpopulation. In this technique, the project or activity area is stratified based on key features such as soil quality, topography, level of degradation and vegetation status and particularly the density and size of the trees. Area under each stratum is subdivided into a large number of equal-sized grids and the grids are numbered. The sample plots are chosen randomly among the grid numbers of each stratum, using the approach adopted for simple random sampling. The steps involved in stratified random sampling are as follows:

- ❖ Stratified random sampling becomes more effective with increasing homogeneity within each stratum.
- ❖ The approach is to implement the sampling procedure separately in each of the strata and then pool the information for a given project activity or land-use category.
- ❖ Stratified sampling avoids the possibility of large differences between strata contributing to the sampling error. The stratification of the sample leaves only the relatively small variation within each stratum to be reflected in the sampling error.

(Fig 4.8) Examples of different strata that can be distinguished in forests



Source:(Kyoto,2009)

The exercise of stratification should ideally be done jointly between the technical staff and the local community people. As most community forests are characteristically small in size, both boundary tracking and forest stratification is to be done by means of a hand held computer equipped with GPS and ArcPad GIS software.

The nature of stratification should first be explained to the community team, who though they may easily think of areas of forest that have very different species present, may not be so quick to see that a degraded patch of forest should be a separate stratum. Discussion on what constitutes 'different strata' (in terms of quantity of standing woody biomass, i.e. carbon) should be followed by walking first around the forest boundaries and then if necessary inside the forest area (supporting organization together with the community team) to identify strata (typical tree species and typical condition of trees (stunted, harvested etc.).

4.7.3 Number of Plots or Sample Size

It is important that sampling is carried out with statistical rigour, as it is likely this will be a requirement of the Designated Operating Entity. In employing this rigour, the first step is identifying the number of plots required to reach the desired precision in the results (Timothy et al., 2005). An online tool for calculating number of plots is available at: http://www.winrock.org/Ecosystems/tools.asp.

To use the tool, input the desired precision and the number, area, mean carbon density and co-efficient of variation for each strata.With this information, the tool calculates the required number of plots.

To calculate number of plots without the tool, use the following steps:

Step 1.Identify the desired precision level.

The level of precision required for a carbon inventory has a direct effect on inventory costs as described above. Accurate estimates of the net change in carbon stocks can be achieved at a reasonable cost to within 10 per cent of the true value of the mean at the 95 per cent confidence level. The level of precision should be determined at the outset – ±10 per cent of the mean is frequently employed, although a precision as low as ±20 per cent of the mean could be used. There are no hard and fast rules for setting the precision level, but the lower the precision, the more difficult it will be to say with confidence that a change in carbon stocks has occurred between two time periods.

Once the level of precision has been decided upon, sample sizes can be determined for each stratum in the project area. Each carbon pool will have a different variance (that is, amount of variation around the mean). However, experience has shown that focusing on the variance of the dominant carbon pool (for example, trees for forestry activities) captures most of the variance. Even though variation in the other components may be higher, if a high precision is attained in the dominant component, a lack of precisionin the other components will not harm the overall results.
Step 2. Identify an area to collect preliminary data. For example, if the activity is to afforest agricultural lands and will last for 20 years, then an estimation of the carbon stocks in the trees of about six to 10 plots within an existing 15 to 20-year-old forest would suffice.
Preliminary data are necessary in order to evaluate variance and, from this, the required number of plots for the desired level of precision. Between six to 10 plots is usually sufficient to evaluate
variance. If the project consists of multiple strata, preliminary data is required for each stratum.

For L strata, the number of plots (n) needed =

$$n = \frac{\left(\sum_{h=1}^{L} N_h * s_h\right)^2}{\frac{N^2 * E^2}{t^2} + \left(\sum_{h=1}^{L} N_h * s_h{}^2\right)}$$

Where:
E = allowable error or the desired half-width of the confidence interval. Calculated by multiplying the mean carbon stock by the desired precision (that is, mean carbon stock x 0.1, for 10 percent precision, or 0.2 for 20 per cent precision),
t = the sample statistic from the t-distribution for the 95 per cent confidence level. t is usually set at 2 as sample size is unknown at this stage,
Nh = number of sampling units for stratum h (= area of stratum in hectares or area of the plot in hectares),
n = number of sampling units in the population (n= $\sum N_h$)
sh = standard deviation of stratum h.

This equation can be simplified.
For a single-stratum project:

$$n = \frac{(N \times s)^2}{\frac{N^2 \times E^2}{t^2} + N \times s^2}$$

For two strata:

$$n = \frac{\langle (N_1 \times s_1) + (N_2 \times s_2) \rangle^2}{\frac{N^2 \times E^2}{t^2} + N_1 \times s_1 + N_2 \times s_2{}^2}$$

The following two examples demonstrate the use of the formula and also illustrate the advantage of stratification. In this example, a 5,000-hectare project area requires 29 plots without stratification to be monitored to high precision, but only 18 plots with stratification.

Table 4.2 Example of Size of plots per various strata

For three strata:

	Stratum 1	Stratum 2	Stratum 3	Total
Area (ha)	3,400	900	700	5,000
Plot size	0.08	0.08	0.08	0.08
Mean carbon density (t C/ha)	126.6	76.0	102.2	101.6
Standard deviation	26.2	14.0	8.2	27.1
N	3,400/0.08 = 42,500	900/0.08 = 11,250	700/0.08 = 8,750	5,000/0.08 = 62,500
Desired precision (%)				10
E				101.6 x 0.1 = 10.16

$$n = \frac{\langle (42{,}500 \times 26.2) + (11{,}250 \times 14) + (8{,}750 \times 8.2) \rangle^2}{\frac{62{,}500^2 \times 10.16^2}{2^2} + (42{,}500 \times 26.2^2) + (11{,}250 \times 14.0^2) + (8{,}750 \times 8.2^2)}$$

= 18 plots

Source: (Timothy *et al,* 2005)

The more variable the carbon stocks, the more plots are needed to attain targeted precision levels. However, if a stratified project arearequires more measurement plots than an unstratified area, remove one or more of the strata. The purpose of the stratification is to allow more efficient sampling.

If a project site is stratified, the following formula can be used to allocate the calculated number of plots among the various strata:

Number of plots for each stratum:

$$n_h = n \times \frac{N_h \times s_h}{\sum_{h=1}^{L} N_h \times s_h}$$

Where:

n = the total number of plots, nh = the number of plots in stratum h,
N = the number of sampling units in the population,
Nh = the number of sampling units in stratum h,
s = the standard deviation,
sh = the standard deviation in stratum h.
For example, using the data from the calculations above:
Stratum 1

$$n_h = \left[\frac{(42{,}500 \text{ x } 26.2)}{(42{,}500 \text{ x } 26.2) + (11{,}250 \text{ x } 14) + (8{,}750 \text{ x } 8.2)}\right] \text{x } 18$$

= 15 plots

Stratum 2

$$n_h = \left[\frac{(11{,}250 \text{ x } 14)}{(42{,}500 \text{ x } 26.2) + (11{,}250 \text{ x } 14) + (8{,}750 \text{ x } 8.2)}\right] \text{x } 18$$

= 2 plots

Stratum 3

$$n_h = \left[\frac{(8{,}750 \text{ x } 8.2)}{(42{,}500 \text{ x } 26.2) + (11{,}250 \text{ x } 14) + (8{,}750 \text{ x } 8.2)}\right] \text{x } 18$$

= 1 plot

The formulas above can equally be used with non-tree carbon pools or soil. Such plots will be temporary and new random locations should be chosen at each measurement period.However, since tree biomass will dominate total biomass (and therefore will also dominate the summed variance for the project), it is practical to estimate the number of plots needed for the other carbon pools based loosely on the number of plots for the dominant biomass component(Ibid).

The other option to determine plot size is through estimating the average, standard deviation and variance of carbon stock preliminary data. The time-averaged C stock is calculated for each land use system or land use legend from the preliminary data (or obtained from the literature if studies in similar areas are available).

Output: Average, standard deviation and variance of carbon per land use system/legend.

$$\bar{X} = \frac{X_1 + X_2 + \ldots + X_n}{n} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad S^2 = \frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1} \qquad S = \sqrt{S^2}$$

Average Variance Standart Deviation

Calculating the required number of sampling plots Once the variance for each land use system/legend, the desired level of precision and estimated error (referenced in the confidence level selected) are known, the number of sampling plots required can be calculated. The generic formulas for calculating the number of plots for different land systems are**:**

1) For one land use system**:**

$$n = \frac{(N * s)^2}{\frac{N^2 * E^2}{t^2} + N * s^2}$$

2) For more than one land use system:

$$n = \frac{\left(\sum_{h=1}^{L} N_h * s_h\right)^2}{\frac{N^2 * E^2}{t^2} + \left(\sum_{h=1}^{L} N_h * s_h^2\right)}$$

Where:

n = number of plots

E = allowed error (average precision × level selected). As seen in the previous step, the recommended level of accuracy is ±10% (0.1) of the average but can be up to ±20% (0.2).

t = statistical sample of the t distribution for a 95% level of confidence (usually a value of 2 is used) N = number of plots in the area of the layer (stratum area divided by the plot size in ha)

s = standard deviation of the land use system

Taking vegetation stratification indicated in Fig (4.8) by (Kyoto, 2008) Measure the height of three trees (i.e small, médium and largest).

The calculation of sample size required is based on the variability of trees and saplings as measured in the pilot survey. In the pilot survey the herb and grass layers are not sampled. The number of sampling units (n) is calculated using the formula:

$$n = \frac{cv^2 t^2}{E^2}$$

Where: CV = is the coefficient of variation which is the measure of variability of tree cross-sectional area at breast height

t = is the expression of confidence that the true average is within the estimated range. For 15 plots this always has a value of: 2.32.

