OCTOBER 2005

INTEGRATING CARBON BENEFIT ESTIMATES INTO GEF PROJECTS

UNDP

GEF

CAPACITY DEVELOPMENT AND ADAPTATION GROUP

GUIDELINES

ACKNOWLEDGEMENTS

We would like to acknowledge the valuable inputs and review comments of Yamil Bonduki, Andrew Bovarnick, Tim Boyle, Richard Hosier, Maryam Niamir-Fuller and Bo Lim. This document has been edited by Rebecca Carman and designed by Rebecca Buttrose.

For more information on the work of the Capacity Development and Adaptation group contact:

Bo Lim
Principal Technical Advisor on Capacity Development and Adaptation
United Nations Development Programme
Global Environment Facility
Bureau of Development Policy
301 East 45th St, 9th floor
New York, NY 10017
USA

Email: bo.lim@undp.org
Tel: +1-212-906-5730
Fax: 1-212-906 6998
Internet: www.undp.org/gef/

U N
D P

GEF

UNITED NATIONS DEVELOPMENT PROGRAMME
GLOBAL ENVIRONMENT FACILITY

INTEGRATING CARBON BENEFIT ESTIMATES INTO GEF PROJECTS

PREPARED BY
T. R. H. Pearson[1], S. Brown[1] and N. H. Ravindranath[2]

TEAM MEMBERS
K. MacDicken[1], D. Shoch[1], I. K. Murthy[2], P. Sudha[2] and C. A. Sahana[2]

1. Winrock International, Arlington, Virginia, USA
2. Indian Institute of Science, Bangalore, India
Email: tpearson@winrock.org, sbrown@winrock.org, ravi@ces.iisc.ernet.in

CONTENTS

EXECUTIVE SUMMARY

The Global Environment Facility (GEF) was established to help developing countries fund programmes that protect the global environment and promote sustainable livelihoods in local communities. There are 15 operational programmes (OPs) through which the GEF provides grants. A number of these programmes, especially in biodiversity and land degradation, are concerned with land management practices that can increase or decrease carbon stocks. Throughout these guidelines, the term "GEF projects" is used generically to describe such programmes.

The purpose of these guidelines is to provide methods for measuring and estimating carbon stocks and the changes in carbon stocks that may result from relevant GEF project interventions. Methods are proposed for estimating all relevant carbon pools as well as emissions, or avoided emissions, of non-CO_2 greenhouse gases. The methods focus on terrestrial systems, but can also be applied to wetlands, mangroves and any coastal- or freshwater system dominated by plants.

The guidelines are aimed at assisting project developers, managers, and evaluators, as well as implementing and monitoring agencies. They are targeted at non-experts and a user-friendly format has been adopted to make the guidelines easier for non-expert audiences to understand. The methods presented here are supported by a range of tools, techniques, procedures and default values.

There are strategic reasons for measuring the carbon in GEF projects. Of particular importance is the baseline condition of the project site, because measures of the carbon stocks on the land serve as a valuable indicator of the state of the resources. Many ecosystem services are highly correlated to the carbon stocks in vegetation and soil. Before making a decision to measure carbon, project developers should make a preliminary assessment of activities eligible for carbon finance and, if eligible, estimate if the magnitude of changes in carbon pools and stocks are sufficient to justify transaction costs. For example, projects which are related to afforestation and reforestation of fast-growing species in the tropics are likely to accrue significant changes in above-ground biomass over a 60-year period. Such projects would be potential candidates for carbon finance at the present time.

The baseline carbon stocks also serve as the basis for comparison to determine whether project activities have had an effect or not. For any GEF project interested in engaging in carbon measurements over the longer term, a key step is to quantify the initial carbon stocks on the project lands. The carbon assessments need not be exhaustive, but the methods should be rigorous. A GEF project with poorly measured carbon stocks and very low precision will not be able to demonstrate the undoubted positive impacts that its project activities have had.

These guidelines seek to present user-friendly, yet rigorous, methods for carbon assessment. The methods presented can be tailored to fit within the resources available for assessing changes in carbon stocks, yet still give credible results.

1. GEF PROJECTS AND THEIR CARBON IMPACT

The Global Environment Facility (GEF) was established to help developing countries fund programmes that protect the global environment and promote sustainable livelihoods in local communities. Six broad focal areas are addressed: biodiversity, climate change, international waters, land degradation, the ozone layer and persistent organic pollutants.

There are 15 operational programmes (OPs) through which the GEF provides grants. Five focus on biodiversity, four on climate change, three on international waters, one on persistent organic pollutants, one on land degradation and one on multi-focal integrated ecosystem management [1].

1.1 CLIMATE CHANGE AND CARBON

Carbon exists in everything that is living or has ever lived, and there is a perpetual cycle of carbon being sequestered on earth and emitted back into the atmosphere. Humankind increasingly influences this carbon cycle. It is argued that the accelerating accumulation of greenhouse gases, particularly carbon dioxide (CO_2), in the atmosphere from human activities is driving climate change. It is likely that current atmospheric CO_2 concentrations are at a 20-million-year high and that current rates of accumulation are unprecedented [2].

Emissions of CO_2 from land use and land-use change represent up to 20 per cent of current CO_2 emissions from burning fossil fuels [3, 4]. Land-use projects can either decrease the CO_2 emissions that would occur without intervention or sequester (i.e., absorb and store) CO_2 from the atmosphere into vegetation and the soil beneath vegetation. Preventing deforestation, decreasing the impact of logging and preventing the drainage of wetlands or peat lands are all activities that decrease CO_2 emissions. Planting trees, changing agricultural tillage or cropping practices and re-establishing grasslands are activities that sequester carbon.

The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) recognises the role that changes in the use of land and forests have on the global carbon cycle and includes a mechanism (the Clean Development Mechanism [CDM]; Article 12) by which industrialised (Annex I) nations can offset some of their emissions by investing in projects in non-industrialised nations. For land use and land-use change, the CDM permits credits through afforestation and reforestation only – all other potential land-use projects are currently excluded.

Unlike CDM, GEF projects are not limited exclusively to forestation activities. They can focus on forest conservation and forest management, restoration of grazing lands or wetlands, or improved management of cropland or grazing lands.

Projects included in the CDM are required to have accurate and precise measurements (see Section 2 for further discussion on accuracy and precision) of changes in carbon stocks that are audited by an accredited agency. However to show that there has been a climate change impact for any GEF project, it is necessary to assess the changes in carbon stocks – the carbon assessments need not be exhaustive, but the

The table below summarises the similarities and differences between CDM Land Use, Land-Use Change and Forestry (LULUCF) projects under the Kyoto Protocol and GEF projects.

	CDM – LULUCF	GEF PROJECTS
Carbon is primary focus	Yes	No
Context of programme	Climate change	Environmental protection and sustainable development
Purpose	Tradable credits	Evaluation of achievements project and potential for generating carbon credits
Requirement for precise carbon measurement and auditing	Yes	No
Eligible project activities	Forestation only†	All
Length of project	Up to 60 years	Up to 3 years

† Afforestation is the process by which forests are established and grown on bare or cultivated land that has not been forested in recent history. Reforestation increases the capacity of land to sequester carbon by replanting forest biomass in areas where forests were recently harvested. In the context of the Kyoto Protocol, there are specific time limits applied to both of these processes.

methods should be rigorous. A GEF project with poorly measured carbon stocks and very low precision will not be able to demonstrate the undoubted positive impacts that its project activities have had. These guidelines seek to present user-friendly, yet rigorous, methods for carbon assessment. The methods presented here can be tailored to fit within the project resources available for assessing changes in carbon stocks, while still giving credible results.

Even though GEF biodiversity and land degradation projects are not designed to specifically address climate change mitigation, there might be strategic reasons to measure the baseline carbon stocks using the methods given in these guidelines. In particular, it is important to assess the baseline or initial conditions of the project area because:

- As noted earlier, baseline carbon stocks can serve as the basis for comparison in the future to determine whether project activities have had an effect or not.
- Measures of the carbon stocks on the land serve as a valuable indicator of the state of the resources. Many ecosystem services are highly correlated to the carbon stocks in vegetation and soil.
- For any GEF project that might evolve into a longer-term carbon project, a key step is to quantify initial carbon stocks on project lands – that is, to quantify the baseline.

2. THE SCOPE OF THESE GUIDELINES

The purpose of these guidelines is to provide methods for estimating carbon stocks and the changes in carbon stocks resulting from project intervention. The guidelines are designed to be applicable to any study evaluating carbon over shorter (less than three years) to longer (more than three years) time periods and provide practitioners with methods that can achieve long-term climate change benefits and leave open options for seeking carbon financing in the future.

Methods are proposed for estimating all relevant carbon pools as well as emissions, or avoided emissions, of non-CO_2 greenhouse gases. The methods focus on estimating carbon stocks and changes in carbon stocks for a variety of terrestrial land-cover and land-use classes, but also apply to wetlands, mangroves and any coastal or fresh-water systems.

The guidelines aim to assist project developers. managers and evaluators, as well as implementing and monitoring agencies. They are targeted at non-experts and a user-friendly format has been adopted to make the guidelines easier for non-expert audiences to understand. The methods presented here are supported by tools, techniques, procedures and default values for measuring and estimating carbon stocks and their change over time.

Information is drawn from the Winrock Carbon Methods Manual [5], the Intergovernmental Panel on Climate Change (IPCC) Special Report on Land Use, Land-Use Change and Forestry [6]; the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories [7]; the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry [8]; the US Voluntary Greenhouse Gas Emission Reporting (1605b) Program [9]; and additional published literature.

2.1 THE CONCEPTS OF ACCURACY, PRECISION AND BEING CONSERVATIVE

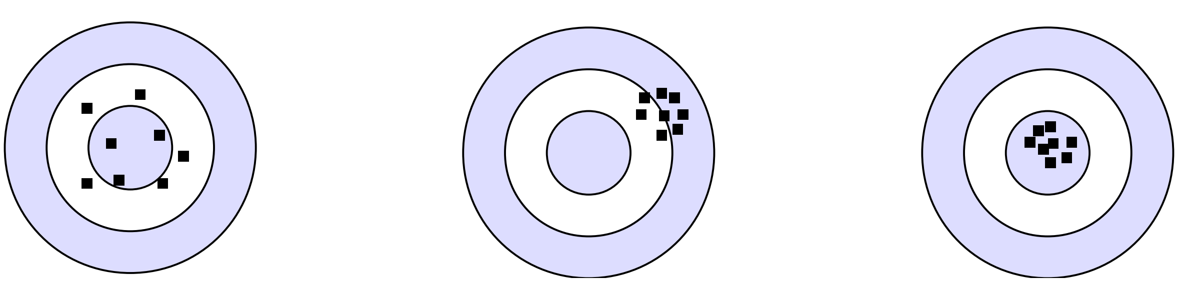
To estimate the carbon stocks on land, one could measure everything – every single tree, for example, in the tens or hundreds or thousands of hectares of the project area. However, complete enumerations are almost never possible in terms of time or cost. Consequently, we sample.

Sampling is the process by which a subset is studied in order for generalisations to be made about the whole population or area of interest. The values attained from measuring a sample are just an estimation of the equivalent value for the entire area or population. We need to have an idea of how close the estimation is to reality and this is provided by statistics.

In sampling, there are two statistical concepts that have to be understood: accuracy and precision. **Accuracy** is how close your sample measurements are to the actual real value. **Precision** is how well a value is defined – in this case, how closely grouped are the results from the various sampling points or plots.

A popular analogy is a bull's eye on a target – how tightly the arrows are grouped is the precision and how close they are to the centre is the accuracy. Below in Figure (A), the points are close to the centre and therefore accurate, but widely spaced and therefore imprecise. In (B), the points are closely grouped and therefore precise, but are far from the centre and so inaccurate. In (C), the points are close to the centre and tightly grouped and are thus both accurate and precise.

(A) Accurate but not precise | (B) Precise but not accurate | (C) Accurate and precise



When sampling for carbon, we want measurements that are both accurate (i.e., close to the reality for the entire population) and precise (i.e., closely grouped, so we can have confidence in the result). However, we also have to consider the amount of project resources available for generating accurate and precise estimates and tailor our precision levels accordingly (see box right).

Carbon sampling on land inevitably involves measuring a number of plots. The number of plots is predetermined to ensure accuracy and precision (see Section 6.4 for more information). The average value when all the plots are combined represents the wider population. We can tell how representative the average value is by looking at the **confidence interval**. A 95% confidence interval is frequently used, which tells us that 95 times out of 100 the true carbon density lies within the interval. If the interval is small – in this case ±5% of the mean – then the result is precise.

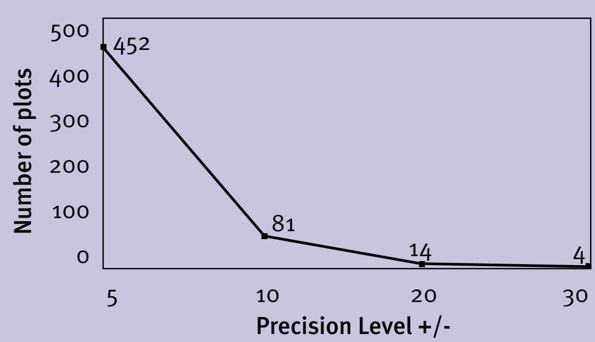
One final concept that is followed in carbon measurement work is that of being **conservative**. Sometimes it is not possible to measure a particular pool or a very broad estimate has to be made. In these cases, the method that is followed, or the numbers that are used, are the most conservative within the possible biological range.

Tailoring the sampling approach to available resources

GEF projects will vary in the amount of resources they have available for implementing a carbon measuring and monitoring plan. As mentioned earlier, poorly measured carbon stocks with unknown, or very low, precision will not be able to demonstrate the undoubted positive impacts that a project has had. Therefore the measurement plan will have been of little value.

The methods presented in these guidelines can be tailored to fit the project resources available for assessing changes in carbon stocks, while still giving credible results. The amount of resources that need to be spent on implementing a monitoring plan is highly related to the number of plots to be measured and the desired precision level. The number of plots needed to attain a given precision level decreases as the desired precision level decreases.

The figure below shows an example of measurements taken in a complex tropical forest in Bolivia with five different forest strata covering more than 640,000ha. It can be seen that to attain a high precision – that is, a 95% confidence interval of ±5% of the mean – 452 plots would be needed. However only 81 plots needed for ±10% of the mean and 14 plots for ±20% of the mean.



Thus, when resources are limited, the precision level can be set lower and fewer plots sampled. Even at ±20% of the mean, the results would be accurate with a known precision and likely to be able to show a change in carbon stocks with confidence.

3. THE TYPES OF PROJECTS

Integrated ecosystem management projects are unique in that they are multifocal, bringing synergy between the GEF focal areas of biodiversity, climate change, international waters and land degradation within the context of sustainable development.

The **multiple environmental benefits** of these projects include:

- reduction of net emissions and increased storage of carbon in terrestrial and aquatic ecosystems;
- conservation and sustainable use of biological diversity;
- prevention of pollution of globally important terrestrial and aquatic ecosystems; and
- conservation and sustainable use of land and water bodies.

The multiple land-use components

A project area might be dominated by only one type of land use or land cover, such as forests, grasslands or agricultural lands. More often, however, the landscape includes multiple land-use systems with inter-linkages such as watersheds, agro-ecosystems and grazing lands. Most of these projects are likely to be multiple land-use systems.

For simplicity, we define three broad land-use types – forest, grazing land and cropland:

- **Forest** includes all land with a significant canopy cover. This incorporates natural forest, plantations and forested wetlands, including peat swamps and mangrove forests.
- **Grazing land** is a very broad category that includes managed pastures, prairies, steppe and savannas. Grazing lands will often include trees but only at low density. Aquatic systems such as flooded grasslands and salt marshes would also fall into this category.
- **Cropland** defines any land on which non-timber crops are grown. This includes both herbaceous crops and higher-carbon-content systems such as fruit orchards and coffee, cacao and palm oil plantations.

The table below shows examples of potential projects, along with the broad project and land-use type each falls under and whether carbon is sequestered or prevented from being emitted under the project.

Broad Project Type	Broad Land-Use Type	Sequestered Carbon or Avoided Emissions	Examples of Potential Projects	CDM Eligible?
Conservation	Forest Grazing land	Avoided emissions	Stopping logging, Stopping deforestation Stopping clearing for an alternative land use	No
Management	Forest Grazing land Cropland	Avoided emissions Sequestered carbon	**Forests:** Changing to reduced impact logging Increasing harvest rotation lengths Extending riparian buffers Adopting sustainable practices **Grazing lands:** Altering grazing patterns **Croplands:** Increasing length of fallow period Halting burning practices Conservation tillage Switching to higher carbon content crops	No
Restoration	Forest Grazing land	Sequestered carbon	**Forests (Forestation):** Replanting multi-purpose species on cropland Planting trees on degraded land Rehabilitating forested wetlands/mangroves Planting timber Short-rotation biomass energy plantations **Grazing lands:** Increasing tree density Reseeding with deep-rooted native species Rehabilitating forested wetlands	Yes/No†

† Depends on density of trees and country-specific definition of forest as prescribed by the Marrakech Accords of the Kyoto Protocol. Host countries must define a forest within the following guidelines: • minimum tree crown cover between 10% and 30%; • minimum land area between 0.05ha and 1.0ha; and • minimum tree height between 1m and 5m

4. THE PROBLEM OF LEAKAGE

The implementation of GEF projects should not lead to the loss of carbon, either directly or indirectly, outside the project area. If carbon is lost outside, this is referred to as leakage – that is, an unanticipated loss of net carbon benefits of a project as a consequence of project activities [10].

At a simple level, leakage can be split into three categories (adapted from [10]):

- **Activity shifting** occurs when the activities that cause emissions are not permanently avoided, but are simply displaced to another area. Common examples are: (1) when a forest conservation project leads land-conversion activities to shift to a non-project area; (2) extraction of biomass (e.g., fuelwood or timber) is banned in the project area and causes forest-dependent communities to shift extraction to non-project locations; and (3) a ban on grazing in project villages leads grazing to shift outside the project area boundary.

- **Market effects** occur when emission reductions under the project are countered by the emissions created by a shift in supply and demand of the products and services affected by the project. This is of minimal importance for farming activities but can be important for large-scale commercial timber harvesting. For example, a stop-logging project might decrease the supply of timber, leading other practitioners to increase their rate of harvest in response to market signals in supply and demand.

- **Super-acceptance** may result from alternative livelihoods programmes created for the project. If the activities are very successful, they can draw in people from the surrounding regions. The result may be a positive or negative leakage – positive if the immigrants were previously deforesting or practising a similarly high greenhouse gas-emitting lifestyle, but negative if the immigrants previously had lower greenhouse gas-emitting lifestyles and now have access to new land, for example, to deforest.

The science of evaluating leakage is not well developed and currently it is not possible to monitor or track leakage accurately – it is simply not feasible to separate impacts outside the boundary of the project from the without-project scenario, nor is it feasible to track the potentially worldwide market effects.

Calculating leakage is generally only critical when the aim of the project is to produce credits to offset greenhouse gas emissions from anthropogenic sources. GEF projects, with their focus on sustainable development, should not be as susceptible to leakage since community alternative livelihood programmes will automatically be built into the projects – thereby diminishing the risk of the local community leaking carbon benefits outside the project boundaries. The potential for activity shifting can be high in conservation projects, however, and the issue should be considered on a project-by-project basis.