E = is the error that you are willing to accept in the final estimation of the mean.

Example: Given CV of basal area = 40%, t value for the 15 plots = 1.761 and E = 10%

Then n= (0.42 x 1.7612)/0.12 = 50 plots

4.7.4 Sample size and tree measurement on Agro-forestry

- For activities involving row planting of trees in crop lands, whole farms could be selected. If the farms are very large, a 1-ha plot could be sampled. (100m x 100m)
- Sample size: As a rule of thumb, a minimum of 30 farms could be selected. However, if the farm is larger than about 2 ha, select a 0.5 to 1 ha plot as a subplot for each farm.

4.7.5 Preparations for the Agro forestry Tree Measurement

Step 1: Obtain a map of the project area where the agro-forestry activity is planned

Step 2: Mark the boundaries of farms where agro-forestry is proposed and number each farm

Step 3: Obtain the area of each farm subjected to agro-forestry activity. Determine the hectare of each tree on farm, wood plots, home gardens and strip plantings and other agroforestry.

Step 4: Tabulate the farms according to size (0 to 5 ha, 5 to 10 ha, etc.)

Step 5: Further stratify the farms if necessary and if clear variations can be observed with respect to soil type, availability of irrigation, etc.

- Determine the sample size using the equation given for the tree plots. If the use of equations is not feasible, use the following guideline of sampling at least 30 farms for each project activity stratum.

Step 6: Select five whole farms in each class of farm size (depending on the total number of farms) and if necessary from substrata of the farms to represent different conditions as mentioned in Step 5

- If the number of farms is less than 100, select 5 sample farms
- If the number is from 100 to 200, select 10 sample farms
- If the number is greater than 200, select 20 sample farms
- The total should be more than 30 farms

Step 7: Measure the DBH and height of all trees

- ❖ Consider the whole farm as a "tree plot" and measure all trees
- ❖ Shrub and herb plots are not needed

Table 4.3 Some suggestion size and number of plots for different land-use systems or project activities under baseline and project scenario.

Land use system	Trees		Shrub		Herb/grass		Soil	
	Size of plot (m)	No. of plots	Size of plot (m)	No. of plots	Size of plot (m)	No. of plots	Size of plot (m)	No. of plots
Natural forest or heterogeneous vegetation	50 X 40 50 X 40	5 4	5 X 5 5 X 5	10 10	1 X 1 1 X 1	20 20	1 X 1 1 X 1	20 20
Plantations with homogenous vegetation or uniform species distribution and density	50 X 20 Or 40 X 25	5	5 X 5	8	1 x 1	16	1 X 1	16
Savannah or grassland or rangeland with few trees	50 X 40	5	5 X 5	10	1 X 1	20	1 X 1	20
Degraded forest or barren or fallow land	50 X 40	5	5 X 5	10	1 X 1	20	1 X 1	20

Source: (Ravindranath and Madelene, 2008).

4.7.6 Type and Shape of Sample Plots

4.7.6.1 Type of Plots

Two types of sample plots could be adopted for land-based projects, namely permanent sample plots and temporary sample plots: the type of vegetation determines which of the two is to be adopted.

Permanent plots: Are used mainly for measuring changes in carbon stocks in perennial vegetation where, for example, the trees may have to be measured over a number of years. This approach is suitable for most of the land-based projects involving tree carbon pools:

- ❖ Forests and plantations
- ❖ Agro-forestry
- ❖ Shelterbelts

Permanent sample plots are generally regarded as statistically more efficient in estimating changes in forest carbon stocks compared to temporary plots because typically there is high covariance between observations taken at successive sampling events in temporary plots. The disadvantage of permanent plots is that their location can be known and they could be treated differently (e.g. application of fertilizer and irrigation to increase the rate of carbon stock accumulation). Further, these plots might be damaged or destroyed by fire or other disturbances during the project period. This disadvantage could be overcome by ensuring that silvicultural practices are identical for the whole area under a given activity during the period of monitoring and verification. If the plot is damaged, say because of fire, new sample plots can be chosen, with identical soil and plant growth patterns.

Temporary plots: The location of temporary plots could vary from year to year or over a number of years. In temporary plots, the measurements are made for a given year and biomass is calculated only for that year. Next year, biomass is estimated from a different plot. Such approach is suitable for projects involving annual vegetation:

- Estimation of grass production in grassland reclamation and savannah projects
- Estimation of production of herbaceous vegetation in forests and plantations.

The advantages of temporary plots are that they may be established more cost effectively to estimate the carbon stocks of relevant pools and that the sampling would not be affected by disturbances. The main disadvantage of the temporary plots is related to precision in estimating change in forest carbon stocks (IPCC 2003). In temporary plot approach, individual trees are not tracked (Clark *et al.* 2001) and the covariance cannot be estimated, which makes it difficult to attain the targeted precision level without measuring a large number of plots. Thus, the cost advantage of using temporary plots may be lost by the need to establish more temporary plots to achieve the targeted precision. Thus, the permanent plot approach could be adopted for forests, plantations, agro-forestry and other perennial vegetation systems whereas the temporary plot approach could be adopted for annual vegetation systems such as grassland and cropland.

4.7.5.2 Shape of Plots

The shape of a plot has implications for accuracy and ease of measurement. The standard plot shapes used in vegetation studies are rectangles and squares, although strips and circles are also used.

Rectangular or square plots: Establishing rectangular or square plots involves measuring out the length or the breadth and using the diagonal to ensure a true right angle at each of the four corners. A square or a rectangle is the most commonly adopted shape for plots for estimating biomass in most vegetation types including forests, plantations, agro-forestry, shelterbelt, grassland and cropland because of the following factors:

- Easy to lay out and ensure square corners
- Suitable for young and mature forests as well as for non-tree vegetation such as grassland and cropland
- Suitable for large plots (e.g. 50×50 m or 100×100 m) or small plots (e.g. 1×1 m or 5×5 m)
- Easy to establish corner points for drawing the boundary for periodical visits and long-term monitoring
- Easy to record GPS readings and to locate the sample plots in later years for monitoring.

Circular plot: Circular plots could be adopted for vegetation types such as trees, herbs and grasses. It is easier to draw circular plots of small dimension in the field. However, a circular plot is not popular because of the following reasons:

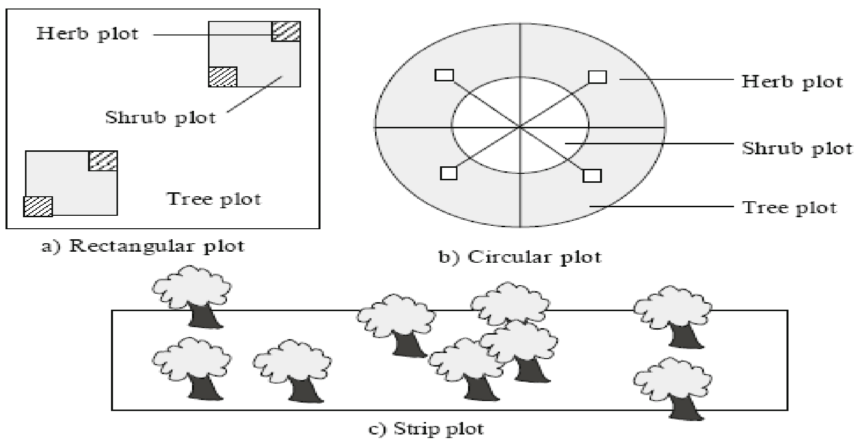
- Difficult to mark a circular plot in forests and plantations where large trees exist
- Difficult to verify the boundary line and area of the plot
- Difficult to mark the boundary line for periodic visits and not suitable for long term monitoring
- May not be suitable for agro-forestry, shelterbelt and avenue trees
- Not very efficient (Loetsch *et al.* 1973, cited in Ravindranath and Madelene, 2008), since, as the perimeter increases, so will the numbers of trees on the edge of the plot.

Timothy *et al* (2005) stated that Nested plots are composed of several full plots (typically two to four, depending upon forest structure), each of which should be viewed as separate. The plots can take the form of nested circles or rectangles. Circles work well if you have access to distance measuring equipment ([DME], for example, from Haglöf, Sweden) because then the actual boundary around the plot need not be marked. If DME is not available, it may be more efficient to use rectangular plots that are laid out with tape measures and stakes.

Strip plots: Strip plots or belt transects are long and narrow rectangular plots, normally used for studying rare populations. A strip plot is not usually adopted for biomass studies due to the following reasons:

- Difficult to mark long strips in the field, especially if there are large trees.
- Size of the project area may be a limitation. For example, a sample plot of 2000 m requires a strip 200 m long, and several such sample strips may be required.
- Difficult to draw boundary lines for the long narrow strips for periodic monitoring.
-

Fig 4.9 Shape or type of sampling plots: (a) rectangle, (b) circle and (c) strip



Source :(Ravindranath and Madelene ,2008)

4.8 Preparation for Fieldwork and Recording of Information

Estimation and monitoring of biomass in land-use systems involves measurement of plant-based parameters such as DBH and height of trees and weight of non-tree biomass. It is important to plan fieldwork well in advance for efficient use of staff and time, and necessary to procure all the background information before launching field studies. Field studies require:

- Trained staff
- Background information
- Instruments and materials for measurement
- Arrangement for collection of plant samples
- Formats for recording data

Trained staff: Field studies require at least one trained person and one or two field assistants. The trained person takes the measurements and records them in the formats provided; the field assistants help in laying plots, holding the measuring device (tape, pole or scale), establishing the boundary and putting in corner pegs. It is always desirable that whosoever records the data in the field should also be the one to enter the data into the computerized database.

Background information: Before embarking on field studies, it is important to obtain all the relevant background information, which will help in laying plots or taking measurements. Such background information could be obtained from the project office, land surveyor forest departments, local government offices and local communities. It is particularly important to collect all the available maps and prepare a map showing the project area and boundary, baseline land-use systems and characteristics and the project scenario activities. The type of background information required includes:

- Projection of location maps showing latitude and longitude, topographic sheets, forest map and soil maps
- Names for land-use systems and their location and area
- Elevation, topography, broad soil type and rainfall
- Proximity to human settlements, roads, urban centres, markets
- Land tenure or ownership
- Livestock population and grazing locations
- Past land-use changes and features
- Data on afforestation, reforestation, soil and water conservation, i.e. programmes or activities implemented or proposed
- Sources of fuel wood and timber
- Socio-economic and demographic features

Instruments and materials for measurement: The materials and instruments required for field survey on above-ground biomass estimation are given in the Table 4.4. The materials used should be of durable quality and the scales and measuring instruments validated or calibrated.

Table 4.4 Materials and instruments required for field studies on above-ground biomass estimation

s/n	Type of equipment for tree measurement	Purpose
A	Topographic map	For boundary delineation
	GPS	For recording geo-referenced data
	Measuring tape 50 m long	To measure distance
	Plastic rope lengths of 40 m and 5 m	For setting up observation of sub-plots
	Wooden sticks 1.3 m long	To guide diameter at breast height measurement
	Diameter tape (d-tape) or caliper	To measure DBH
	Clinometer or Hypsometer	To measure tree height
	Silva compass	To guide the transect
	Digital camera	To take field picture/Photo/
	Format	For data recording
B	Equipment for fieldwork _ Leaf litter, herb/grass collection	
	Frame (1m x 1m	For delineating the sample collection area
	Plastic bags	White plastic bags for collecting subsamples and big plastic bags to collect and weigh herb/grass and leaf litter

	Cloth bags for twigs and woody parts	These materials from the litter or understorey vegetation should be collected in cloth bags as plastic bags may get torn
	Knife and sickle	For cutting understory vegetation
	Scissors	For cutting understory vegetation (woody)
	Weighing scales	For weighing litter, herbs and grass; one allowing weights up to 10 kg , with a precision of 10 g for fresh samples and one with a 0.1 g precision for subsamples

4.9 Location and Laying of Sample Plots

This section presents an approach to locating and laying out sample plots in the field in different land-use systems. The criteria in locating the plots are as follows:

- Plots located must be representative of the land-use system.
- Plots must be located in an unbiased way within the land-use system, except those for estimating leakage.
- Plots should be accessible to investigators for measurement and monitoring.

The selected number of plots needs to be located and laid in the carbon inventory area in an unbiased manner, given the variations in soil, topography, vegetation, etc. Sample plots are required to be located and laid out during the project-development phase as well as project-monitoring phase. The main approach involves:

(i) Fixing the number of plots for each stratum or project activity;

(ii) Selection of sampling design; and

(i) Location of the sample plots in the carbon inventory area converted to grids in each sampling stratum.

The sample plots can be laid without any bias as follows:

1: Select and stratify the project area or the area under each activity.

2: Obtain a map of the total project area and convert it into grids of appropriate size depending upon the area under a project activity or baseline land-use system. The grids could be 10 × 10 m to 100 × 100 m. It is desirable to make the grid size larger than the size of the sample plots. Further, the number of grids is usually several times the number of sample plots.

3: Numbers the grids 1 to n, where n is the total number of grids.

4: Select the number of sample plots for each land-use system under the baseline scenario and project activity stratum.

5: Select the sampling design: simple random sampling stratified random sampling or systematic sampling.

6: Locate the sample plots in the carbon inventory area using the sampling design adopted (using the steps described in the following section).

(i) **Simple random sampling**

- Randomly pick as many grid numbers as the number of sample plots, using a table of random numbers or by drawing lots. For instance, if five tree plots are to be selected, pick five random numbers.
- Ensure that the randomly drawn plots do not all fall into a single cluster, which is rare.
- Locate tree plots in the grids selected in the field with respect to some permanent visible landmark and mark the boundary of each tree plot or use GPS.
- Prepare and store a map with all the details, including the location of sample plots marked on it. If GIS is available, it can be very useful.

(ii)**Stratified random sampling**

- Stratify the land-use system or project activities into homogeneous units.
- Select the stratum.
- Adopt for each stratum the procedure given for simple random sampling.
- Repeat the procedure for laying plots for the next stratum and continue until all the strata are covered.

(iii) **Systematic sampling**

- Stratify the land-use system into a number of homogenous units.
- Obtain a map showing the grids in each sampling stratum and estimate the total number of grids for each stratum (N): e.g. 200 grids with a total project area of 40 ha (which is worked out below as an illustration). The plot numbers and the locations of the sample plots are marked on the grid map of the carbon inventory area.
- Calculate the sampling interval "k" by using the following equation:

k = N/n

Where:

k = sampling interval of grids or plots = 200/5 = 40, N = total number of grids representing a given strata (200) and n= number of sample plots (quadrats) to be selected (e.g. 5).

- Draw a random number smaller than k (smaller than 40 in this example), say 25.
- Select and mark the first grid based on the random number.
- The first sampling grid number is 25.
- The second sampling grid or plot = sampling interval k (40) + first sampling grid (25) = 65.
- The third sampling grid or plot = sampling interval k (40) + second sampling grid (65) = 105.
- Repeat the procedure for the remaining number of sample plots.

Marking the plot in the field: The plot numbers and the locations of the sample plots are marked on the grid map of the carbon inventory area. These grid numbers have to be located in the field for long-term periodical monitoring of vegetation. The following steps could be considered to facilitate the process:

Step 1: Use the carbon inventory project area maps with sample plots marked on the grid map along with their geographic coordinates (latitude and longitude).

Step 2: Locate the sample grids on the ground using GPS points from the map or using any permanent visible landmark in the field.

Step 3: Mark the corners of the sample quadrats on the ground using pegs or any other permanent marking arrangements for long-term periodical monitoring. To avoid any special treatment to the permanent sample plots, it may be desirable to hide the corner points of the quadrats.

Step 4: Use GPS positions of the quadrat corners for long-term periodic visits to avoid any bias in treatment of the vegetation in sample plots. The boundary line of the plot should be marked with a rope or coloured chalk powder during measurement.

Marking of tree, shrub and herb quadrats: Tree sample plots or quadrats are normally several times larger than the shrub quadrats, which are several times larger than the herb or grass quadrats:

- Measure and mark the corners and boundary of the tree quadrats in the field.
- Mark the shrub quadrats within each of the tree quadrats, normally at two opposite corners, keeping two shrub plots per tree quadrat.
- Mark the herb or grass quadrats within the shrub quadrats at the opposite corners, keeping two herb plots per shrub plot. Location and layout of the tree, shrub and herb quadrats could be along the following lines (Fig. 4.6).

4.10. Field Measurement of Indicator Parameters

Estimation of carbon stock in biomass or its growth rate requires measurement of indicator parameters such as tree height and DBH. These parameters are measured in the field through a sampling design. Field measurements for biomass carbon assessment are required at:

- Project development phase for baseline scenario land-use systems and proposed project scenario activities
- Project monitoring phase for baseline scenario land-use systems and implemented project scenario activities

Above-ground biomass is estimated in any typical land-based projects for trees, shrubs and herbs/grasses.

4.10.1 Above-Ground Biomass of Trees

Trees are woody perennial plants having a single, usually elongated main stem with few or no branches on their lower part. Trees could be large or mature (DBH > 30 cm), medium-sized or growing (DBH 10–30 cm) or regenerating seedlings (DBH < 10 cm). A plant belonging to a tree species is considered for measurement in tree quadrats if it is taller than 1.5 m and its DBH is greater than 5 cm (a girth of about 15 cm). The height and DBH class to be considered in the tree quadrat will vary with the project type and age of the stand. In the case of old, mature forests with large trees, a tree could be defined to have a DBH of greater than 30 cm. Locate the tree plots in the field and measure the DBH, height and other parameters for all the trees using the procedure described in this section.

Parameters to be measured include: Species, number of stems, DBH, height, status of regeneration, state (living, dead and standing, dead and fallen) and extent of damage to crown.

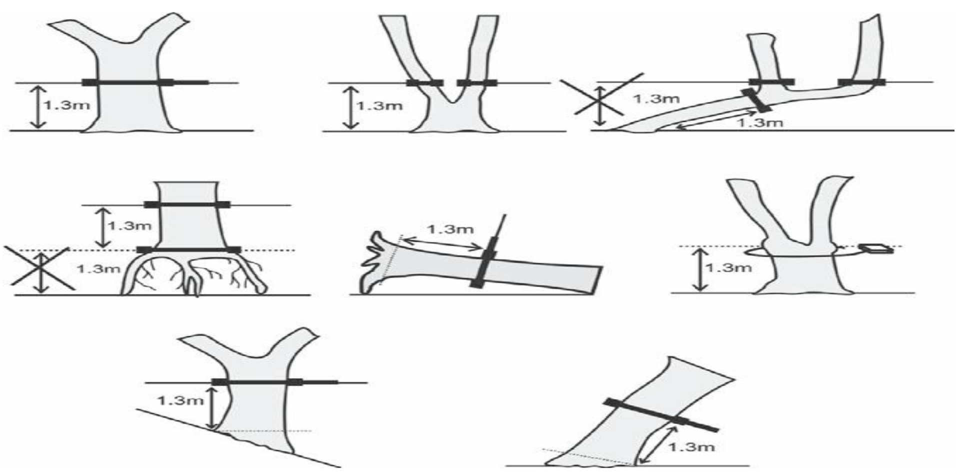
4.10.1.1 Measuring DBH

DBH is easy to measure and verify. It requires only a measuring tape and a marker. DBH is measured using the following procedure:

- ❖ Mark a point 130 cm or 1.3 m above the ground on the tree trunk.
- ❖ Place the measuring tape around the trunk at the 130 cm or 1.3 m mark.
- ❖ Measure and record the DBH or GBH in centimeters:
  - ➢ If a tree has multiple shoots, count and measure GBH/DBH for all shoots.
  - ➢ If the tree is large, girth is normally measured with a measuring tape.
  - ➢ If the tree is young and slender, measure the DBH with a slide caliper.
  - ➢ If the tree is on the boundary, include it for measurement in the sample plot only if more than 50% of its girth is inside the plot.