Consequently, the optimum strategy to reduce the possibility of leakage is to plan alternative livelihood programmes that diminish leakage to the greatest possible extent and target those stakeholders responsible for the greatest negative carbon impact. It can be assumed that if the adoption rate of these alternative livelihoods is high, then leakage is essentially zero. Even if a project does have some leakage, it does not mean the project is "no good" – it just means efforts must be made to quantify the leakage effect. Leakage is not unique to land-use projects – estimating leakage from energy or landfill projects is just as challenging.

5. THE BASELINE SCENARIO

For any project, a baseline (or "without-project" reference case) needs to be developed against which project results can be measured. Here, the baseline scenario is a projection of the changes in land use and carbon stocks in the project area in the absence of the project activity – in other words, the changes in carbon stocks between the time the project starts and some point in the future.

The 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 in the foreseeable future (i.e., 10 to 30 years) are unlikely. Carbon stocks here, and throughout these guidelines, represent the quantity of carbon per unit area – typically tons of carbon per hectare (t C/ha). Carbon credits are the difference between carbon stocks in the baseline and carbon stocks with project activities.

To develop the baseline, we assess two components:

- A projection of business-as-usual changes in land use in the project site; and
- The changes in carbon stocks without project activities in the project site during this time.

The baseline is the product of the area of land-use and the change in carbon stocks for that land use over the projected time frame.

For example, in a forestation project, the land-use component of the baseline could be a slow rate of natural regeneration in the project area while the carbon component would be the projection of changes in the carbon stocks on the slowly naturally-regenerating land. The carbon baseline (in this case, net removals or carbon sequestration) would then be the product of the area undergoing natural regeneration and the change in carbon stocks over time[1].

Evaluating the land-use scenario component of the baseline requires an understanding of trends in land use in the region. An extrapolation can be made from the changes in land use happening at the time of project commencement, or from changes in land use continuing on land adjacent to the project site. These factors are frequently assessed using satellite imagery or aerial photographs from the past to the present. More complex analyses, using spatial modelling (e.g. GEOMOD [11, 12]), can be used to project future pressures on the land that will drive future changes in land use.

To evaluate the carbon component of the baseline, it should be judged whether the baseline will be a steady, fixed state, such as agricultural land (in which case only a single initial set of measurements are required), or whether a changing carbon component, such as natural regeneration, is more appropriate (in which case control plots should be employed in a proxy area outside the project boundaries).

In the table below, the form of the two components of the baseline is detailed for different project activities.

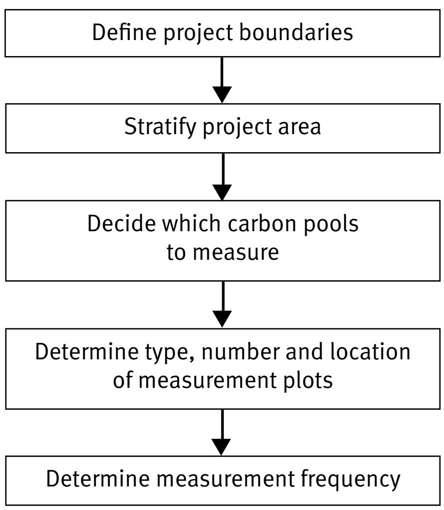
Project Type	Land-Use Component	Carbon Component
Conservation	**Projection into future:** governed by numerous biophysical drivers and socioeconomic pressures	**Fixed** initially if cleared for agriculture or development **Changing** if regrowth occurs, e.g., after logging
Management practices	**Changing:** governed by prevailing practices	**Changing:** governed by prevailing
Forestation of degraded lands	**Fixed:** unless natural regeneration/ rehabilitation is occurring	**Fixed:** unless natural regeneration/ rehabilitation is occurring

1 In a management project, the land-use component might be maintenance of the status quo – that is, continuous cropping, and the baseline would be the product of the land under cropping and the change in carbon over time (in this case, practically zero). Finally, for a conservation project, the land-use component would be the projected rate of deforestation for the project area and the carbon component would be the carbon stocks in the forests being cleared. The carbon baseline (in this case, emissions) would be the product of the rate of clearing and the carbon stock in the forests being cleared over time.

STEP 1	Determine business-as-usual changes in land use at project site. This is usually possible through discussions with local residents. For land-use changes for conservation projects, see Section 9.1.
STEP 2	Determine whether the carbon stock without project activities will be fixed or changing (see previous table).
STEP 3a	If fixed, accurately and precisely estimate carbon stocks in each stratum at the start of the project, with measurements in a predetermined number of plots based on the desired precision level (see Section 6.4 for more information).
STEP 3b	If changing, set up plots in a proxy area close to, and representative of, the project site, and measure in parallel with measurements to the project site.
STEP 4	The **baseline = area of land use x carbon stock** for that land use. Repeat for each land use and each change in land use within project site.

6 DEVELOPING A MEASUREMENT AND MONITORING PLAN

As discussed earlier, it is important to assess changes in carbon stocks with as much accuracy and precision as possible, according to the resources available. There are five steps to developing a robust measuring and monitoring plan, which are summarised in the following flow chart, and explained further below.



6.1 DEFINE THE PROJECT BOUNDARIES

Projects can vary in size from tens of hectares to hundreds of thousands of hectares. They can be confined to a single geographic area or several. The project site may be one contiguous block of land with a single owner, or many blocks of land spread over a wide area, with either a large number of small landowners or a few large ones. The spatial boundaries of the land need to be clearly defined and properly documented from the start to aid accurate measuring and accounting.

STEP 1 Obtain a map(s) of the project area.

STEP 2 Define the project boundaries using features on the map or co-ordinates obtained with a global positioning system.

6.2 STRATIFY THE PROJECT AREA

To facilitate fieldwork and increase the accuracy and precision of measuring and estimating carbon, it is useful to divide the project area into sub-populations (or strata) that form relatively homogenous units. In general, stratification also decreases the costs of monitoring because it typically diminishes the sampling effort needed to maintain the same level of confidence (because of smaller variation in the carbon stocks in each stratum as opposed to the whole area). Useful tools for defining strata include ground-truthed maps from satellite imagery, aerial photographs and maps of vegetation, soils or topography.

The size and spatial distribution of the land area does not influence site stratification – one large contiguous block of land or many small parcels can be stratified in the same manner. The stratification should be carried out using criteria directly related to the variables to be measured and monitored, e.g., the carbon pools in trees for a forestation project. There will be a trade-off between the number of strata and the sampling intensity – the purpose of stratification is to partition natural variation in the system and so reduce monitoring costs. If stratification leads to no change or minimal change in costs, it should not be undertaken.

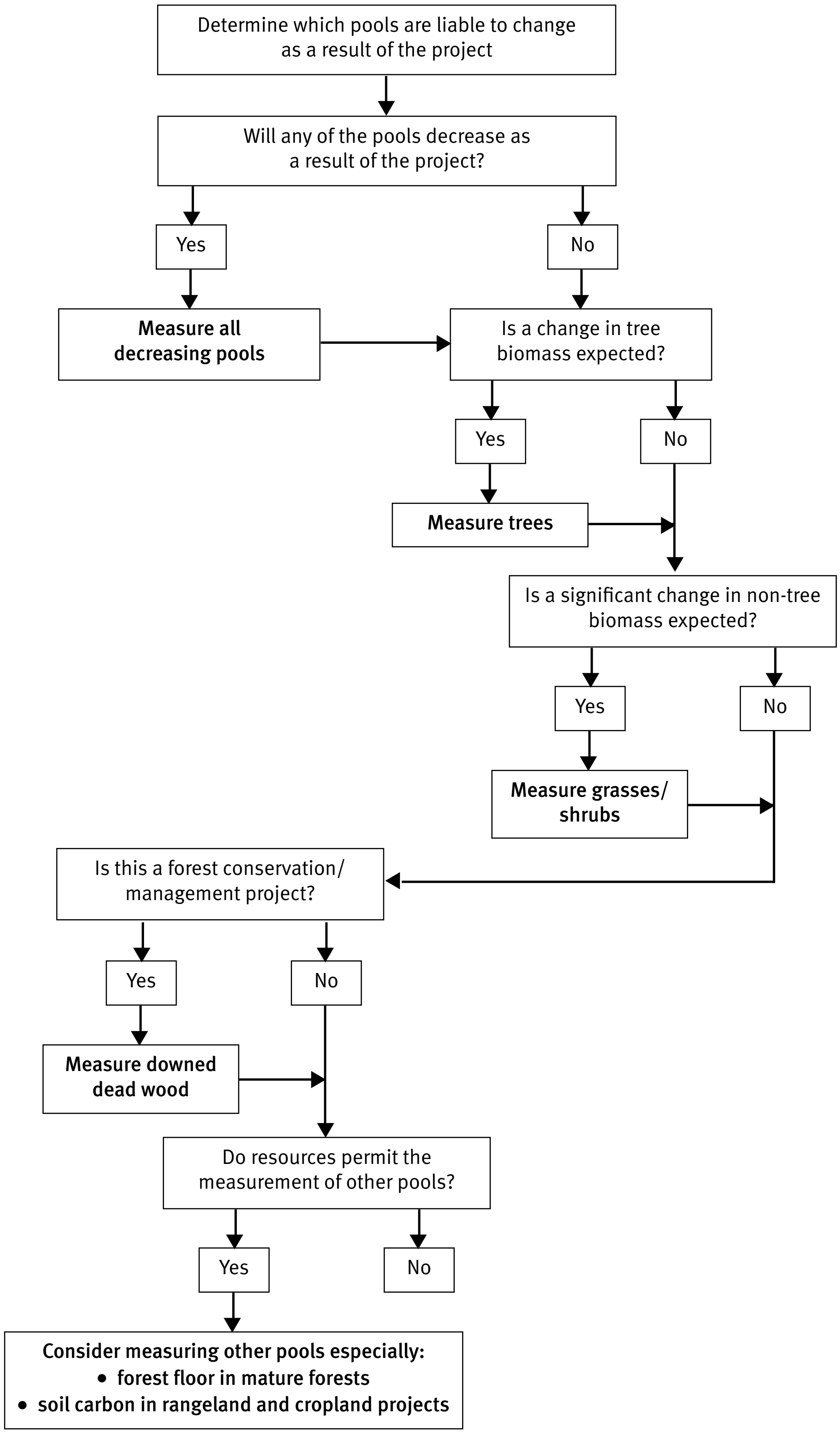
Typically, a project might be divided into between one and six different strata. Potential stratification options include:

- Land use, e.g. forest, plantation, agro-forestry, grassland, cropland, irrigated cropland;
- Vegetation species (if several);
- Slope, e.g. steep, flat;
- Drainage, e.g. flooded, dry;
- Age of vegetation;
- Proximity to settlement.

6.3 DECIDE WHICH CARBON POOLS TO MEASURE

There are seven carbon pools – **aboveground trees, aboveground non-trees, belowground roots, forest floor (or litter), dead wood, soil,** and **long-term wood products**. However, not all seven pools will be significantly impacted in a given project.

The flow diagram (overleaf) provides guidance on which pools to evaluate for changes in carbon stocks between with- and without-project scenarios.


Determine which pools are liable to change as a result of the project
Will any of the pools decrease as a result of the project?
Yes
No
Measure all decreasing pools
Is a change in tree biomass expected?
Yes
No
Measure trees
Is a significant change in non-tree biomass expected?
Yes
No
Measure grasses/ shrubs
Is this a forest conservation/ management project?
Yes
No
Measure downed dead wood
Do resources permit the measurement of other pools?
Yes
No
Consider measuring other pools especially:
• forest floor in mature forests
• soil carbon in rangeland and cropland projects

Selecting which carbon pools to measure depends on several factors, including the : (1) expected rate of change; (2) magnitude and direction of change; (3) availability and accuracy of methods to quantify change; and (4) cost to measure. All pools that are expected to decrease as a result of project activities should be measured and monitored. Pools that are only expected to increase by a small amount relative to the overall rate of change need not be measured or monitored.

Climate change issues and evaluation of carbon credits are a secondary purpose for GEF projects. So the emphasis in these guidelines is on methods that capture the carbon changes that occur, but with consideration for minimising costs of measurement.

Clearly, it makes sense to measure and estimate the carbon pool in live trees and their roots for all activity types – trees are simple to measure and contain substantial amounts of carbon. Aboveground non-trees or understory, such as shrubs or herbaceous plants, may also need measuring if this is a significant carbon component – for instance, where trees are absent or are only present at low densities (e.g., woodlands and savannas). But non-tree vegetation may not need to be measured in closed forests, for example, where it is likely to account for only a very small proportion of the total carbon stock and is unlikely to change very much through time.

Forest floor and dead wood only apply to forest projects and tend to only be a significant carbon component in mature forests. Dead wood is composed of standing dead trees and downed dead wood. For project activities related to changes in management for timber production, dead wood must be measured as often this pool decreases as a result of a change in management. For example, changing from more-intensive harvesting to less-intensive harvesting will cause the dead wood pool to decrease (as less timber is removed and less slash is left behind).

Soil organic carbon is likely to change at a slow rate and is also likely to be an expensive pool to measure relative to the amount of change in the stock. To minimise costs, soil carbon need not be measured in most projects. Following the conservative principle, it is only essential to measure a pool if it faces a decrease as a result of the project activity. However, sequestration of carbon into the soil or prevention of emissions of carbon from soils can be important, especially in grazing land and cropland systems and omitting soil carbon in this case is an omission of a source of reductions in atmospheric greenhouse gases. Indeed for some potential project activities, such as conservation tillage in agriculture, the only climate change effects will be carbon sequestration into the soil. Such projects, however, are currently not eligible for carbon finance.

The decision matrix shown below presents the main carbon pools and which ones will show a significant change in carbon (yes [Y]), or could show a significant change in carbon (maybe [M]) for each project type. Where a cell is shaded, the pool is not applicable.

CARBON POOLS TO BE MEASURED AND MONITORED							
Project Type	**Living Biomass**			**Dead Organic Matter**		**Soil**	**Wood Products**
	Aboveground trees	**Aboveground non-trees**	**Below ground**	**Forest floor**	**Dead wood**		
Conservation							
Forests	Y	M	Y	M	Y	M	Y
Grazing lands	Y	Y	Y			Y	
Management							
Forests	Y	M	Y	M	Y	M	Y
Grazing lands	Y	Y	Y			Y	
Cropland	Y	Y	Y			Y	
Restoration							
Forests	Y	M	Y	M	M	M	M
Grazing lands	Y	Y	Y			Y	

The decision to monitor wood products depends on whether trees will ultimately be harvested or not. Activities related to changes in forest management need to include wood products as often this reduces the change in the live carbon pool; likewise for forest conservation if the original activity was a timber production forest. In other words, not all the live biomass "protected" by the activity (either as conservation or reduced logging intensity) can be claimed as a savings for the atmosphere because some of the biomass would have gone into long-term wood products.

6.3.1 What to measure over short time frames

A short-term project of three years or less limits the potential for measurable changes in carbon stocks. The table below presents the pools where it can be anticipated that there will be measurable changes in carbon stocks over three years for certain activities. As the change in carbon stocks in croplands occurs mostly in the soil, it is not expected that any changes that occur could be significant over a three-year period without an intensive sampling effort.

6.4 DETERMINE THE TYPE, NUMBER AND LOCATION OF MEASUREMENT PLOTS

A number of decisions must be made with regards to the plots to be measured. The type of vegetation will affect whether plots are temporary or permanent, and their size, shape and location. The number of plots required is related to the desired precision level and whether the site is stratified. Finally, it must be decided whether to locate plots across the project site in a random or systematic pattern.

6.4.1 Determine type of plots

STEP 1 Determine if vegetation is tree or non-tree.

6.4.1.1 Tree carbon pools

<u>Selecting temporary or permanent plots</u>

When estimating biomass carbon changes in trees, either permanent or temporary sampling plots can be used. **We recommend permanent plots for trees** as we see more advantages and fewer disadvantages. Permanent sample plots are generally regarded as statistically more efficient in estimating changes in forest carbon stocks than temporary ones [13]. In addition, permanent plots permit efficient verification, if needed, at relatively low cost: a verifier can find and measure permanent plots at random to verify, in quantitative terms, the design and implementation of the carbon monitoring plan.

When using permanent sample plots, marking or mapping the trees to measure the growth of individuals at each time interval becomes critical so that the growth of survivors, mortality and ingrowth of new trees can be tracked. Changes in carbon stocks for each tree are estimated and summed per plot. Statistical analyses can then be performed on net carbon accumulation per plot, including ingrowth and losses due to mortality.

However where measurements are only made at one point in time – such as for conservation projects – there is no value in marking plots and trees.

<u>Selecting the shape and size of plots</u>

The size and shape of the sample plots is a trade-off between accuracy, precision, time and cost for measurement. There are two basic forms of plots – a single plot of a fixed size or a series of nested plots of increasing size.

Single plots are useful for forestation projects, such as plantations of timber or multipurpose species, where stands are likely to be composed of trees of a fairly narrowly sized distribution through time. If a single plot is going to be used, the question becomes: how big should it be? While increasing sample size increases precision, increasing plot area decreases variability between samples according to the following relationship:

$$CV_1^1 = CV_1^2 \mp \sqrt{\left(\frac{P_1}{P_1}\right)}$$

where CV_1 is the coefficient of variation based on the P_1 (plot one) area and CV_2 is the coefficient of variation based on the P_2 (plot two) area. Thus, by increasing plot area, variation among plots is reduced, which allows for a smaller sample size while targeting the same precision level.

Experience shows the optimum area for a single plot can be anticipated by the planting density of the trees in the plantation and the planned thinning schedule. It is likely that the number of trees in the single plot could be higher in the earlier stages of the project before any thinning is performed, but at the young ages the trees can be quickly measured. The plot size should "capture" about eight to 12 trees per plot at the latter stages of the project when the trees are larger.

Nested plots are sample plots containing smaller sub-units of various shapes and sizes. They are cost-efficient for forests with a wide range of tree diameters or stands with changing diameters and stem densities (e.g., in natural forest management or forest preservation). Nested plots are composed of several (typically two to four, depending upon forest structure) full plots, each of which should be viewed as a separate plot. The plots could take the form of nested *circles* or *squares*. Circles work well if you have access to distance measuring equipment (DME [e.g., from Haglöf, Sweden]) because then the actual boundary around the plot need not be marked. If a DME is not available, it may be more efficient to use square-shaped plots that are laid out with tape measures and stakes. When trees attain the minimum size (according to diameter at breast height [dbh]) for a nested plot, they are measured and included; when they exceed maximum size for a nested plot, measurement in that nest stops and begins in the next largest nest. How to track and analyse the data from nested plots is described, with examples, in Section 8.1.

Nested plots for recording discrete size classes of stems are a practical design for sampling, and are well-suited to stands with a wide range of tree diameters or to stands with changing diameters and stem densities.

It is possible to calculate the appropriate plot size specifically for each project, however this adds an additional complication and an additional effort to the process. For simplicity, plot-size rules are presented in the table below that can be applied to any project. Experience has shown these plot sizes represent a reasonable balance of effort and precision.

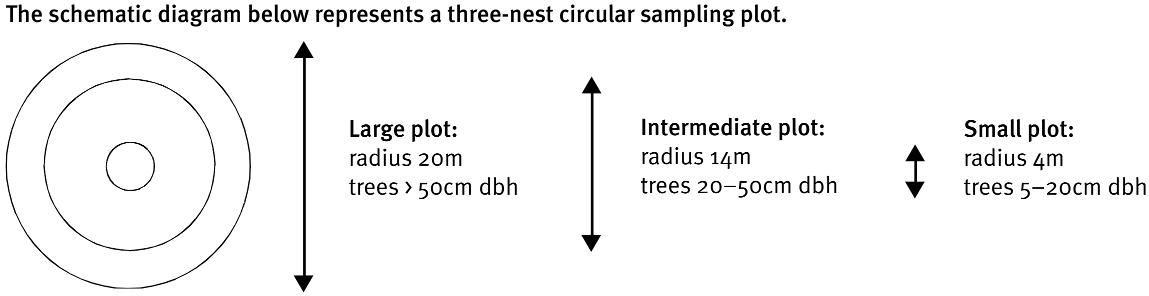
Stem Diameter	Circular Plot Radius	Square Plot Dimensions
† < 5cm dbh	1m	2m x 2m
5–20cm dbh	4m	7m x 7m
20–50cm dbh	14m	25m x 25m
> 50cm dbh	20m	35m x 35m

† stems < 5cm dbh would only be measured in very young forest.

Data and analyses from the plot level are extrapolated to an area of one hectare to produce carbon stock estimates (since we report carbon stocks in tons of carbon per hectare). We do this by using expansion factors to calculate the proportion of a hectare that is occupied by a given plot (see Section 8 for information on calculating expansion factors). As an example, if a series of nested circles measuring 4m, 14m and 20m in radius were used, their areas are 50m^2, 616m^2 and 1,257m^2 respectively. The expansion factors for converting the plot data to a hectare basis are 198.9 for the smallest, 16.2 for the intermediate and 8.0 for the largest nested plot.

Because all carbon measurements are reported on a horizontal-projection basis, plots on sloping lands must use a correction factor. This correction factor accounts for the fact that when distances measured along a slope are projected to the horizontal plane, they are smaller. If the plot falls on both level and sloping ground, it is easiest to move the plot so that it is entirely level or entirely sloping. If the plot falls on a slope, the slope angle should be measured using a clinometer. Where the sample plot is located on a slope that is >10%, the slope should be quantified so that an adjustment can be made

The schematic diagram below represents a three-nest circular sampling plot.



to the plot area at the time of analysis. True horizontal radius is calculated using the following formula:

$$L = L_S \times \cos S$$

where L is the true horizontal plot radius, L_S is the standard radius measured in the field along the slope, S is the slope in degrees, and cos is the cosine of the angle.

Correcting for slope results in a plot of area:

CIRCULAR PLOT: Area = π x standard radius (L_S) x slope plot radius (L)

SQUARE PLOT: Area = Plot width x calculated true plot length (L)

For example, for a plot on a slope of 25°, L_S for the 20m radius circular plot is 20 x 0.91 or 18.1m (0.91 = cos 25). Thus, the area of the plot would be 3.142 x 20 x 18.1 = 0.11ha. For a plot on a slope of 15°, L_S for a 25m square plot is 25 x 0.97 or 24.1m (0.97 = cos 15). Thus the area of the plot would be 25 x 24.1 = 0.06ha.

STEP 1 Decide if plot will be temporary or permanent.

STEP 2 Decide if plot will be nested or single.

STEP 3 Calculate size of plot (using correction factor if land is sloping).

6.4.1.2 Non-tree carbon pools

Non-tree carbon pools differ from tree pools in that it is not physically feasible to measure an identical sample at two periods in time. For non-tree vegetation, forest floor and soil, the process of measuring the sample destroys that sample because it is collected, weighed and dried in an oven. For downed dead wood, the sample is not necessarily destroyed, but tracking pieces of dead wood between two periods of time is logistically very challenging. Consequently, for each of these pools, the samples are temporary. To maintain statistical independence (an abstract concept that is important to guarantee representative results), the sampling location should be moved at each census.

For the destructively sampled components, the size of the plot should be big enough to capture a sufficiently large sample while still maintaining a high level of sampling efficiency. Typically, for herbaceous vegetation and forest floor, a small sub-plot of between 0.25m^2 and 0.5 m^2 in area is used. For shrubs, a larger plot, perhaps 1m^2, could be used. For soil, coring devices are used and typically four 30cm soil cores are pooled to create a single sample for carbon concentration, with two additional cores for bulk density (see Section 7.6 for more information).

For project activities related to grazing lands or croplands, the concept of a permanent plot does not exist either. Thus, in general, more plots are needed for these project activities to demonstrate significant changes in carbon stocks over time.

6.4.2 Determine number of plots

It is important that sampling is carried out with statistical rigour, otherwise it will be difficult to have confidence about the achievements of the project. In employing this rigour, the first step is identifying the required number of plots to reach the desired precision in the results.

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 earlier in Section 2. Accurate estimates of the net change in carbon stocks can be achieved at a reasonable cost to within 10% of the true value of the mean at the 95% confidence level [14]. The level of precision should be determined at the outset – ±10 % of the mean is frequently employed, although a precision as low as ±20 % 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 between two time periods has occurred.

Once the level of precision has been decided, sample sizes can be determined for each stratum in the project area. Each carbon pool will have a different variance (i.e., amount of variation around the mean). However experience has shown that focusing on the variance of the dominant carbon pool (e.g., trees for forestry activities, or soil for cropland or grazing land systems) captures most of the variance. Even though variation in the other components may be higher, if high precision is attained within the dominant component, a lack of precision in the other components will not harm the overall results.

STEP 2a Identify existing data either specific to the area (perhaps from local universities, government agencies or research laboratories) or from the scientific literature.

STEP 2b If no existing data are found, identify an area to collect preliminary data. For example, if the activity is to afforest agricultural lands and the activity will last for 20 years, then an estimation of the carbon stocks in trees for about six to 10 plots of an existing 15- to 20-year-old forest would suffice. For a forest conservation project, six to 10 preliminary plots in the forest area would work.

If the project site consists of multiple strata, preliminary data are required for each stratum.

STEP 3 Estimate carbon stock, standard deviation and variance from preliminary data.

STEP 4 Calculate the required number of plots.

For a single stratum project, the number of plots (n) is calculated as follows:

$$n = \left(\frac{ts}{E}\right)^2$$

where:
E is the desired half-width of the confidence interval, calculated by multiplying the mean carbon stock by the desired precision (i.e., mean carbon stock x 0.1 for 10% precision or 0.2 for 20% precision); t is the sample statistic from the t-distribution for the 95% confidence level – t is usually set at 2, as sample size is unknown at this stage, and s represents the standard deviation.

For example:

Area	= 5,000ha
Mean stock	= 101.6 tC/ha
Standard deviation	= 27.1 tC/ha
Desired precision	= 10%
E	= 101.6 x 0.1 = 10.16

$$n = \left(\frac{2 \times 27.1}{10.16}\right)^2$$

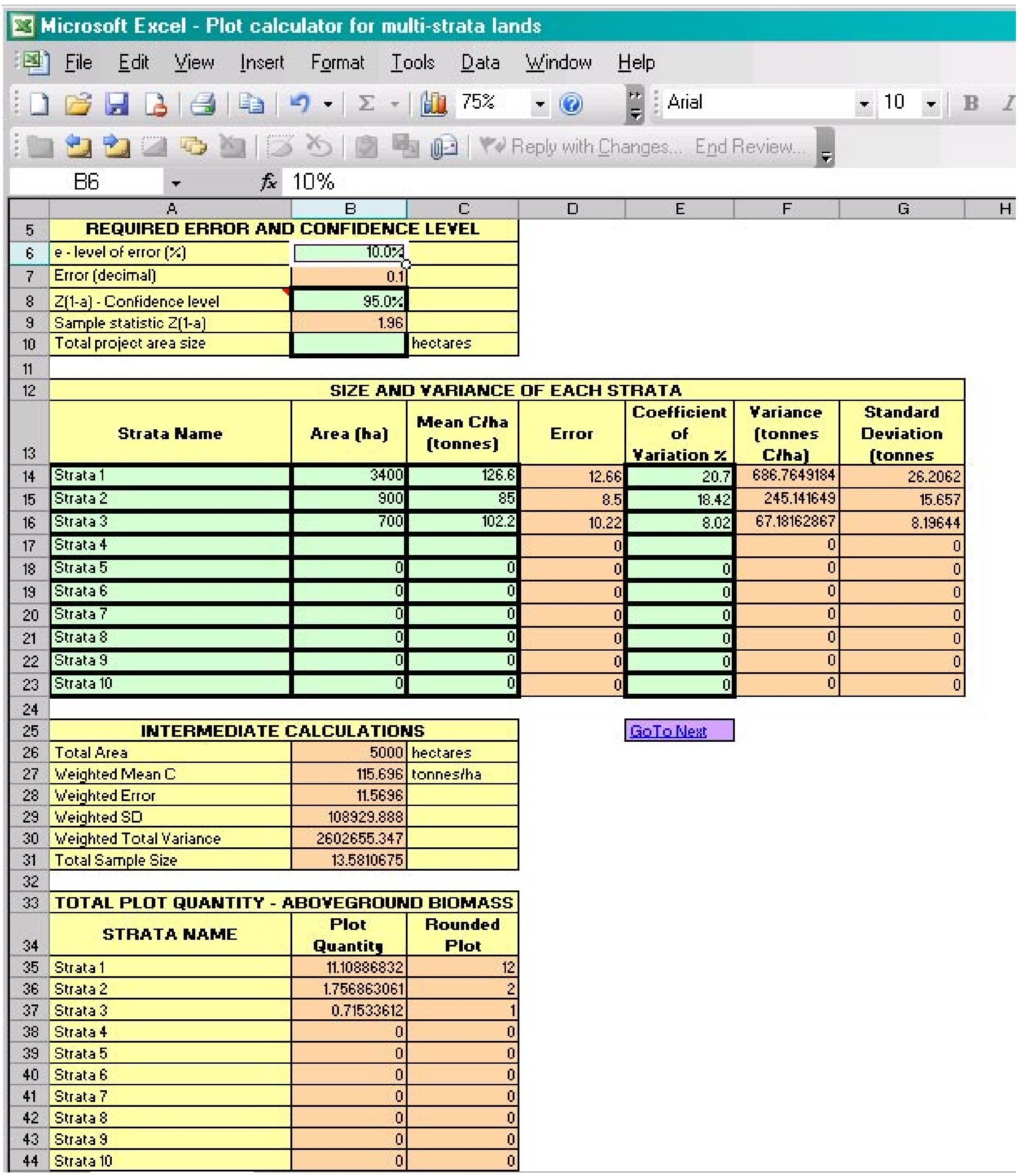
= 28 plots

The more variable the carbon stocks, the more plots are needed to attain the desired precision levels.

If the project is stratified, calculations for the number of plots are more complex. A tool for calculating number of plots for projects of any size, with and without strata, is available on the Winrock International website (http://www.winrock.org/what/ecosystem_pubs.cfm). An illustration of the application of this tool is shown overleaf for the same project area of 5,000ha, but based on the assumption that the area is divided into three strata with corresponding areas, carbon stock estimates, and coefficients of variation. Using this spreadsheet, it can be seen that stratifying the area resulted in a total of 15 plots – distributed as 12 in the first stratum, two in the second and one in the third.

The formulas and spreadsheet can equally be used for non-tree and soil carbon pools. Such plots will be temporary, and new random locations should be chosen at each measurement period. To estimate the number of plots needed for other carbon pools can be loosely based on the number of plots for the dominant component. For example, a single 100m line intersect (for downed dead wood, see Section 7.4.2), four clip plots (for herbaceous vegetation and the forest floor, see Sections 7.3 and 7.5) and four soil samples (see Section 7.6) would be sufficient per tree plot.

If a stratified project area requires 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.



REQUIRED ERROR AND CONFIDENCE LEVEL		
e - level of error (%)	10.0%	
Error (decimal)	0.1	
Z(1-a) - Confidence level	95.0%	
Sample statistic Z(1-a)	1.96	
Total project area size		hectares

SIZE AND VARIANCE OF EACH STRATA						
Strata Name	Area (ha)	Mean C/ha (tonnes)	Error	Coefficient of Variation %	Variance (tonnes C/ha)	Standard Deviation (tonnes
Strata 1	3400	126.8	12.66	20.7	686.7649184	26.2062
Strata 2	900	85	8.5	18.42	245.141649	15.657
Strata 3	700	102.2	10.22	8.02	67.18162867	8.19644
Strata 4			0		0	0
Strata 5	0	0	0	0	0	0
Strata 6	0	0	0	0	0	0
Strata 7	0	0	0	0	0	0
Strata 8	0	0	0	0	0	0
Strata 9	0	0	0	0	0	0
Strata 10	0	0	0	0	0	0

INTERMEDIATE CALCULATIONS		
Total Area	5000	hectares
Weighted Mean C	115.696	tonnes/ha
Weighted Error	11.5696	
Weighted SD	108929.888	
Weighted Total Variance	2602655.347	
Total Sample Size	13.5810675	

Go To Next

TOTAL PLOT QUANTITY - ABOVEGROUND BIOMASS		
STRATA NAME	Plot Quantity	Rounded Plot
Strata 1	11.10886832	12
Strata 2	1.756863061	2
Strata 3	0.71533612	1
Strata 4	0	0
Strata 5	0	0
Strata 6	0	0
Strata 7	0	0
Strata 8	0	0
Strata 9	0	0
Strata 10	0	0

6.4.3 Determine location of plots

To maintain statistical rigour, plots must be located without bias. The entirety of the project site should be sampled – if plots follow a road or trail then all locations in the project do not have an equal chance of selection and a systematic bias has been introduced. Instead, the location of plots should either be random or located using a fixed grid that covers the entire area. If little is known about the population being sampled, a random selection of sample units within a stratum is generally safer than systematic selection. If plot values are distributed irregularly in a random pattern, then both approaches are about equally precise. If some parts of the stratum have higher carbon content than others, then systematic selection will usually result in greater precision than random selection.

Where the other carbon pools are to be measured in addition to the dominant component, it is reasonable to base the location of these secondary pool plots near the location of the original plot. However, these plots should be outside the original plot and if remeasurement occurs, any temporary plots should be in a new location at each census. Good practice would be to locate the secondary pool plot adjacent to the original plot and to choose a new compass bearing from the centre of the original plot at each census.

STEP 1 Prepare a map of the project showing the boundaries with strata, if applicable, delineated within the project boundaries.

STEP 2 Decide whether plots will be distributed systematically or randomly.

STEP 3a Random location of plots can be achieved using random number tables, the random function in GIS programs or by using the millisecond counter in a stop watch to take a random bearing and random distance for assigning plots on the map.

STEP 3b Systematic location of plots within each stratum can be achieved by overlaying a grid on the map and allocating plots in a regular pattern across the strata.

6.5 DETERMINE FREQUENCY OF MEASUREMENT

It is recommended that for carbon accumulation, the frequency of measurements should be defined in accordance with the rate of change of the carbon stock:

- Forest processes are generally measured over periods of five-year intervals.
- Carbon pools that respond more slowly, such as soil, are measured every 10 or even 20 years,
- For activities that conserve mature ecosystems and little change in carbon stocks is expected, only an initial measurement would be required, followed by monitoring of the area to ensure that illegal activity has not decreased carbon stocks.
- For forest management projects, measurements should aim to capture the spectrum of vegetation conditions over the cycles of logging or harvest and regrowth.

7 FIELD MEASUREMENTS

7.1 PREPARATION FOR FIELDWORK

Efficient planning is essential to reduce unnecessary labour costs, avoid safety risks and ensure reliable carbon estimates. The equipment used in fieldwork should be accurate and durable enough to withstand the rigours of use under adverse conditions. The type of equipment required will depend on the type of measurements, but the following list covers most of what is typically used in the field.

Compass[1] for measuring bearings
Fibreglass meter tapes (100m and 30m) for measuring distances
Global Positioning System (GPS) for locating plots
Aluminum nails and numbered tags[2] for marking trees
Tree diameter (dbh) tape[3] for measuring trees
Clinometers (percent scale) for measuring tree height and slope
Coloured rope and pegs or metal rods and PVC pipe for marking square plot boundaries
Digital measuring device (DME) for measuring plot boundaries
100m line or 2 x 50m lines for measuring dead wood
Calipers for measuring dead wood
Relascope or transparent measuring ruler for measuring standing dead wood
Hand saw, machete or chainsaw for collecting dead wood samples and cutting destructive samples
1kg and 300g spring scales for weighing destructive samples
Clip frame or sampling frame for measuring forest floor layer and non-tree vegetation
Large plastic sheets or tarpaulin for mixing forest floor/understory samples
Soil sampling probes or shovel and bulk density ring for sampling soil
Rubber mallet for inserting soil probes
Cloth[4] **(e.g., Tyvek) or paper bags** for collecting soil and understory samples

1 *A compass with declination adjustment is preferred so that accurate and replicable bearings can be taken.*
2 *If trees are to be tagged, aluminum nails and tags should always be used to avoid rust.*
3 *Dbh tapes are critical when making tree measurements. Steel or aluminum dbh tapes are normally used – cloth ones should be avoided as they can stretch and result in inaccurate measurements. Dbh tapes are relatively inexpensive and are readily available from suppliers such as: www.forestry-suppliers.com or www.benmeadows.com.*
4 *Cloth bags are preferred for collecting soil samples as paper ones have a tendency to rip. Plastic bags do not allow for the samples to dry, which can result in increased respiration and inaccurate results.*

7.2 MEASURING TREES, PALMS AND LIANAS

7.2.1 Trees

The biomass and carbon stocks of trees are estimated using appropriate equations applied to the tree measurements. For practical purposes, tree biomass is often estimated from equations that relate biomass to dbh. Although the combination of dbh and height is often superior to dbh alone, measuring tree height can be time consuming and will increase the expense of any monitoring programme. Furthermore, databases of trees from around the world show that highly significant biomass regression equations can be developed with very high accuracy using just dbh. In forestry, breast height is defined as 1.3 meters above the ground.

STEP 1 Accurately locate the plot centre (use of a GPS is the preferred approach).

STEP 2 If the plot is permanent, mark the centre (if plot is circular) or the boundaries (if plot is square) and assign a unique number to the plot. Experience has shown that metal rods and/or PVC pipe work well.

STEP 3a Starting at the north of the plot, begin measuring trees. Flag the first tree to mark the start/end point. Measure diameter at breast height (1.3m) using the guidance below.

STEP 3b After measuring each tree, move clockwise to the next tree. If the plots are to be remeasured, tag the trees using an aluminum numbered tag and nail. It is not necessary to record tree species unless species with different forms exist in the same area (e.g., pines and broadleaf species or palms or some early colonising species).

Tagging trees

When trees are tagged, the aluminium numbered tag and nail should be placed 10cm below dbh to avoid errors arising from bumps or other imperfections that can develop at the point where the nail enters the tree. (In future inventories, the dbh measurement will be taken by measuring 10cm up from the nail.) The aluminium nail should be inserted deep enough to hold the tag firmly, but with enough nail exposed for the tree to grow. If the trees in the project area will be subjected to harvest in the future, the nail and tag should be placed at the base of the tree to avoid any accidents from chainsaws or other equipment. Each plot should contain a description of which approach was used, so future measurements can be completed efficiently and accurately.

STEP 3c To allow accurate accounting of ingrowth (i.e., growth of trees into the minimum size class of the nested plot), the position of new trees should be recorded at each census with regard to each of the nested plots.