A tree could have multiple shoots and/or crooked trunks, could be growing at an angle, and could be on a sloping hill. The measurement technique for irregularly shaped trees and different land conditions is illustrated in Fig. 4.10

Fig 4.10 Measuring DBH or GBH for trees of different shapes and forms



Source :(Ravindranath and Madelene, 2008)

Fig (4.11) Example of Dbh Measurement using Diameter Tape and Caliper

Above Dbh Measurement with Diameter Tape and below with Caliper

Source :(Kyoto, 2009)

4.10.1.2 Slope Correction

The distance with in the plot area where trees are measured should be corrected mathematically on sloping land. Because all measurements of a sample plot are reported on a horizontal-projection basis, the establishment of plots on sloping lands must use a correction factor (see appendix 1). The slope angle must be measured with a clinometer.
Formula to correct the plot area on slopes over 10%.
New distance = Old dis* Cfrnew =
New distance of the sample plot
Old Dis = Normal width of the sample plot
Cf = Correction factor

An example A project has planted trees on several mountain slopes to fight erosion. One of the sample plots is placed on a hillside with a slope of 58%. According to the table above the correction factor is 1.16. On flat terrain the project uses circular plots of 250m^2 with a radius of 8.92 meters. rnew = rold * Cf = 8.92 * 1.16 = 10.34 m This means that the plot will have to be measured with a radius of 10.34 m to represent 250 m^2 on flat terrain.

4.10.1.3 Height measurement

Tree height normally refers to total tree height defined as the vertical distance from the ground level to the uppermost point. Tree height is also often referred to as merchantable height since many allometric equations are derived for this height.

Unlike DBH, measurement of tree height is difficult for tall trees, especially in a dense forest or plantation with tree close together and overlapping crowns. Height can be measured using different methods.

(i)**Measurement using instruments** tree height can be measured using various instruments or even using a measuring tape. However, measuring the height of individual trees with overlapping tree crowns and trees in a dense forest or plantation poses a challenge for measurement even using instruments. Trees taller than 5 m can be measured using a graduated height-stick by holding the stick against the side of the tree. Clinometer is one of the instruments used for measuring the height of trees but it is not suitable for dense vegetation where visibility is limited.

Mark out a spot 10 m from the tree from which the tree can be viewed using a clinometer. If necessary, move beyond 10 m. If the plot is located on a steep slope, view the tree from across the slope to maintain the required distance. Sighting the tree through the clinometer, align the centre line with the base of the tree (ground level on the upside slope) and record the reading on the percent scale (base angle %). Next, aim the clinometer at the top of the tree and record the reading on a percentage scale. Calculate the height using the following equation:

$$\text{Height (m)} = \frac{[\text{top angle (\%)} - \text{base angle (\%)}] \times \text{horizontal distance}}{100}$$

(ii) **Height classes** trees can be grouped into different height classes (e.g. 0–5, 6–10, 11–15, 16–20 m). These classes can be used as reference height classes to get an approximate estimate of the height of trees in a plot. Trees are observed during fieldwork and categorized into these height classes. Field investigators with a little practice and experience can estimate the height class of a tree by mere observation and place it in the appropriate class.

Fig 4.12. Example of How Tree height is measured

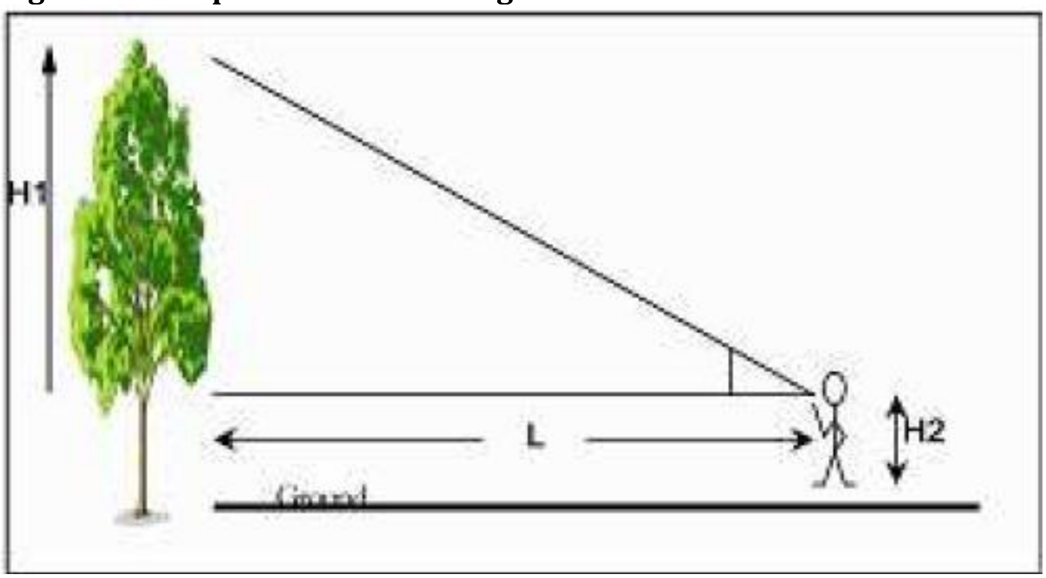


Fig (4.13) Height measurement using a hypsometer

Source :(Kyoto, 2009)

The user stands at 15 or 20 m from the tree to be measured
• Then sights to the bottom of the tree and read the readings
• Again sights to the top of the tree and read the other readings
• The sum of the two readings is the total height of the tree
It is important:
• To take the correct distance from the tree. This depends on the scale you are using
i.e 15 or 20 m scale in the hypsometer
• To correctly identify the tip of the tree
• Avoid measuring the height of abnormal or leaning trees

4.10.2 Above-Ground Biomass of Shrubs

Shrubs are woody plants that are usually short, often less than five metres, with several stems arising from the base and lacking a single trunk. Shrub plots include shrub species as well as younger trees with DBH lower than what is defined for the trees in the tree plots. Shrub plots are located inside the tree plots (Fig. 4.9).
Parameters to be measured include species, number of stems, DBH, height and weight of the shrub biomass from the sample plot.
Frequency of measurement for shrub vegetation could vary based on vegetation types. Normally, adopt the same frequency as that used for the tree plot measurements.
Demarcation of the shrub plots and the boundary can be undertaken by following the method of laying out shrub plots. Shrub plots are usually located at two opposite corners of a tree plot (see cover of the book). If a shrub is on the boundary of the plot, treat it as part of the plot so long as more than 50% of the shrub crown is inside the plot.

Procedure for measuring shrubs and young trees in shrub plots the following steps could be adopted to measure the parameters in the shrub plots:

1: Locate and number of the shrub plots in each of the tree plots.
2: Start from one corner of the shrub plots and record the indicator parameters and mark the plants after measurement with a chalk or paint.
3: Record the species and the number of shrub plants under each species.
4: Measure the height of the tree using the methods described for trees.
5: Measure DBH of all trees taller than 1.5 metre in the shrub plot; if multiple shoots are present, record DBH for all the shoots.
6: Record the name, height, DBH and other features for each shrub plant in the format provided.

Procedure for measuring non-tree vegetation other than trees could include annual or perennial shrubs as well as very young seedlings (shorter than 1.5 m). Estimation of non-tree biomass in shrub plots follows the same method as that for annual and perennial shrubs. Tree seedling should be excluded from harvest procedure.

Biomass of annual shrubs is estimated by cutting the shrubs in the shrub plot, one species at a time, and recording the fresh weight of all the plants. Dry weight of the biomass can be estimated by taking a known quantity (0.5–1.0 kg) of a plant sample and drying it to constant weight in the oven.

Biomass of perennial shrubs is estimated by harvesting the perennial shrub plants in the shrub plot, again species by species, and estimating the fresh and dry weight of the plants. However, if the shrub species is yielding any economically valuable product, such shrub species need not be harvested or a few representative shrub plants could be harvested to get the mean weight for the species. The mean weight of sample shrubs harvested can be extrapolated to the whole plot.

Periodic monitoring of shrub and tree biomass periodic monitoring of shrub biomass could be through harvesting, using the "permanent plot". However, for harvesting, each time select a plot adjacent to the plot harvested before so that measurements are comparable and the impact of earlier harvest is avoided.

4.10.3. Above-Ground Biomass of Herbs

Herbs are non-woody plants that usually die at the end of the season. Herb-layer biomass includes all annual plants, regenerated saplings and grass biomass. Herb-layer plots are usually small (1 × 1 m) but more numerous. Biomass in the herb layer is part of the annual carbon cycle and is estimated by harvesting during the peak growth period.

Parameters species name, number of plants and fresh weight of standing herb biomass are the parameters to be recorded.

Frequency of estimation the biomass of herbs is recorded annually during the peak growth period.