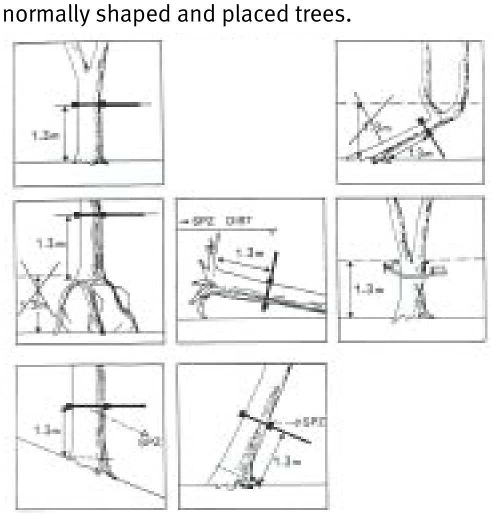
STEP 3d Occasionally trees are close to the plot border. Plots are typically small and plot data is extrapolated to estimate biomass carbon on a per hectare basis. It is therefore important to carefully decide if a tree is in or out of a plot. If more than 50% of the trunk is within the plot boundary, the tree is in. If more than 50% of the trunk is outside of the boundary, it is out and should not be measured. If it is exactly on the border of the plot, flip a coin to determine if it is in or out.

Using a dbh measuring tape

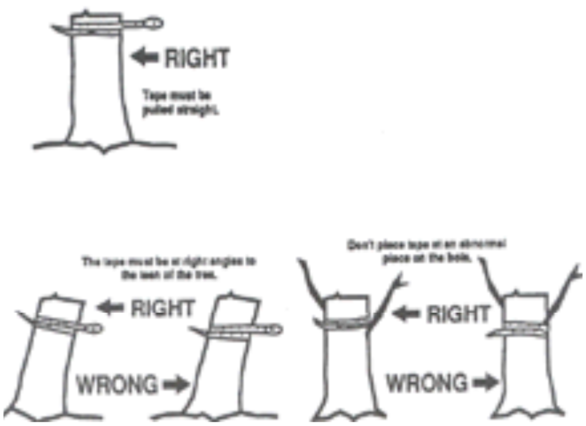
It is important that the dbh tape is used properly to ensure consistency of measurements.

- Have a 1.3m staff or pole available so the dbh location on the tree can be identified accurately. If one is not available, a sturdy stick (at least 2cm in diameter) can be used. Alternatively, each member of the inventory team should measure the location of breast height (1.3m above ground) on their own bodies and use that location to determine the placement of the tape.
- Dbh tapes have a hook on the end. Push the hook into the bark of the tree and pull the tape to the right. The dbh tape should always start left and be pulled right around the tree – even if the person taking the measurement is left-handed.
- As the dbh tape wraps around the tree and returns to the hook, the tape should be above the hook. The tape should not be upside down; the numbers must be right-side up.
- If the tree is on a slope, always measure breast height on the uphill side.
- If the tree is leaning, the dbh tape must be wrapped according to the tree's natural angle, not straight across parallel to the ground.
- If the tree is forked at dbh, measure just below the fork point. If it is impossible to measure below the fork, then measure as two trees.
- If a tree has fallen over but is still alive, place the measuring stick at the bottom and measure at dbh as if the tree was standing upright. Trees are considered alive if there are green leaves present.
- If a liana or vine is growing on a tree that is going to be measured, do not cut the liana to clear a spot to measure the tree's dbh. If possible, pull the liana away from the trunk and run the dbh tape underneath. If the liana is too big to pull away from the trunk, use the back of the dbh tape and pull it across the front of the tree to estimate the diameter visually (or use a caliper). Cutting a liana from a tree should only be a last resort, because over time and with repeated measurements, interfering with the natural dynamics in the plot will make it different from the surrounding forest. The same standard should be followed for any other type of natural organisms (mushrooms, epiphytes, fungal growths, termite nests, etc.) that are found on the tree.

Dbh measurement locations for irregularly and normally shaped and placed trees.



Proper use of a dbh tape.



7.2.2 Palms

If palms are present, only their height should be recorded, as biomass for palms is more closely related to height than to diameter.

STEP 1 Determine if palms are present in the nested plots and if any exceed 1.3m in height.

STEP 2 For any palms exceeding 1.3m, measure height using a clinometer or directly if the palm is only a few meters tall. Measure only the height of the stem, i.e., from the base up to the spot where the stem is no longer visible.

STEP 3 If the plot is to be remeasured, insert an aluminum numbered tag at 10cm below dbh.

7.2.3 Lianas

Lianas are difficult to measure because they are often long and cross the plot in several places – unless they form a significant component of the ecosystem, don't measure them.

It is hard to find biomass equations to use with lianas. An equation (created in Venezuela) is provided in Appendix D linking biomass with basal area at breast height.

STEP 1 Determine if lianas are a significant biomass component.

STEP 2 If necessary, measure at dbh. Take care the same liana is not measured more than once. Lianas do not normally grow to more than 10cm in diameter, so typically they will only be measured in the smallest nested plot.

7.3 NON-TREE VEGETATION

Non-tree vegetation is measured by simple harvesting techniques. For herbaceous plants, a 30cm x 30cm square sample frame made from PVC pipe is sufficient for sampling. For shrubs and other large non-tree vegetation, use larger frames ($1m^2$ to $2m^2$, depending on the size of vegetation).

STEP 1 Place clip frame at the sampling site. If necessary, open the frame and place around the vegetation.

STEP 2 Clip all vegetation within the frame to ground level. The frame should be viewed as extending vertically and any vegetation falling outside the boundaries of the plot (even if is begins inside the plot) should be excluded.

STEP 3 Weigh the sample and remove a well-mixed subsample for determining dry-to-wet mass ratio. Weigh the subsample in the field, then oven-dry to a constant mass (usually ~ 70°C).

7.4 DEAD WOOD

7.4.1 Standing dead wood

Within plots delineated for live trees, standing dead trees should also be measured. The dbh and a decomposition state of the dead tree should be recorded. Decomposition classes for standing dead wood are defined practically as follows:

1. Tree with branches and twigs and resembles a live tree (except for leaves).
2. Tree with no twigs but with persistent small and large branches.

3. Tree with large branches only.
4. Bole (trunk) only, no branches.

For categories two, three and four, the height of the tree and the diameter at ground level should be measured and the diameter at the top should be estimated. Height can be measured using a clinometer. Top diameter can be estimated using a relascope or through the use of a transparent measuring ruler – hold the ruler approximately 10cm to 20cm from your eye and record the apparent diameter of the top of the tree. The true diameter is then equal to:

$$\text{True diameter (m)} = \frac{\text{Distance eye to tree (m)}}{\text{Distance eye to ruler (m)}} \times \text{Ruler measurement (m)}$$

7.4.2 Downed dead wood

Lying dead wood is most efficiently measured using the line-intersect method [15, 16]. Only measure coarse dead wood (i.e., wood with a diameter > 10 cm) with this method – dead wood with a smaller diameter is measured with forest floor.

STEP 1 Lay out one 100m line or two 50m lines in a straight line or two 50m lines at right angles.

STEP 2 Along the length of the line(s), measure the diameter of each intersecting piece of coarse dead wood (> 10 cm diameter) – calipers work best for this. A piece of dead wood should only be measured if: (1) more than 50% of the log is aboveground, and (2) the sampling line crosses through at least 50% of the diameter of the piece. If the log is hollow at the intersection point, measure the diameter of the hollow – the hollow portion in the volume estimates is excluded.

STEP 3 Assign each piece of dead wood to one of three density classes: **sound, intermediate or rotten**. To determine which density class the dead wood belongs to, each piece should be struck with a saw or machete. If the blade does not sink into the piece (i.e., it bounces off), it is classified as sound. If the blade sinks partly into the piece and there has been some wood loss, it is classified as intermediate. If the blade sinks into the piece and there is more extensive wood loss and the piece is crumbly, it is classified as rotten.

STEP 4 Samples of the three dead wood density classes, representing the range of species present, should be collected for density (dry weight per green volume) determination. Use a chainsaw or handsaw to cut a complete disc from the selected piece of dead wood. The average diameter and thickness of the disc should be measured to estimate volume. The fresh weight of the disc does not have to be recorded; rather, the disc should be oven-dried to a constant weight.

7.5 FOREST FLOOR LAYER

The forest floor (or litter) layer is defined as all dead organic surface material on top of the mineral soil. Some of this material will still be recognisable (e.g., dead leaves, twigs, dead grasses and small branches) and some will be unidentifiable, decomposed fragments of organic material. Note that dead wood with a diameter of less than 10cm is included in the litter layer.

Litter should be sampled at the identical time of year at each census to eliminate seasonal effects. A 30cm x 30cm square sample frame made from PVC pipe is sufficient for sampling.

STEP 1 Place the clip frame at each sample site.

STEP 2 Collect all litter inside the frame. A knife can be used to cut pieces that fall on the border of the frame. Place all the litter on a tarpaulin beside the frame.

STEP 3a Where the sample bulk is low (less than 0.5kg), it is not necessary to weigh the sample in the field. Rather, oven-dry the total sample to a constant weight.

STEP 3b Where the sample bulk is excessive, the fresh weight of the total sample should be recorded in the field and a subsample of manageable size (approximately 80g to 100g) taken for moisture content determination, from which the total dry mass can be calculated.

7.6 SOIL

To obtain an accurate inventory of organic carbon stocks in mineral or organic soil, three types of variables must be measured: (1) depth; (2) bulk density (calculated from the oven-dried weight of soil from a known volume of sampled material); and (3) the concentrations of organic carbon within the sample.

For convenience and cost-efficiency, it is advised to sample to a constant depth, maintaining a constant sample volume rather than mass – a 30cm probe is an effective measurement tool (see Steps 1 and 2, right).

In well-developed forest stands, however, the core can be problematic as roots are often encountered. In this case, use a folding entrenching shovel (a flat, military-type of shovel) to dig small pits to 30cm depth, making sure one of the walls is perpendicular to the soil surface. Then use the shovel to collect a slice of soil from the perpendicular wall. The slice should be uniform throughout the 30cm profile, i.e., an equal amount of soil should be collected from the first 15cm of soil as the last 15cm.

To sample for bulk density using the pit approach, bulk density rings are commonly used. From one of the remaining sides of the soil pit, place the bulk density ring at 15cm depth, cover with a piece of wood and hammer the ring into the side of the soil pit (avoid compacting the soil). When the ring is flush with the side of the soil pit, dig it out, being careful not to drop any soil out of the ring. The sample at the 15cm depth is used to represent the whole soil profile to 30cm.

STEP 1 Insert the soil probe steadily to 30cm depth. If the soil is compacted, use a rubber mallet to fully insert. If the probe will not penetrate to full depth, do not force it – it is likely a stone is blocking its route and, if forced, the probe will be damaged. Pull the probe out and try again nearby. It is important that a whole core be extracted.

STEP 2 Carefully extract the probe and place the sample into a cloth bag. Because the carbon concentration of organic materials is much higher than that of the mineral soil, including even a small amount of surface material can result in a serious overestimation of soil carbon stocks.

STEP 3 To reduce variability, aggregate four samples from each collection point for carbon concentration analysis.

STEP 4 At each sampling point, take an additional two aggregated cores for determination of bulk density. When taking cores for measurements of bulk density, care should be taken to avoid any loss of soil from the cores.

STEP 5 Soil samples can be sent to a professional lab for analysis. Commercial laboratories exist throughout the world and routinely analyse plant and soil samples using standard techniques. It is recommended that the selected laboratory be checked to make sure that they follow the commonly accepted standard procedures with respect to sample preparation (e.g., mixing and sieving), drying temperatures and carbon analysis.

For bulk density determination, make sure the lab dries the samples in an oven at 105°C for a minimum of 48 hours. If the soil contains coarse rocky fragments, the coarse fragments must be retained and weighed. For soil carbon determination, the material is sieved through a 2mm sieve and then thoroughly mixed. The dry combustion method, using a controlled-temperature furnace (e.g., a LECO CHN-2000 or equivalent), is the recommended method for determining total soil carbon [17] but the Walkley-Black method is also commonly used.

8. DATA ANALYSES

Most calculations determine values for the biomass of a particular carbon pool, except soil, which usually measures carbon directly. To convert biomass to carbon, divide by two:

$$\text{Carbon} = \frac{\text{Biomass}}{2}$$

However, if local values for the carbon content are available, use these instead.

Extrapolating from per plot values to per hectare values requires expansion factors, which indicate the area each sample represents. This standardisation is required so that results can be easily interpreted and compared to other studies.

$$\text{Expansion factor} = \frac{10{,}000\ \text{m}^2}{\text{Area of plot, frame or soil core (m}^2)}$$

8.1 ABOVEGROUND (LIVE TREE) BIOMASS

Biomass equations for live trees relate dbh to biomass. Published equations are available both for individual species and groups of species, although this literature is inconsistent and incomplete. Before applying a biomass equation, it is important to consider the original location of the equation because trees in a similar functional group can differ greatly in their growth form between geographic areas. Choose an equation based on a location similar to the project area. If no suitable biomass equation can be found, a new equation can be developed but this is a resource-intensive operation.

STEP 1 Search for a suitable biomass equation. Either use equations presented in these guidelines (see Appendix D), search the literature for equations, consult with experts (perhaps in local universities or government forestry departments) or, as a last resort, create new equations (see Appendix C). When making biomass calculations, the given maximum diameter for the equation should be carefully observed. Using equations for trees that exceed the maximum diameters can lead to substantial error (see [18] for ideas on how to address the problem of trees that exceed the size limit of the database).

STEP 2 For each tree, calculate biomass using the chosen biomass equation.

For example:
A 55cm dbh tree was measured in moist tropical forest in Bolivia. A general equation for moist tropical forests was chosen (adapted from [18]) and 55cm was well within the maximum dbh (148cm) for this equation:

Biomass (kg) = exp (-2.289 + 2.649 x ln*dbh* – 0.021 x [ln*dbh*]^2)

1. 2.649 x ln(55) = 10.615
2. 0.021 x [ln55]^2 = 0.337
3. -2.289 + 10.615 – 0.337 = 7.989
4. exp(7.989) = 2,948kg = 2.95 tons of biomass or 1.47 tons of carbon

STEP 3a For projects doing a one-time measurement or when measuring to establish the required number of plots or the baseline carbon stock, sum the biomass of each tree in each nest, then multiply by the expansion factor to get biomass per hectare for each nested plot. Finally, sum the nested plots to get the total estimated number of tons per hectare for that plot.

STEP 3b For projects that are tracking the accumulation of carbon in trees, subtract the biomass of a given tree at Time 1 from the biomass of the same tree at Time 2 to get the increment of accumulation.

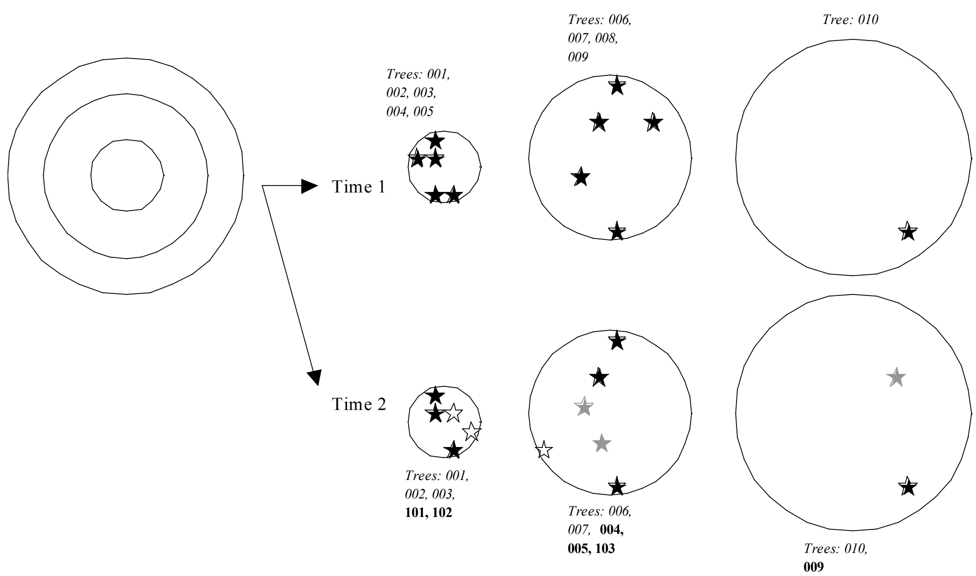
To be accurate in the calculations of change in carbon stocks, the biomass increment for ingrowth trees (trees that were too small to be measured at the previous census) must be included correctly. To be conservative, the ingrowth tree is assigned the maximum dbh possible for that plot at the previous census. For example, if the minimum diameter for measurement is 10cm and a tree is measured for the first time at 12.5cm, then at the very least the tree has grown from just less than 10cm dbh to 12.5cm dbh.

Trees that die between census periods are given no increment of growth. They have left the live tree pool and entered the dead tree pool.

Within nested plots, sum the increments and multiply the sum by the expansion factor. Then sum the nests to get the total estimated increment in tons per hectare for that plot (see the example overleaf).

Calculating changes in aboveground tree carbon stocks using allometric regression equations:
As a hypothetical example, a single plot will be examined that consists of three nested subplots:
4m radius for trees measuring 5cm to < 20cm dbh
14m radius for trees measuring ⩾ 20cm to < 50cm dbh
20m radius for trees measuring ⩾ 50 cm dbh

The figure and table below show measurements over two time periods. Note at Time 2, ingrowth of trees too small to be measured at Time 1 (trees 101 and 102 in the small nest and 103 in the intermediate nest) and outgrowth from one plot size and ingrowth into the next size when the maximum/minimum thresholds are passed (trees 004, 005 small to intermediate, 009 intermediate to large). Tree 008 has died.



The three nested plots at Time 1 and Time 2: the stars indicate the position of trees. At Time 2, black stars indicate trees that have remained in the same size class as at Time 1. Grey stars indicate trees that have grown into the next class and white stars are trees that have exceeded the measurement minimum for the first time.

TIME 1				TIME 2			
Tag	Nest	Dbh (cm)	Biomass (kg)	Tag	Nest	Dbh (cm)	Biomass (kg)
001	Small	5.6	9.1	001	Small	6.1	11.4
002	Small	8.3	25.1	002	Small	8.9	30.0
003	Small	12.1	65.7	003	Small	13.2	82.0
004	Small	16.2	137.8	004	Intermediate	20	234.7
005	Small	18.1	182.4	005	Intermediate	22.1	301.9
006	Intermediate	20.2	240.6	006	Intermediate	20.9	262.2
007	Intermediate	22.3	308.8	007	Intermediate	23.3	344.8
008	Intermediate	38.6	1221.9	008	DEAD	DEAD	1221.9
009	Intermediate	48.2	2124.8	009	Large	51	2444.9
010	Large	57	3222.0	010	Large	58	3364.0
				101	Small	5.5	8.7
				102	Small	5.9	10.5
				103	Intermediate	20.3	243.7

Biomass increment in each subplot =
(Σ increments of trees remaining in subplot size class)
+ (Σ increments for outgrowth trees [= Σ maximum biomass for size class – biomass at Time 1])
+ (Σ increments for ingrowth trees [= Σ biomass at Time 2 – minimum biomass for size class†])
where Σ = the sum of

† *Minimum biomass for each size class is calculated by entering the minimum dbh for that size class into the regression equation.*

In this example, 6.8 is the minimum biomass for the small plot (with minimum dbh of 5cm), 234.7 for the intermediate plot (dbh 20cm) and 2327.5 for the large plot (dbh 50cm).

Small subplot = [(11.4–9.1) + (30.0–25.1) + (82.0–65.7)] + [(234.7–137.8) + (234.7–182.4)] + [(8.7-6.8) + (10.5-6.8)]
= 178.3kg

Intermediate subplot = [(262.2–240.6) + (344.8–308.8)] + [(2327.5–2124.8)] + [(234.7–234.7) + (301.9–234.7) + (243.7–234.7)]
= 336.5kg

Large subplot = ((3364.0–3222.0)) + ((-)) + ((2444.9–2327.5))
= 259.4kg

Biomass = the sum of biomass in each subplot x the expansion factor for that subplot:

Small	178.3 x 198.9 = 35,463.9 kg/ha
Intermediate	336.5 x 16.2 = 5,451.3 kg/ha
Large	259.4 x 8.0 = 2,075.2 kg/ha

Sum = 42,990.4 kg/ha = 43.0 t/ha for the time interval.

TIME 1			TIME 2		
Tag	Dbh (cm)	Biomass (kg)	Tag	Dbh (cm)	Biomass (kg)
001	5.6	9.1	001	6.1	11.4
002	8.3	25.1	002	8.9	30.0
003	12.1	65.7	003	13.2	82.0
004	16.2	137.8	004	20	234.7
005	18.1	182.4	005	22.1	301.9
006	20.2	240.6	006	20.9	262.2
007	22.3	308.8	007	23.3	344.8
			101	5.5	8.7
			102	5.9	10.5

For single plots without nests, calculations are much simpler. An example is given below for a single 10m square plot.

Biomass increment in each subplot =
(Σ increments of trees present at previous census)
+ (Σ increments for ingrowth trees [= Σ biomass at Time 2 – minimum biomass for size class†])

† *Minimum biomass for each size class is calculated by entering the minimum dbh for that size class into the regression equation.* In our example, 6.8 the minimum biomass for a plot with a minimum dbh of 5cm.

= [(11.4–9.1) + (30.0–25.1) + (82.0–65.7) + (234.7–137.8) + (301.9–182.4) + (262.2–240.6) + (344.8–308.8)]
+ [(8.7–6.8) + (10.5–6.8)]
= 303.1 kg

Biomass = the sum of biomass in each subplot x the expansion factor for that subplot:
= 303.1 x 100 = 30,310 kg/ha = 30.3 t/ha for the time interval

8.2 BELOWGROUND (ROOTS) BIOMASS

The measurement of aboveground biomass is relatively established and simple. Belowground biomass, however, can only be measured with time-consuming methods. Consequently, it is more efficient and effective to apply a regression model to determine belowground biomass from knowledge of biomass aboveground. The following regression models [19] are widely used:

Boreal:
BBD (t/ha) = exp(-1.0587 + 0.8836 x ln ABD + 0.1874)

Temperate:
BBD (t/ha) = exp(-1.0587 + 0.8836 x ln ABD + 0.2840)

Tropical:
BBD (t/ha) = exp(-1.0587 + 0.8836 x ln ABD)

Where BBD = belowground biomass density in tons per hectare (t/ha) and ABD = aboveground biomass density in t/ha.

Applying these equations allows an accurate assessment of belowground biomass. This is the most practical and cost-effective method of determining biomass of roots.

For one-time measurements of root biomass, simply insert the aboveground biomass into the appropriate equation.

When calculating the increment in root biomass between two census periods, the exact usage of these equations is important. For tagged trees in permanent plots, it is not possible to simply calculate the total aboveground biomass at Time 1 and Time 2, apply the equations and then divide by the number of years as this approach can not account for ingrowth or mortality trees. Instead, belowground biomass increments should be calculated using the following method:

STEP 1 Calculate aboveground biomass at Time 1 using allometric equations and the appropriate expansion factors.

STEP 2 Calculate increment of biomass accumulation aboveground between Time 1 and Time 2 (see Section 8.1) and add to Time 1 to obtain an estimate of aboveground biomass density at Time 2.

STEP 3 Apply the appropriate belowground equation to estimate belowground biomass at each time interval.

STEP 4 (Time 2 belowground – Time 1 belowground)/ number of years = annual increment of biomass belowground.

8.3. ABOVEGROUND (NON-TREE) BIOMASS

STEP 1 Calculate the dry mass of the sample. Where a subsample was taken for determination of moisture content:

$$\text{Dry mass} = \left(\frac{\text{subsample dry mass}}{\text{subsample dry mass}}\right) \times \text{fresh mass of whole sample}$$

STEP 2 The biomass density (the number of tons of biomass per hectare) is calculated by multiplying the dry mass by an expansion factor calculated from the sample frame or plot size.

$$\text{Expansion factor} = \frac{10{,}000\text{m}^2}{\text{Area of plot (m}^2\text{)}}$$

8.4 DEAD WOOD BIOMASS

8.4.1 Standing dead wood

STEP 1 For decomposition classes 1, 2 and 3 (see Section 7.4.1), estimate the biomass of the tree using dbh and an appropriate equation as for live trees.

STEP 2a For class 1, subtract the biomass of leaves (about 2%–3% of aboveground biomass for hardwood/ broadleaf species and 5%–6% for softwood/ conifer species. For an example, see [20].

STEP 2b For classes 2, 3 and 4 where it is not clear what proportion of the original biomass has been lost, it is the conservative approach to estimate the biomass just of the bole (trunk) of the tree.

Volume is calculated using dbh and height measurements and the estimate of the top diameter. Volume is then estimated as the volume of a truncated cone.

$$\text{Volume (m}^3\text{) (Class 4)} = \tfrac{1}{3}\pi h(r_1^2 + r_2^2 + r_1 \times r_2)$$

where h is the height in meters, r_1 is the radius at the base of the tree and r_2 is the radius at the top of the tree.

Biomass = Volume x Wood density (from samples)

As the wood must be sound to support the still-standing tree, the sound wood density from downed dead wood measurements (see Section 8.4.2) can be used.

8.4.1 Downed dead wood

STEP 1 Calculate the wood density for each density class (sound, intermediate and rotten) from the pieces of dead wood collected. Density is calculated using the following formula:

$$\text{Density (g/mc}^3\text{)} = \frac{\text{mass (g)}}{\text{volume (cm}^3\text{)}}$$

Where mass = the mass of the oven-dried sample and volume = π x (average diameter/2)² x average width of the fresh sample

Average the densities to get a single density value for each class.

STEP 2a For each density class, the volume is calculated separately as follows:

$$\text{Volume } (m^3) = \pi^2 \times \left[\frac{d_1^2 + d_2^2 \ldots d_n^2}{8L}\right]$$

Where d_1, d_2, d_n = diameters of intersecting pieces of dead wood and L = length of the line.

STEP 3 Biomass of downed dead wood (t/ha) = Volume x Density.

In the following example, dead wood is sampled along 100m of line using the line-intersect method to determine biomass density. Diameters and density classes are recorded and a sub-sample collected to determine density in each of the three density classes (sound, intermediate, and rotten). The following numbers represent the hypothetical results:

13.8cm	sound
10.7cm	sound
18.2cm	sound
10.2cm	intermediate
11.9cm	intermediate
56.0cm	rotten

Densities of sub-samples	Sound:	$0.43\ t/m^3$
	Intermediate:	$0.34\ t/m^3$
	Rotten:	$0.19\ t/m^3$

Volume of sound wood = $\pi^2 \times [(d_1^2 + d_2^2 \ldots d_n^2)/8L]$
= $\pi^2 \times [(13.8^2 + 10.7^2 + 18.2^2)/800]$
= $7.85\ m^3/ha$

Volume of intermediate wood = $\pi^2 \times [(10.2^2 + 11.9^2)/800]$
= $3.03\ m^3/ha$

Volume of rotten wood = $\pi^2 \times [56.0^2/800]$
= $38.7\ m^3/ha$

Biomass density = (7.85 x 0.43) + (3.03 x 0.34) + (38.7 x 0.19)
= 11.8 t/ha

8.5 FOREST FLOOR BIOMASS

STEP 1 Calculate the dry mass of the sample. Where a subsample was taken for determination of moisture content:

$$\text{Dry mass} = \left(\frac{\text{subsample dry mass}}{\text{subsample fresh mass}}\right) \times \text{fresh mass of whole sample}$$

STEP 2 The biomass density (number of tons of biomass per hectare) is calculated by multiplying the dry mass by an expansion factor calculated from the sample frame or plot size.

$$\text{Expansion factor} = \frac{10{,}000m^2}{\text{Area of plot } (m^2)}$$

8.6 SOIL CARBON

STEP 1 Calculate the bulk density of the mineral soil core

$$\text{Bulk density } (g/cm^3) = \frac{\text{Oven dry mass } (g/cm^3)}{\text{core volume } (cm^3) - \left(\frac{\text{mass of coarse fragments (g)}}{\text{density of rock fragments } (g/cm^3)}\right)}$$

Where the bulk density is for the < 2mm fraction, coarse fragments are > 2mm. The density of rock fragments is often given as 2.65 g/cm^3.

STEP 2 Using the carbon concentration data obtained from the laboratory, the amount of carbon per unit area is given by:

C (t/ha) =[(soil bulk density (g/cm^3) x soil depth (cm) x C)] x 100

In this equation, carbon (C) must be expressed as a decimal fraction. For example, 2.2% carbon is expressed as 0.022 in the equation.

8.7 WOOD PRODUCTS

For project activities where the amount or timing of wood harvest has changed, the change in quantity of timber going into wood products between the with- and without-project scenarios should be estimated. For example, a project that stops or reduces timber harvest cannot count credit for all the carbon that was prevented from entering the atmosphere because some of the wood harvested in the baseline case would have gone into long-term products rather than the atmosphere. As a second example, a forest management activity that lengthens harvest cycles and increases the proportion of harvested wood in long-lived products could get credit for higher carbon retention in use relative to the baseline case.

STEP 1 Determine which wood products will be created from the extracted timber. Details can be obtained from mill managers.

STEP 2 Determine the waste proportion when converting a log to wood products – details can be obtained from mill managers. The waste is assumed to be oxidised in the year of production.

STEP 3 Apply the wood product proportion estimated to endure more than five years (from [21]):
0.8 for sawnwood,
0.9 for wood base panels,
0.7 for other industrial roundwood, and
0.6 for paper and paperboard.
The remainder is oxidised.

STEP 4 For each subsequent year of the project, calculate the oxidised proportion using the decomposition rates in the table below (from [21]).

Commodity	Forest Region *Boreal*	*Temperate*	*Tropical*
Sawnwood	0.005	0.01	0.02
Wood base panels	0.010	0.02	0.04
Other industrial roundwood	0.020	0.04	0.08
Paper and paperboard	0.005	0.01	0.10

8.8 ESTIMATING NET CHANGE

The method below for estimating net change is one that can be used with accuracy and without excessive complication. Technically, if a strong relationship (or covariance) exists between two values that are being combined (such as Time 1 and Time 2 values, or associated carbon pools such as dead wood and live vegetation), the confidence intervals should be deduced using a more complex analysis. These analyses can be carried out using Monte Carlo software such as Simetar, @Risk or Crystal Ball (www.simetar.com, www.palisade.com/risk, www.crystalball.com). The simple method can generally be used with confidence.

STEP 1 If results have been calculated in tons of biomass per hectare, divide by two to give tons of carbon per hectare (t C/ha).

STEP 2 Where trees are included in the project, the carbon stock for living and standing dead trees, above- and belowground, can be tracked through time for individual plots, and the change in carbon stocks can be calculated directly at the plot level. The change in carbon stocks for the different components should be summed within plots to give a per plot carbon stock change in t C/ha. The plot level results are then averaged to give mean and 95% confidence intervals for the stratum.

STEP 3 Where soil, downed dead wood, forest floor, non-tree vegetation and wood products are included, they have to be calculated differently. The change in carbon stock is calculated by subtracting the mean carbon stock at Time 2 from that at Time 1. The confidence interval is calculated as:

$$Total \cdot 95\% \cdot CI = \sqrt{95\%CI_{Time\ 1}^{\ 2} + 95\%CI_{Time\ 2}^{\ 2}}$$

Where [$95\%CI_{time1}$] = 95% confidence interval for Time 1 and [$95\%CI_{time2}$] = 95% confidence interval for Time 2.

STEP 4 The results of the various pools are combined to produce an estimate of the mean and the 95% confidence interval. The total confidence interval is calculated as follows:

$$Total \cdot 95\% \cdot CI = \sqrt{95\%CI_{veg}^{\ 2} + 95\%CI_{soil}^{\ 2} + 95\%CI_{DDW}^{\ 2} + 95\%CI_{FF}^{\ 2} + 95\%CI_{NTV}^{\ 2}}$$

Where [$95\%CI_{veg}$] = 95% confidence interval for vegetation, [$95\%CI_{soil}$] = 95% confidence interval for soil, etc. DDW = downed dead wood, FF = forest floor and NTV = non-tree vegetation.

STEP 5 The baseline is subtracted from the net change in carbon to calculate the net change in carbon stock (or carbon benefit). Ideally the baseline will also have a 95 % CI, in which case the confidence interval after the subtraction of means will equal:

$$Total \cdot 95\% \cdot CI = \sqrt{95\%CI_{Carbon \cdot Stocks}^{\ 2} + 95\%CI_{Baseline}^{\ 2}}$$

STEP 6 If the project was ordered into multiple strata, then each stratum would be calculated separately as detailed in Steps 1 to 4 and then combined. The new confidence interval for the combined strata would be estimated as follows:

$$Total \cdot 95\% \cdot CI = \sqrt{95\%CI_{s1}^{\ 2} + 95\%CI_{s2}^{\ 2} \cdots\cdots 95\%CI_{sn}^{\ 2}}$$

Where [$95\%CI_{s1}$] = 95% confidence interval for stratum 1, etc., for all strata measured in the project.

STEP 7 The mean change in carbon stocks per unit area is then multiplied by the area of the project or entity to produce an estimate of the total change in carbon.

STEP 8 The total is converted to tons of CO_2 equivalent by multiplying by 3.67.

An example of the simple calculations is given below. In this case, the initial carbon stock in vegetation and soil on the land is assumed to remain constant throughout the estimation period. The baseline only has to be subtracted one time – at subsequent reporting intervals the gross increment is the net increment.

Calculating net change for the system

This hypothetical example is a reforestation project on 500 hectares of degraded cropland. The baseline for carbon stocks in the absence of the project is continued coverage by annual crops with a carbon density of 0.9 t C/ha. The following table reports the carbon increment between years 1 and 10:

Plot Number	Increment in Carbon Pools (t C/ha)			Sum (t C/ha)
	Living Biomass		Dead Organic Matter	
	Aboveground Trees	Belowground	Standing Dead Wood	
Plot 1	12.1	2.4	0.0	14.5
Plot 2	11.5	2.3	0.0	13.8
....	...	...	...	...
....	...	...	...	...
Plot 31	12.6	2.5	0.0	15.1
Plot 32	10.9	2.2	0.0	13.1

Mean	13.8
95% CI	*2.4*
+ Non-tree Vegetation	1.8
NTV 95% CI	*0.1*
+ Downed Dead Wood	0.1
DDW 95% CI	*0.1*
+ Forest Floor	0.2
FF 95% CI	*0.1*
+ Soil	0.5
Soil 95% CI	*0.1*
+ Wood Products	0
WP 95% CI	*0*
– Baseline	0.9
Baseline 95% CI	*0.1*
NET change in carbon stock	15.5
95% CI	*2.4*

Net change in stocks over project area:	15.5 t C/ha x 3.67 t CO_2eq/ha / t C/ha x 500ha
± the 95% CI:	2.4 t C/ha x 3.67 t CO_2eq/ha / t C/ha x 500ha
Therefore the net change is:	28,443 ± 4,419 t CO_2eq over the measurement interval.

8.9 NON-CO2 GASES

Other gases influence climate change as directly as carbon dioxide (CO_2). Two gases that are related to land-use change activities are methane (CH_4) and nitrous oxide (N_2O). Although these gases are produced in smaller quantities than CO_2, their effect for a given mass on global warming is greater. This is illustrated by the calculated global warming potential. Over a 100-hundred-year period, CH_4 is expected to have a global warming potential equal to 23 times that of CO_2 while N_2O has a potential equal to 296 times that of CO_2 [2]. Consequently, these gases need only be produced in quantities equal to 4% and 0.3% respectively of the mass of CO_2 emitted to have an equal effect with respect to climate change over 100 years.

CH_4 and N_2O are produced mainly as the result of anthropogenic activities – for example fires, the draining of wetland regions, the fertilisation of land, and the storage and processing of livestock effluent [2].

The methods below for estimating these non-CO_2 greenhouse gas emissions are provided in the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry [8].

8.9.1 Fertilisation

Direct N_2O emissions from fertilisation =

$$(F_{SN} \times EF_1) \times CO_2EF_N$$

Where:

F_{SN}	= *Annual amount of synthetic fertiliser nitrogen applied to soils*
EF_1	= *Emission factor for N_2O emissions from fertilisation in unit of N – default value = 1.25%*
CO_2EF_N	= *CO_2 equivalent factor (296)*

8.9.2 Draining

Forest soils

N_2O emissions $= (A_{FF} \times E_{FF}) \times 44/28 \times 10^{-6} \times CO_2EF_N$

Where:

A_{FF}	= *Area of drained forest soils, ha*
E_{FF}	= *emission factor for drained soils, kg N_2O-N ha^{-1} yr^{-1}*
	= *8 for tropical climates*
	= *0.1 for nutrient-poor organic soils in temperate and boreal climates*
	= *0.6 for nutrient-rich organic soils in temperate and boreal climates*
	= *0.06 for mineral soils in temperate and boreal climates*
CO_2EF_N	= *CO_2 equivalent factor (296)*

Peatlands

N_2O emissions $= (A_{PEAT} \times E_{PEAT}) \times 44/28 \times 10^{-6} \times CO_2EF_N$

Where:

A_{PEAT}	= *area of drained soils, ha*
E_{PEAT}	= *emission factor for drained soils, kg N_2O-N ha^{-1} yr^{-1}*
	= *18 for tropical climates*
	= *0.1 for nutrient-poor organic soils in temperate and boreal climates*
	= *1.8 for nutrient-rich organic soils in temperate and boreal climates*
CO_2EF_N	= *CO_2 equivalent factor (296)*

8.9.3 Fire

Biomass burning is the greatest natural (or semi-natural) source of non-CO_2 gas production [8]. The quantity of CH_4 and N_2O released can be estimated using emission factors based on the quantity of C released [8].

CH_4 emissions = Carbon released x 0.016 x CO_2EF_M

Where:

CO_2EF_M = *CO_2 equivalent factor (23)*

N_2O emissions = Carbon released x 0.00011 x CO_2EF_N

Where:

CO_2EF_N = *CO_2 equivalent factor (296)*

9. GUIDANCE FOR SPECIFIC PROJECT TYPES

This section provides an overview of issues to consider when measuring carbon for different project types. It is important to note that, at the present time, not all the project types described below are eligible under CDM. Only forest management, agroforestry and forestation projects can be developed under the CDM scheme.