Demarcation of herb plots and the boundary herb plots are usually 1 × 1 m and marked at the two opposing corners of each shrub plot (Fig. 4.9).

Measurement of herb vegetation measuring herb vegetation involves recording the species name and harvesting the herb biomass to determine its weight. The following steps could be adopted:

1: Record the species name and number in each herb plot. The percentage of ground covered by herbs in the plot could also be recorded, by species, based on visual observation.

2: Cut the herb plants, by species, in each herb plot.

3: Take the fresh weight of the herb biomass, again by species.

4: Estimate the dry weight by taking a small sample of fresh herb biomass and drying it to constant weight in an oven. If there is any ban on harvesting certain herb species, avoid harvesting those species. Also avoid harvesting saplings or seedlings of valuable tree species.

4.10.4 Above-Ground Biomass of Grass Production

Grasslands are characterized by dominance of grass species, with a few trees or total absence of trees or other perennials. Estimates of above-ground grass production, which is part of the annual carbon cycle, may not be very relevant to carbon inventory projects or greenhouse gas inventory programmes. However, estimating grass production is essential for grassland reclamation projects. The method for estimating grass production is similar to that for annual herbs, and the following steps could be adopted:

1: Select the grassland category or grassland improvement project activity and stratify the land area.

2: Adopt standard sampling procedures: decide on the size and number of plots and locate them in the field using the procedure described for herb plots.

3: Select four to five tree quadrats the same way tree or shrub quadrats are selected, or select the tree quadrat itself in forests or plantations

4: Divide each shrub or tree quadrat into 12 subplots of 1 × 1 m to represent 12 months of a year and mark and fence the plots.

5: Harvest the grass by clipping the above-ground biomass in subplot 1 of quadrat 1 and determine the fresh and dry weight of the grass biomass harvested.

6: Repeat the harvest procedure for subplot 1 of all the quadrats the same month, estimate the fresh and dry weight of grass biomass (grams/square metres) and convert it to per hectare estimate of grass production (grams/ hectare) in terms of dry weight.

7: Next month, repeat the harvest and biomass estimation in subplot 2 of each of the four or five quadrats, estimate fresh and dry weight, and estimate the grass production (dry weight) for that month in terms of grams/hectare.

8: Repeat the process monthly to cover the remaining months. Compile the monthly production of grass biomass (grams/hectare), calculate the average biomass for all the grass-growing months, and select the month in which grass production is maximum to assess the productivity of that grassland category. Harvesting could be avoided when no biomass growth is likely.

4.11. Recording Data and Compilation

Data recording formats have been developed for tree, shrub and herb species in sample plots. These formats are largely for use in the field. The data entered in these formats in the field need to be verified and entered into a database for analysis. Some of the precautions and steps to be followed to ensure correct recording in the field and proper compilation for obtaining reliable estimates of biomass are as follows:

- Use the appropriate data entry format for trees, shrubs and herbs.
- Remember to enter the location name, date, plot number, vegetation type and name of the field investigator.
- Enter and verify GPS readings of the plots.
- Enter and verify the units of height, DBH and weight.
- Ensure that all the relevant data-recording cells in the formats are filled before leaving the field.
- Verify the data recording formats as soon as possible after returning from the field for any corrections or conversion of traditional units of measurement to standard units such as the SI units.
- Codify any entry as required by converting qualitative information into codes, for example, presence or absence (0 or 1), land-use systems (1: agriculture, 2: grassland, 3: settlement, 4: tree plantations).

- Develop a user-friendly data entry system for computer analysis and for archiving data.
- Verify all the data entered and store them in a database.

4.12 Data Analysis (Estimating AGB of trees-agriculture, watershed, and Forestry projects

The document of world Bank (2012) described that AGB of trees includes commercial (or merchantable) timber and total tree biomass, which includes not only commercial timber, but also twigs, branches, and bark, expressed as tons of oven-dried biomass. The two commonly used methods for estimating AGB for trees in forests or in agro-forestry plots are as follows:

- Estimating tree volume using height and DBH values and the tree form factor
- Estimating tree biomass using allometric equations where biomass of a tree is estimated using the DBH and height values.

Estimating tree volume and biomass: The plot method provides values for tree parameters such as DBH and height. These values could be used to estimate the volume of the trees, which can be converted into weight using wood density. This method involves the following steps:

Step 1: Measure the height and DBH of all the trees in the sample plots (as described in Part D)

Step 2: Tabulate the values of height and DBH by species and by plot

Step 3: Estimate the volume of each tree in the sample plots using the following formulae depending on the shape of the tree, whether cylindrical or conical:

$$V = \pi \times r2 \times H \text{ (for cylindrical trees)}$$

$$V = (\pi \times r2 \times H)/3 \text{ (for conical trees)}$$

Where

V = volume of the tree in cubic centimeters or cubic meters

r = radius of the tree at a point 130 cm above the ground = DBH/2

H = height of the tree in centimeters or meters

Step 4: Obtain the wood density value for each of the tree species from literature, at least for the dominant species (IPCC, 2003-GPG):

- If the density value for any dominant tree species is not available in the literature, select the species most closely related to the species present on the site.

Step 5: Multiply the volume of the tree with the respective wood density to obtain the dry weight of that tree and convert the weight from grams to kilograms or tons.

- Weight of tree (in grams) = volume of the tree (in cm3) × density (g/cm3)

Step 6: Add up the weights of all trees of each species in the selected sample plots or farms in case of agro-forestry or shelterbelts (in kilograms or tons for each species)

Step 7: Add up the weight of all the trees of all tree species for all the sample plots or farms, based on the weight calculated for each plot (in kilograms or tons)

Step 8: Extrapolate the weight of each species from the total sample area (sum of all the plots or farms) to a per ha value (tons of biomass per ha for each species)

Step 9: Add up the biomass of each species to obtain the total biomass of all the trees in tons per ha (dry matter)

Estimation of biomass using equations: Biomass of a tree can be estimated using the DBH and height data of trees. Biomass equations can be linear, quadratic, cubic, logarithmic, and exponential. Species-specific and generic biomass estimation equations are available in the literature. Often generic biomass equations are used for estimating the AGB.

In addition to biomass equations for individual trees, they are also available for estimating biomass in per-ha terms. Usually only the volume of a tree is measured, since measuring the weight, particularly of large trees, in the field is difficult. Many biomass equations are indeed biomass volume equations. Tree volume is related to parameters such as DBH and height.

The volume (m3) estimated using the equations needs to be converted to biomass in tons per tree or per ha using the density of the species. The following steps are adopted for estimating the volume as well as the biomass of the trees:

Step 1: Select the project area, activities, and sample plots, and measure the DBH and height of all the trees in the sample plots

Step 2: Select the biomass volume estimation equation for the dominant tree species or for all the species for which species-specific equations are available

- ➢ If no species-specific equations are available, use generic equations (see appendix 4) or those specific to a given forest or plantation type.

Step 3: Enter the DBH, height, and the biomass volume equation into a software package such as Excel.

Step 4: Calculate the volume of each tree based on the DBH and height using the software

Step 5: Aggregate the volume of all the sample trees by species if species-specific equations are used to obtain the total volume of the trees (m3)

Step 6: Convert the volume of the trees in the sample plots or farms to biomass in tons using the density of biomass for the selected species

- ➢ If species-specific density values are not available or cannot be derived for all the species, use the density of the dominant tree species for converting the whole forest or plantation volume to biomass
- ➢ If the equation provides only the merchantable volume, use the biomass conversion and expansion factor (BCEF) to obtain total biomass in kg per ha or tons per ha

Step 7: Extrapolate the biomass from the sample plot or farm area to tons of biomass per ha.

BCEF: The data on biomass volume and the default biomass stock as well as growth rates are often estimated considering only the merchantable or commercial volume. Estimating only the commercial component of the tree biomass, which is largely the main tree trunk, may be adequate for estimating industrial round wood. However, for estimating carbon stocks and changes, all the AGB, including twigs and branches and even leaves, needs to be estimated. To convert the merchantable tree volume into total biomass, BCEF are used (IPCC 2006). Biomass expansion factors (BEF) could be used if a biomass equation provides the merchantable biomass (tons per ha) directly. BEF expands the dry weight of the merchantable volume of the growing stock to account for non-merchantable components of trees. Total biomass can be estimated in two ways depending on the units of merchantable biomass estimates (as volume in m3 or in tons per ha):

Total biomass (t/ha) = Total merchantable biomass (t/ha) × BEF

Total biomass (t/ha) = volume of merchantable biomass (m3/ha) × BCEF (t/m3)

Tree biomass can be also estimated using allometric equation for specific tree species. Tree allometry establishes quantitative relations between some key characteristic dimensions of the tree which are usually fairly easy to measure (such as tree diameter and height) and other properties that are often more difficult to assess (biomass). However one of the largest sources of uncertainty is the lack of standard models using allometric equations to convert tree measurements to aboveground biomass. This has resulted mainly because of the very large diversity of trees species and variety of tree ages (related to diameter) growing in a tropical forest, so it is not possible to use only one specific regression model as can often be done in the temperate zone (Brown, 1997). Furthermore, direct tree harvest data (especially from big trees) are very limited, so it is impossible to independently assess the model's quality.