In addition to project eligibility, there are important financial issues to consider before making a decision on measuring carbon. Firstly, will it be cost-effective to develop a carbon finance proposal? The analysis should consider the upfront cost of developing such a proposal compared to the potential financing and payment. Secondly, will the carbon payments be sufficient to develop carbon-rich land uses? The investment may not be worthwhile if the project renders only a small increase in carbon stocks and low payout. It should also be noted that payments will only be provided on maturation of the trees – meaning income streams will not come on line for approximately five to 10 years. Therefore carbon finance proposals should be developed in conjunction with other financial sources that can provide incentives for conservation until these future income streams occur..

9.1 CONSERVATION

Conservation projects prevent the emission of carbon into the atmosphere that would occur as a result of vegetation clearance. Alongside their substantial carbon benefits, conservation projects arguably have the greatest co-benefits of any climate change project. Challenges for conservation projects include establishing the without-project baseline and evaluating carbon leakage.

Any carbon gain must be net of the business-as-usual scenario. If an area would not have been cleared, then there is no carbon benefit to protecting it. The project developer can choose to establish rates of deforestation at different levels of rigour, according to the resources available:

Level 1: Take the rate of deforestation for the appropriate country from the website of the Food and Agriculture Organization of the United Nations (www.fao.org/forestry). This is the least rigorous method and is subject to error, as rates of deforestation vary widely within a country. Use this rate to project into the future, but no more than about 10 years.

Level 2: Obtain remote sensing images (e.g., aerial photographs or satellite images) from two points in time and calculate a rate of deforestation for that time period. Use this rate to project into the future, but no more than about 10 to 15 years.

Level 3: Combine projected rates of deforestation with a model that projects where the change is likely to occur, based on multiple drivers such as past changes, demographic pressures, roads, rivers, slope, elevation, etc. An example of such a model is GEOMOD (for examples, see [11, 12]).

The carbon benefit is equal to the area that would have been cleared during the project timeframe multiplied by the carbon that would have been lost through the land clearance. The form of land clearance is important in determining the carbon benefit. Is the land cleared to a state of practically zero carbon (e.g., annual crops)? Will the post-clearance carbon remain steady (as in agriculture) or will regrowth occur (e.g., fallow for a number of years as in a shifting cultivation cycle)? If harvesting is occurring, then the benefit is net of any wood products that originate from the vegetation on the land.

For protection against harvest, the following default factors can be used to predict the proportions extracted from the forest and the proportion left behind to decompose [8]. To avoid significant error, however, it is desirable to calculate these proportions on a project-by-project basis.

Region	Fraction out of total harvest left to decompose in forest
Boreal: intensively managed	0.07
Temperate: intensively managed	0.1
Temperate: semi-natural forests	0.15
Tropical plantations	0.25
Tropical selective logging in mature forests	0.4

Typically, the baseline for the project is evaluated with a single set of measurements on the land prior to the start of project activities. It is a cost-effective and conservative assumption that mature vegetation systems will not continue to gain carbon. The baseline is usually measured at representative proxy sites close to the project site.

The measurement and evaluation plan should consider trees (or non-tree vegetation in tree-less habitats), downed dead wood and wood products (see the example in Appendix B).

9.2 FOREST MANAGEMENT

1. Direct measurement method

The simplest approach for evaluating any changes in carbon stocks from activities related to changes in forest management is to install plots in the project area and in a reference area (an area where no change will occur). This approach is well suited to situations where the harvesting practice is to clear cut, which is typical in forests composed of very few species. The change in carbon stocks due to different logging practices can be followed in each plot and compared to produce an estimated carbon benefit.

With a well-designed sampling regime, re-measurements will reveal shifts of pre-harvest living biomass to the dead wood pool (i.e., through logging, slash and collateral mortality) and subsequent decomposition over time, as well as resulting regrowth after harvest. Mean total carbon stocks and 95% confidence intervals are calculated in the same way as for project activities on non-forested lands.

Extracted biomass in long-term wood products from both the reference and project sites must also be tracked.

2. Indirect measurement method

In forests where trees are harvested by selective logging (e.g., tropical forests) and harvest intensity per hectare is low, the number of plots required to capture the variation in harvested areas is so great that the measurements are neither financially or practically feasible. In this case, it is possible to use targeted measurements plus the statistics of the relevant logging companies. The following information is typically required to calculate carbon gains and losses through the indirect measurement method:

- Total volume removed;
- Area damaged per cubic meter removed;
- Amount of slash and damage to residual stand per volume removed;
- Rate of regrowth in both the harvested and unharvested areas;
- The efficiency of conversion of timber to long-term products;
- Destination and longevity of both short- and long-term timber products;
- Decomposition rates of both slash and long-term products.

The amount of slash and the damage to the residual stand will probably have to be estimated through measurements. The slash directly from the timber tree (stump and top of tree) can be estimated by subtracting the extracted biomass (extracted volume multiplied by wood density[2]) from the biomass determined using an allometric equation. If the timber log has already been extracted, calculate dbh using the following formula:

$$dbh = ds - \left(\left(\frac{ds\text{-}dt}{length}\right) \times 1.3 - hs\right)$$

where ds = diameter of the stump, dt = diameter of the tree at the top end of the extraction log, length = length of the timber log and hs = height of the stump.

Damage to the residual stand is estimated by measuring the dbh of all trees snapped, uprooted or otherwise fatally damaged by the tree's fall. The biomass of large branches of surrounding trees knocked down during tree fall should also be included.

How the measurements from this approach were combined for a harvest operation in the Republic of Congo to arrive at an estimated net carbon benefit from changing harvesting practices is described in [22].

9.3 CROPLAND MANAGEMENT

1. High carbon content crops

For a change to high carbon content crops, the carbon stocks in both the current agricultural crop and in the higher carbon crop should be measured. The carbon benefit is equal to the new stock minus the old stock. It should be considered that carbon stocks in herbaceous crops are present for only a limited number of months up to harvest each year, while high carbon-content crops retain their biomass year round.

2 Wood density is equal to the fresh volume divided by the dry weight. Wood density can be determined by collecting samples or from scientific literature.

Additionally, the rate at which the higher carbon crops can be established should be considered. It will likely take many years, for example, for orchard trees to reach their potential.

Extreme care should be taken if fertilisers are applied as this will result in the release of the greenhouse gas, N_2O, which will need to be deducted from the benefits of increased carbon storage.

2. Conservation tillage

In conservation tillage, crops are grown with minimal cultivation of the soil. The decrease in cultivation allows an increase in the amount of carbon stored in the soil. It is likely that the accumulation of carbon will be gradual over 20 years or so.

As with conversion to higher carbon crops, any nitrogen-based fertilisers applied to the land must be monitored and the carbon benefits adjusted accordingly.

9.4 GRAZING LAND MANAGEMENT

The aboveground carbon stock in grasslands is measured using clip plots. Root biomass can conservatively be estimated using a 1:1 ratio (i.e., the root biomass can be estimated as equal to the aboveground biomass). Significant additional carbon stocks can be found in the soil of grasslands.

1. Grazing management

Intensifying grazing can increase the total above- and below-ground biomass by concentrating the area of livestock impact. The heavy organic fertiliser input from intensive grazing can also increase future yields.

2. Fire management

Fire on grasslands will lead to emissions of CO_2 and N_2O (unless the grassland is wet, significant CH_4 emissions are unlikely). A grassland fire will not adversely affect root biomass and soil carbon. If the purpose of the fire is to enhance fertility or reduce the danger of a future fire threatening local communities, then the consequence will be a net emission that must be quantified and set against net carbon gains from other facets of the wider project.

9.5 AGROFORESTRY

Agroforestry projects often act as alternative livelihood programmes to decrease the risk of the project causing carbon leakage through activity shifting. However, agroforestry can independently sequester substantial quantities of carbon. The carbon benefit is net of the carbon stocks on the land prior to the project. The dominant carbon pool will be the trees. Full establishment of agroforestry gardens may take many years.

9.6 FORESTATION (INCLUDING PLANTATIONS)

Forestation is the only land-use programme accepted under the first cycle of the Clean Development Mechanism of the Kyoto Protocol. The reason is its simplicity – trees grow and they sequester carbon.

Complications arise, however, over whether regeneration would have occurred in the absence of project activities or, in the case of plantations, as to whether the project activity is really in addition to the business-as-usual scenario.
The dominant carbon pool to include is trees – both above- and belowground. Additional benefits will slowly accumulate in dead wood and the soil.

If the project is centred on plantations, the harvest strategy must be considered. For a harvest plantation, a long-term average carbon stock can be calculated that would equal the sum of the stock in each year of the harvest cycle divided by the number of years. For additional benefit, long-term wood products should be included.

9.7 MANGROVES/WETLANDS/SALT MARSHES

Exactly the same principles apply to wetland project activities as to terrestrial ones. Biomass carbon can be estimated on a representative subset of the wetland and then multiplied for the entire area. For example, replanting coastal areas with mangrove trees would use the same approach for monitoring and estimating the change in carbon stocks as would a forestation project on non-wetland areas.

Herbaceous plants and other non-tree vegetation should be destructively sampled (in $1m^2$ clip plots, for example). For trees, allometric equations are most effective choice. If suitable equations do not exist, project-specific equations can be created (see Appendix C).

Preventing the drainage of wetlands (including peat lands) can prevent the emission of large quantities of CO_2 and N_2O. However, any carbon benefits gained from preventing drainage have to subtracted from the background rates of production of CO_2, N_2O and, especially, CH_4 from the flooded lands.

10. MITIGATION AND ADAPTATION

Two basic responses to climate change are mitigation and adaptation. **Mitigation** refers to efforts to prevent climate change itself, and hence future climate impacts. **Adaptation** is the adjustment in natural and human systems to actual or expected climate stimuli and the impacts of those stimuli on natural and socio-economic systems. Adaptation moderates harm or explores beneficial opportunities.

The focus of the UNFCCC and the GEF has been on mitigation. Mitigation alone, however, is not adequate. The impacts of mitigation efforts to reduce greenhouse gas concentrations in the atmosphere will be felt only in the long term, whereas climate impacts are likely in the next few decades. Adaptation can complement mitigation efforts in a cost-effective manner and so reduce climate change risks. There has been a realisation at the global level – including the UNFCCC, GEF and IPCC – that there is a need to understand and promote both mitigation and adaptation. The focus is on promoting "synergy between mitigation and adaptation" in addressing climate change.

10.1 MITIGATION AND ADAPTATION SYNERGIES

The GEF OPs relevant to climate change mitigation – namely OP#5, OP#6, OP#7 and OP#11 – deal only with technologies aimed at reducing GHG emissions. Integrated ecosystem management OP#12 projects have multiple global environmental goals, two of which aim at promoting biodiversity conservation and enhancing carbon sinks through carbon sequestration.

A majority of mitigation strategies in the forestry and agricultural sectors provide opportunities for enhancing adaptation. In the forestry sector, any mitigation strategy that additionally aims at forest and/or biodiversity conservation will reduce the vulnerability of the forest ecosystem to projected climate change.

Some examples of adaptation strategies and practices that could become an integrated component of GEF projects are as follows:

- Forest, grassland and other natural ecosystem conservation practices and strategy in the project area;
- Activities aimed at biodiversity conservation in forests and grasslands;
- Expanding protected areas;
- Incorporating multiple species, particularly native species, in afforestation and reforestation activities;
- Adopting fire control and management practices;
- Assisting natural migration through anticipatory planting of species from lower latitude and altitude;
- Reducing of forest and grassland fragmentation;
- Adopting silvicultural practices, such as sanitation harvest, shortening rotations and increased thinning.

10.2 IMPLICATIONS OF ADAPTATION PRACTICES FOR CARBON INVENTORY

GEF projects provide opportunities for enhancing the synergies between mitigation and adaptation to address climate change. Incorporating adaptation practices is unlikely to have any implications on the methods described in these guidelines for assessing the carbon inventory. Indeed, in the long run, incorporation of adaptation practices in GEF projects may contribute to sustaining carbon benefits by reducing vulnerability of forest, grassland and agricultural ecosystems.

Examples of potential adaptation activities for different types of GEF projects are provided in the table overleaf.

Examples of GEF Projects or Activities	Examples of Adaptation Practices in GEF Projects
Conservation/protection	Conservation leads to biodiversity conservation and halting fragmentation reduces the vulnerability of ecosystems
Sustainable extraction/logging	Sustainable extraction practices lead to conservation of forest and biodiversity, which reduces vulnerability
Rangeland/grassland rehabilitation	Controlled grazing, fire management and soil water conservation reduces vulnerability of grasslands
Agroforestry	Planting multiple tree species, including native species, at appropriate density reduces vulnerability of cropping system
Shelter belt	Planting of multiple tree species, including native species, reduces soil erosion, controls desertification and reduces vulnerability of cropping system
Watershed	Soil and water conservation practices, regulation of grazing in catchment areas and reforestation in catchment areas using multiple species, including native species, reduces vulnerability of cropping systems
Afforestation/reforestation	Soil and water conservation practices and multi-species forestry, including native species, and promotion of natural regeneration reduces vulnerability
Village ecosystem or agro-ecosystem management	Promotion of natural regeneration and multi-species forestry in different land categories will reduce vulnerability

REFERENCES

[1] **GEF.** 2000. Operational Program #12: Integrated Ecosystem Management. http://www.gefweb.org/Operational_Policies/Operational_Programs/OP_12_English.pdf

[2] **Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell and C.A. Johnson** (eds). 2001. Climate Change: 2001: The Scientific Basis. Contribution to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, USA. 881 pp.

[3] **Dixon, R. K., S. Brown, R. A. Houghton, A. M. Solomon, M. C. Trexler, and J. Wisniewski.** 1994. Carbon pools and flux of global forest ecosystems. *Science* 263: 185-190.

[4] **Brown, S., J. Sathaye, M. Cannell, and P. Kauppi.** 1996. *Management of forests for mitigation of greenhouse gas emissions.* Chapter 24 in **R. T. Watson, M.C. Zinyowera, and R.H. Moss** (eds.), Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, and New York, USA.

[5] **MacDicken, K.G.** 1997. A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects. Winrock International, Arlington, VA, USA. 87 pp. www.winrock.org/what/ecosystem_pubs.cfm

[6] **Watson, R T., I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verado and D.J. Dokken.** 2000. Land-Use, Land-Use Change and Forestry, A Special Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

[7] **Houghton, J.T., L.G. Meira Filho, B. Lim, K. Treanton, I. Mamaty, Y. Bonduki, D.J. Griggs and B.A. Callender** (eds). 1996. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Volumes 1, 2 and 3. IPCC/OECD/IEA, UK Meterological Office, Bracknell.

[8] **Namburs, G-J, N.H. Ravindranath, K. Paustian, A. Freibauer, W. Hohenstein and W. Makundi** (eds). 2004. *LUCF Sector Good Practice Guidance*. Chapter 3 in **Penman, J, M. Gytarsky, T. Hiraishi, T. Krug, D. Kruger, R. Pipatti, L. Buendia, K. Miwa, T. Ngara, K. Tanabe and F. Wagner.** Good Practice Guidance for Land Use, Land-Use Change and Forestry, IPCC National Greenhouse Gas Inventories Programme, Intergovernmental Panel on Climate Change.

[9] **Birdsey, R.A.** (ed.). 2004. Carbon accounting rules and guidelines for forestry. U.S. Voluntary Greenhouse Gas Emissions Reporting (1605b) program. US DOE.

[10] **Aukland, L., P. Moura Costa and S. Brown.** 2003. A conceptual framework and its application for addressing leakage on avoided deforestation projects. *Climate Policy* 3: 123-136.

[11] **Brown, S.** Finalizing Avoided-Deforestation Project Baselines. Report prepared by Winrock International for the United States Agency for International Development. Contract No. 523-C-00-02-00032-00. http://www.winrock.org/what/pdf/Deforestation-baselines-Report-ENG.pdf

[12] **Brown, S.** (Principal Investigator.) 2002. Land Use and Forests, Carbon Monitoring, and Global Change. Cooperative Agreement between Winrock International and the EPA ID# CR 827293-01-0. Winrock International. http://www.winrock.org/what/ecosystem_pubs.cfm

[13] **Avery T.E. and H.E. Burkhart** (eds.). 1983. Forest Measurements, 3rd edition. McGraw-Hill, New York.

[14] **Brown, S.** 2002. Measuring, monitoring, and verification of carbon benefits for forest-based projects. *Phil. Trans R. Soc.* Lond. A 360: 1669-1683.

[15] **Brown, J. K.** 1974. Handbook for inventorying downed woody material. General Technical Report INT-16. Ogden, Utah: USDA Forest Service Intermountain Forest and Range Experiment Station.

[16] **Harmon, M. E. and J. Sexton.** 1996. Guidelines for Measurements of Woody Detritus in Forest Ecosystems. US LTER Publication No. 20. US LTER Network Office, University of Washington, Seattle, WA, USA.

[17] **Nelson, D.W., and L.E. Sommers.** 1996. *Total carbon, organic carbon, and organic matter.* p. 961-1010. In: **D.L. Sparks et al.** (eds.) Methods of soil analysis. Part 3. Chemical methods. SSSA, Madison, WI.

[18] **Brown, S.** 1997. Estimating Biomass and Biomass Change of Tropical Forests: A Primer. UN Food and Agriculture Organization Forestry Paper 134, Rome, Italy. 55 pp.

[19] **Cairns, M. A., S. Brown, E. H. Helmer, and G. A. Baumgardner.** 1997. Root biomass allocation in the world's upland forests. *Oecologia* 111: 1-11.

[20] **Jenkins, J.C., D.C. Chojnacky, L.S. Heath, and R.A. Birdsey.** 2003. National-scale biomass estimation for United States tree species. *Forest Science* 49: 12-35.

[21] **Winjum, J.K., S. Brown, and B. Schlamadinger.** 1998. Forest harvests and wood products: sources and sinks of atmospheric carbon dioxide. *Forest Science* 44: 272-284.

[22] **Brown, S., T. Pearson, N. Moore, A. Parveen, S. Ambagis and D. Shoch.** 2005. Impact of selective logging on the carbon stocks of tropical forests: Republic of Congo as a case study. Report submitted to the United States Agency for International Development. Cooperative Agreement No. EEM-A-00-03-00006-00. http://www.winrock.org/what/ecosystem_pubs.cfm

APPENDIX A: GLOSSARY

Accuracy: how close a measurement is to its true value.
Activity shifting: when activities that cause greenhouse gas emissions are not permanently avoided through project implementation, but are instead displaced to another area causing carbon leakage (see Section 4 for more information).
Baseline: the emission or removal of greenhouse gases that would occur without the project.
Biomass: organic material (above- or belowground, live or dead).
Boreal: mean annual temperature of less than 0°C.
Carbon pool: organic material containing carbon.
Carbon stock: the quantity of carbon in a given pool or pools per unit area.
Confidence interval: a measure of the spread of the data. It gives a range of values in which there is a percentage probability (usually 95%) of the true mean occurring. Calculated by multiplying the standard error by the appropriate t value. T values for calculating the 95% confidence interval are given below.

Number of Observations	t value	Number of Observations	t value
5	2.776	60	2.001
10	2.262	65	1.998
15	2.145	70	1.995
20	2.093	75	1.993
25	2.064	80	1.990
30	2.045	90	1.987
35	2.032	100	1.984
40	2.023	110	1.982
45	2.015	120	1.980
50	2.010	150	1.976
55	2.005	200	1.972

Cropland: defines any land on which non-timber crops are grown. This includes both herbaceous crops and higher carbon-content systems including vineyards and orchards.
diameter at breast height (dbh): tree diameter parallel to the ground at 1.3m above the ground. Usually measured using a dbh tape, which is calibrated to diameter when the user measures the circumference of the tree.
Forests: includes all land with a canopy cover greater than 30%. This can include natural forest, plantations, forested wetlands and mangroves.
Grazing land: a very broad category that includes managed pastures, prairies, steppe and savannas. Grazing lands will often include trees, but only when the canopy cover is less than 30%. Aquatic systems such as flooded grasslands and salt marshes are also included in this category.
Greenhouse gases: gases in the atmosphere (both natural and anthropogenic) that absorb and emit radiation. This property of the gases causes the greenhouse effect. The primary gases in the earth's atmosphere are water vapour, carbon dioxide, nitrous oxide, methane and ozone.
Hardwoods: this botanical group of trees has broad leaves and produces a fruit or nut.
Leakage: the loss of carbon outside the boundaries of the project as a result of project activities. There are three categories of leakage: activity shifting, market effects and super-acceptance.
Market effects: when emission reductions under a project are countered by emissions created by shifts in supply and demand of the products and services affected by the project (see Section 4 for more information).
Mean: is the sum of observations divided by the number of observations. Mean is calculated in Microsoft Excel using: =AVERAGE (...list of observations....).
Precision: the repeatability of a measure or the range of value between which the true value may lie.
Sequestration: the process of increasing the carbon stock in an ecosystem.
Softwoods: softwoods and conifers (from the Latin word meaning cone-bearing) have needles.
Standard deviation: a measure of the spread of the data. It is calculated in Microsoft Excel using: =STDEV (...list of observations....).
Standard error: a measure of the spread of the data. It is calculated by dividing the standard deviation by the square root of the number of observations.
Super-acceptance: occurs when alternative livelihoods activities created for a project are very successful and draw in people from the surrounding regions. The result may be a positive or negative carbon leakage (see Section 4 for more information).
Temperate: mean annual temperature between 0°C and 20°C.
Tropical: mean annual temperature greater than 20°C.
Variance: a measure of the spread of the data. It is calculated in Microsoft Excel using: =VAR (...list of observations...).
Without-project scenario: see *baseline*.

APPENDIX B: ILLUSTRATION OF CARBON INVENTORY METHODS FOR AN "INTEGRATED ECOSYSTEM MANAGEMENT" PROJECT

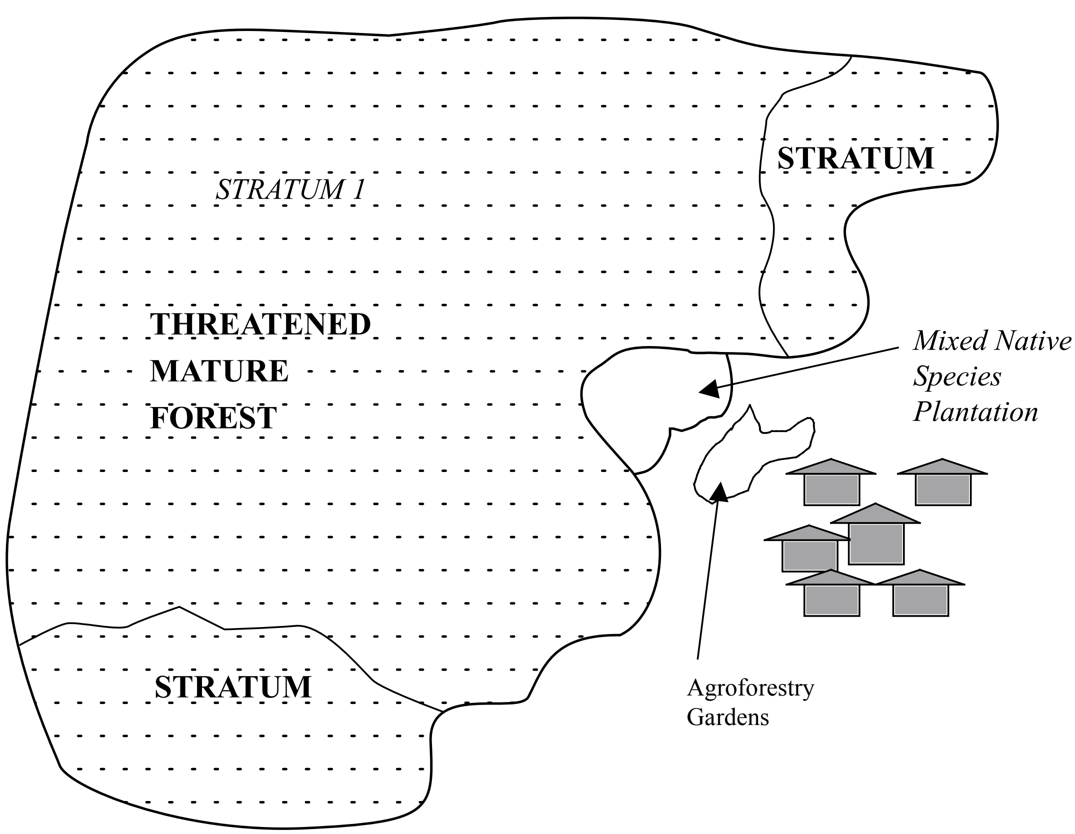
For simplicity and clarity, the project discussed here will be fictional. The project is located in moist tropical Africa and consists of three components:

1. Mature forest preservation
2. Native species plantations
3. Agroforestry gardens

The native species plantations and agroforestry components will both sequester carbon and serve as alternative livelihood programmes.

Co-benefits of the project, in keeping with the objectives of OP#12, will be:

- Prevention of land degradation;
- Sustainable development;
- Conservation of the biodiversity contained in the threatened forest; and
- Protection of the watershed, which affects water supply and fresh water biodiversity.



STAGE 1: EVALUATE THE POTENTIAL FOR LEAKAGE

1. As there is an alternative livelihoods programme (native species plantations, agroforestry gardens), activity shifting is unlikely
2. The deforestation occurring prior to the start of the project was caused by the local community seeking agricultural lands with products for local consumption, thus there is little potential for market effects.
3. Super-acceptance of the alternative livelihoods is possible and should be evaluated as the project progresses.

STAGE 2: EVALUATE THE WITHOUT-PROJECT SCENARIO

2.1 Business-as-usual changes in land use

i. Conservation of mature forests

Evaluation of aerial photographs and remote sensing products from today and five years ago reveals a rate of deforestation equal to 4% per year. The benefit of conservation comes not from the entire forest area, but from the proportion that would have been deforested in the absence of the project. Given a project area of 5,000ha in the absence of the project, we would expect the following losses:

Year	Remaining Forest Area (ha)	Cumulative Loss of Forest (ha)
1	5000	
2	4800	200
3	4608	392
4	4424	576
5	4247	753
6	4077	923
7	3914	1086
8	3757	1243
9	3607	1393
10	3463	1537

ii. Native species plantations

No native species plantations exist in the region and local communities lack the expertise to establish the plantations. Consequently, there is no land-use trend towards such plantations in the absence of the project. Moreover, the area to be planted has been deforested for at least the last 10 years.

iii. Agroforestry gardens

Fruit trees exist in the project region, but not in established gardens and with no strong commercial direction. Consequently, there is no land-use trend towards such gardens in the absence of the project.

2.1 Changes in carbon stock without project activities

i. Conservation

In the absence of the project, the forest would be subject to slash and burn. After being cut and burnt, such sites are planted with rice for a year, then peanuts for a year, before being abandoned for seven years. They are then cut and burnt again to restart the cycle.

The without-project carbon baseline is the average carbon stock on the land over the nine-year cycle (two years under cultivation and seven years in fallow).

Limited measurements (five plots per age class) were made of proxy sites in some years of the cycle, with missing years estimated from the trend produced by the measurements. These measurements recorded a mean carbon density over the nine years of 7.4 t C/ha.

Year of Slash and Burn Cycle	Status of Land	Carbon Stock Over Year (t C/ha)
1	Rice	1.0
2	Peanuts	0.5
3	Fallow	1.0
		2*
5	Fallow	3.5
		7.7*
7	Fallow	11.0
		15.6*
9	Fallow	24.0
Average		7.4

* = estimated

ii. Plantations and agroforestry gardens

These projects will be established on land subject to the slash, burn and fallow cycle, rather than existing forest. The carbon density in the absence of the project is therefore the same as for the conservation component, that is, 7.4 t C/ha.

STAGE 3: DEVELOP MEASUREMENT PLAN

3.1 Define project boundaries

Using a global positioning system, the boundaries of each of the components of the project were traced: **Conservation:** 5,000ha; **Plantations:** 100ha; **Gardens:** 50ha

3.2 Stratify project area and estimate number of plots

The plantations and the agroforestry gardens each formed single strata. Discussions with the local community and visits to the forest revealed three clear strata in the conservation zone, based on species composition, aspect and drainage: **Stratum 1**: 3,400ha; **Stratum 2**: 900ha; **Stratum 3**: 700ha.

3.3 Decide which carbon pools to measure

i. **Conservation:** initial measurements and estimates for carbon stocks at the beginning of the project are to be made on live above- and belowground tree biomass, and standing and downed dead wood.

ii. **Plantations and agroforestry gardens:** measurements will be taken through the life of the project for live above- and belowground tree biomass and non-tree vegetation in the agroforestry gardens.

To reduce costs, it was decided soil and forest floor would not be considered in this project, even though it is likely that for the conservation component there would be a loss of soil carbon over time without the project.

3.4 Determine type and number of measurement plots

3.4.1 Type of plots

Trees (live and dead) will be measured in permanently marked plots. Downed dead wood will be measured using the line-intersect method. Non-tree vegetation will be measured in temporary plots outside the permanent ones.

<u>*Size and shape*</u>

i. Conservation

Square nested plots will be used for trees. Based on the guidelines provided, the size of the plots is as follows :

7m by 7m	SMALL NEST
25m by 25m	INTERMEDIATE NEST
35m by 35m	LARGE NEST

The standard 100m line will be used with one line per tree plot for downed dead wood.

ii) Plantations and agroforestry gardens

The same size tree plots will be used as for the conservation component. For non-tree vegetation, $1m^2$ destructive sample plots will be used, located just outside the permanent plot.

3.4.2 Number of plots

Twelve plots were measured in each stratum to determine mean stocks, variance and standard deviation. For the plantations and agroforestry gardens where establishment has not yet occurred, nearby representative proxy areas were measured. The conservation plots will only be measured once (at the start of the project). Carbon increments will be tracked in the plantations and gardens, so the analysis is split in two. The required number of plots and distribution of the plots were calculated using the Winrock plot calculator.

i. Conservation

	Forest Stratum 1	Stratum 2	Stratum 3	Total
Area (ha)	3400	900	700	5000
Observations (t C/ha)	100 141 136 82 180 124 150 98 113 137 126 132	81 87 63 85 91 71 83 89 65 88 62 47	100 105 91 89 104 119 100 103 101 99 113 102	
Mean	126.6	76.0	102.2	101.6
Standard deviation	26.2	14.0	8.2	27.1
Variance	685.4	196.9	66.5	737.0
95 % CI	16.6	8.9	5.2	7.0
Number of plots	12	2	1	15

ii. Plantations and agroforestry gardens

	Plantation Stratum 4	Gardens Stratum 5	Total
Area (ha)	100	50	150
Observations (t C/ha)	48 60 48 32 51 49 45 61 51 53 68 50	21 27 17 20 19 32 30 18 22 24 21 14	
Mean	51.3	22.1	36.7
Standard deviation	9.0	5.3	16.6
Variance	81.2	28.4	275.6
95% CI	5.7	3.4	6.8
Number of plots	10	3	13

3.5 Determine measurement frequency

i. Conservation

To minimise costs, and because minimal additional growth is expected in mature forests, these strata will only be measured at the start of the project. However, it will be necessary to determine that the area has not undergone deforestation – this can be checked by simple ground surveys, aerial imagery or satellite data in the future.

ii. Plantations and agroforestry gardens

Measurement of the plots in these strata will be carried out every five years.

STAGE 4: MEASUREMENT AND ANALYSIS

i. Conservation

Measurements of live and dead aboveground tree biomass were made in 15 plots and 15 100m dead wood line transects at the project start. Calculations of tree biomass were made using the tropical moist equation of Brown (1997, see Section 8.1). Belowground biomass was calculated using the tropical variant of the equation of Cairns et al. (1997, see Section 8.2). Example results from Stratum 1 (12 plots) are shown below:

	Quantity of carbon (t C/ha)			
	Aboveground live biomass	Belowground live biomass	Standing dead biomass	TOTAL
Plot 1	120	24	0	144
Plot 2	145	28	2	175
...	...	...	...	...
Plot 11	103	21	10	134
Plot 12	135	26	0	161
Mean	130	26	3	159
95% CI	12	2	2	13
			Downed dead wood	12
			95% CI	*4*
			Baseline	7.4

For Stratum 1, the mean carbon benefit per hectare will therefore be the sum of carbon density of the trees (above- and belowground and standing dead) plus the downed dead wood minus the baseline, which represents the average amount of biomass that will remain on the land even under slash and burn agriculture.

$$= 159 + 12 - 7.4 = 169 \text{ t C/ha}$$

The 95% confidence interval (CI) for this number is the square root of the squared values for the trees and the downed dead wood:

$$\sqrt{13^2 + 4^2} = 13.6$$

Therefore the carbon benefit for conserving hectares of forest in Stratum 1 equals 169 t C/ha ± 13.6. The same measurements and analyses were made for Stratum 2 (four plots) and Stratum 3 (two plots).

Combining the strata:

Stratum 1 (3,400ha) = 169 t C/ha ± 13.6
Stratum 2 (900ha) = 93 t C/ha ± 9.1
Stratum 3 (170ha) = 130 t C/ha ± 7.2

Given that we do not know where the deforestation will occur (i.e., in which stratum), we have to take a weighted mean for the three strata based on their relative areas.

= [(169 x 3,400) + (93 x 900) + (130 x 700)]/5000

= 149.9 t C/ha

The confidence interval = $\sqrt{13.6^2 + 9.1^2 + 7.2^2}$ = 17.9

The carbon benefit of conserving the forest is therefore equal to the area deforested multiplied by 149.9 t C/ha. From our predictions on the rate of deforestation, this equals 230,446 tons of carbon over 10 years, with a 95% confidence interval of 27,518 (±11.9 %).

Year	Remaining Forest Area (ha)	Cumulative Loss of Forest (ha)	Carbon Benefit (t C)
1	5,000		
2	4,800	200	29,980
3	4,608	392	58,761
4	4,424	576	86,390
5	4,247	753	112,915
6	4,077	923	138,378
7	3,914	1,086	162,823
8	3,757	1,243	186,290
9	3,607	1,393	208,819
10	3,463	1,537	230,446

ii. Plantations and agroforestry gardens

For these components, sequestration of carbon is recorded rather than avoided emissions. In this situation, direct estimation is possible through recording the increments of accumulation of biomass carbon in the vegetation using permanent plots.

Thirty-six plots were measured every five years from the commencement of the project – 10 plots in the mixed native species plantations and three plots in the agroforestry gardens.

Here is how the increment between year 1 and year 5 was calculated:

Trees: Plantations 8.6 t C/ha ± 0.91
Gardens 3.2 t C/ha ± 0.43

Non-tree vegetation:
Gardens Year 1 1.8 t C/ha ± 0.71
Year 5 3.9 t C/ha ± 0.82

Therefore the increment in non-tree vegetation
= 2.1 t C/ha ± $\left(\sqrt{0.71^2 + 0.82^2} = 1.1\right)$

Combining trees and non-tree vegetation, the five-year increment in the agroforestry gardens:

= 3.2 t C/ha + 2.1 t C/ha
= 5.3 t C/ha

The 95% confidence interval = $\sqrt{1.1^2 + 0.43^2}$ = 1.17

Reporting annually gives a carbon sequestration between year 5 and year 10 of the project of:

(8.6/5) = 1.73 t C/ha per year for the mixed native species plantations

(5.3/5) = 1.06 t C/ha per year for the agroforestry gardens

SUMMARY FOR FIRST FIVE YEARS

Component	t C/ha	Area (ha)	Total (t C)	95% CI (t C)
Conservation	149.9	753	112,915	13,479
Plantations	8.6	100	860	91
Agroforestry	5.3	50	265	59
Total			114,040	13,479

APPENDIX C: CREATING BIOMASS REGRESSION EQUATIONS

METHOD I: DEVELOPING A BIOMASS EQUATION

Developing local biomass equations can be a resource-intensive operation. When dealing with native forests, it is highly likely that general equations exist (such as those in Appendix D). However for many multi-purpose species, this may not be the case and it is necessary to develop local biomass equations. The procedures for developing location- and species-specific biomass equation involves the following steps:

STEP 1 Select the dominant tree species.

STEP 2 Select about 30 trees randomly to represent the full range of diameter classes existing or expected.

STEP 3 Measure dbh and height of each tree.

STEP 4 Harvest the selected trees to the ground.

STEP 5 Cut the tree into appropriate size to directly estimate the fresh mass of the tree.

STEP 6a If cutting a large tree trunk for weighing is not feasible, estimate the volume using data on the diameter at both ends of the trunk and the length of the trunk (Volume $=[(\pi r1^2 + \pi r2^2)/2] \times L$), *where r1 = radius at one end of trunk, r2 = radius at the other end of trunk and L = length of trunk.*

STEP 6b Collect a complete cross-sectional sample of fresh wood from each log, estimate its volume, oven-dry it and measure its dry mass. Estimate the density (g/cm^3) by dividing the dry mass by its volume.

STEP 6c Estimate mass of trunk using volume and wood density (Mass = Volume x Density) and add to the other components (e.g., branches, leaves, etc.) to obtain the total mass of the tree.

STEP 7 Develop biomass equations linking tree biomass data to dbh alone, or dbh and height.

Simple equations can be created by fitting a regression line to the data in the graphing feature of Microsoft Excel. Methods for developing the linear or non-linear biomass equations using data on dbh, height and mass of trees are given in most text books on statistics or forest mensuration. Further discussion regarding development of biomass equations and their use can be found in Brown (1997) and Parresol (1999).

One of the limitations of Method I is that harvesting of about 30 trees of a given tree species may not be feasible or permitted, except for plantation species.

METHOD II: MEAN TREE BIOMASS ESTIMATE

To avoid felling a large number of trees (>30) and the cost of estimating their mass, a second option is calculating the mean tree biomass. This method is not as accurate, however, as the species-specific biomass equation derived using Method I.

STEP 1 Using dbh data from field measurements, prepare frequency tables using appropriate class intervals (e.g., 5cm for each tree species). The smaller the class interval the lower the error.

STEP 2 Locate a tree with a dbh close to the mean dbh value in the forest or plantation for each class.

STEP 3 Harvest the selected tree and estimate the mass, by estimating the dry mass as described in Method I.

STEP 4 Estimate the total mass of all trees in each dbh class using the mass of the tree with mean dbh and number of trees in the dbh class.

Below is an illustrative example of the mean tree dbh method for estimating aboveground biomass in moist tropical forest:

Dbh class (cm)	Mean Dbh (cm)	Mean mass of tree (kg/tree)	No of trees/ha	Total biomass (dry mass-kg/ha)
5-10	8	23	5	115
10-15	12.5	73	25	1,834
15-20	18	190	20	3,797
20-25	24	402	15	6,028
25-30	28	601	8	4,805
>30	33	922	5	4,609

REFERENCES

Brown, S. 1997. Estimating biomass and biomass change of tropical forests: a primer. FAO Forestry Paper 134, Rome, Italy.