Allometric equations can be locally developed by destructive sampling, or derived from the literature for supposedly comparable forest types. The equations developed by Brown (1997) are based on diameter (D) at breast height (1.3 m) and the height of the tree (H) and have been used widely in the tropics. Separate equations have been developed for tropical forests in different annual rainfall regimes: dry < 1500mm ($AGB = 0.139\ D^{2.32}$with DBH range 5-40); moist 1500-4000mm ($AGB = 0.118\ D^{2.53}$with DBH range 5-148);and wet >4000mm ($AGB = 0.037\ D^{1.89}\ H$ with range of 4-112). For the humid tropics, however, using the generic allometric equation developed by Brown (1997) resulted in an overestimate (double the correct amount). Using tree-specific allometrics that include estimates of wood density lead to lower biomass estimates, especially in the low-to-medium biomass categories (van Noordwijk *et al.,* 2002). A critical reassessment of the quality of models across tropical forests and agroforestry types performed by Chave*et al*. 2005) suggested that the most important predictors of aboveground biomass (AGB) of a tree were, in decreasing order of importance, its trunk diameter, wood specific gravity, total height and forest type (dry, moist or wet) (Ravindranath and Madelene ,2008).

After calculating the Biomass of the tree carbon of individual trees is calculated as:

Carbon stock per tree = Biomass of tree/2

Carbon stock in subplot = Summation of carbon stock of trees in subplot

$$\text{Carbon stock of the principal sample plot} = \frac{\text{Summation of carbon stock in sample plots}}{\text{Areas of the sample plots}} \times 10{,}000\text{m}^2$$

Estimating AGB of young trees or shrubs: Shrub biomass is relevant only for forestry projects or activities such as afforestation, management of PA, and biodiversity conservation projects. Shrub biomass could be ignored if the quantities involved are small compared to tree biomass. Shrub biomass is expressed as tons of dry biomass production per ha per year and is estimated separately, since the sample plot size as well as the form of the plants is different. Biomass for shrubs is estimated through the harvest method:

Step 1: Record the fresh and dry weight of the shrub biomass harvested from sample plots (kilograms per plot)

- If there are young regenerating valuable tree plants and any economically valuable perennial shrubs, harvesting such plants may not be desirable
- A few representative plants could be harvested and weighed and the height and spread of each of these plants recorded along with the name of the species
- These data could be used for estimating the weight of plants that cannot be harvested
- Alternatively, some of the perennial or economically valuable shrub species could be ignored if they cover only a small proportion of the ground area (less than 10%, for example)

Step 2: Estimate the biomass of young trees (less than 5 cm DBH) using the steps described for estimating tree AGB

Step 3: Pool all the biomass harvested from different shrub plots to obtain the total dry shrub biomass for the total area of the sample plots

Step 4: Extrapolate the sample area biomass to a per-ha value (dry tons per ha)

4.13. Methods for Estimating Below-Ground Biomass

Below-ground biomass is defined as the entire biomass of all live roots, although fine roots less than 2 mm in diameter are often excluded because these cannot easily be distinguished empirically from soil organic matter. Below-ground biomass is an important carbon pool for many vegetation types and land-use systems and accounts for about 20% (Pearson et al. 2005b to 26% (Cairns et al. 1997) of the total biomass. Below-ground biomass accumulation is linked to the dynamics of above-ground biomass. The greatest proportion of root biomass occurs in the top 30 cm of the soil surface (Bohm 1979; Jackson et al. 1996 cited in Ravindranath and Madelene, 2008). Revegetation of degraded land leads to continual accumulation of below-ground biomass whereas any disturbance to topsoil leads to loss of below-ground biomass. Since below-ground biomass could account for 20–26% of the total biomass, it is important to estimate this pool for most carbon mitigation as well as other land based projects. Estimation of stock changes in below-ground biomass is also necessary for greenhouse gas inventory at national level for different land-use categories such as forest lands, cropland and grassland. This chapter of the guideline focuses on methods of estimating and monitoring below-ground biomass.

4.13.1 Below-Ground Biomass: Features and Broad Methods

Methods for measuring and monitoring above-ground biomass are relatively well established, in regular use and cost-effective; however, those for below-ground biomass are less developed and less frequently used in the field. Further, the methods for below-ground biomass for different land-use systems are not standardized (IPCC 2006). Live and dead roots are generally not distinguished and hence root biomass is reported as total of live and dead roots.

The choice of method depends on site conditions, vegetation type and the accuracy required, but in most carbon inventory projects root to shoot ratio and allometric equations are the most commonly used. Data on below-ground biomass are required for estimating and projecting total change in carbon stock for the following:

- ❖ Baseline scenario land-use systems
- ❖ Project scenario land-use systems
- ❖ Above-ground biomass equation based on DBH and height values of the trees

4.13.2. Methods for Estimating Dead Organic Matter: Deadwood and Litter

Dead organic matter consists of deadwood and litter. Stems and branches of deadwood 10 cm or larger in diameter form the deadwood pool and those smaller than that constitute litter. Inclusion of dead organic matter pool makes the estimated changes in total carbon stock more accurate. Most of the biomass not harvested or burnt is added to the deadwood, litter and soil carbon pools. The dynamics of dead organic matter vary with the type of forest or plantation as well as with the purpose behind protecting a forest or raising a new forest. In fuel wood plantations or community forestry projects, the woody part of the dead organic matter is likely to be removed and used as fuelwood. However, in the case of avoided deforestation projects involving protection of forests, dead organic matter accumulates on the forest floor. Further, land-use change, particularly from forests and plantations to other land uses such as cropland or grassland, leads to complete loss of dead organic matter. Dead organic matter is not likely to be a dominant carbon pool for grassland reclamation, agro-forestry and cropland management projects: it may account for about 10% of total carbon stocks in forests and tree plantations but may be practically absent in other land-use categories.

DOM = DW + LT
Where
DOM = dead organic matter, DW = deadwood and LT = litter

The relevance of dead organic matter to project development and monitoring phases of land-based projects is as follows:

- ❖ **Project development phase** dead organic matter is not relevant to baseline scenario, except for avoided deforestation or conversion of forest land to other land uses. Dead organic matter pool is either ignored for the project scenario or estimated using default values during the project development phase.
- ❖ **Project monitoring phase** during the project monitoring phase, dead organic matter is likely to be an important pool for carbon mitigation projects such as avoided deforestation, conversion of forest land to other uses and afforestation and reforestation projects. Thus, dead organic matter could be periodically measured and estimated during the project monitoring phase. This pool is relevant neither to commercial round wood production programmes nor to non-tree land-based projects on grassland and cropland.

Dead organic matter pools can be estimated by “Gain–Loss” or “Stock-Difference” methods. These two methods are explained in IPCC (2003, 2006, cited in cited in Ravindranath and Madelene, 2008).

4.13.2.1 Deadwood

Deadwood includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Deadwood includes wood lying on the land surface, dead roots and stumps 10 cm or larger in diameter.

4.13.2.2 Standing Deadwood

Standing deadwood usually includes trees that are dead but not yet fallen to the ground and thus are part of the vegetation. The trees may have died because of disease or physical damage. Standing deadwood could be a key carbon pool in older forests and plantations but unlikely to be so in young plantations, cropland and grassland development projects. The method adopted for estimating standing deadwood is identical to that used for estimating above-ground biomass. The key steps in estimation of the stock of deadwood at a given time are as follows.

1: Select and stratify the land-use category or project activity for which the deadwood has to be estimated.
2: Decide on the sampling method including sample size, number of sample plots and sampling design, used for estimating the above-ground tree biomass of trees.
3: Select the sample plots identified for above-ground biomass and use the same plots.
4: Assemble the material required for field study, namely:

- Measuring tape for recording diameter and height, rope and pegs for marking the plot, a balance for weighing fresh wood samples, a cotton bag for storing samples, and a knife for cutting litter

5: Identify the parameters to be measured and recorded:

- ❖ DBH and height
- ❖ The status of the dead and standing trees, based on expert judgment
    - ➢ Tree with crown, branches and twigs but without leaves
    - ➢ Tree without crown and branches
    - ➢ Tree stump (with a short stem)
- ❖ Wood density
- ❖ Measure fresh weight, dry weight and volume of the sample wood block

6: Record these parameters together with those for live above-ground biomass:
7: The method for calculating the biomass stock of dead and standing trees is identical to that used for estimating above-ground biomass.

4.13.2.3 Fallen Deadwood

Fallen deadwood occurs in forests and older plantations and could be the result of natural death or of strong winds, disease or pest attack and felling. In many project areas, fallen deadwood may be removed by the local communities for fuel wood and other uses. The sampling method could be identical to that used for estimating above-ground biomass. The following are the key steps in measuring fallen deadwood:
1: Select and stratify the land-use category or project activity for which the fallen deadwood has to be estimated.

2: Decide on the sampling method including sample size, number of plots, and sampling design used for estimating above-ground biomass of trees.
3: Select the sample plots identified for above-ground biomass and use the same plots.
4: Assemble material required for field study, namely:

- ❖ Measuring tape for recording diameter and length and rope and pegs for marking the plot, and balance for weighing deadwood

5: Identify the parameters for measuring fallen deadwood:

- ❖ Measure the diameter or girth at both ends and midpoint, and length of the fallen tree or branch
  - ➢ If more than half of the fallen wooden log or branch is inside the plot boundary, include it as part of the plot for measurement
- ❖ Record status of the fallen wood, based on expert judgment
  - ➢ Good physical condition (not rotten or decomposing)
  - ➢ Cavity formed in the middle due to rotting or decomposition
  - ➢ If cavity exists in the middle of the fallen stem, measure the diameter of the cavity (and exclude it from the volume calculation of the fallen deadwood)
  - ➢ If the fallen stem is not very long or large and if feasible, measure the weight using a spring balance by tying a rope to the fallen deadwood and lifting it
  - ➢ Measure the weight of all the fallen deadwood logs and if weighing is not possible, measure the length and the diameter
- ❖ Take a sample of deadwood for density estimation
  - ➢ Measure fresh weight; estimate the dry weight and volume of the sample wood block

4.13.2.4 Litter Biomass

Litter includes all non-living biomass other than deadwood (normally less than 10 cm in diameter lying dead in various states of decomposition above the mineral soil. Litter, which includes woody and non-woody components, consists of plant parts that fall to the ground as part of the annual cycle, as a result of pest attack, physical damage such as that due to wind or lopping of branches and leaves, and could be further categorized into coarse woody litter (diameter greater than 6 mm), fine woody litter (diameter 6 mm or smaller) and non-woody litter (leaves and reproductive parts). Litter biomass, lying on the top of the mineral soil and on the floor of forests or plantations, could be a key pool only for older forests and plantations.