Parresol, B.R. 1999. Assessing tree and stand biomass: a review with examples and critical comparisons. *Forest Science* 45, 573-593.

APPENDIX D: PUBLISHED BIOMASS REGRESSION EQUATIONS

Some examples of biomass equations are presented below. For more sources of equations, review:

- IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm)
- Winrock International Ecosystem Services website (www.winrock.org/what/ecosystem_pubs.cfm)

Temperate equations:

General Classification	Species Group	Equation	Source	Data Originating From	Max dbh
Hardwood	General	Biomass = 0.5 + ((25000 x $dbh^{2.5}$)/($dbh^{2.5}$ + 246872))	Schroeder et al. (1997)	Eastern USA	85.1cm
Softwood	Pine	Biomass = 0.887 + ((10486 x $dbh^{2.84}$)/($dbh^{2.84}$ + 376907))	Brown and Schroeder (1999)	Eastern USA	56.1cm
Softwood	Fir/spruce	Biomass = 0.357 + ((34185 x $dbh^{2.47}$)/($dbh^{2.47}$ + 425676))	Brown and Schroeder (1999)	Eastern USA	71.6cm
Hardwood	General	Biomass = Exp(-2.9132 + 0.9232 x ln$(dbh^2 \times height)$	Winrock	Eastern USA	85.1cm
Hardwood	Aspen/alder/cottonwood/willow	Biomass = Exp(-2.2094 + 2.3867 x ln*dbh*)	Jenkins et al. (2003)	USA	70cm
Hardwood	Soft maple/birch	Biomass = Exp(-1.9123 + 2.3651 x ln*dbh*)	Jenkins et al. (2003)	USA	66cm
Hardwood	Mixed hardwood	Biomass = Exp(-2.4800 + 2.4835) x ln*dbh*	Jenkins et al. (2003)	USA	56cm
Hardwood	Hard maple/oak/hickory / beech	Biomass = Exp(-2.0127 + 2.4342 x ln*dbh*)	Jenkins et al. (2003)	USA	73cm
Softwood	Cedar/larch	Biomass = Exp(-2.0336 + 2.2592 x ln*dbh*)	Jenkins et al. (2003)	USA	250cm

General Classification	Species Group	Equation	Source	Data Originating From	Max dbh
Softwood	Douglas-fir	Biomass = Exp(-2.2304 + 2.4435 x ln*dbh*)	Jenkins et al. (2003)	USA	210cm
Softwood	True fir/hemlock	Biomass = Exp(-2.5384 + 2.4814 x ln*dbh*)	Jenkins et al. (2003)	USA	230cm
Softwood	Pine	Biomass = Exp(-2.5356 + 2.4349 x ln*dbh*)	Jenkins et al. (2003)	Western USA	180cm
Softwood	Spruce	Biomass = Exp(-2.0773 + 2.3323 x ln*dbh*)	Jenkins et al. (2003)	Western USA	250cm
Woodland	Juniper/oak/ mesquite	Biomass = Exp(-0.7152 + 1.7029 x ln*dbh*)	Jenkins et al. (2003)	USA	78cm
Hardwood	Beech	Biomass = Exp(-3.0366 + 2.5395) x ln*dbh*)	Joosten et al. (2004)	Germany	~ 70cm
Softwood	Scots Pine	Biomass = 0.152 x $dbh^{2.234}$	Xiao and Ceulemans (2004)	The Netherlands	9.87cm

Tropical equations:

General Classification	Species Group	Equation	Source	Data Originating From	Max dbh
Dry *(900–1500mm rainfall)*	General	Biomass = $0.2035 \times dbh^{2.3196}$	Brown (unpublished)		63cm
Dry *(< 900mm rainfall)*	General	Biomass = $10^{(-0.535+\log_{10}\text{basal area})}$	Brown (1997)	Mexico	30cm
Moist *(1500–4000mm rainfall)*	General	Biomass = $\exp(-2.289+2.649 \times \ln dbh-0.021 \times \ln dbh^2)$	Brown (1997, updated)		148cm
Wet *(> 4000mm rainfall)*	General	Biomass = $21.297 - 6.953 \times dbh + 0.740 \times dbh^2$	Brown (1997)		112cm
Cecropia	Cecropia species	Biomass = $12.764 + 0.2588 \times dbh^{2.0515}$	Winrock	Bolivia	40cm
Palms	Palms (asai and pataju)	Biomass = $6.666 + 12.826 \times \text{height}^{0.5} \times \ln(\text{height})$	Winrock	Bolivia	33m height
Palms	Palms (motacu)	Biomass = $23.487 + 41.851 \times (\ln(\text{height}))^2$	Winrock	Bolivia	11m height
Lianas	Lianas	Biomass = exp(0.12+0.91xlog (BA at dbh))	Putz (1983)	Venezuela	12cm

REFERENCES

Brown, S. 1997. Estimating biomass and biomass change of tropical forests: a primer. FAO Forestry Paper 134, Rome, Italy.

Brown, S.L. and P.E. Schroeder. 1999. Spatial patterns of aboveground production and mortality of woody biomass for eastern US forests. *Ecological Applications* 9: 968-980. (errata: Brown, S.L., Schroder, P.E. 2000. Ecological Applications 10: 937).

Jenkins, J.C., D.C. Chojnacky, L.S. Heath, and R.A. Birdsey. 2003. National-scale biomass estimation for United States tree species. *Forest Science* 49: 12-35.

Joosten, R., J. Schumacher, C. Wirth and A. Schulte. 2004. Evaluating tree carbon predictions for beech (Fagus sylvatica L.) in western Germany. *Forest Ecology and Management* 189: 87-96.

Putz, F.E. 1983. Liana biomass and leaf area of a 'Tierra Firme' forest in the Rio Negro Basin, Venezuela. *Biotropica* 15: 185-189

Schroeder, P., S. Brown, J. Mo, R, Birdsey and C. Cieszewski. 1997. Biomass estimation for temperate broadleaf forests of the United States using inventory data. *Forest Science* 43: 424-434.

Xiao, C-W and R. Ceulemans. 2004. Allometric relationships for below- and aboveground biomass of young Scots pine. *Forest Ecology and Management* 203: 177-186.

APPENDIX E: INDICATIONS OF MAGNITUDE OF CHANGE IN CARBON IN DIFFERENT SYSTEMS AND TYPICAL STOCKS IN DIFFERENT SYSTEMS

On the following pages, values are presented for stocks, and increments in stocks, for forests, based on the information sources listed below. No values are presented for grasslands and croplands, as such values are not widely available and these pools are relatively straightforward to measure.

Additional data can be found at the following links:

- **Brown, S.** 1997. Estimating biomass and biomass change of tropical forests: a primer. FAO Forestry Paper 134 (www.fao.org/docrep/W4095E/W4095E00.htm)
- **IPCC.** 2004. Good Practice Guidance for Land Use, Land-Use Change and Forestry (www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm)

E.1 BIOMASS STOCKS

E.1.1 Aboveground biomass stock in naturally regenerated forests. All values in tons of dry matter per hectare.

Tropical Forests						
	Wet	Moist with short dry season	Moist with long dry season	Dry	Montane moist	Montane dry
Africa	310 (131-513)	260 (159-433)	123 (120-130)	72 (16-195)	191	40
Asia & Oceania						
Continental	275 (123-683)	182 (10-562)	127 (100-155)	60	222 (81-310)	50
Insular	348 (280-520)	290	160	70	362 (330-505)	50
America	347 (118-860)	217 (212-278)	212 (202-406)	78 (45-90)	234 (48-348)	60

Temperate Forests			
Age Class	Coniferous	Broadleaf	Mixed Broadleaf-Coniferous
Eurasia & Oceania			
≤ 20 years	100 (17-183)	17	40
> 20 years	134 (20-600)	122 (18-320)	128 (20-330)
America			
≤ 20 years	52 (17-106)	58 (7-126)	49 (19-89)
> 20 years	126 (41-275)	132 (53-205)	140 (68-218)

Boreal Forests			
Age Class	Mixed Broadleaf-Coniferous	Coniferous	Forest-Tundra
Eurasia			
≤ 20 years	12	10	4
> 20 years	50	60 (12.3-131)	20 (21-81)
America			
≤ 20 years	15	7	3
> 20 years	40	46	15

Note: Data are given in mean value and as range of possible values (in parentheses).

E.1.2 Aboveground biomass stock in plantation forests.
All values in tons of dry matter per hectare.

Tropical and Sub-Tropical Forests							
	Age class	Wet	Moist with short dry season	Moist with long dry season	Dry	Montane moist	Montane dry
		R > 2000	2000 > R > 1000		R < 1000	R > 1000	R < 1000
Africa							
Broadleaf spp	≤ 20 years	100	80	30	20	100	40
	> 20 years	300	150	70	20	150	60
Pinus sp	≤ 20 years	60	40	20	15	40	10
	> 20 years	200	120	60	20	100	30
Asia							
Broadleaf	All	220	180	90	40	150	40
Other species	All	130	100	60	30	80	25
America							
Pinus	All	300	270	110	60	170	60
Eucalyptus	All	200	140	110	60	120	30
Tectona	All	170	120	90	50	130	30
Other broadleaf	All	150	100	60	30	80	30

Temperate Forests				
	Age class	Pine	Other coniferous	Broadleaf
Eurasia				
Maritime	≤ 20 years	40	40	30
	> 20 years	150	250	200
Continental	≤ 20 years	25	30	15
	> 20 years	150	200	200
Mediterranean & steppe	≤ 20 years	17	20	10
	> 20 years	100	120	80
S. America	All	100	120	90
N. America	All	175 (50-275)	300	–

Boreal Forests				
	Age class	Pine	Other coniferous	Broadleaf
Eurasia	≤ 20 years	5	5	5
	> 20 years	40	40	25
N. America	All	50	40	25

Note 1: R = annual rainfall in mm/yr
Note 2: Data are given in mean value and as range of possible values (in parentheses).

E.2 AVERAGE ANNUAL INCREMENT IN ABOVEGROUND BIOMASS

E.2.1 Average annual increment in aboveground biomass in naturally regenerated forests.

All values in tons of dry matter per hectare per year.

Tropical and Sub-Tropical Forests

Age class	Wet	Moist with short dry season	Moist with long dry season	Dry	Montane moist	Montane dry
	R > 2000	2000 > R > 1000		R < 1000	R > 1000	R < 1000
Africa						
≤ 20 years	10.0	5.3	2.4 (2.3-2.5)	1.2 (0.8-1.5)	5.0	2.0 (1.0-3.0)
> 20 years	3.1 (2.3-3.8)	1.3	1.8 (0.6-3.0)	0.9 (0.2-1.6)	1.0	1.5 (0.5-5.4)
Asia & Oceania						
Continental						
≤ 20 years	7.0 (3.0-11.0)	9.0	6.0	5.0	5.0	1.0
> 20 years	2.2 (1.3-3.0)	2.0	1.5	1.3 (1.0-2.2)	1.0	0.5
Insular						
≤ 20 years	13.0	11.0	7.0	2.0	12.0	3.0
> 20 years	3.4	3.0	2.0	1.0	3.0	1.0
America						
≤ 20 years	10.0	7.0	4.0	4.0	5.0	1.8
> 20 years	1.9 (1.2-2.6)	2.0	1.0	1.0	1.4 (1.0-2.0)	0.4

Temperate Forests

Age Class	Coniferous	Broadleaf
≤ 20 years	3.0 (0.5-6.0)	4.0 (0.5-8.0)
> 20 years	3.0 (0.5-6.0)	4.0 (0.5-7.5)

Boreal Forests

Age Class	Mixed Broadleaf-Coniferous	Coniferous	Forest-Tundra	Broadleaf
Eurasia				
≤ 20 years	1.0	1.5	0.4 (0.2-0.5)	1.5 (1.0-2.0)
> 20 years	1.5	2.5	0.4 (0.2-0.5)	1.5
America				
≤ 20 years	1.1 (0.7-1.5)	0.8 (0.5-1.0)	0.4 (0.2-0.5)	1.5 (1.0-2.0)
> 20 years	1.1 (0.7-1.5)	1.5 (0.5-2.5)	0.4 (0.2-0.5)`	1.3 (1.0-1.5)

Note 1: R = annual rainfall in mm/yr

Note 2: Data are given in mean value and as range of possible values (in parentheses).

E.2.2 Average annual increment in aboveground biomass in plantation forests.

All values in tons of dry matter per hectare per year

Tropical and Sub-Tropical Forests							
	Age class	Wet	Moist with short dry season	Moist with long dry season	Dry	Montane moist	Montane dry
		R > 2000	2000 > R > 1000		R < 1000	R > 1000	R < 1000
Africa							
Eucalyptus spp	≤ 20 years	–	20.0	12.6	5.1 (3.0-7.0)	–	–
	> 20 years	–	25.0	–	8.0 (4.0-13.6)	–	–
Pinus sp	≤ 20 years	18.0	12.0	8.0	3.3 (0.5-6.0)	–	–
	> 20 years	–	15.0	11.0	2.5	–	–
Others	≤ 20 years	6.5 (5.0-8.0)	9.0 (3.0-15.0)	10.0 (4.0-16.0)	15.0	11.0	–
	> 20 years	–	–	–	11.0	–	–
Asia							
Eucalyptus spp	All	5.0 (3.6-8.0)	8.0	15.0 (5.0-25.0)	–	3.1	–
Other species	–	5.2 (2.4-8.0)	7.8 (2.0-13.5)	7.1 (1.6-12.6)	6.45 (1.2-11.7)	5.0 (1.3-10.0)	–
America							
Pinus	–	18.0	14.5 (5.0-19.0)	7.0 (4.0-10.3)	5.0	14.0	–
Eucalyptus	–	21.0 (6.4-38.4)	16.0 (6.4-32.0)	16.0 (6.4-32.0)	16.0	13.0 (8.5-17.5)	
Tectona	–	15.0	8.0 (3.8-11.5)	8.0 (3.8-11.5)	–	2.2	–
Other broadleaf	–	17.0 (5.0-35.0)	18.0 (8.0-40.0)	10.5 (3.2-11.8)	–	4.0	–

Note 1: R=annual rainfall in mm/yr.
Note 2: Data are given in mean value and as range of possible values (in parentheses).
Note 3: Some boreal data were calculated from original values in Zakharov *et al* (1962), Zagreev *et al* (1993), Isaev *et al* (1962) using 0.23 as belowground/aboveground biomass ratio and assuming a linear increase in annual increment from 0 to 20 years.
Note 4: For plantations in temperate and boreal zones, it is good practice to use stemwood volume increment data (I, in equation 3.2.5) instead of above ground biomass increment as given in the above table.

E.3 COUNTRY-SPECIFIC DATA

The following tables for the three main tropical regions include examples of biomass estimates for different forest types estimated from forest inventories. All biomass estimates are based on trees with a minimum dbh of 10cm and represent average values over the very large inventoried area.

From **Brown, S.** 1997. Estimating biomass and biomass change of tropical forests: a primer. FAO Forestry Paper 134, Rome, Italy (www.fao.org/docrep/W4095E/W4095E00.htm).

E.3.1 Tropical African countries

Country	Forest type	General climate	Aboveground biomass (t/ha)
Benin	Closed forest	Dry	175
	Tree savanna	Dry	96
Burkina Faso (National)	Degraded tree savanna	Dry: long dry season	20
Cameroon	Primary	Moist	310
Gambia	Gallery forest	Moist: dry season	140
(National)	Closed woodland	Dry	97
	Open woodland	Dry	50
	Tree savanna	Dry	28
Ghana	Closed forest	Moist: short dry season	395
Guinea (National)	Mixed: closed, open, secondary	Moist	135
Mozambique	Dense forest	Moist: short dry season	120
	Dense forest	Moist: dry season	130
	Dense forest	Dry: long dry season	70

E.3.2 Tropical American countries

Country	Forest type	General climate	Aboveground biomass (t/ha)
Bolivia	Closed forest	Moist	230
Brazil	Closed forest	Moist	315
Ecuador	Closed forest	Moist	182
French Guyana	Closed forest	Moist	309
	Riparian forest	Moist	275
	Savanna forest	Moist	205
Guatemala (Peten area)	Closed forest	Moist	242
Guyana	Closed forest	Moist	254
	Logged forest	Moist	190
	Wallaba forest	Dry	145
	Mixed forest	Moist	275
	Low mixed forest	Moist	192
	Liana forest	Moist	125
	Wallaba forest	Moist	148
	Wallaba forest on white sands	Moist	405
Nicaragua	Orifino forest	Moist	240
	Lowland mixed	Moist	235
Nicaragua	Mature forest	Moist	240
	Secondary	Moist	183
Panama	High density: mixed	Moist	239-366
	Low density: mixed	Moist	169-245
	Campnosperma forest: high density	Moist	860
	Campnosperma forest: low density	Moist	470
	High density: mixed	Wet	194-214
	Low density: mixed	Wet	120-125
	High density: mixed	Pre- & lower montane rain	186-252

Country	Forest type	General climate	Aboveground biomass (t/ha)
Panama (cont.)	Low density-mixed	Pre- & lower montane rain	118-143
Peru	Primary	Moist	210
	Lightly logged	Moist	192
	Heavily logged	Moist	125
	Late secondary	Moist	140
	Young secondary	Moist	20
	Flooded secondary	Moist	195
	Low forest	Moist	155
Suriname	Upland forest	Moist	255
	Small crown: upland	Moist	136
	Savanna forest	Moist	195
	Riparian forest	Moist	217
	Liana forest	Moist	120
	Wallaba forest	Moist	250
Venezuela	Semi-deciduous	Dry	78
	Closed forest	Moist	230

E.3.3 Tropical Asian countries

Country	Forest type	General climate	Aboveground biomass (t/ha)
Bangladesh	Closed: large crowns	Moist	210
	Closed: small crowns	Moist	150-160
	Disturbed closed	Moist	190
	Disturbed open	Moist	85
Cambodia	Dense	Moist	295
	Semi-dense	Moist	370
	Secondary	Moist	190
	Open	Moist	160
	Open	Dry	70
	Well to poorly stocked evergreen	Moist	100-155
	Deciduous	Moist	120
India	High to low volume closed	Dry	44-81
	Forest fallow	Dry	16
Malaysia Peninsular	Superior to moderate hill	Moist	245-310
(National)	Poor hill	Moist	180
	Upper hill	Moist	275
	Disturbed hill	Moist	200
	Logged hill	Moist	180
	Forest fallow	Moist	140
	Freshwater swamp	Moist	220
	Disturbed freshwater swamp	Moist	285
	Logged freshwater swamp	Moist	185
Malaysia Sarawak	Mixed dipterocarps: dense stocking, flat to undulating terrain	Moist	325-385

Country	Forest type	General climate	Aboveground biomass (t/ha)
Malaysia Sarawak (cont.)	Mixed dipterocarps- dense stocking, mountainous	Moist	330-405
	Mixed dipterocarps- medium stocking, flat to mountainous	Moist	280-330
Myanmar	Evergreen	?	60-200
	Mixed deciduous	?	45-135
	Indaing forest	?	10-65
Philippines	Old-growth dipterocarp	Moist	370-520
	Logged dipterocarp	Moist	300-370
Sri Lanka	Evergreen: high yield	Moist	435-530
	Evergreen: medium yield	Moist	365-470
	Evergreen: low yield	Moist	190-400
	Evergreen: logged	Moist	255
	Secondary	Moist	280
Thailand	Degraded dry evergreen	Dry	85