Litter may not be a key pool in barren or degraded lands, particularly in the baseline scenario. On the importance of measuring litter pool for different project types as well as for the frequency of measurement. Litter biomass can be measured using two methods:
(i) Annual litter production
(ii) Litter stock change method

4.13.2.5 Annual Litter Production Method

Litter production is measured to assess the annual woody and non-woody litter fall as well as the turnover rates expressed as dry tonnes/hectare/year. Estimating annual litter biomass production is a complex task and involves fixing litter traps in all the sample plots and collecting and weighing the litter every month. This requires protecting litter traps and preventing removal of litter from litter traps in field situations. The method involves significant human effort. The following steps could be adopted for estimating annual litter production:

1: Select and stratify the land-use category or project activity.

2: Select the plots earmarked for measuring shrub biomass

- Normally 8–10 plots per stratum, each measuring 5 × 5 m

3: Assemble material required for field study, namely:

- XRope and pegs for marking the plot, litter trays, a balance for weighing litter, cotton bags for collecting sample for drying, a knife for cutting litter

4: Fabricate square litter trays made of 1.5 mm wire mesh with a wooden frame:

- Dimensions = 1 × 1 × 0.1 m (depth) with the wooden frame
- Number = 8–10 per stratum

5: Install the litter trays randomly in the shrub plots by fixing the trays about 15 cm above the ground to ensure that water does not accumulate in them and that they are not easily removable or damaged.

6: Collect the litter fallen into the trap once in a month on a fixed date. Remove deadwood (>10 cm diameter) if any.

7: Record the fresh weight of the litter:

- Separate the woody and non-woody litter
- Weigh each component separately for each trap
- Take about 0.5 kg of fresh litter for dry matter estimation

8: Repeat the field collection and measurement of litter once in every month for 12 months.

9: Calculate and tabulate dry weight of woody and non-woody litter on monthly basis.

10: Calculate the per hectare annual litter production using the following procedure:

- Pool the weights of woody and non-woody litter from all the plots in a stratum
- Convert the fresh weight to dry weight on a monthly basis
- Add the total dry weight from all the plots for each of the 12 months
- Extrapolate total dry annual litter fall from sample plots to dry tonnes/hectare/year

4.14 Long-Term Monitoring for Above-Ground Biomass

Long-term observations and monitoring are central to the study of almost every important ecological concept and every environmental issue. Long-term monitoring is extensively adopted in ecological studies to understand ecosystem changes, vegetation succession, carbon dynamics, biodiversity changes and other ecological processes. Long-term monitoring is critical to carbon inventory since carbon gains and losses occur over long periods, spanning decades and centuries. Above-ground biomass accumulates over decades and centuries, although it may peak sometime during that period. The peak time varies with forest type and plantation species. However, carbon stock could be lost from different land-use systems within a short time because of disturbance, especially in the form of fire, land conversion and harvesting.

Long-term monitoring in the context of carbon inventory for above-ground biomass is required for such projects or situations as:

- ❖ Land conversion from forests or plantations to degraded land, cropland or grazing land
- ❖ Afforestation and reforestation of degraded lands to sequester carbon
- ❖ Avoided deforestation to conserve forest carbon sink
- ❖ Round wood production and bio-energy plantation programmes
- ❖ Agro-forestry and shelterbelt programmes
- ❖ Land reclamation projects

A long-term monitoring plan should be developed and incorporated into the project during the planning and project development phase and adopted during the post-implementation phase. This section briefly presents the methods for and steps in long-term monitoring of changes in above-ground biomass.

Methods for long-term monitoring of above-ground biomass: The two promising methods are permanent plot method and remote sensing techniques. Because remote sensing techniques with practical applications in land-based carbon mitigation projects, round wood production programmes and national greenhouse gas inventory are still evolving, the permanent plot method is the most suitable one for long-term monitoring on account of the same merits, namely cost effectiveness, suitability to small and large projects and minimal staff and training requirements.

(i) **Sampling:** sampling methods involving selection of size, number and shape of the plots and the design for locating the plots are the same as those described earlier. For long-term monitoring, the quadrat method with a large plot size (e.g. 50 × 50 m) is desirable for revisits and measurements.

(ii) **Location and layout of plots** the plots should be located using the chosen sampling design using the method explained earlier. For long-term monitoring, it is important to mark the plots in the field as well as on the map using GPS readings and with reference to any permanent landmark for easy identification on the ground.

(iii) **Recording and archiving of data** it is very important to develop formats for recording data in the field as well as entering them in a database.

(iv) **Staff and training** the staff involved in field and laboratory studies as well as data entry and analysis require training. In the long term, staff turnover in any project is quite likely. Therefore, it is important to maintain detailed guidelines and manuals on field and laboratory studies as well as data entry and analysis protoco

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Appendix (1):
Slope Correction

Slope		Correction Factor
%	0^0	
10-17	6-10	1.01
18-22	10-13	1.02
23-26	13-15	1.03
27-30	16-17	1.04
31-33	18-19	1.05
34-36	20-21	1.06
37-39	22-23	1.07
40-42	24-25	1.08
43-44	25-26	1.09
45-47	27-28	1.10
48-49	29-29	1.11
50-51	30-31	1.12
52-53	31-32	1.13
54-55	33-33	1.14
56-57	34-35	1.15
58-59	35-36	1.16
60-61	37-38	1.17

Appendix (2):
Some of basic instruments for field survey:

1. *Maps*:

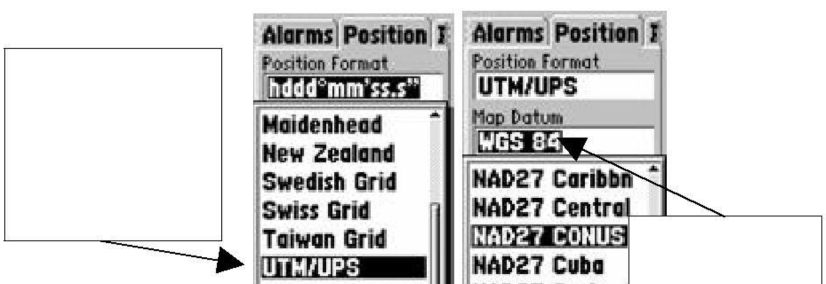
Each of the survey teams must have working maps of the area designated for inventory for a particular day/ week. The map should display the topography, administrative boundaries as well as the boundaries of different strata (AEZs), the grid points (cluster location) located in this area, and other physical features such as settlements roads, rivers, etc. useful for navigation.

2. **GPS**: Please check the settings of your GPS, and recalibrate, if necessary. Our pre-defined settings must be:

    1. Map coordinate system: **UTM UPS**

    2. Map datum: **WGS 84**

3. Units: metric system, meters



4. Compass: Make sure that you have at least onecompass per team and that you have familiarized yourself with the compass since there are various different types available.

5. **Measuring Tapes**: Two types of measuring tapes are needed.

1. 50m tape for measuring the transect distance and sideways.

2. Diameter tape in order to measure the diameters of the 6 trees

6. **Digital Camera**: The digital camera must be fullycharged and enough memory

7. **Record Tally sheets:** Enough copies/ print outs oftally sheets for the data recording must beavailable.

The office preparation and planning for a field inventory is of fundamental importance for the sake of a smooth operational implementation. This includes the following tasks:

- **Setting up the survey teams**: Each team should consist of three persons + a driverand a local guide who will be picked up in the field. If new persons join the survey teams it must be assured that they are trained in conducting the survey and hand-ling the equipment.
- **Division of labor:** During a meeting it should be clarified in which part of the pro-ject region each of the teams will conduct the survey. Within each of the teams three positions must be assigned:
    1. Booker, who is entering the field data into the tally sheets, taking compass read-ings and interviewing the farmers
    2. Measurer, taking tree diameters and GPS readings
    3. Local guide, assisting mainly the booker in identifying and describing the land use systems within the size of the plot.

8. Clinometer for measuring slope

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

SCIENTIFIC NAME	VERNACULAR NAME	WOOD DENSITY (KG M^{-3})
Hardwoods		
Acrocarpusfraxinifolius	-	610
Albiziagrandibracteata	Alele (O)	600
Albiziagummifera	Sissa (Am)	580
Albiziashimperiana	Sessa (Am)	530
Allophylusabyssinicus	Lekeme (Am)	580
Aningeriaadolfifriederici	Kerero (Am/O)	560
Antiaristoxicaria	Tengi (Sh)	470
Apodytesdimidiata	Cheleleka (O)	710
Blighiaunijugata	Tucho (O)	700
Bosqueiaphoberos	Gabu (O)	560
Celtiskraussiana	Kaut (Am)	760
Chlorophoraexcelsa	Dego (An)	570
Croton macrostachyus	Bisanna (Am)	560
Diospyrosabyssinica	Loko (O)	790
Ekebergiarueppennalia	Sombo (O)	580
Eucalyptus globulus	Nechi-bahrzaff (Am)	780
Eucalyptus grandis	Grandis-bahirzaff (Am)	560
Eucalyptus saligna	Saligna-bahrzaff (Am)	680
Fagaropsisangolensis	Dero (O)	700
Hageniaabyssinica	Kosso (Am)	560
Manilikarabutugi	Butugi (E)	870
Mimusops kummel	Kolati (O)	880
Morusmesozygia	Shamgareza (Am)	690
Ocoteskenyensis	Soecho (Si)	560
OleaHochsttetri	Gagama (O)	990
Oleawelwitschii	Baha (O/S)	820
Polysciasferruginea	Zinjero-wonder (Am)	440
Prunusafricana	Tiuku-enchet (Am)	850
Sysygiumguineense	Dokma (Am)	740
Warburgiaugandensis	Befti (O)	770
Softwoods		
Cupresssuslucitanica	Yeferenji-tidh	430
Pinuspatula	Patula pine (E)	450
Pinusradiata	Radiata pine (E)	450
Podocarpusfalcatus	Zgba (Am)	520

Source :(Yitebitu*et al.*, 2010)

Appendix (4A):

General Allometric Equations

Ecological zone	Reference	Equation	Variables
Tropical rainforest	Brown, S.(1997)	Y (kg) =21.297-6.953*(X)+0.740*((X^2))	X= DBH(cm)
Tropical moist deciduous forest	Brown, S.(1997)	Y (kg) =42.69-12.800*(X)+1.242*((X^2))	X= DBH(cm)
Tropical dry forest	Brown, S.(1997)	Y (kg) =exp(-1.996+2.32*ln(X))	X= DBH(cm)
Tropical dry forest	Brown, S.(1997)	Y (kg) =10^(-0.535+ln(X))	X= DBH(cm)
Tropical dry forest	Brown, S.A.J. et al.. (1989)	Y (kg) =34.4703-8.0671*X+0.6589*(X^2)	X= DBH(cm)
Tropical shrubland	Brown, S.A.J. et al.. (1989)	Y (kg) =34.4703-8.0671*X+0.6589*(X^2)	X= DBH(cm)
Tropical rainforest	Brown, S.A.J. et al.. (1989)	Y (kg) =exp(-3.1141+(0.9719*ln(((X^2)*Z)))	X= DBH(cm),Z= H(m)
Tropical moist deciduous forest	Brown, S.A.J. et al.. (1989)	Y (kg) =exp(-3.1141+(0.9719*ln((X^2)*Z)))	X= DBH(cm),Z= H(m)
Tropical rainforest	Brown, S.A.J. et al.. (1989)	Y (kg) =exp(-2.4090+(0.9522*ln((W^(2))*X*Z)))	X= DBH(cm),Z= H(m), Z= As(m2)
Tropical moist deciduous forest	Brown, S.A.J. et al.. (1989)	Y (kg) =exp(-2.4090+(0.9522*ln((W^(2))*X*Z)))	X= DBH(cm),Z= H(m), Z= As(m2)
Tropical rainforest	Ponce-Hernandez, R.(2004)	Y (kg) =exp(2.134+(2.530*ln(X)))	X= DBH(cm)
Tropical moist deciduous forest	Ponce-Hernandez, R.(2004)	Y (kg) =exp(2.134+(2.530*ln(X)))	X= DBH(cm)
Tropical dry forest	Chave, J. et al. (2005)	Y (kg) =X*exp(-0.667+(1.784*ln(Z))+(0.207*(ln(Z))^2)-(0.0281*(ln(Z))^3))	X= WD(g.cm-3),Z= DBH(cm)
Tropical dry forest	Chave, J. et al. (2005)	Y (kg) =exp(-2.187+(0.916*ln(X*Z^2*W)))	X= WD(g.cm-3),Z= DBH(cm), Z= H(m)
Tropical moist deciduous forest	Chave, J. et al. (2005)	Y (kg) =X*exp(-1.499+(2.148*ln(Z))+(0.207*(ln(Z))^2)-(0.0281*(ln(Z))^3))	X= WD(g.cm-3),Z= DBH(cm)
Tropical moist deciduous forest	Chave, J. et al. (2005)	Y (kg) =exp(-2.977+ln(X*Z^2*W))	X= WD(g.cm-3),Z= DBH(cm), Z= H(m)

Tropical rainforest	Chave, J. et al. (2005)	Y (kg) =exp(-2.977+ln(X*Z^2*W))	X= WD(g.cm-3),Z= DBH(cm), Z= H(m)
Tropical rainforest	Chave, J. et al. (2005)	Y (kg) =X*exp(-1.349+(1.980*ln(Z))+(0.207*(ln(Z))^2)-(0.0281*(ln(Z))^3))	X= WD(g.cm-3),Z= DBH(cm)
Tropical rainforest	Chave, J. et al. (2005)	Y (kg) =exp(-2.557+0.940*ln(X*Z^2*W))	X= WD(g.cm-3),Z= DBH(cm), Z= H(m)
Tropical rainforest	Chave, J. et al. (2005)	Y (kg) =X*exp(-1.239+(1.98*ln(X))+(0.207*(ln(X))^2)-(0.0281*(ln(X))^3))	X= WD(g.cm-3),Z= DBH(cm)
height-diameter relationship	Lewis, S.L. et al. (2009)	H (m) = 54.01 * (1-exp(-0.053(d^0.759)))	d = DBH (mm)
	Henry, M et al., 2010	Y=3.47*10^-3*d^(2)*h*wd	d=DBH, h=height, wd= wood density

Species Specific Allometric Equations

General Classification	Species Group	Equation	Source	Data originating from	Max DBH
Shade grown	*Coffea Arabica*	Biomass=exp(-2.719 + 1.991 (ln(dbh))) (log10dbh)	Segura et al. 2006	Nicaragua	8 cm
Pruned coffee	*Coffea Arabica*	Biomass = 0.281 x $dbh^{2.06}$	Van Noordwijk et al. (2002)	Java, Indonesia	10 cm
Banana	*Musa X paradisiacal*	Biomass = 0.030 x $dbh^{2.13}$	Van Noordwijk et al. (2002)	Java, Indonesia	28 cm
Orange trees	*Citrus sinensis*	Biomass = -6.64 + 0.279 x BA + 0.000514 x BA^2	Schroth et al. (2002)	Amazonia	8–17cm
Lianas	Lianas	Biomass = exp(0.12+0.91xlog (BA at dbh))	Putz (1983)	Venezuela	12 cm

Source:(Gene*neet al.,* 2013)

Appendix 4B: Allometric equations

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

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

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

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

General allometric equations for estimating biomass from tree diameter (D > 5 cm) and height.

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

Source:(Yitebitu*et al.*, 2010)

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

Appendix (5).

Biomass baseline survey data collection format(For trees measurement)

Form 1: Tree data collection form

Name of recorder _____________ Date____/____/____

Project_____________ Stratum number/ Vegetation type__________________

Plot number _______________ Elevation ____________ Location (GPD) coordinates N_________/E____________

Plot disturbance situation (fire, grazing, browsing, erosion, gullies, charcoal making, etc...) ____________Plot Size____________

Land use category 1.Degraded forest land 2.Agroforestry/cropland 3.homstead	Tree number	Name of trees /shrubs species		Tree measurement (in the bigger plot		Shrub measurement(in the shrub plot with in the bigger plot)			Total no of seedlings less than 1.5 m height at the center of bigger plot	Algometric equation used Based on Agro-ecology 1. dry < 1500mm $(AGB = 0.139 D^{2.32}$ 2. moist 1500-4000mm $(AGB = 0.118 D^{2.53}$	Estimated amount of Biomass Kg/tree or Kg/shrub	Carbon stock /Tree or per shrub
		Local Name	Scientific Name	DBH at 1.30m in CM	Circumference at 1.30 m in CM	DSH above 30cm from ground	DBH at 1.30 m in CM	Circumference at 1.30 m in CM			Biomass: in Kg	0.50*Biomass

Source: own modified (2014)

Biomass baseline survey data collection format

Form 2: Crop land /Agroforestry / Homesteads

Name of recorder ____________ Date____/____/____

Elevation ___________ Location GPS (coordinated) N____________________/E___________________

Area of the parcel / homestead where trees are measured_________________

Land use category 1.Degraded forest land 2.Agroforestry/cropland 3.Homestead	Tree number	Name of trees /shrubs species		Tree measurement (in the cropland, homestead		Algometric equation used Based on Agro-ecology 1. dry < 1500mm (AGB = 0.139 $D^{2.32}$ 2. moist 1500-4000mm (AGB = 0.118 $D^{2.53}$	Estimated amount of Biomass Kg/tree	Carbon stock /Tree
		Local Name	Scientific Name	DBH at 1.30m in CM	Circumference at 1.30 m in CM		Biomass: in Kg	0.50*Biomass

Source: own modified (2014)

Form 4: Biomass of understorey vegetation-destructive sampling

Collector ___________________ Date_____/_____/_____

Project________________________ Stratum number____________________

Plot No	Sub plot size	Total Fresh weight (kg		Sub sample fresh weight (g)		Sub sample dry weight (g)		Total dry weight (g)	
		Leaf/herb	wood	Leaf/herb	Wood	Leaf/herb	wood	g/frame	g/m^2

Form 4: Litter dry weight data collection form

Collector ___________________ Date_____/_____/_____

Project________________________ Stratum number_____________

Stratum No	Sub plot size	Total fresh weight (kg)	Sub sample fresh weight (g)	Subsample dry weight (g)	Total dry weight (g)

Form 5: Deadwood data collection form

Collector ___________________ Date_____/_____/_____

Project________________________ Stratum number____________________

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

Source:(Yitebitu*et al.*, 2010)